The Distracted Driver: Mechanisms, Models and Measurement

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Abstract

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, anti-distraction devices, and anti-distraction 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.
The Distracted Driver: Mechanisms, Models and Measurement

Human factors research in the field of driver distraction has greatly evolved over the last 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 because of 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 over-taxing 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.

In order 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, p. 2):

*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 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.

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). Based
on 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, diverting them 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., the driver paying insufficient attention to the driving task) can be classified as examples of driver distraction.

Unresolved definitional problems form an important first obstacle towards 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 and a crash still prevented? These questions need to be answered in order for accident analysis, accident reporting, and enforcement of anti-distraction 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 over 25%, depending on the type of study and the definition utilized. Traditional crash studies have attributed 10 - 12% of all automobile crashes to driver distraction (Gordon, 2009). However, these figures are underestimates of the true percentage, due 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.** Over the last 10 years, driving has become more complex due to 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. Though this connectivity may also benefit the driver (e.g., increased traffic throughput due to 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 come up with new guidelines, test procedures, and development processes to help ensure safe and usable systems for drivers (Green, 2008). Some of these developments will be 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 over the last 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, 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, anti-distraction devices, and anti-distraction 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 will be on sources of attentional demand on the driver and the effects of those demands on the processes required for “safe” driver performance and behavior, setting 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 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 are mostly executed at will by the driver and involve objects or events inside the car. Note that some of these activities are done 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 done using portable devices (e.g., cell phones or navigation systems). Still others in Box 1 are done without the use of particular vehicular or electronic devices, involving instead 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 refer to stable personal characteristics which 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). These are conditions related to the specific context of the primary and secondary tasks, such as (1) the natural occurrence of traffic-related hazards, objects, and events on the road that may require (or attract) a driver’s attention; (2) the (transient) behavioral factors underlying...
secondary task use; and (3) 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 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 which requires attention and a response from the driver. It is this co-occurrence which disrupts the human’s capacity for multitasking performance.

Given the interconnected nature of the different constructs in Figure 1, it is difficult to isolate specific research focused on each. Therefore, the discussion below roughly follows the flow of Figure 1 from left to right, looking at clusters of boxes, starting with Box 0 and ending with Box 5.

**Sources of Attentional Demand on Driver Attention**

Demands on drivers arise from both “primary driving tasks,” and from other additional (secondary) tasks that are mostly discretionary (undertaken at the will of the driver). These sources of attentional demands are described below.

**Demands from primary driving (figure 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). 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-time horizon), tactical control (mid-term 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) that must ordinarily be coordinated simultaneously – and collectively comprise 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
### Table 1. Types of Demand from Primary Driving Tasks.

<table>
<thead>
<tr>
<th>Level of Control</th>
<th>Type of Control</th>
<th>Characteristic Description</th>
<th>(Illustrative) Key Demands on Driver</th>
<th>Technology Available in Typical Vehicles (Examples)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operational</td>
<td>Lateral control</td>
<td>Lanekeeping</td>
<td>Visual (to view position of lane and provide feedback on lane position and heading) Manual (steering)</td>
<td>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, lanekeeping, and lanecentering</td>
</tr>
<tr>
<td></td>
<td>Longitudinal control</td>
<td>Speed control (acceleration, deceleration/braking)</td>
<td>Visual (optical flow, provide feedback on results of acceleration inputs) Manual (acceleration, deceleration, braking)</td>
<td>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</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Following behavior &amp; headway maintenance</td>
<td>Visual (tau = visual subtended angle of an object divided by its rate of position change, time and distance headway, provide feedback on results of acceleration inputs) Manual (acceleration, deceleration, braking)</td>
<td>Generally under driver control in today’s vehicles, though emerging technologies include adaptive cruise with forward collision alerts (or variations of this)</td>
</tr>
<tr>
<td>Tactical</td>
<td>Manoeuvres</td>
<td>Turning, overtaking, gap acceptance, determining how to approach an intersection, how to deal with a sudden detour</td>
<td>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 (to coordinate and to project next state of situation)</td>
<td>Manoeuvres are under driver control in today’s vehicles; new systems provide stabilization in event of overly aggressive manoeuvres (electronic stability control)</td>
</tr>
<tr>
<td></td>
<td>Event monitoring &amp; response</td>
<td>Looming cues, motion cues, pedestrians crossing, lead vehicle braking suddenly, responding adaptively</td>
<td>Visual (monitoring and detection of events and hazards) Working Memory (Use of Situation Model in Awareness to interpret events/hazards) Central Executive Attention (to select response, coordinate execution, and to project next state of situation, update SA)</td>
<td>Generally under driver control; some advanced technologies are in early development to assist with some elements of this; 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</td>
</tr>
<tr>
<td>Strategic</td>
<td>Planning</td>
<td>Route planning (before or during a trip)</td>
<td>Visual (to view map, route, instructions, or sometimes to enter destination or operate navigation system) Working Memory (remembering where to turn, coordinating route instructions with forward view) Central Executive Attention (monitoring for and executing instructions at appropriate points -- i.e., task interruption/switching, project next state of situation and update SA)</td>
<td>Some vehicles/carried-in systems can do this for the driver</td>
</tr>
<tr>
<td></td>
<td>Goal identification (before or during a trip)</td>
<td>Working Memory (use of Situation Model in Awareness to interpret events/hazards) Central Executive Attention (to select response, coordinate execution, and to project next state of situation, update SA)</td>
<td>Under driver 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</td>
<td></td>
</tr>
</tbody>
</table>
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 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 utilization and its relation to driver distraction.

