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CHAPTER 1

The Distracted Driver: Mechanisms, Models, and Measurement

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This chapter investigates driver distraction, a pressing road safety issue. First, research findings regarding the demands placed on drivers by the primary driving tasks and various non-driving-related secondary tasks are reviewed. Second, promising theories and models are reviewed for characterizing how driver distraction is caused and how it affects the driving task. Third, a review is provided of current investigation and measurement methods used in distraction research, guidelines, standards, antidistraction devices, and antidistraction legislation. Fourth, the most important implications from this review are summarized for the various stakeholders in the driver distraction debate. And finally, some important issues for future research into driver distraction are discussed, as is the importance of considering driver distraction in the context of an integrated safety vision.

Human factors research in the field of driver distraction has greatly evolved in the past decade. This research has provided new insights on how distracted driving occurs, its potential consequences, and how its prevalence can be reduced. Research on driver distraction, however, continues, mainly for three reasons:

1. Driving a vehicle is a multitasking skill requiring, at times, more of the driver's limited mental resources than is possible.
2. Occasional overtaxing of the driver's limited mental capacity may result in dangerous driving behaviors and perception or action failures.
3. These dangerous behaviors and perception failures result in increased traffic collisions.

To provide some context to these general observations, it may be instructive to briefly look at the following example of driver distraction, as recently described in a report of the National Safety Council (2010):

> In January 2004, at 4:00 p.m., in Grand Rapids, Michigan, a 20-year-old woman ran a red light while talking on a cell phone. The driver's vehicle slammed into another vehicle crossing

Keywords: driver distraction, driving safety, multitasking performance, attentional demands, attentional resources, task interruption and resumption, multiple-resource model, visual scanning models, antidistraction technology, antidistraction standards and guidelines, distraction measurement methods

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> with the green light directly in front of her. The vehicle she hit was not the first car through the intersection, it was the third or fourth. The police investigation determined the driver never touched her brakes and was traveling 48 mph when she hit the other vehicle. The crash cost the life of a 12-year-old boy. Witnesses told investigators that the driver was not looking down, not dialing the phone, or texting. She was observed looking straight out the windshield talking on her cell phone as she sped past four cars and a school bus stopped in the other south bound lane of traffic. Researchers have called this crash a classic case of inattention blindness caused by the cognitive distraction of a cell phone conversation. (p. 2)

This example illustrates the scope and complexity of driver distraction. Specifically, it shows the problems the individual driver experiences regarding the proper distribution of attention across two simultaneously performed tasks (i.e., driving and talking on a cell phone) that both require attention. In this example, distraction appears to be a result of driver choice, because this driver used a cell phone while driving. However, the diversion of attention away from the primary driving task may result from other causes and may not always be avoidable. Moreover, the origin of distraction may be understood as the "looked-but-did-not-see" phenomenon (Simons & Chabris, 1999).

DEFINITIONS

Because the research field is still relatively young, various definitions can be encountered in the literature, depending on the focus of the researcher or practitioner and depending on the most recent research insights (Hanowski, Perez, & Dingus, 2005; Regan, Lee, & Young, 2009). On the basis of the most common elements and recent research insights, driver distraction is defined as follows by the present authors.

Driver distraction is the occurrence of any event or object (either inside or outside the vehicle) or driver activity, driving related or not, physical or mental, that claims part or all of the driver's attentional resources, voluntarily or not, and diverts the driver from what is needed to maintain the safety of the driver or other road users. By attentional resources, we mean cognitive, perceptual, or motor resources that are related to human attentional processes.

This definition does not preclude that some cases of driving-related cognitive overload are classified as examples of driver distraction, namely, when the psychological result of overload is that attention is drawn away from the intended (i.e., primary driving) task. Moreover, driver distraction cannot always be avoided by the driver. Finally, this definition implies that all cases of driver inattention (i.e., when the driver is paying insufficient attention to the driving task) can be classified as examples of driver distraction.

Unresolved definitional problems form an important first obstacle to better understanding and preventing driver distraction. For example, accurate coding of crashes becomes difficult when it is not known precisely how a distraction-based accident should be defined or is caused, especially so when the distraction is cognitive. How much distraction was present? How much distraction would have been acceptable while a crash was still prevented? These questions need to be answered for accident analysis, accident reporting, and enforcement of antidistraction laws to be effective. Therefore, in the next two sections, important terms are scientifically defined and practical examples provided that help describe and classify driver distraction.

The Importance of Human Factors Research and Applications Related to Driver Distraction

An increasing number of automobile accidents are attributed to distracted driving, varying from 5% to more than 25%, depending on the type of study and the definition used. Traditional crash studies have attributed 10% to 12% of all automobile crashes to driver distraction (Gordon, 2009). However, these figures are underestimates of the true percentage attributable to methodological problems inherent in these studies.

Unlike traditional crash studies, naturalistic studies, such as the 100-Car study (Neale, Dingus, Klauer, Sudweeks, & Goodman, 2005), do not depend on eyewitness accounts or driver recall. They assess crash occurrence in the context of exposure to the distracting task (i.e., how often a distracting task occurs with no measurable consequence). These studies provide prevalence rate estimates as high as 23% for distraction as a causal factor in crashes and are based on the performance of non-driving-related secondary activities, such as personal grooming and reaching for an object in the car a few moments before the crash. This percentage may be even higher if inattention-based crashes are included (e.g., paying insufficient attention to the forward roadway for internal or unknown reasons).

Developments in society, legislation, and industry. In the past 10 years, driving has become more complex because of increased traffic density; the increased use of embedded, car-based information technologies; and the increased connectivity of vehicles to other vehicles on the road and, more generally, to the road infrastructure. Although this connectivity may also benefit the driver (e.g., increased traffic throughput from offloading of busy highways; increased driver ability to avoid dangerous traffic situations), these developments have also caused concerns among applied researchers, policy makers, and legislators about the extent to which the design of these technologies is "safe" and about the ability of the average driver to use these technologies responsibly and safely.

As a result, there is increased legislation banning the use of handheld phones and prohibiting "texting" while driving. Also, private- and public-sector initiatives have included new guidelines, test procedures, and development processes to help ensure safe and usable systems for drivers (Green, 2008). Some of these developments are discussed in the section Measurement, Mitigation, and Management.

Shifts in the study of driving behavior. The changed nature of driving has influenced research into, and theoretical models about, driver behavior. For example, the confluence of all kinds of electronic equipment in the car has encouraged the development of multitasking models of driving behavior. Increased connectivity may also give rise to models and research efforts aimed at understanding the social factors underlying driver behavior. Much of this research has its origin in human factors engineering (AAA Foundation for Traffic Safety, 2006).

Chapter Organization

The breadth and depth of research into driver distraction in the past decade is astonishing. The goal of this chapter is to summarize the most relevant results of this research. The latest driver distraction research findings have been organized into several key areas.

First, in the section Sources of Driver Distraction and Demand, an overview of sources of demand on drivers is offered that is based on the empirical accident and distraction literature. When available, supporting evidence linking the sources of demand to measurable decrements in driving safety is provided.

Second, in the section Psychological Mechanisms Underlying Driver Distraction: Promising Theories and Models, promising theories and driver models are covered that attempt to characterize how distraction is caused and how it affects driving. Validated theories and models may help the human factors practitioner make early contributions to product design.

Third, in the section Measurement, Mitigation, and Management, a review is provided of distraction-related analysis and measurement methods, guidelines, standards, antidistraction devices, and antidistraction legislation.

Finally, the chapter concludes with the section Lessons Learned and Unresolved Issues, consisting of two parts. First, the most important implications are summarized for three types of stakeholder in the driver distraction debate: designers, legislators, and individual drivers. Second, based on current trends and our current findings, the most important future issues related to driver distraction, especially in the context of an integrated safety vision, are briefly discussed.

SOURCES OF DRIVER DISTRACTION AND DEMAND

Introduction

The focus of this section is sources of attentional demand on the driver and the effects of those demands on the processes required for "safe" driver performance and behavior. The section sets the stage for the subsequent review of theories and models of driver distraction in the section Psychological Mechanisms Underlying Driver Distraction: Promising Theories and Models.

Figure 1.1 is a useful framework for making distinctions among sources of attentional demand on the driver. Effects from these demands (depending on their type, magnitude, and frequency) may degrade driving performance, which, in turn, may influence the probability of a near crash or crash.

Box 2 in this diagram depicts the demands imposed on a driver. Two main sources of demands are illustrated by the two arrows entering Box 2. The arrow coming from Box 0 represents the demands imposed by the primary task(s) of driving in a particular set of vehicle-, weather-, traffic-, and road-related conditions. The arrow coming from Box 1 represents the demands imposed by secondary activities that a driver might undertake. These activities are mostly executed at will by the driver and involve objects or events

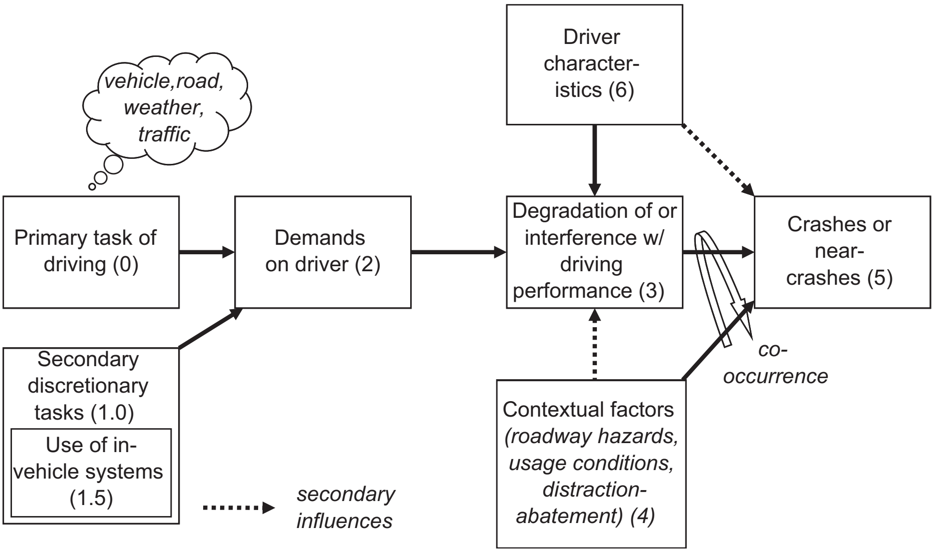

Figure 1.1. *Diagram of sources of demand on the driver and their safety relevance. Adapted and modified from the CAMP Driver Workload Metrics final report (Angell et al., 2006). WM = working memory; S = stimulus; R = responses; LTM = long-term memory*

inside the car. Note that some of these activities are performed while using embedded (in-vehicle) devices (those in Box 1.5), which are called out to emphasize that in-vehicle device use represents only a small portion of secondary activities. Many of the Box 1 activities are performed while using portable devices (e.g., cell phones or navigation systems). Still others in Box 1 are performed without the use of particular vehicular or electronic devices and instead involve objects such as wrappers, cups, and utensils.

The demands on the driver, placed by the tasks or actions that he or she undertakes, may produce degradation of, or interference with, driving performance (depicted in Box 3), depending on certain driver characteristics (Box 6). *Driver characteristics* refers to stable personal characteristics that can influence the effects of distractors on driving behavior and safety, such as age, experience, accumulated knowledge and skills, and cognitive ability. They also include fatigue, boredom, and the general emotional state.

The degradation of, or interference with, driving performance may give rise to crashes or near-crashes (shown in Box 5) if it occurs in the presence of one or more contextual factors (Box 4). Contextual factors are conditions related to the specific context of the primary and secondary tasks, such as (a) the natural occurrence of traffic-related hazards, objects, and events on the road that may require (or attract) a driver's attention; (b) the (transient) behavioral factors underlying secondary task use; and (c) the presence of distraction-countering technologies and the degree to which the vehicle and/or road determines the bandwidth of "normal" driving behavior.

A key point from Figure 1.1 is that crashes often depend on the occurrence of excessively high demands at a point in time when a hazard or event on the road also occurs that requires attention and a response from the driver. It is this co-occurrence that disrupts the driver's capacity for multitasking performance.

Given the interconnected nature of the different constructs in Figure 1.1, it is difficult to isolate specific research focused on each. Therefore, the discussion roughly follows the flow of Figure 1.1 from left to right, in terms of clusters of boxes, starting with Box 0 and ending with Box 5.

Demands From Primary Driving (Figure 1.1, Box 0)

Categories. A useful description of the primary tasks of the driver was offered by Michon (1971, 1979, 1985) and by Janssen (1979) (see Table 1.1). The framework describes the primary tasks of the driver in terms of three levels of control that differ with respect to the time horizon within which control must be exercised: operational control (short-term horizon), tactical control (midterm horizon), and strategic control (long-term horizon). These levels of control give rise to various control tasks (illustrated in the second column of Table 1.1) that must ordinarily be coordinated simultaneously and that collectively compose the "primary driving task." Each of these levels of control imposes a variety of demands on the driver. Notice the heavy loading of the visual input channel and the manual response channels for the primary task of driving. Some of the variations in technology affecting primary tasks are described in the fifth column of the table.

When considering distraction, the demands of these primary driving tasks are important from the point of view of tapping the driver's resources (visual resources, manual resources, and/or working memory [WM] resources, including central executive attention) and the needs of secondary tasks. The section Psychological Mechanisms Underlying Driver Distraction: Promising Theories and Models will elaborate on the psychological mechanisms underlying resource use and its relation to driver distraction.

With higher degrees of automation, more electronic devices may be present (embedded or not) in the vehicle. Although aimed at supporting the driver (i.e., lowering the demands imposed on the driver), these devices may also be distracting. For the sake of convenience, in this chapter, the use of embedded, standard driving-related instruments, such as a speedometer, will be classified as a secondary activity (as will the use of other in-vehicle device-based distractors).

Empirical evidence related to the demands imposed by primary driving tasks (Figure 1.1, Boxes 0, 2, and 3). The demands of primary driving tasks, reflected in Box 0 of Figure 1.1, vary as a function of maneuver (e.g., steering), road (e.g., straight, curved), traffic (e.g., motorway, rural), and environmental variables. In Europe, researchers at TNO (Netherlands Organization for Applied Scientific Research; Martens & van Winsum, 2000) and at project IN-ARTE (Integration of Navigation and Anti-collision for Rural Traffic Environment; Harms & Patten, 2003) have used the "peripheral detection task" (PDT) methodology (now being called the "detection response task" methodology) to examine variations and peaks in workload during driving situations, both in the simulator (e.g., Martens & van Winsum, 2000; van Winsum, Martens, & Herland, 1999) and on the road (e.g., Hoedemaeker, Hogema, & Pauwulussen, 2006). These studies have found that primary driving tasks in the context of complex driving situations may result

Table 1.1. Types of Demand From Primary Driving Tasks

Level of Control	*Type of Control*	*Characteristic Description*	*(Illustrative) Key Demands on Driver*	*Technology Available in Typical Vehicles (Examples)*
Operational	Lateral control	Lane keeping	**Visual** (viewing position of lane and providing feedback on lane position and heading) **Manual** (steering)	Steering systems available in all vehicles; some provide power assist; some provide by-wire capability; some newly emerging safety-enhancing systems provide lane departure warning, lane keeping, and lane centering
	Longitudinal control	Speed control (acceleration, deceleration/ braking)	**Visual** (optical flow, providing feedback on results of acceleration inputs) **Manual** (acceleration, deceleration, braking)	Throttle control, braking control supported in all vehicles at basic level; some provide power assist; some are fully electronic and by-wire; some provide cruise control; some new and emerging systems include adaptive cruise control with forward collision alerts; some provide levels of autonomous braking intervention
		Following behavior and headway maintenance	**Visual** (tau = visual subtended angle of an object divided by its rate of position change, time and distance headway, providing feedback on results of acceleration inputs) **Manual** (acceleration, deceleration, braking)	Generally in driver's control in today's vehicles, although emerging technologies include adaptive cruise with forward collision alerts (or variations)
Tactical	Maneuvers	Turning, overtaking, gap acceptance, determining how to approach an intersection, determining how to deal with a sudden detour	**Visual** (forward and side views of road, traffic, environment) **Manual** (properly timed and coordinated steering, acceleration, and braking control) **Working memory** (maintenance of situation awareness [SA]) **Central executive attention** (coordination and projection of next state of situation)	Maneuvers are in driver's control in today's vehicles; new systems provide stabilization in event of overly aggressive maneuvers (electronic stability control)

(continued)

Table 1.1. (continued)

Level of Control	*Type of Control*	*Characteristic Description*	*(Illustrative) Key Demands on Driver*	*Technology Available in Typical Vehicles (Examples)*
	Event monitoring and response	Looming cues, motion cues, pedestrians crossing, lead vehicle braking suddenly, responding adaptively	**Visual** (monitoring and detection of events and hazards) **Working memory** (use of situation model in awareness to interpret events/hazards) **Central executive attention** (selection of response, coordination of execution, and projection of next state of situation, updating of SA)	Generally in driver's control; some advanced technologies are in early development to assist with some elements; some are intended to enhance driver ability to see in some conditions (e.g., night vision systems) or to augment vision in obstructed areas (e.g., backup cameras); some are in development to assist with driver vigilance to forward road
Strategic	Planning	Route planning (before or during a trip)	**Visual** (viewing of map, route, instructions or sometimes entrance of destination or operation of navigation system) **Working memory** (remembering where to turn, coordination of route instructions with forward view) **Central executive attention** (monitoring for and execution of instructions at appropriate points, i.e., task interruption/switching, projection of next state of situation and updating of SA)	Some vehicles/carried-in systems can do this for the driver
		Goal identification (before or during a trip)	**Working memory** (use of situation model in awareness to interpret events/hazards) **Central executive attention** (selection of response, coordination of execution, and projection of next state of situation, updating of SA)	In driver's control in today's vehicles; newly emerging or carried-in systems may provide widely varying types of support for goal attainment but likely require driver to manage across goals

in higher proportions of missed signals on the PDT and longer response times (indicating a higher workload on the driver).

For example, maneuvers in which drivers suddenly had to respond to a stop sign, overtake a lead vehicle, or brake in response to a lead vehicle or a package that fell off a truck all led to more missed signals and longer response times than straight road driving, mild to moderately curved road driving, or driving at the moderate rate of 50 km/h. In responding to a lead vehicle that braked suddenly, the proportion of missed signals on PDT was 5 times as high as a comparison scenario (of driving on an 80 km/h road; van der Horst & Martens, 2010). In addition, research findings have shown that the extent of secondary task interference with driving depends on type and level of the primary driving maneuver that is underway.

In summary, the total set of demands on the driver from primary tasks is an important consideration before one entertains any additional demands that secondary activities may introduce.

Additional (Secondary) Sources of Demand on the Driver's Attention (Figure 1.1, Box 1)

Additional sources of demand may vie for the driver's attention as a result of his or her engaging in one or more secondary activities. These demands arise from two main sources: the use of in-vehicle devices (Box 1.5), such as an embedded navigation system, and activities in the rest of Box 1 (those that do not involve interacting with devices). The latter include such activities as eating food, drinking beverages, interacting with items the driver has elected to bring into the vehicle (e.g., cell phone, portable GPS unit, MP3 player), reaching for objects in a briefcase or purse, talking with a passenger, and interacting with a pet, among many others.

The impact of secondary tasks on driver distraction can also be considered from a control-theoretic point of view. Specifically, the distinction among levels of control that was mentioned earlier also applies to the performance of secondary tasks (Lee, Regan, & Young, 2009). Distraction may arise at any level and can be seen as a disturbance of "normal" control performance. These disturbances are typically caused by combinations of various predictable and unpredictable events, both driving related and not driving related.

The control-theoretic framework shows that driver distraction does not always occur involuntarily but may also be under the control of the driver. Moreover, it shows that distraction at one level of control may cascade upward or downward to another level of control and thereby cause additional distraction. This principle can be used in driver training or education programs (Donmez, Boyle, & Lee, 2009).

Categories: The use of in-vehicle devices (Figure 1.1, Box 1.5). In Table 1.2, major types of common in-vehicle device sources are identified, including illustrative examples, characteristic functionality, types of driver demand, and current availability. It provides a quick view of secondary device demands on driver attention. Although visual-manual channels are focused on primary tasks, many in-vehicle devices are also taxing. Regan, Young, Lee, and Gordon (2009) offer an in-depth classification of sources, tasks, actions, demands, and types of resources needed for various secondary activities. Designers can also benefit from analytic techniques employed by Sarno and Wickens (1995).

Most of the devices listed in Table 1.2 are optional in present-day vehicles, and the activities performed by drivers involving these devices can, therefore, be considered "discretionary" and not driving related. An exception is vehicle instruments and controls, which usually complement the primary driving task.

Among embedded electronic devices, perhaps the best-known examples are electronic navigation systems. The various implementations impose different loads on input and output modalities and can have an impact on the distraction potential of these systems (Perez, Kiefer, Haskins, & Hankey, 2009; Srinivasan & Jovanis, 1997; Tsimhoni, Smith, & Green, 2004).

Catagories: Nondevice activities (undertaken by drivers in the vehicle). Table 1.3 identifies other activities in which drivers may engage. Stutts, Reinfurt, Staplin, and Rodgman (2001) indicated that drivers spent at most 4% to 5% of the total driving time engaging in nondevice activities. A recent online survey conducted among 1,800 drivers from three continents ("Drive Responsibly," n.d.) suggests, however, that non-driving-related activities could be broader in scope and more common.

Nondevice activities also include paying attention to non-driving-related objects and events outside the vehicle, such as (electronic) billboards along the highway and things happening on the other side of the highway divider (e.g., slowing down to watch a crash on the other side of the freeway).

In this context, it is relevant to mention the importance of *secondary task design* for predictions of the degree to which secondary tasks cause distraction. For example, *task interruptability* is a design condition in which an activity can be broken down by its performer into chunks, which can be stopped and resumed as required by demands of the environment in which the activity is completed. Research shows that easy-to-interrupt secondary tasks interfere less with primary driving tasks than do not-so-easy-to-interrupt secondary tasks (Rauch, Gradenegger, & Kruger, 2009).

Empirical evidence for the distracting effects of secondary activities (Figure 1.1, Boxes 1 to 3). There is a vast literature on empirical work measuring the demands of secondary tasks and the degree to which they interfere with driving. The literature contains a mix of studies done in laboratory, simulator, test track, and road settings. Since these studies differ in methodology, it goes without saying that they have yielded a range of results. Nonetheless, some findings are robust across these differences. These findings are summarized in the following bullets and serve to summarize key findings from this body of work. Each key finding is illustrated by one study but with a range of additional citations identified. To span the amount of work done on secondary task effects, the focus is on visual, manual, and cognitive sources of task demand that have been studied.

- Many research findings have shown that the extent of secondary task interference with driving depends on the type of primary driving maneuver that is underway (Duncan, Williams, Nimmo-Smith & Brown, 1992; Groeger, 2000; Shinar, Meir, & Ben-Shoham, 1998; Verwey, 1991). Specifically, what is critical for the amount of interference between

text continues on page 16

Table 1.2. Types of Demands From In-Vehicle Devices

Source	*Examples*	*Characteristic functionality*	*Demands on driver*	*Availability in typical vehicles*
Vehicle instruments and controls	Speedometer, gauges, telltales[a]	Cluster and gauge functions, including telltale notifications	Visual-manual	Standard equipment, often used to support primary driving tasks
	Windshield defrost and wipers	Windshield clearing		
	Headlighting controls	Control forward visibility		
Comfort and convenience features	Heating, vents, and air conditioning	Temperature, humidity, circulation control, and source of air	Visual-manual	Some features are standard; others are optional features
	Seat adjustments	Seating adjustments		
Embedded infotainment and telematics devices	Built-in navigation systems	Destination entry Route-following assistance Points-of-interest and other features Route replanning	Some are visual-manual; some are auditory-vocal; some offer both modalities	Optional equipment; 1.2 million sold (out of ~16 million new cars) per year, a 7%–8% take rate—and fewer than 1% per year of all cars registered in the United States
	Built-in advanced entertainment and “infotainment” systems (including embedded MP3 players)—usually requiring navigation screen		Some are visual-manual; some are auditory-vocal; some offer both modalities	Optional equipment; usually bundled with navigation
	Music: Search, play, store	Music: Search, play, store, download/upload (in parking gear)		

(continued)

Table 1.2. (continued)

Source	***Examples***	***Characteristic functionality***	***Demands on driver***	***Availability in typical vehicles***
	Images: Moving/still	Not in front seat	Locked out by some manufacturers if images do not meet visual demand limits	
	Embedded communication (phoning, messaging)	Calls for assistance (emergency, navigation, etc.) Incoming calls Management of calls (initiating, answering, deferring calls) Notifications (e.g., storm information, emergency instructions)	Visual-manual in some; auditory-vocal in others	Optional equipment; estimated at 30% of new vehicles sold each year (or ~4.8 million per year, accumulating across years; Juliussen, 2009)
	Interactive information (e.g., Internet connectivity)	Real-time traffic advisory (on request) Headlines, advertising, address book, database search, financial services, directory, horoscopes, stock quotes	Visual-manual in some; auditory-vocal access to information in others	If available as an option integrated in the vehicle, it is optional functionality and is bundled with navigation
Nomadic devices	Portable navigation systems	Destination entry Route following assistance Points-of-interest and other features Route replanning	Some are visual-manual; some are auditory-vocal; some offer both modalities	44% of U.S. respondents report use of portable navigation devices (Navteq Global Study, 2010, at www.gizmag.com/consumer-experience-with-navigational-devices-doubled-in-last-three-years/13895)
	Entertainment systems (iPods and their counterparts)		Visual-manual	220 million total sales of iPods by 2008

Table 1.2. (continued)

Source	*Examples*	*Characteristic functionality*	*Demands on driver*	*Availability in typical vehicles*
	Music: Search, play, store	Music: Search, play, store, download (when stopped)		(relative to 247 million registered vehicles on the road —cars, trucks, buses); iPods have 90% of portable MP3 market
	Images: Moving/still	Images on portable devices: Moving/still—including photos, video games, movies, TV, etc.		
	Communication (phoning, messaging); also smartphones, phones, iPads, PDAs	Incoming calls Outgoing calls Management of calls (initiating, answering, deferring calls) Voice mail	Visual-manual though some may provide for voice dialing	250 million subscribers (compared with 247 million vehicles—cars, trucks, and buses registered in the United States)
	Interactive information (Internet connectivity via phone, PDA, etc.)	Headlines, advertising, address book, database search, e-commerce, financial services, directory, stock quotes, personal info	Visual-manual	More cell phones than PCs currently connect to the Internet; exact percentage could not be found

a. A telltale is an indicator on or near the dashboard of a vehicle (usually in the instrument cluster) that informs the driver about whether key systems within the vehicle are operating properly.