With higher degrees of automation, more electronic devices may be present (embedded or not) in the vehicle. Though 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 (together with the use of other in-vehicle device-based distractors).

*Empirical evidence related to the demands imposed by primary driving tasks (figure 1, box 0, 2 and 3).* The demands of primary driving tasks, reflected in Box 0 of Figure 1, vary as a function of manoeuvre (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, 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 in higher proportions of missed signals on the PDT, and longer response times (indicating a higher workload on the driver).

For example, manoeuvres in which drivers suddenly had to respond to a stop sign, to overtake a lead vehicle, and to brake in response to a lead vehicle or a package falling 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 braking 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 upon 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 entertaining any additional demands that secondary activities may introduce.

**Additional (secondary) sources of demand on the driver's attention (figure 1, box 1)**

*Categories.* Additional sources of demand may vie for the driver’s attention as a result of him 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 upwards or downwards to another level of control and thereby cause additional distraction. This principle can be utilized in driver training or education programs (Donmez, Boyle, & Lee, 2009).

The use of in-vehicle devices (figure 1, box 1.5). In Table 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 focussed 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 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.
<table>
<thead>
<tr>
<th>Source</th>
<th>Examples</th>
<th>Characteristic Functionality</th>
<th>Demands on Driver</th>
<th>Availability in typical vehicles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle instruments &amp; controls</td>
<td>Speedometer, gauges, telltales; Windshield defrost &amp; wipers; Headlighting controls; etc.</td>
<td>Cluster &amp; gauge functions, including telltale notifications Windshield clearing Control forward visibility</td>
<td>Visual-Manual</td>
<td>Standard equipment, often used to support primary driving tasks</td>
</tr>
<tr>
<td>Comfort &amp; convenience features</td>
<td>Heating, vents, &amp; air conditioning; Seat adjustments; etc.</td>
<td>Temperature, humidity, circulation control &amp; source of air Seating adjustments</td>
<td>Visual-Manual</td>
<td>Some features are standard; Others are optional features</td>
</tr>
<tr>
<td>Built-in navigation systems</td>
<td>Destination Entry Route following assistance Points-of-interest &amp; other features Route re-planning</td>
<td></td>
<td></td>
<td>Optional equipment; 1.2 million sold (out of ~16 million new cars) per year, a 7 -8% Take Rate -- and less than 1% per year of all cars registered in the US</td>
</tr>
<tr>
<td>Built-in advanced entertainment and “infotainment” systems (including embedded MP3 players) -- usually requiring navigation screen</td>
<td>Music: Search, play, store Images: Moving/Still</td>
<td></td>
<td></td>
<td>Optional equipment; usually bundled with navigation (above)</td>
</tr>
<tr>
<td>EMBEDDED communication (phoning, messaging)</td>
<td>Calls for assistance (emergency, navigation, etc.) Incoming calls Management of calls (initiating, answering, deferring calls) Notifications (e.g., storm information, emergency instructions)</td>
<td></td>
<td>Visual-Manual in some; Auditory-Vocal in others</td>
<td>Optional equipment; estimated at 30% of new vehicles sold each year (or ~4.8 million per year, accumulating over years) [iSupply, 2009]</td>
</tr>
<tr>
<td>Interactive information (e.g., internet connectivity)</td>
<td>Real-time traffic advisory (on request) Headlines, advertising, address book, database search, financial services, directory, horoscopes, stock quotes</td>
<td></td>
<td>Visual-Manual in some; Auditory-Vocal access to information in others</td>
<td>If available as an option integrated in the vehicle, it is optional functionality; and is bundled with navigation (above)</td>
</tr>
<tr>
<td>Portable navigation systems</td>
<td>Destination entry Route following assistance Points-of-interest &amp; other features Route re-planning</td>
<td></td>
<td>Some are Visual-Manual; Some are Auditory-Vocal; Some offer both modalities</td>
<td>44% of US respondents report use of portable navigation devices (Navigating Global Study, 2010 at <a href="http://www.gizmag.com/consumer-experience-with-navigational-devices-doubled-in-last-three-years/13895">www.gizmag.com/consumer-experience-with-navigational-devices-doubled-in-last-three-years/13895</a>)</td>
</tr>
<tr>
<td>Entertainment systems (iPods &amp; their counterparts)</td>
<td>Music: Search, play, store Images: Moving/Still</td>
<td>Music: Search, play, store, download/upload (in Parking gear) Not in front seat</td>
<td></td>
<td>220 million total sales of iPods by 2008 (relative to 247 million registered vehicles on the road -- cars, trucks, buses); iPods have 90% of portable MP3 market</td>
</tr>
<tr>
<td>Communication (phoning, messaging); also smart phones, phones, iPads, PDAs</td>
<td>Incoming calls Outgoing calls Management of calls (initiating, answering, deferring calls) Voice mail</td>
<td></td>
<td>Visual-Manual; though some may provide for voice dialing</td>
<td>250 million subscribers (compared to 247 million vehicles -- cars, trucks, and buses registered in the US)</td>
</tr>
<tr>
<td>Interactive information (internet connectivity via phone, PDA, etc.)</td>
<td>Headlines, advertising, address book, database search, e-commerce, financial services, directory, stock quotes, personal info</td>
<td></td>
<td>Visual-Manual</td>
<td>More cell phones than PCs currently connect to the internet; exact percentage could not be found</td>
</tr>
</tbody>
</table>
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).

Non-device activities (undertaken by drivers in the vehicle). Table 3 identifies other activities in which drivers may engage. Stutts, Reinfurt, Staplin, and Rodgman (2001) indicated that drivers spent at most 4-5% of the total driving time engaging in non-device activities. A recent online survey conducted among 1800 drivers from three different continents (Drive responsibly, n.d.) suggests, however, that non-driving-related activities could be broader in scope and more common.

Non-device 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 in order 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 by 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 not-so-easy-to-interrupt secondary tasks (Rauch, Gradenegger, & Kruger, 2009).

Empirical evidence for the distracting effects of secondary activities (figure 1, box 1 - 3). There is a vast literature on empirical work measuring the demands of secondary tasks, and the
Table 3. Types of Demand from Non-Device Activities.

<table>
<thead>
<tr>
<th>Activity/Source</th>
<th>Types of interaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>In-vehicle Interactions with passengers &amp; pets</td>
<td>Vocal &amp; non-vocal/Physical</td>
</tr>
<tr>
<td>Looking at things outside the vehicle (buildings, accidents, billboards)</td>
<td>Visual/Cognitive</td>
</tr>
<tr>
<td>Eating and Drinking</td>
<td>Visual/Manual</td>
</tr>
<tr>
<td>Grooming</td>
<td>Visual/Manual</td>
</tr>
<tr>
<td>Storing/Retrieving items</td>
<td>Visual/Manual</td>
</tr>
<tr>
<td>Reading</td>
<td>Visual/Manual</td>
</tr>
<tr>
<td>Writing</td>
<td>Visual/Manual</td>
</tr>
<tr>
<td>Opening/Closing packaged items</td>
<td>Visual/Manual</td>
</tr>
</tbody>
</table>

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.

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

2. **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/near the road than auditory-vocal tasks, even when the total task times for auditory-vocal tasks are longer (Angell, Auflick, Austria, Kochhar, Tijerina, et al., 2006; Dingus & Klauer, 2008). For more confirming evidence see: Bowyer, Hsieh, Moran, Young, Manoharan, et al., 2009; Hsieh, Young, R.A., Bowyer, S.M., Moran, J.E., Genik II, et al., 2009; Shutko, Mayer, Laansoo, & Tijerina, 2009; and Young, Aryal, Muresan, Ding, Oja, et al., 2005. In the Shutko et al. (2009) study, reading a text message on a hand-held phone could take the driver’s eyes off the road for 11 seconds compared to about 2 seconds when listening to the text message with text-to-speech output. These findings are also consistent with results from naturalistic driving showing that talking/listening on a phone while driving was no riskier than normal driving, whereas manually dialing a hand-held 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 it by 2300% over just driving, Hanowski, Olson, & Bocanegra, 2009); however, other multi-step tasks also increase risk significantly above “just driving” (to 3.1 times as high for complex tasks: Klauer, Dingus, Neale, Sudweeks, & Ramsey, 2006; Klauer, Sudweeks, Hickman, & Neale, 2006).