Table 1.3. Types of Demand From Nondevice Activities

Activity/Source	*Types of Interaction*
In-vehicle interactions with passengers and pets	Vocal and nonvocal/physical
Looking at things outside the vehicle (buildings, accidents, billboards)	Visual/cognitive
Eating and drinking	Visual/manual
Grooming	Visual/manual
Storing/retrieving items	Visual/manual
Reading	Visual/manual
Writing	Visual/manual
Opening/closing packaged items	Visual/manual

tasks is the presence of structural overlaps between the resources demanded by the tasks that the driver is attempting to coordinate. This is a central tenet of the multiple-resource model (Wickens, 2002). For example, simultaneous loadings of the primary driving task and a secondary task on the visual-manual channel are an example of such structural overlap. As a related finding, it has been found that sudden violations of expectations in the primary task may amplify the effect of secondary-task-based distraction, probably caused by the sudden co-occurrence of demands placed on the executive attention component of WM (DeLucia & Tharanthan, 2009). For more details on the multiple-resource model and other theoretical models, see the section Psychological Mechanisms Underlying Driver Distraction: Promising Theories and Models.

- *Visual-manual interactions produce different profiles of interference with driving than auditory-vocal interactions*, and the magnitude of interference by visual-manual tasks is greater. Manual tasks tend to require more eyes-off-road time and interfere more with detection of events occurring on or near the road than do auditory-vocal tasks, even when the total task times for auditory-vocal tasks are longer (Angell et al., 2006; Dingus & Klauer, 2008). For more confirming evidence, see Bowyer et al. (2009); Hsieh et al. (2009); Shutko, Mayer, Laansoo, and Tijerina (2009); and Young et al. (2005). In the Shutko et al. study, it was found that reading a text message on a handheld phone could take the driver's eyes off the road for 11 s, compared with about 2 s for listening to the text message with text-to-speech output. These findings are also consistent with results from naturalistic driving showing that talking or listening on a phone while driving was no riskier than normal driving, whereas manually dialing a handheld device (which requires looking away from the road) was almost 2.8 times riskier than normal driving. Texting, a very intensive visual-manual task, poses the highest risk measured to date (increasing risk by 2,300% compared with just driving; Hanowski, Olson, & Bocanegra, 2009); however, other multistep tasks also increase risk significantly compared with just driving (to 3.1 times as high for complex tasks; Klauer, Dingus, Neale, Sudweeks, & Ramsey, 2006; Klauer, Sudweeks, Hickmanm, & Neale, 2006).
- Looking away from the road increases crash risk. It also forms the single largest contributing factor to crashes when an unexpected road event or condition occurs just prior to the crash (Dingus & Klauer, 2008). For example, in 93% of rear-end crashes observed during the 100-Car study, the driver glanced away from the forward roadway within 3 s of the crash-precipitating event (Dingus & Klauer, 2008). Finally, the 100-Car study showed that when the eyes were off the road for 2 s or more within 6 s of a conflict's

onset, the risk of a crash or near-crash was elevated by more than 2 times (Klauer, Guo, Sudweeks, & Dingus, 2010; Lee et al., in press).

- *Effects of cognitive load and auditory-vocal loads (when separated from other demands and their effects) are measurable.* In particular, the effects of cognitive tasks turn out to be smaller (producing less interference with driving tasks) than those of visual-manual tasks in many conditions (Angell et al., 2006; Engström, Johansson, & Ostlund, 2005; Mattes, Föhl, & Schindhelm, 2007; Victor, 2005; Victor, Engström, & Harbluk, 2009; Victor, Harbluk, & Engström, 2005). Note, however, that device interactions of a cognitive nature often are initiated by input through some sensory modality (visual, auditory, or tactile) and thus occur in combination with other types of loading.
- Billboards and other highly salient, non-driving-related objects outside the vehicle may interfere with driving performance and driving safety, depending on their type and location. Despite the scarcity of systematic research into this topic, one naturalistic study demonstrates that some types of billboard (especially dynamic types) may receive driver glances lasting as long as 0.75 s (Beijer, Smiley, & Eizenman, 2004). Furthermore, Wallace (2003) reports evidence that the presence of billboards is related to elevated crash risk in two circumstances: when billboards are located near intersections and when they are located on long, monotonous roads, where the driver may be surprised by the sudden appearance of a billboard. Finally, Crundall, Van Loon, and Underwood (2006) found that signs that were located in the driver's zone for potential hazards (i.e., at street level instead of at raised level) were fixated more frequently but were remembered more poorly than when the signs were located outside this zone. Apparently, attentional capture by a salient sign is no guarantee that the attended sign will be recognized later on.

Findings on distraction caused by cell phones and cell phone–enabled tasks. Given the enormous number of studies in the literature that have focused specifically on cell phone use (or tasks put forward as representing cell phone tasks), it is most instructive to review this literature in terms of two meta-analyses that have identified overarching findings that are robust across individual studies. The two meta-analyses are those of Caird, Willness, Steel, and Scialfa (2008) and the one by Horrey and Wickens (2006). These meta-analyses include the studies of Strayer and colleagues (Strayer, Drews, & Crouch, 2003; Strayer & Johnston, 2001).

Caird et al. (2008) reviewed 106 studies in the literature that had been published during the period from 1969 to 2007. From these, a set of 33 performance studies was selected for a meta-analysis of cell phone use in two categories: (a) response times to critical events and (b) variability in vehicle control (lane position, headway, and speed). Caird et al. (2008) also examined phone type (handheld or hands-free), type of research venue (laboratory, simulator, and on road), conversation target (passenger or nonpassenger), and conversation type (information processing, experimental task, or naturalistic conversation).

Horrey and Wickens (2006) examined 23 studies (some with multiple conditions) that were conducted across a range of venues: simulators varying in fidelity and some road or track settings. Studies varied in the types of "cell phone conversation tasks" they used and in whether the conversations were remote (over the phone) or in vehicle with a passenger.

Both studies agree that slowed response times to events (on the order of 130 ms to 250 ms) during conversations are associated with *all* types of conversations: those held with passengers in the vehicle as well as those held via technology, both hands-free and handheld. The effect of conversation is similar: Talking to a passenger had the same effect as talking on a cell phone of either type. Both studies also concluded that conversation tasks had the largest interfering effects on time to respond to critical stimuli; had smaller, nonsignificant effects on lane keeping and vehicle control variables; and had a small effect on driving speed (in which speed slowed slightly during cell phone use). Interestingly, Horrey and Wickens (2006) commented that engagement may play a larger role for conversation tasks than for other types of task and hypothesized that the costs of engagement may be more pronounced for intense conversation (those that are emotionally loaded or heated).

In interpreting and integrating the literature on cell phone effects with the rest of the literature on distraction, a few observations are important:

1. Magnitude of response time delays during conversation: The slowing of responses to events during conversations (on the order of 130 ms to 250 ms) is quite consistent with effects on response times measured for other tasks. This range of response time delays places conversation at the upper end of the auditory-vocal tasks and the lower end of the range for visual-manual tasks that have been measured in studies such as the CAMP Driver Workload Metrics Study (Angell et al., 2006). This is perhaps not surprising, since the studies represent a mixture of handheld (visual-manual) and hands-free (auditory-vocal) interface types. Caird et al. (2008), however, did find that effects of conversation were more pronounced in older than in younger drivers (460 ms vs. 190 ms to respond to events).
2. Events detected or missed: Neither meta-analysis reported percentage of events missed (or not detected) during conversation, although this measurement is another critically important element of responsiveness to events. Some research has, however, been done to address effects of conversations on event detection (Hsieh et al., 2009), and these effects lie roughly within the range of other auditory-vocal-cognitive tasks.
3. Tasks used and usage conditions: Many phone-related tasks that have been studied did not involve real participant-initiated conversations, or conversation at all, but instead involved artificial tasks of various types done in an auditory-vocal modality. Moreover, in these studies, driver behavior was investigated in specific (experimenter-set) conditions with respect to traffic density and driving task. Thus, caution must be exercised in generalizing from the findings of cell phone studies. Caird et al. (2008) found that use of an artificial cognitive task to approximate conversation resulted in greater slowing of response times to events than did naturalistic conversation (330 ms vs. 140 ms).

Driver Characteristics (Figure 1.1, Box 6)

Driver characteristics are sources of mental, physical, or behavioral variation distinguishing individuals from each other. They can interact with the demands imposed by tasks in affecting driving performance. To a lesser extent, they may also affect the likelihood of a crash or a near-crash, given a certain level of driving performance (e.g., some drivers are better able to recuperate from their distracted driving performance than are others, thereby reducing crash risk). Generally speaking, driver characteristics refer to three sources of variation: age-based differences, gender-based differences, and experience-based or learning-based differences (including effects of training and feedback). Some other sources have been grouped under the heading of “other differences”; these include differences in cognitive ability and general emotional state.

The empirical evidence with respect to the relationships between driver characteristics, on one hand, and driver distraction, on the other, is still incomplete in most cases. Therefore, only the most relevant empirical findings are briefly summarized.

Age-based differences. Older individuals experience a decline in sensory, motor, and cognitive functions, and this decline may be part of the reason they are more vulnerable to driver distraction. For example, older drivers have been shown to be poorer at multitasking performance and in the ability to discard irrelevant information (e.g., Koppel, Charlton, & Fildes, 2009).

DeLucia and Mather (2006) showed that older drivers extrapolate motion more slowly than younger drivers. When distracted by a secondary activity, their projections about the movements of surrounding traffic during that time are likely to be incorrect, leading to an incorrect assumption of lower risk, since surrounding traffic will have advanced farther than they will expect.

However, at the same time, many older drivers are known to compensate for their declining abilities, when they are aware of them. For example, they may avoid the use of secondary devices while driving, use them less often (Angell et al., 2006), drive at slower speeds, drive on familiar routes only, or drive in lower-risk conditions (e.g., when traffic density is low).

Younger drivers (especially teenagers) also experience problems with distraction. However, for them, distraction is caused not by declines in vision or cognition but, rather, by the lack of driving experience (Fisher & Pollatsek, 2007; McGehee, Raby, Carney, Lee, & Reyes, 2007) and by an elevated willingness to take risks (Compton & Ellison-Potter, 2008). In addition, other social factors have been found to exacerbate distraction for younger drivers when they are present, such as showing off, talking excessively to peers while driving, and being willing to take risks while driving (Covey, 2009; Lee, 2007; Lerner & Boyd, 2005; U.S. Department of Transportation, 2009).

A major methodological problem inherent in many studies that address age effects is that the effects of age (if any) may be confounded with those of driving experience. Such confounding effects can sometimes be removed through statistical means (Young, Regan, & Lee, 2009).

Gender-based differences. The evidence with respect to gender-based differences in driver distraction is mixed. For example, older females have been reported to be more vulnerable to distraction while driving than their male counterparts (Hancock, Lesch, & Simmons, 2003). To the extent that such differences are observed, these effects seem to be attributable to experience factors and to social factors rather than to biological differences in multitasking or time-sharing ability (K. L. Young et al., 2009).

Experience-based or learning-based differences. There is evidence that multitasking and attention-related performance is (partly) a skill (or set of skills) that is trainable. Although it is not always easy to define these skills precisely or to determine precisely for what driving tasks they are important, there is evidence that the following types of multitasking skill are, at least partly, trainable:

1. *Visual scanning strategy:* for example, visually scanning sources of potential danger outside the vehicle in an adequate way (Fisher & Pollatsek, 2007; Fisher, Pollatsek, & Pradhan, 2006; Horrey, Lesch, Kramer, & Melton, 2009).
2. *Task management strategy:* the efficiency of interruption management or resource allocation strategy (Cades, Trafton, & Boehm-Davis, 2006; Gopher, 2007; Gopher, Weil, & Siegel, 1989). An example of the importance of task management strategy was provided earlier: Older drivers may change their driving style in dense traffic conditions.
3. *Size of the visual lobe* (also called *functional field of view* or *useful field of view* [UFOV]; Ball & Owsley, 1993): the skill of detecting events in the periphery of the visual field (Ball, Roenker, & Bruni, 1990; Pringle, Irwin, Kramer, & Atchley, 2001). A test developed for measuring this skill, called the UFOV, has been used to relate visual lobe differences to driving performance (Owsley et al., 1998). However, it is not yet clear if and by how much the UFOV is related to the amount of distraction caused by particular secondary tasks (Hurts & Sjardin, 2009).

Other differences. In this final subcategory, we group the following driver characteristics: time-sharing ability (Ackerman, Schneider, & Wickens, 1984), WM capacity (Bühner, König, Pick, & Krumm, 2006; Conway et al., 2005; Engle, 2002), general (physiological) state (e.g., arousal, alcohol intoxication, and fatigue; Matthews & Davies, 2001; Rakauskas et al., 2008; Williamson, 2007), or general psychological and physical well-being. The latter set includes, for example, grieving while driving (Rosenblatt, 2004). Verschuur and Hurts (2008) report effects of general psychological and physical well-being (as measured by questionnaire items) on the probability of committing self-reported attentional errors while driving: The worse the psychological or physical well-being, the higher the frequency of self-reported attentional errors.

Risk of Crashes and Near-Crashes (Figure 1.1, Boxes 0 to 5)

Findings on the risk of crash and near-crashes come from two sources: (a) counts and derived statistics based on crashes and fatalities recorded in national accident databases and (b) estimates of risk computed from samples of research data collected in epidemiological studies. A review of findings from both sources suggests that the actual numbers of distraction-related crashes in national databases are fewer in number than the early epidemiological studies predicted. Nonetheless, this number (much smaller than the number of alcohol-related crashes: ~32%, or 11,773 fatalities in alcohol-impaired driving crashes in 2008) should be reduced.

Findings from U.S. national crash databases. According to the National Highway Traffic Safety Administration (NHTSA), distraction accounted for 5,870 fatalities in the United States in 2008 (out of the 37,261 fatalities that occurred in motor vehicle crashes that year; NHTSA, 2009). Although a serious loss of life, the numbers of fatalities and crashes in the United States have declined slightly in the past decade. In addition, the number of fatal crashes attributed to distraction remained largely unchanged at half the rate of alcohol-impaired crashes (Sayer & Flannagan, 2011; Virginia Tech Transportation Institute, 2009). In comparison, in the same period, the number of cell phone subscriptions has grown dramatically, to more than 250 million. In other words, it remains unclear from the NHTSA data how the factors that underlie distraction-based fatalities have changed over time.

Therefore, there is a need for empirical studies aimed at identifying and understanding distraction-based crashes more precisely than was done before. It is to these studies that we turn next.

Findings from estimates of risk based on samples in studies. Two types of epidemiological studies are retrospective and prospective naturalistic studies. In prospective studies, the timing between device use (such as a cell phone call) and the onset of a crash is measured through instrumentation set up in advance, and actual baselines are used. In retrospective studies, the timing is crudely estimated and baselines are estimated (sometimes only by human memory of events; Young & Schreiner, 2009). Obviously, these differences have implications for the accuracy of estimating crash risk.

Based on these differences, early estimates of cell phone risk (e.g., McEvoy et al., 2005; Redelmeier & Tibshirani, 1997) derived from retrospective studies were problematic. Redelmeier and Tibshirani (1997) estimated the risk of crashing while talking on a cell phone to be 4 times that of just driving and argued that it was similar to the risk of driving while intoxicated. McEvoy et al. (2005) derived an odds ratio of similar value. Moreover, at the time of these early studies, few hands-free systems were in use, and insufficient data were available to estimate risk for different types of these systems, so the estimates largely applied to handheld devices.

Finally, it is worth noting that both studies involved one specific epidemiological method known as "case-crossover." Prieger and Hahn (2007) have argued that a primary flaw of this method is that it samples only those drivers who have crashed. Therefore, any factor that increases crash rates while also exerting an independent positive effect on risk factors being evaluated (such as cell phone use) can bias the case-crossover results upward. For example, factors such as high-risk-taking or high-novelty-seeking behavioral characteristics might characterize both drivers who crash and those who use cell phones while driving. Since the case-crossover method does not examine drivers who might have used the phone and did not crash, there is no way to know whether this bias has occurred.

Data from naturalistic studies, including the 100-Car Naturalistic Study (Dingus et al., 2006; Klauer, Dingus, et al., 2006; Klauer, Sudweeks, et al., 2006) and naturalistic studies of commercial truck drivers (Hanowski et al., 2009), allow the derivation of more precise odds ratios. These studies provide information not only on the risk of crash and near crash but also, for example, on the *conditions of use* and the occurrence of *unexpected events* that enter into crash risk.

Naturalistic studies have now generated enough data to yield odds ratios for a wide range of tasks, as shown in Table 1.4, in which intensive visual-manual tasks interfere with driving the most (increase crash risk by 9 times, compared with just driving). At the upper end of the range is the task of texting while driving, which increases crash risk by a dangerous 23 times (2,300%; Blanco et al., 2009, in press; Hanowski, et al., 2009). In contrast, dialing a portable cell phone increased the risk by only about 3 times, and conducting a conversation on a handheld portable phone was even less risky (odds ratio of about 1.3). These data are compiled from naturalistic studies of light vehicles, heavy trucks, and heavy truck driving-related activities (Dingus, 2009).

These results and others (Hahn & Prieger, 2007; Prieger & Hahn, 2007; Young, 2001; Young & Schreiner, 2007, 2009) differ from the fourfold crash risk increase estimated by Redelmeier and Tibshirani (1997) and by McEvoy et al. (2005) for cell phone use. However, they are consistent with the findings from experimental literature, which show very little intrusion of auditory-vocal tasks and conversation on driving.

Effects of contextual factors on crash risk (Figure 1.1, Boxes 4 and 5). The risk of crash from distraction depends on factors that go beyond the demands that are imposed by primary and secondary tasks (Box 2). These include (often understudied) factors related to the types of drivers who choose to engage in secondary tasks while driving, the time (during driving) that they decide to initiate secondary tasks, the traffic-related conditions in which the tasks are performed, and the types of event most often co-occurring when there is a crash or near-crash, such as roadway hazards. Contextual factors also include the presence of distraction-countering technology in the vehicle or on the road and the "forgiveness" of the road and/or vehicle.

Roadway hazards and other road-based events. Although many critical road objects and events are expected by the driver and responded to in a more or less routine way, others are not. Researchers who analyzed distraction-related crashes from national crash databases converged on two findings regarding the conditions in which drivers engage in secondary activities (Tijerina, Angell, Austria, Tan, & Kochhar, 2003).

First, drivers tend to engage in discretionary in-vehicle activities in conditions in which they expect no trouble, for example, (a) in daylight on a level straightaway, (b) on dry pavement in clear weather, and (c) with speed between 45 mph and 55 mph (varying up to 65 mph). Second, crashes may occur when these expectations are violated and some random, unpredictable events occur on the road.

Obviously, unexpected objects and events outside the vehicle may also be nontraffic related (such as billboards). Their distracting potential was already discussed in the context of secondary, non-device-based activities.

Behavioral factors of secondary task use. Rauch et al. (2009) showed that success in task switching between primary and secondary task depends on the ability of the driver to correctly estimate the situational demands of the primary task (i.e., driving). Also, the ability of drivers to switch to a secondary task has been found to depend on the degree of interference of this task with driving (Petit, Clarion, Ramon, & Collet, 2009). Other interactional strategies have been described by Esbjörnsson, Juhlin, and Weilenmann (2007).

Frequency of use is important when estimating the crash risk that may result from performance degradation (Box 3 in Figure 1.1). Secondary tasks that impose high demand on the driver (or high intrusion on driving) and that are engaged in frequently will pose a higher risk of crash than will tasks that pose lower demand and are engaged in less frequently, all other things being equal (Wierwille & Tijerina, 1998).

Table 1.4. Relative Risk Odds Ratios for Crash/Near-Crash for Non-Driving-Related Task Interactions

Task/Interaction	*Light Vehicle Data*	*Heavy Vehicle Data*	*Heavy Truck Driving Related*
Check speedometer			0.3
Interact with occupants		0.4	
Talk/listen to hands-free phone		0.4	
Look outside vehicle		0.5	
Interact with passenger	0.5		
Talk/listen to CB		0.6	
Adjust radio		0.6	
Drink beverages	1		
Talk/listen to handheld device	1.3		
Adjust instrument panel		1.3	
Eat	1.6		
Handle CD	2.3		
Dial handheld device	2.8		
Apply makeup	3.1		
Reach for object		3.1	
Read	3.4		
Read book, paperwork, newspaper		4.0	
Perform personal grooming		4.5	
Dial handheld device		5.9	
Use/reach for electronic device		6.7	
Look at paper map		7.0	
Use calculator		8.2	
Reach for moving object		8.8	
Write on pad/notebook		8.9	
Interact with, look at dispatching device		9.9	
Text message on cell phone		23.2	

Source: Dingus (2009).
Note. Tasks/interactions deliberately placed in order of increasing odds ratio.

Findings from a naturalistic study (Angell, Perez, & Hankey, 2008) show that both frequency and duration of interaction with secondary devices are important for evaluating eyes-off-road time associated with distraction. However, in the same study, it was also found that for some types of goal and task interaction patterns, frequency has a larger impact on eyes-off-road time, whereas in other cases, duration has a larger impact. Therefore, it is possible that human factors practitioners can use this information about trade-off differences to redesign tasks so that eyes-off-road time is maximally reduced.

The precise way in which non-driving-related objects or events are scanned visually also depends on the distinction between noticing an object or event, on one hand, and watching an object or event, on the other hand. Noticing often occurs involuntarily and, therefore, usually cannot be avoided by the driver (unless, of course, his or her attention is drawn by objects deliberately carried into the vehicle). It is mainly determined by bottom-up influences, such as stimulus newness or onset, and may be only brief in duration.

On the other hand, watching the same object or event usually takes more time and is more the result of conscious deliberation. It depends more on top-down influences, such as the degree to which the object or event arouses interest, as when studying an advertisement sign. Therefore, it can, in principle, be avoided by the driver (Theeuwes, 1996, 2001). This distinction between noticing and watching can be used by human factors practitioners, for example, to estimate the impact of visual scanning of non-driving-related objects located along the highway, such as advertisement signs.

Finally, back-channel communication is an important contextual factor determining whether a driver will be distracted by a secondary task or device (Clark & Brennan, 1991). For example, front-seat passengers may interrupt an ongoing conversation with the driver when they realize that the traffic situation is too dangerous for the driver to engage in anything but driving.

Distraction-countering technology and road or vehicle "forgiveness." *Distraction-countering technology* refers to the presence of automatic warning systems in the vehicle or on the road, which may be very effective. Obviously, the more often this technology is used, and the higher its quality, the less likely a (near-) crash will be. These technologies are further discussed in the section Measurement, Mitigation, and Management.

Forgiveness of the road or vehicle refers to the presence of car or road characteristics affecting the chance that a driving maneuver is considered safe or unsafe (tolerance bandwidth). For example, a highway equipped with highway dividers is intrinsically safer than a freeway without such dividers. Further discussion of these design characteristics is outside the scope of this chapter.

Final Note

It is expected that new driver assistance and safety-enhancing technologies will make their appearance on the consumer market in the coming 10 years or so. Therefore, human factors research into driver distraction is not likely to diminish. New findings are expected to come out of this research, both experimental and naturalistic, and old ones to be revisited. This will also depend on the availability of validated models and theories describing how driver distraction is caused and predicting how it will affect driving safety. It is to these models and theories that we turn now.

PSYCHOLOGICAL MECHANISMS UNDERLYING DRIVER DISTRACTION: THEORIES AND MODELS

Introduction

In the section Sources of Driver Distraction and Demand, it was shown that the co-occurrence of the task demands of multiple tasks with unexpected events on the road can give rise to crashes. The present section addresses the attentional processes through which distraction or delayed responding to co-occurring events in the presence of overload leads to driving errors. These processes cannot always be observed. This allows for speculation into how those attentional problems arise, in the form of different theories and models.

A Hybrid Psychological Model for Understanding Driver Distraction

A hybrid psychological model is presented in Figure 1.2, summarizing the constructs and mechanisms used by the most influential psychological theories and models related to driver distraction.

Note that the focus in Figure 1.2 is on the events and processes occurring *before* any change in driving performance or an imminent crash can be observed. The various components of Figure 1.2 will be discussed below.

The core of Figure 1.2 is formed by the box labeled *Working Memory*. This label refers to "the system or mechanism underlying the maintenance of task-relevant information during the performance of a cognitive task (Baddeley & Hitch, 1974; Daneman & Carpenter, 1980)" (Shah & Miyake, 1999, p. 1).

We adopt Cowan's (1997, 1999) memory model for relating attentional phenomena to working memory phenomena. According to Cowan, all memory elements reside in a single memory structure, called "long-term store" by him (and long-term memory, or LTM, by others). WM forms the active part of the long-term store and is, therefore, also called "activated long-term memory" by him. Within WM, three subdivisions can be distinguished that contain elements of different types and activation levels. Driver distraction may be considered a disturbance in the planned way of managing attentional tasks, depending on the particular WM subdivisions that are involved in these tasks.

WM subdivisions. WM contains (a) a limited capacity (can hold only few items) but very active focus of attention, (b) less active and transient (short-duration) short-term stores, and (c) a virtually unlimited-capacity, rather inactive, but long-duration, long-term WM (LTWM). (Note that in Cowan's [1997, 1999] memory model, only the first two WM subdivisions are distinguished.) The more active a subdivision, the more conscious the driver is of its contents.

1. The *focus of attention* is the most active part of the long-term store. It may contain only a few (three to five) elements of unlimited duration as long as they remain in the focus. Although its capacity is small, the elements in the focus can be linked to chunks residing in LTM, thereby increasing its effective capacity. It is used for high-level task management, such as goal setting (e.g., determining where to drive) and monitoring performance outcomes (e.g., determining whether one has reached the destination). When behavior is heavily dependent on the focus, "pure" time sharing (parallel performance of multiple tasks) is not possible.
2. *Short-term stores* differ by modality and type of code (e.g., verbal or spatial processing code; Baddeley & Hitch, 1974). They are similar to the various resources distinguished by the *multiple-resource model*, to be discussed later in this section. They also come close

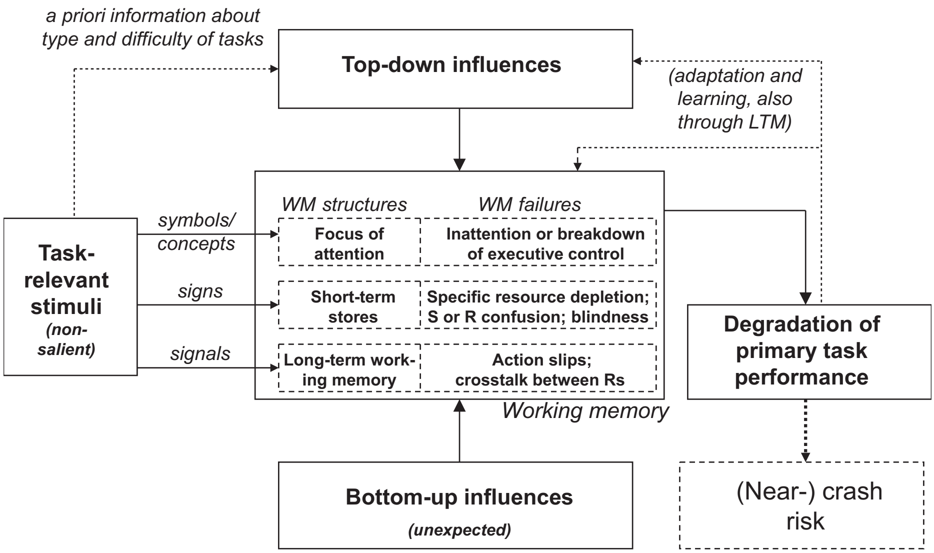

Figure 1.2. *Hybrid psychological model for understanding mechanisms involved in the causation of driver distraction. LTM = long-term memory; S = stimulus; R = response.*

to the traditional notion of short-term memory as the place where unrelated memory elements can temporarily be stored. Their average activation level is their primary limitation, as this level decays over time, with the result that their elements are permanently lost after 10 s to 20 s, unless they are rehearsed. The stores are involved in executing routine tasks that, however, are not performed automatically (e.g., decelerating or accelerating in response to traffic lights changing colors). These tasks also involve the coordination of the execution of lower-level schemata (low-level task management). A limited amount of "pure" time sharing is possible when behavior is primarily controlled by the short-term stores. The more different the types of code (e.g., spatial and verbal), the easier it is to time-share tasks.

3. *LTWM* is a construct borrowed from Ericsson and Kintsch (1995). It contains task-specific clusters (also called *schemata*) of declarative and procedural information that are used for skilled task performance. These clusters reside in LTM, are not limited by capacity, and are permanent (will not get lost), although their average activation level is low when they are not used. However, when they are needed for task execution, they may be activated (retrieved) relatively easily, depending on the presence of appropriate contextual cues. As task execution continues, they may be modified or updated. The declarative parts are similar to *situation models*: mental representations (often spatial in nature) of the parts of the world that are relevant to the task at a particular moment in time, for example, knowing the average density of surrounding traffic. The procedural parts are conglomerates (chunks) of response- and perception-related information (e.g., watching over left shoulder when making a left turn; pressing brake pedal when gap with vehicle ahead is diminishing). LTWM shares some features with Baddeley's (2000) *episodic buffer*. Several schemata may be active at the same time, allowing parallel processing when behavior is largely under control of LTWM.

Task-relevant stimuli. Task-relevant stimuli are nonsalient stimuli that originate in the driver's sensory buffers and have been processed by the driver to the degree that they are recognizable as task relevant. Obviously, the higher the frequency of these stimuli, the more attention they demand from the driver. If they represent unexpected traffic-related events (e.g., a danger on the road ahead), the driver will focus his or her conscious attention on them, and ongoing tasks must be aborted or paused (called *symbols* in Figure 1.2). On the other hand, if they represent signs, and the driver must respond to them in a more or less routine (although nonautomatic) way (e.g., when the traffic light changes color), they enter the short-term stores. Finally, if the stimuli are merely signals to which the driver must respond in a skill-based manner (e.g., when the road ahead curves to the right or to the left), they enter LTWM and trigger the automatic execution of a schema (e.g., lane keeping).

Top-down influences. Top-down influences are usually attributed to the role of the central executive (CE) in determining to what stimuli, events, or tasks the driver wants to (or thinks he or she must) pay attention. This role is based on intentions or task goals to be pursued (e.g., wanting to drive home as soon as possible), expectations (e.g., estimations of what is likely to happen on the road ahead), and task priority.

Together with bottom-up influences (next subsection) and the influences of task-relevant stimuli, top-down influences determine the contents of the focus of attention and form the basis of high-level task management, such as goal setting, task (re)configuration, monitoring of performance outcomes, and complex problem solving, but also deliberately performed perceptual, memory, or motor acts (e.g., trying to remember the city in which one stayed a week ago). For more information on the role and nature of the CE and executive control processes, see Groeger (2000), Norman and Shallice (1980), Posner and Peterson (1990), and Shallice (1982).

Bottom-up influences. These influences refer to low-level aspects of external stimuli, such as salience, onset, and newness, that make a driver involuntarily attend to these stimuli if they appear near the spatial location where (or near the time when) another stimulus was expected (stimulus capture; Jonides & Yantis, 1988). They may be task relevant or not. Highly practiced skills or behaviors may also (involuntarily) attract attention in this bottom-up sense, even if they are inappropriate at the current moment or location, for example, in the case of "action slips." Finally, the amount of effort that is necessary to attend to a particular stimulus (e.g., amount of visual scanning necessary to detect a stimulus appearing in the periphery of the visual field) is also considered a bottom-up influence. Bottom-up influences may determine the contents of both the focus of attention and the short-term stores. The driver usually becomes aware of these influences when they have occurred, although he or she has no or little control over when and whether they occur.

Degradation of primary task performance. If distraction is severe enough, it may result in driving errors (behaviors that compromise safe driving) or even in degraded driving performance. The precise result of distraction will depend on factors that were reviewed in the section Sources of Driver Distraction and Demand.

Adaptation and learning. Finally, drivers may learn to prevent future driving errors through a process of feedback and learning.

Levels of driver distraction. It was seen that various combinations of top-down factors, task-relevant stimuli, and bottom-up factors influence the contents of WM. In this context, driver distraction may be seen as any disturbance in the steady-state, planned way of allocating attentional resources and managing attentional tasks, which can be caused by an array of factors.

We briefly describe a representative set of these factors in the following, using the distinction between subdivisions of WM as an organizing framework. The factors were derived from the general psychological literature with respect to multitasking, time sharing, and interruption management (e.g., Norman & Shallice, 1980; Pashler & Johnston, 1998; Rasmussen, 1983; Shiffrin & Schneider, 1977; Wickens, 2002, 2005).

Note that some (more or less) obvious factors were deliberately left out from this inventory for the sake of simplicity. For example, poorly practiced tasks and poorly designed displays or traffic signs may disrupt the "normal" (anticipated) execution of tasks (driving related or not) at any WM level. Also, note that disturbances may cascade upward or downward from one WM level to another, thus introducing new disturbances and exacerbating the consequences of the original disturbance (see also the discussion of the three levels of control, introduced in the section Sources of Driver Distraction and Demand).

1. *Level of focus of attention.* Here, driver distraction takes on the form of either a general state of inattention (as in daydreaming) or a breakdown of executive control: The limited capacity of the focus is temporarily exceeded (Lavie, Ro, & Russell, 2003; Pashler & Johnston, 1998). Engle, Kane, and Tuholski (1999) showed that people who are able to prevent such breakdown also have high WM spans, which may be the basis of successful performance of complex cognitive tasks. Such breakdown may occur if (a) too many (unexpected) events must be responded to by the driver at the same time (e.g., the driver approaches a busy intersection), (b) too much task (re)configuration is required when switching from one task to another (e.g., after a complex passenger question has been answered, a monitoring routine is started too late, resulting in an important exit sign being missed) (Monsell, 2003; Trafton & Monk, 2007), or (c) complex problem solving is required by one of the tasks (e.g., while answering a complex passenger question, the driver forgets which turn to make to reach his or her destination).
2. *Level of short-term stores.* Here, driver distraction takes on the form of (a) overloading of specific resources (e.g., driving and watching the navigation system display at the same time may cause decay of one or more visual memory elements to the point of becoming inaccessible; Wickens, 1980); (b) confusion among similar elements (stimuli or responses) that are close to each other in terms of spatial location or time of occurrence (Wickens, 1991), for example, when a left-pointing arrow on the navigation system display is confused with an unrelated right-pointing arrow on a traffic sign outside the vehicle; or (c) inattentional (or change) blindness, whereby stimuli (or changes in stimulus patterns) are not (consciously) perceived although in normal circumstances they would have been perceived (Carpenter, 2002; Rensink, 2002).
3. *Level of LTWM.* At this level, processing is able to resist distraction to a large extent because of the high degree of automation of skill execution (Desimone & Duncan,

1995; Posner & Peterson, 1990; Shiffrin & Schneider, 1977; Theeuwes, 1996). Nonetheless, driver distraction may take on the form of (a) action slips (Reason, 1990), in which the driver performs a behavior in association with a wrong stimulus or at the wrong time, possibly because of the driver's failure to monitor performance outcomes or to inhibit familiar or highly practiced (but inappropriate) habits (e.g., driver forgets to make a turn on a familiar road for doing an errand and, instead, drives straight home), or (b) cross talk (Hurts, 2011; Navon & Miller, 1987), whereby responses belonging to different tasks are confused with each other because they require similar, but incompatible, movements. For example, the driver prepares to turn the steering wheel to the right but is confused by a planned movement of his fingers on the volume knob of the radio tuner in the opposite direction (i.e., lowering volume).

The Multiple-Resource Model and Visual Scanning Models

The multiple-resource model. The multiple-resource model emphasizes the limited possibility for divided attention as people engage in multitasking activities, primarily at the operational level of driving behavior. It provides a high-level, practical description of the types of mental resources required by everyday tasks, as determined by easy-to-conduct task analyses. Although based on recent research insights about the structure of the human brain, the model deliberately abstracts away from the detailed mental mechanisms underlying task execution and interference (Wickens, 2002, 2005).

According to this model, the degree of time-sharing success between any two tasks can be predicted by the joint difficulty of the two tasks (demand level) and the degree to which they overlap in the demand for common resources. The resources vary along multiple dimensions:

1. Processing stage (perceptual-cognitive vs. action or early vs. late processing)
2. Processing code (verbal vs. spatial)
3. Perceptual modality (auditory vs. visual)
4. Visual channel (focal vs. ambient)

For example, driving is primarily a visual-spatial-motor task and therefore is compatible with secondary tasks that are auditory and language based. Therefore, the multiple-resource model predicts less driver distraction when secondary tasks are assigned to different input and output modalities.

A computational version of the multiple-resource model has been used to successfully predict how much better interfaces using separate resources are when compared with those that demand common resources (Horrey & Wickens, 2003). This computational model calculates the total amount of interference expected between two tasks with a conceptual formula as follows:

$$\text{Total Interference} = \text{Demand} + \text{Conflict}.$$

In this equation, *Demand* refers to the sum of the resource requirements for each task, and *Conflict* refers to overlapping resource needs of concurrent tasks and the penalties associated with these conflicts. *Total Interference* is a dimensionless, rank-order value presumably correlated with degradation on one or both tasks.

To implement such a computational model, one needs the following:

1. A task analysis that identifies the demands placed by the task on resources and codes them as a vector of resource demands.
2. A conflict matrix that determines the penalty of conflict between resource pairs and across tasks.
3. A formula for computing overall dual-task interference on the basis of the combined demand and conflict values.

Note that the multiple-resource model is not able to predict which of two time-shared tasks will suffer the most from the total interference, as computed by the formula. At present, little is known about the heuristics that drivers might use to prioritize their attention to concurrently performed tasks. (However, see later discussion of newer models that have the potential to compensate for this caveat.)

Also note that whether interference among two or more time-shared tasks is observed depends not only on resource demands but also on the notion of compatibility. Specifically, certain types of processing code (e.g., verbal or spatial) are more compatible with certain modalities than others. Therefore, if two independent tasks both involve the same type of processing code (e.g., spatial direction), it may be more advantageous to present the task stimuli in the same input modality (e.g., vision) rather than in different modalities. The notion of compatibility also applies across the various processing stages: stimulus–central processing–response compatibility (Wickens, Vidulich, & Sandry-Garza, 1984).

Visual scanning models. Visual scanning models address the limitations of visual selective attention that may be observed if many visual events or objects must be attended to at the same time or in close succession. These models have their historical roots in seminal work done by Senders (e.g., Senders, Fisher, & Monty, 1978), Moray (1986), and Sheridan (1970), all of whom contributed to the foundation for optimal sampling theory. The work of Wade Allen (e.g., Allen & McRuer, 1979) and Thomas Rockwell (e.g., Rockwell, 1972) on visual scanning in driving further contributed to the basis for these models.

SEEV is a model of steady-state visual attention and scanning movements to areas of interest in a display (Horrey, Wickens, & Consalus, 2006). The acronym SEEV refers to the set of factors determining the part of the visual field that is likely to draw visual attention: salience (S) of an area, effort (E) to move between areas (in terms of distance), expectancy (E) that something will happen at an area, and value (V) of the information gained. The first two factors are classified as bottom up and the latter two as top down. Movement of the eyes to areas of interest occur probabilistically, with a frequency proportional to the interest of an area, which in turn depends on the strength of the factors S, E, E, and V.

The related N-SEEV model predicts the *noticeability* of a visual event (that occurs in the context of scanning), given a point of eye gaze (Wickens, Hooey, Gore, Sebok, & Koenicke, 2009). The noticeability of an event is influenced by four factors: (a) top-down, (b) bottom-up, (c) workload-related, and (d) physiological factors, that is, degree of eccentricity from the center of the visual field (with greater eccentricity leading to decreased noticeability). In addition to salience, bottom-up factors refer to contrast, uniqueness, onset (blinking), and surrounding (clutter). The effect of workload in the model is to shrink the functional field of view, essentially amplifying the cost of eccentricity.

Additionally, the SEEV model has been linked to situation awareness in the so-called A-SA model (Wickens, McCarley, et al., 2008), in which A (attention) corresponds to SEEV as well as to Endsley and Garland's (2000) Level 1 situation awareness. This set of interrelated models may (when completed) provide a more powerful set of predictions about glance behavior and event responsiveness during secondary task performance than has been possible thus far.

Models of Task Interruption and Resumption and Goal Activation

Trafton, Altmann, Brock, and Mintz (2003) have applied the *goal-activation model* (Altmann & Trafton, 2002) in studying interruptions to perform a secondary task, such as answering an incoming phone call. In this model, goals are central to the way that people process interruptions and resume tasks. Understanding goal retrieval after interruption may provide a powerful way to predict behavior in the context of driver distraction.

In the goal-activation model, activation of items in memory occurs when a driver attempts to resume the primary driving task after an interrupting secondary task. Activation of primary task goals in memory will decay as a function of the lag, possibly enough to suspend the items from WM. Executive attention can increase an item's level of activation by rehearsal or attention to it. Also, the occurrence of environmental contextual cues can "prime" the activation of items in memory. Importantly, if a goal that relates to resuming a primary task, such as driving, has been suspended, it must acquire new activation to become retrievable through priming.

Thus, the theory predicts that an interrupted driver must have access to contextual cues to remember to return to the primary task. Within this model, two attributes of timing may predict the interruption and resumption lags. The interruption lag occurs between a "notice of interruption" and the "start of the interruption." The resumption lag occurs between the end of handling the interruption and the resumption of the primary task. Individuals can learn strategies for using lag periods that make task resumption faster and more efficient. The presence of contextual cues also becomes potentially important and can perhaps even be addressed through future design of tasks and devices.

The value of the goal-activation model is its ability to make predictions of how primary task performance is affected by a specific interrupting task and a given allocation policy.

Models Based on Cognitive Architectures

This subsection briefly discusses the power of models that address the way driving tasks are interleaved with ongoing secondary tasks. They are based in *cognitive architectures*, software tools that were specifically developed for simulating human behavior and performance and that embody various assumptions about human cognitive functioning.

A prime example of a cognitive architecture is ACT-R (Adaptive Control of Thought–Rational). It provided the basis for the integrated driver model developed by Dario Salvucci (2001a, 2001b; Salvucci, Boer, & Liu, 2001) to predict driving performance during concurrent task performance.

Subsequent theoretical advances have resulted in the development of a general executive for the ACT-R cognitive architecture that provides the basis for integrated multitasking behavior during driving through task interleaving and scheduling (Salvucci, Kushleyeva, & Lee, 2004). Salvucci and Taatgen (2008) later developed and tested a *threaded cognition model*, which models task-switching phenomena in which an active set of task goals is maintained with threads of processing across available resources. Importantly, the model claims that task-switching phenomena can be explained without the need for a central executive. Similar to the goal-activation model discussed earlier, the threaded cognition model holds some promise in the direction of modeling allocation and prioritization issues, thereby allowing integration with the multiple-resource model.

Other models of driving were developed by Aasman (1995; based on SOAR[1]), Anderson and Lebiere (1998), Salvucci (2001b), and Tsimhoni and Liu (2003). SOAR is a formalism based on a cognitive architecture created for modeling different aspects of (intelligent) human behavior (Laird, Rosenbloom, & Newell, 1987).

Models of Crash Risk

Crash risk models are relevant because perhaps the most important consequence of distracted driving is the number of crashes associated with each risk factor. Although many of these models focus on Box 5 in Figure 1.1 ("crash and near-crash risk"), those that are based on naturalistic data have the ability to examine the linkages within the whole of Figure 1.1.

Crash databases may underestimate the size of the distraction problem, because drivers will often hide the fact that they were distracted or because the precise crash cause remains unknown. However, naturalistic data, such as those obtained through the 100-Car study, yield estimates of the relationships between different distractions and actual or near-crashes (see the section Sources of Driver Distraction and Demand for details; Hanowski et al., 2005).

Finally, the NHTSA program known as Advanced Collision Avoidance Technologies should be mentioned in this context, as it has the goal of developing a series of new computational crash risk models. The purpose of these models is to use existing data from crash databases, human behavior models, vehicle system specifications, and objective tests to predict "harm" from a particular crash type—and the "safety benefit" (i.e., potential reduction in crash risk) that may result from the deployment of particular crash countermeasures. This is a promising area of research for human factors practitioners concerned with reducing crash risk attributed to driver distraction.

Final Note

Even with the extensive work done in modeling in the past 20 years, there are still gaps in many of the models, and a substantial amount of model validation work is left to do. As brain imaging technologies improve, the functional areas that these models posit may be supported. In the meantime, these models provide essential information that can be used by practitioners, especially as they allow for a better understanding of basic distraction effects on the human brain and the driving task.

MEASUREMENT, MITIGATION, AND MANAGEMENT

Given that distraction is present in everyday driving, the practical question becomes how to measure, manage, and mitigate this distraction to minimize negative effects. In this section, some current methods for measuring, managing, and mitigating driver distraction will be summarized. Distraction may, in some instances, actually benefit drivers (Hanowski et al., 2009), for example, by increasing vigilance and reducing drowsiness. However, in the majority of cases, distraction is undesirable and should be avoided.

Crash Investigation

Crash investigation is essential in measuring the effects of distraction. Crashes can be investigated through crash databases, driver surveys, naturalistic observation, and crash reconstruction. Each method has advantages and drawbacks. For example, statements used to generate crash databases can be inaccurate (Farmer, 2003). Driver surveys can be subject to many biases and low response rates (Elliott, Arbogast, Menon, Durbin, & Winston, 2003) but are useful in study of psychological motivators of driver behaviors (e.g., Rakauskas, Ward, & Gerberich, 2009). Naturalistic observation can be expensive but can yield very powerful data. Crash reconstruction can yield detailed information and provide inferential data related to driver behaviors, but it requires very experienced investigators, can be time-consuming, and can be limited in the ability to make generalizations to other crashes (Brach & Brach, 2005).

Driver Attention and Distraction Measurement

The mitigation and management of distraction cannot occur if methods for measurement are not available. There are many different constructs as well as forms of measurement. The focus of this subsection is on how to quantify the measurable changes in driver behavior.

There are two important aspects to examining how distractions result in measurable changes in driver behavior. First, the distraction has to be somehow observed or elicited. Second, measurement criteria for quantifying the distraction have to be established and applied. Table 1.5, derived largely from the work of Angell et al. (2006), provides a convenient summary and key references for many methods that are used in observing or eliciting distractions. The methods are described in terms of the conditions in which they can be used, the pertinent guidelines, the driver performance measures that correlate with the method, the simplicity and cost, and whether the method allows for comparisons against baseline behavior.

Table 1.5 illustrates the complexity inherent in the measurement of distraction effects on driving. The selection of particular approaches heavily depends on the type of task that will be tested and the acceptable trade-offs. If cost is not a concern, and there is substantial testing time, then a naturalistic approach or a test-track experiment is indicated. If cost is a large concern, and the system tested is available early in the design process—for example, in the form of screen shots or a bench-top simulation—then testing may best start with task analysis and predictive modeling. This may be followed by static tests and, depending on its necessity, by on-road testing. Whether guidelines exist for any particular method is also a valid consideration, especially for any systems that are regulated by government entities (see also Driver Metrics Workshop, 2006; Rupp, 2010).

The distraction observation and elicitation protocols in Table 1.5 are only as useful as the measures that are derived from them, which are typically defined in terms of how the distracting task affects one or more behaviors that are directly related to the driving task. These behaviors are quantified by the following measures, classified according to the general testing method under which they apply:

1. Methods whereby a task is examined with little or no driving context
   a. Task completion time: length of time taken to complete the distracting task in the conditions of the test
   b. Errors: the characteristics of errors that are observed when completing a distracting task
   c. Total shutter open time (applicable only to occlusion tests and visual-manual interfaces): the total time that the occlusion device allowed visual access to the distracting task before it was completed
   d. Subjective measures: driver prompts to assess his or her perception of cognitive load while completing a distracting task (e.g., Endsley, 2004)
2. Methods whereby a task is examined in the context of a primary driving task (simulator, test track, or real-world driving)
   a. Task completion time
   b. Errors
   c. Response time: time between the availability of a stimulus to the driver and the first measurable response to the stimulus
   d. Eye movement measures
      - Number of glances: the number of distinct glances to the task that are required to complete it
      - Glance duration: the average duration of the glances; a limit of 2 s is sometimes used as an upper threshold (Driver Focus-Telematics Working Group, 2006)
      - Total eyes-off-road time (also called total glance time to task): the sum total of the duration of distinct glances outside of the forward roadway that are attributable to driver's glancing at the task; a limit of 20 s is sometimes used as an upper threshold (Driver Focus-Telematics Working Group, 2006)

text continues on page 39

Table 1.5. Matrix of Distraction Observation and Elicitation Methods

Method	***Use Conditions and Environments***	***Associated Guidelines***	***Driver Performance Correlates***	***Simplicity/Cost***	***Does Method Provide for Comparisons With Baseline Data?***
Static ("no load") task time measurement (Society of Automotive Engineers [SAE], 2004a, 2004b)	Laboratory; static; tests the distracting task only	"15-s rule" (Green, 1999)	Has been related to changes in eye glance patterns and speed; for visual-manual tasks only	Very simple/Very low	Not applicable; static method
Occlusion method (International Standards Organization [ISO], 2007)	Laboratory; static; tests distracting task only	20-s total shutter open time (SAE, 2004b); ISO standard approved	Has been related to changes in eye glance patterns, lane position, and speed; for visual-manual tasks only	Relatively simple/Low	Not applicable; static method
Bench-top peripheral detection task (Angell et al., 2006)	Laboratory; static; tests the distracting task combined with the peripheral detection task	Not applicable	Has been related to event detection, but predictive validity is too low to recommend; see instead peripheral detection task imposed on driving scene below	Relatively simple/Low	Not applicable; static method
Modified Sternberg task using road sign stimuli (Sternberg, 1969); similar to peripheral detection task but with memory load component	Laboratory; static; tests the distracting task combined with the memory task	Not applicable	Related to event detection on road for both visual-manual tasks and auditory-vocal-cognitive tasks	Relatively simple/Low	Not applicable; static method

(continued)

Table 1.5. (continued)

Method	*Use Conditions and Environments*	*Associated Guidelines*	*Driver Performance Correlates*	*Simplicity/Cost*	*Does Method Provide for Comparisons With Baseline Data?*
Lane change task (Mattes, 2003; ISO, 2010)	Laboratory; simulator; dynamic; tests the distracting task combined with the lane change task	ISO standard approved	Direct comparisons difficult because of the use of lane change maneuver and the absence of driving data during multitasking while changing lanes; validity still being examined, but some initial promising findings on relationship to event detection and relationship to rank order of task difficulty	Simplicity depends on simulator/ Moderate to high depending on simulator	Simulator baseline driving
Visual peripheral detection task superimposed on driving scene, e.g., real driving, simulated driving (Martens & van Winsum, 2000), or driving video (Angell, Young, Hankey, & Dingus 2002)	Laboratory; simulator; dynamic; tests the distracting task combined with the peripheral detection task and simulated driving	May be included in ISO preliminary work item	Has been related to event detection on the road for visual-manual tasks and for auditory-vocal-cognitive tasks	Simplicity depends on simulator/ Moderate to high depending on simulator	Simulator baseline driving
Head-mounted peripheral detection task, or tactile-auditory peripheral detection task (Engström, Åberg, Johansson, & Hammarbäck, 2005)	Laboratory; simulator; dynamic; test track; tests the distracting task combined with the peripheral detection task and driving	ISO preliminary work item now under way	Assesses effects of task demands on selective attention (cognitive processes, central and executive attention)	Relatively simple/ Low to high depending on testing environment that is used	May be possible to obtain baseline driving data depending on the testing environment that is used

Table 1.5. (continued)

Method	*Use Conditions and Environments*	*Associated Guidelines*	*Driver Performance Correlates*	*Simplicity/Cost*	*Does Method Provide for Comparisons With Baseline Data?*
"Static" load and enhanced static load method and variants (Young & Angell, 2003; Young et al, 2005; Young, Angell, Sullivan, Seaman, & Hsieh, 2009)	Laboratory; simulator; dynamic; test track; tests the distracting task combined with the peripheral detection task and driving	Not applicable (though permitted as a method from which to obtain glance data under Alliance guidelines (Version 2.1; Driver Focus-Telematics Working Group, 2006)	Yields glance data and event detection/response measures as well as task completion time measures with attention load (or divided-attention conditions); has been validated to road data	Relatively simple/ Low to high depending on testing environment that is used	May be possible to obtain baseline driving data depending on the testing environment that is used
Simulator evaluation	Laboratory; simulator; dynamic; tests the distracting task combined with simulated driving	Not applicable	Depends on the fidelity of the simulator, the demands of primary driving task used, and task types tested	Simplicity depends on simulator/ Moderate to high depending on simulator	Simulator baseline driving
Test track evaluation	Test track; dynamic; tests the distracting task combined with driving and other tasks (optional)	Alliance guidelines (Driver Focus-Telematics Working Group, 2006)	Varying levels depending on any additional tasks present	Complexity depends on test conditions/ Moderate to high	Test track baseline driving

(continued)

Table 1.5. (continued)

Method	*Use Conditions and Environments*	*Associated Guidelines*	*Driver Performance Correlates*	*Simplicity/Cost*	*Does Method Provide for Comparisons With Baseline Data?*
Naturalistic evaluation	Public roads; dynamic; tests the distracting task combined with driving	Alliance guidelines (Driver Focus-Telematics Working Group, 2006)	Driver performance extracted directly but may be subject to high levels of noise because of the uncontrolled driving conditions; noise can be reduced by careful route selection	Complex/High	Relative comparisons can be made with normal driving during the experiment
Naturalistic driving	Public roads; dynamic; tests the distracting task combined with driving at driver's pace	None currently	Driver performance extracted directly; since drivers select which tasks to do and when, requires large-scale data collection to achieve sufficient experimental power	Complex/High	With sufficiently large-scale studies (hundreds of drivers and years of data), inferences of risk can be developed

e. PDT miss rate: the proportion of PDT events that are missed while completing the distracting task
f. PDT mean response time: the average response time to PDT events that are responded to while completing the distracting task
g. Lateral control: how effective the driver is at maintaining lateral control of the vehicle while completing a distracting task
h. Longitudinal control: how effective the driver is at maintaining longitudinal control of the vehicle while completing a distracting task

Many other measures can be derived from the types of tests described in Table 1.5. In some cases, there are also guideline values that exist.

An important consideration for these measures is their potential to be applied in a real-time environment. That is, could the measure be automatically monitored so that it can be used as input to a distraction-detection algorithm? Unfortunately, the answer to that question for many of these measures is negative. Eye glance measures and measures of lateral and longitudinal control, however, continue to be tested for such applications, partly because of the relative efficiency with which they can be obtained in real-world environments. Algorithms to use these measures in the detection of distraction continue to be developed (e.g., Liang, Lee, & Reyes, 2007).

The diverse options available for distraction assessment can be daunting. The following heuristic may be useful in making selections:

1. Define the typical tasks that may be performed by users while in a moving vehicle. These tasks should consider the wide variability in drivers who will use the system. Also, many drivers exhibit interactions during driving that are much less specifically bounded than typical laboratory-defined tasks (e.g., "look around for something else to listen to" rather than "tune the radio to 104.5").
2. Secure access to soft and hard prototypes of the device or system for purposes of human factors evaluations.
3. Examine the available guidelines (Commission of the European Communities, 2007; Driver Focus-Telematics Working Group, 2006) and begin by arranging for assessment of task attributes (and/or device attributes, as applicable) against principles that can be done through inspection, verification against design drawings, and engineering analysis.
4. Determine the resources (equipment, personnel, finances) available for testing, allowing for several rounds and levels of iterative testing of increasing complexity.
5. Establish a test plan. Important issues to consider include the following:
   a. Allow for several stages of testing that may increase in complexity as versions "closer to production" are tested.
   b. Allocate time to examine results, redesign tasks, and implement redesigns between waves of testing.
   c. Ensure that the design team understands that usability options that are optimal and useful in device use outside of the vehicle may not be appropriate for use while inside a moving vehicle.
   d. Consider which guidelines are most applicable to the device or tasks of interest and tailor the testing for comparisons against the guideline recommendations.
   e. Along with findings on whether devices or tasks meet or do not meet guidelines, be sure to deliver ideas for improving task design and meeting the guidelines.

   f. When feasible, ensure that the final wave of tests includes some component of real driving concurrent with performance of the distracting task(s) for validation purposes.
6. Execute the test plan—and allow for revisions to the test plan as unforeseen challenges and opportunities arise.

Mitigation and Management

When distraction has been identified as a problem area by crash investigation, it becomes important to identify ways in which the distraction problem can be mitigated and managed. Mitigation and management of distraction have traditionally been attempted through five different approaches, briefly discussed in the following paragraphs.

Standards and guidelines. Automakers and makers of nomadic devices can use guidelines and recommendations to design systems with minimum distraction potential (Commission of the European Communities, 2007; Driver Focus-Telematics Working Group, 2006). In the United States and most countries, adherence to such guidelines is voluntary and manufacturers typically disclaim use of their products while driving. However, in April of 2002, members of the Alliance of Automobile Manufacturers (a consortium of 11 automobile manufacturers with the common goal of advocacy for the automobile industry) took these voluntary guidelines a step farther by signing a "letter of commitment" to the NHTSA. In this letter, participating automakers established that their new products would meet the alliance's guidelines and provided a timeline and terms for verifying this.

The alliance is not a recognized standards organization, and its work sometimes limits public input, but it is a recognized mechanism for enabling standard industry practices in areas of safety innovation (e.g., antilock brakes, electronic stability control, advanced collision avoidance warning systems). Other worldwide groups have published standards and recommended practices that minimize the potential for driver distraction from different types of devices. Some existing guidelines and recommendations include

1. Navigation and Route Guidance Function Accessibility While Driving (Society of Automotive Engineers [SAE], 2004b), SAE Recommended Practice J2364;
2. Calculation of the Time to Complete In-Vehicle Navigation and Route Guidance Tasks (SAE, 2004a), SAE Recommended Practice J2365;
3. Advanced Driver Interface Systems for Commercial Vehicle Operations (SAE, 2003), SAE Recommended Practice J2571;
4. Definitions and Experimental Measures Related to the Specification of Driver Visual Behavior Using Video Based Techniques (SAE, 2000), SAE Recommended Practice J2396;
5. Road Vehicles—Ergonomic Aspects of Transport Information and Control Systems—Specifications and Compliance Procedures for In-Vehicle Visual Presentation (International Standards Organization [ISO], 2002), Draft International Standard No. ISO/DIS 15006.2;

6. Road Vehicles—Ergonomic Aspects of Transport Information and Control Systems—Procedures for Determining Priority of On-Board Messages Presented to Drivers (ISO, 2004), Technical Specification No. 16951-:2004(E);
7. Road Vehicles—Ergonomic Aspects of Transport Information and Control Systems—Occlusion Method to Assess Visual Demand Due to the Use of In-Vehicle Systems (ISO, 2007), International Standard No. ISO 16673; and
8. Road Vehicles—Ergonomic Aspects of Transport Information and Control Systems—Simulated Lane Change Test to Assess In-Vehicle Secondary Task Demand (ISO, 2010), International Standard No. ISO 26022:2010.

Since these standards and guidelines are typically generated for practitioners, they are usually simple and focused. Test criteria, equipment, and setup are typically well described, as are the applicable systems and the pass-fail thresholds. Whenever feasible, different testing alternatives are presented to accommodate varying levels of access to the necessary testing equipment. For example, for testing compliance with one of the alliance's principles, the guidelines allow for completion of a visual occlusion test (which is performed in static conditions and should be completed within 15 s of total shutter open time, that is, "the 15-second rule"; Green, 1999), a static divided attention test (whereby a primary task closely mimics the visual demands of driving and the secondary task of interest is performed concurrently), or on-road, test track, or simulator testing of the task while the participant drives the test vehicle. Practitioners are directed to Table 1.5 for a summary of options that may be applicable to their systems.

Technology lockouts and jammers. Another option for the management and mitigation of distraction is to prevent the distracting behavior altogether by locking the function or device. These lockouts are commonly used in the area of navigation, where many automakers choose, for example, to disallow the visual-manual entry of destinations in dynamic conditions. This approach presupposes that drivers have only a limited capability to self-regulate the use of devices or completion of tasks that may be "too" distracting, an area of open debate in the field. There is, however, some experimental evidence of potential benefits from lockouts. For example, Donmez, Boyle, and Lee (2006) found that locking the driver out from a distracting task improved his or her control of the vehicle in a driving simulator. In addition, add-on devices that jam cellular signals exist (e.g., http://www.trinitynoble.com).

Although shortsighted in some ways (cellular technologies are also used for safety and security applications in some vehicles), the use of jamming devices is likely to remain the choice of particular drivers rather than be enacted as widespread policy. Furthermore, the sale and distribution of jamming devices are regulated (and in many cases, prohibited) by the Federal Communications Commission. New technologies may also help on this front. For example, drivers can now voluntarily download applications onto their phones that help them filter out incoming calls while driving. Care should be taken, however, to gauge public willingness to accept and embrace new technology-based restrictions.

Adaptive interfaces. Somewhat related to the lockouts described previously, recent advances in automated driver monitoring technology have allowed for information about the external driving environment, driver task activity, and/or driver state(s) to be used in making a decision as to whether a driver is distracted and/or the extent of that distraction. This information can be used to issue a warning and/or to restrict the use of the distracting technology until conditions allow. With a few exceptions (e.g., Mayser, Piechulla, Weiss, & König, 2003), these systems are still in development. Some benefits have been observed in experimental settings (Donmez, Boyle, Lee, & McGehee, 2006 ; Donmez et al., 2006; Engström & Victor, 2009; Victor et al., 2005). Reasons for the delay in the deployment of these systems include limitations in the detection technologies that are needed to provide accurate assessments of driver workload and the driving environment. In addition, interfaces for these technologies could be distracting if designed inappropriately, which has already been observed for some salient visual warnings (Perez et al., 2009).

Laws and enforcement. Another distraction management and mitigation strategy is to enact laws that restrict distraction and distracting behaviors while driving (Jacobson & Gostin, 2010). Laws that regulate distraction treat it as a primary or a secondary offense (primary offenses allow for a traffic stop based solely on that transgression). They may also be applicable to certain actions while using certain devices (e.g., talking on a handheld phone but not a hands-free phone), certain technologies (e.g., display devices larger than a certain size on the center console), certain situations (e.g., cell phone use allowed if it is an emergency), or certain environments (e.g., cell phone use disallowed in school zones). The Governors Highway Safety Association provides a compendium of U.S. laws that address driver distraction (http://www.ghsa.org/html/stateinfo/laws/cellphone_laws.html).

These laws are usually not very effective unless there is a general perception that they are enforced (McCartt & Hellinga, 2007), and public opinion on these laws is typically mixed (Wogalter & Mayhorn, 2005). There have been several studies concerning the effectiveness of these laws, especially regarding cell phone use. Many indicate only limited effectiveness, at least after the initial publicity period and enforcement wave have elapsed (McCartt, Hellinga, & Braitman, 2006; McCartt, Hellinga, Strouse, & Farmer, 2010). More recently, there has been a wave of laws, especially in the United States, enacted to ban texting while driving. It is too early to determine the extent to which these laws will be effective.

Training and education. There are two aspects of training and education to mitigate and manage distraction. First, there is a question of whether people need to, and can be trained to, use new technologies designed to help them reduce distraction. Some research suggests that training and experience have very limited effects (Cooper & Strayer, 2008). Others suggest that there may be some benefit by making drivers less likely to engage in distracting activities in a moving vehicle (Horrey et al., 2009).

Second, how do drivers understand the problem of distracted driving and its consequences, and can drivers be better educated? Education could allow drivers to make an informed decision as to whether to engage in distracting tasks based on their willingness to accept risk (as opposed to ignorance of these risks). Some research indicates that driver education could be a potential countermeasure for some types of distraction (Lerner, Singer, & Huey, 2008). Research on novel approaches to developing successful and effective training methods also continues (e.g., Riquelme, Al-Sammak, & Rios, 2010;

Wickens, Toplak, & Wiesenthal, 2008), and adaptive interfaces may play the role of a "virtual trainer" in the future. Some research, however, suggests that drivers are not qualified to assess the effects of their own distraction (Horrey, Lesch, & Garabet, 2008). The extent to which education and training can affect self-assessment is unclear.

Final Note

This discussion has illustrated many of the complexities involved in measuring, managing, and mitigating the distraction phenomenon. Although much progress has been made in the past decade, much remains to be done, especially in terms of making the science available and meaningful to drivers and decision makers. The next section expands on this topic and elaborates on some important issues that will influence how our understanding of driver distraction evolves.

LESSONS LEARNED AND UNRESOLVED ISSUES

This chapter has described driver distraction from a very basic neuropsychological context to a phenomenon with consequences in the form of crashes. The first part of this section summarizes the practical implications of the research discussed in this chapter for three types of stakeholder in the driver distraction arena: designers, legislators, and individual drivers. The second part suggests some additional areas of concern in the area of driver distraction that are expected to emerge in the near future.

Lessons Learned

When discussing driver distraction, there are a number of areas where valuable insights have been gained and need dissemination. These insights depend on the type of stakeholder. In the following, lessons learned are summarized for three types of stakeholder.

Designers of devices that may be used in a moving vehicle typically must deliver designs and prototypes limited by a combination of economic and political constraints. For these stakeholders, guidelines, standards, measurement methods, and legislation are all important topics. There is no widespread consensus on the guidelines and methods to use. The guidelines that have been developed vary in their applicability to different systems (especially variations in device control), the methods that are allowed to establish compliance, and how the test output actually relates to crash risk. Designers of systems with visual-manual control should at a minimum familiarize themselves with the alliance guidelines and the ISO standards and comply with the principles that are applicable to their device. Designers can also reference the writings of the Commission of the European Communities and the Japanese Automobile Manufacturers Association. In the near future, guidelines for systems with voice control may also become available.

Legislators should understand that laws banning certain behaviors may be effective to the extent that they are enforceable and actively enforced. Regarding problematic tasks (e.g., texting), legislators should be cognizant that crash risk is a function of both how demanding a task is and how often it occurs in typical driving conditions. Legislators should also understand that laws are only a part of the overall solution and should consider the funding of training and education programs as well as funding of additional research directed toward creating better interfaces and generating tools that assess their distraction potential.

Individual drivers should understand that distracting behaviors reduce the attention resources available for the driving task. Although in many cases, this reduction does not result in any negative consequence, inattention to the forward roadway comes at the expense additional crash risk. Drivers should also understand that although compensatory behaviors may help reduce risk (e.g., reduction in speed), they do not completely eliminate it and may actually increase it (e.g., if a distracted driver were to slow down too much compared with surrounding traffic). The benefits of every distracting task that a driver chooses to engage in should be weighed against this additional risk. Pretending that drivers will not perform distracting tasks while driving is not realistic, but at the same time, it is important for drivers to make better-informed decisions about the distracting tasks they choose to engage in and the adaptation of their engagement strategy to the current driving situation.

The Future of Driver Distraction and Emerging Areas of Research

An integrated vision of safety should recognize the need to manage distraction and the need to evolve toward a future of connectivity in transportation (which may itself offer new safety advances). These goals are not necessarily mutually exclusive, and this subsection briefly examines such a perspective and some solutions that may promote an integrated vision for safety. The discussion is shaped in the context of five distraction-related topics that will very likely continue to be researched. At the end of this subsection, the most important research questions arising from this discussion are summarized.

Distraction in the context of "connected vehicle" ecosystems. There is an increasing trend toward connecting vehicles with each other and with the road infrastructure through wireless means (e.g., the Connected Vehicles initiative in the United States; http://www.ops.fhwa.dot.gov/travelinfo/infostructure/aboutinfo.htm). This interconnectivity may have future implications for the study of driver distraction. The current increase in connectivity is creating new opportunities and new needs by bringing new entities and applications into the driving environment. The advantages and consequences arising from the availability of this widespread connectivity must be carefully examined and understood. In turn, understanding what can be beneficial and harmful can be used to develop required changes in transportation policies and regulations.

Driver distraction needs to be directly addressed in this technological evolution. It is projected that about one third of the functionality in future vehicles will be provided by portable devices carried into the vehicle, particularly, smartphones. For example, some states are sending their warnings about congestion on state highways to drivers' cell phones, and some teen driver monitoring systems may send notices of inappropriate teen driver behaviors to parents' cell phones or compile them for review on a website (Farmer, Kirley, & McCartt, 2010; McGehee et al., 2007).

The European Union is also exploring a wireless system designed to bring quick assistance to drivers in a crash (i.e., eCall; http://en.wikipedia.org/wiki/ECall), and it is expected that other telematic services will be available through the system. This plan raises the issue of whether future connectivity will be provided mainly by embedded or portable devices. In any case, a critical question that must be addressed is, How should the distraction caused by receiving an important traffic message on a smartphone, or even a billboard, be weighed against the distraction that it may cause if it is accessed while driving?

Insurance companies. Given the large influence of distraction on crashes, and the costs those crashes represent for insurance companies, there have been efforts by these entities to make drivers pay premiums that are based on their level of crash risk. There is potential for these "pay-as-you-drive" programs to begin to incorporate behavior-based measures, especially as systems that are capable of monitoring distractionlike behaviors (e.g., real-time eyes-off-road assessment) become available. For example, in the United States, Progressive Insurance already provides driver discounts based on monitoring technology (http://www.progressive.com/snapshot/).

Potential first applications for these types of technologies are commercial fleets (Roetting, Huang, McDevitt, & Melton, 2003) and teen drivers. Teen drivers, particularly, are important to the insurance industry because of their large rate of crash involvement. As these technologies evolve, they very well may make their way into other drivers' vehicles. Most likely, the enticement for drivers would be discounted insurance premiums based on "good" behavior (e.g., low observed frequencies of distraction and other behaviors, such as speeding). Although it is difficult to imagine these devices in every vehicle, monitoring technologies may become ubiquitous in the next several decades. Furthermore, the key components for such systems are already included in some new vehicles, as automakers attempt to use video to detect and warn about drowsiness or other behaviors that take drivers' eyes off the road for substantial periods. How aware (and wary) drivers are of the existence of these technologies is mostly unknown.

Several important questions about these systems need to be considered as a substantial shift toward monitored driving occurs. For example, who has access to the data that are collected from these devices? Would drivers whose vehicles are equipped with these systems be able to use them to defend themselves in cases in which the cause of a crash was unclear? Could they be deemed responsible for crashes on the basis of what the monitoring technologies indicate was occurring at the time of the crash? Could this information be subpoenaed in a court of law? Could drivers argue that the equipment did not warn them early or clearly enough to help them prevent a crash? Understanding these and many other issues should precede widespread deployment of driver monitoring technologies.

Consumer metrics. Although recent efforts by the U.S. and other governments to bring driver distraction to the forefront (e.g., http://www.distraction.gov) have provided more drivers with information about the issue, they may not translate into drivers making appropriate choices. This may especially be the case when purchasing technologies that are optional to the drivers. It is possible that products intended for in-vehicle use (and those with the potential to be used in the vehicle) are evaluated on the basis of their distraction potential. The results of these evaluations could be provided to consumers in displays akin to the star rating program that the NHTSA uses to provide information about the crashworthiness of new vehicles. Development of these distraction ratings, however, would require data on the crash risks associated with different driver distraction behaviors, which is just starting to become available from naturalistic driving studies (Klauer et al., 2010; Klauer, Dingus, et al., 2006; Klauer, Sudweeks, et al., 2006).

International versus national events. At the current time, guidelines and laws vary from region to region around the globe, although there has been some increasing convergence of content between the EU Statement of Principles, the Alliance of Automobile Manufacturers' Driver Focus Guidelines, and the Japanese Automobile Manufacturers Association guidelines. Of particular note are initiatives such as Sweden's Vision Zero (Whitelegg & Haq, 2006), which has gained international exposure and popularity. Vision Zero is a set of strategic guidelines aimed at increasing and maintaining road transport safety. Although not specifically aimed at avoiding driver distraction, its guidelines apply to manufacturers and retailers of electronic devices that, if used or designed inappropriately, may be distracting to the driver.

The philosophy of Vision Zero includes two principles: (a) Safety responsibility must be shared by road system designers and individual drivers, and (b) the road transport system must be designed with an eye to the level of harm the human body can tolerate. As in aviation, road safety is considered more important than other transportation objectives, such as mobility and traffic throughput, and government policies with regard to road design, traffic laws, and the like should reflect this philosophy. Exact figures about the costs and benefits of a program as complex, multistakeholder oriented, and gradually evolving as Vision Zero are hard to come by; nonetheless, since its inception in 1994, Sweden has managed to reach one of the lowest road fatality rates in Europe.

More recently, the United Nations has issued a "Global Call to Action on Ending Distracted Driving" (http://www.dot.gov/affairs/2010/dot9910.htm). Therefore, driver distraction is receiving worldwide attention. As increased connectivity makes us a global community, it is likely that laws, regulations, recommendations, principles, and practices related to driver distraction will become more similar, although regional differences that reflect cultural perceptions toward driving as a right or privilege will likely remain. It is important, however, that legislative solutions are mindful of society's path toward a connected transportation system.

The future of measurements. Understanding driving behavior hinges on measuring it. The methods described in the section Measurement, Mitigation, and Management showcase the diversity and complexity of extant measurements. The next step is to develop new methods that integrate the positive aspects of existing measurements and simplify the process of measurement.

For example, measurement of brain activity is becoming more prevalent in laboratory driving research as the equipment has become more unobtrusive and isolation of brain activity indicating increased cognitive ability has become easier (Wester, Bocker, Volkerts, Verster, & Kenemans, 2008). Consequently, brain activity could be used in the future to understand the role of cognition while driving as well as to validate brain activation models. As the required equipment evolves and becomes more durable, these systems can be expected to be used in real driving settings. Somewhat invasive, these systems have been criticized for their legality, ethicality, and impracticality. Ethical quandaries arise, for example, in insurance industry applications (see earlier in this subsection). A key question is, Where should the line be drawn between what a private thought is and what is relevant in determining the responsibility for a crash?

Another development, the anticipated public release of large-scale driving data sets (e.g., of naturalistic driving), will provide a full view of the driving behaviors of thousands of drivers. Careful observation of these data sets (e.g., the Second Safety Highway Research Program Naturalistic Driving Study; Transportation Research Board, 2010) will shed light on many of the questions associated with driver distraction, including how often drivers engage in distracting behaviors and how often that engagement results in a negative outcome.

Important questions: Areas for future research. These topics provide fodder for developing some important questions that research must address in the next several years to advance knowledge in the field of distraction and improve the safety of drivers. These questions include the following:

1. How will driver distraction change because of the increased and pervasive connectivity that is becoming prevalent in our society?
2. Can that connectivity be leveraged to improve safety rather than decrease it?
3. What are the ethical and legal implications of widespread use of driver monitoring systems?
4. How can consumers best be informed of the distraction potential of different technologies? How can they be persuaded to make this distraction potential a main consideration in selecting devices for purchase?
5. To what extent should distraction prevention efforts be unified across geographical boundaries? What organization should take the lead in this effort?
6. How can brain monitoring best be leveraged to assist in preventing distraction?

Final Thoughts

Distraction continues to be a source of substantial debate and, recently, much action. This chapter has summarized the state of the art in current thought and investigation aimed at understanding driver distraction. In addition, it provided some practical information as to how distraction is measured, what its effects are, and how it can be avoided.

With this attempt, the authors hope to inspire researchers to conduct investigations that answer the most pressing questions related to driver distraction and produce results that are useful in managing and mitigating any negative effects of distracting behaviors. What is known about distraction has changed considerably in the past decade and very likely will do so again in decades to come.

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