3. **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 had an eye glance away from the forward roadway within three seconds of the crash precipitating event (Dingus & Klauer, 2008). Finally, the 100-Car study showed that when the eyes were off-the-road for 2 seconds or more within 6 seconds of a conflict’s onset, the risk of a crash or near-crash was elevated over two times (Klauer, Guo, Sudweeks, & Dingus, 2010; Lee, Klauer, Olsen, Simons-Morton, Dingus, et al., in press).

4. **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 under many conditions (Angell et al., 2006; Engström, Johansson, & Ostlund, 2005; Mattes, Föhl, and 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.
5. *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 ones) may receive driver glances lasting as long as 0.75 s (Beijer, Smiley, & Eizenman, 2004). Further, Wallace (2003) reports evidence that the presence of billboards is related to elevated crash risk in two circumstances: when billboards are located near intersections, or 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 if 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.** Due to 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 which 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 which had been published during the period from 1969-2007. From these, a set of 33 performance studies were selected for a meta-analysis of cell-phone use in two categories: (1) response times to critical events, and (2)
variability in vehicle control (lane position, headway, and speed). Caird et al. (2008) also examined phone type (hand-held or hands-free), type of research venue (laboratory, simulator, and on-road), conversation target (passenger or non-passenger), 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/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 hand-held. 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 non-significant 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 like the CAMP Driver Workload Metrics Study (Angell et al., 2006). This is perhaps not surprising, since the studies represent a mixture of hand-held (visual-manual) and hands-free (auditory-vocal) interface types. Caird et al. (2008), however, did find that effects of conversation were more pronounced on older than younger drivers (460 ms vs 190 ms to respond to events).

2. Events detected or missed: Neither meta-analysis reported percent of events missed (or not detected) during conversation, although this 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 used did not involve real participant-initiated conversations, or conversation at all, but instead used artificial tasks of various types done in an auditory-vocal modality. Moreover, in these studies driver behavior was investigated under 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, 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 others, thereby reducing crash risk).

Generally speaking, driver characteristics refer to three sources of variation: age-based differences; gender-based differences; and experience-based/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 the one hand, and driver distraction on the other, is still incomplete in most cases. Therefore, only the most relevant empirical findings are briefly summarized below.

**Age-based differences.** Older individuals experience a decline in sensory, motor, and cognitive functions, and this may be part of the reason why 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 period are likely to be incorrect, leading to an incorrect assumption of lower risk, since surrounding traffic will have advanced further than they will expect.

However, at the same time, many older drivers are known to compensate for their declining abilities, once 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 under lower risk conditions (e.g., when traffic density is low).

Younger drivers (especially teenagers) also experience problems with distraction. However, for them, distraction is not caused 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 it is present, such as showing off and talking excessively to peers while driving, and being willing to take risks while driving (Covey, 200; Lee, 2007; Lerner & Boyd, 2005; USDOT, 2009).

A major methodological problem inherent in many studies that look at 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. To the extent that differences are observed, e.g., older females have been reported to be more vulnerable to distraction while driving than their male counterparts (Hancock, Lesch, & Simmons, 2003). These effects seem to be due to experience factors and to social factors rather than to biological differences in multitasking or timesharing ability (Young, Regan, & Lee, 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. Though 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 can be learned (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 under dense traffic conditions.

3. **Size of the visual lobe** (also called functional field of view, or useful field of view): 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 useful field of view (UFOV; Ball & Owsley, 1993), has been used to relate visual lobe differences to driving performance (Owsley, Ball, McGwin, Sloane, Roenker, White, & Overley, 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.** Under this final subcategory, we group the following driver characteristics: time-sharing ability (Ackerman, Schneider, & Wickens, 1984), working memory capacity (Bühner, Konig, Pick, & Krumm, 2006; Conway, Kane, Bunting, Hambrick, Wilhelm, et al., 2005; Engle, 2002), general (physiological) state (e.g., arousal, alcohol intoxication, and fatigue: Matthews & Davies, 2001; Rakauskas, Ward, Boer, Bernat, Cadwallader, 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.

**Effects of Attentional Demands and Contextual Factors on Crash Risk**

**Risk of crashes and near crashes (figure 1, box 0 - 5).** Findings on the risk of crash and near-crashes come from two sources: (1) counts and derived statistics based on crashes and fatalities recorded in national accident databases and, (2) 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). Though this is a serious loss of life, the numbers of fatalities and crashes in the U.S. have declined slightly over the last decade. In addition, the number of fatal crashes attributed to distraction remained largely unchanged at half the rate of alcohol-impaired crashes; Virginia Tech Transportation Institute (VTTI), 2009; Sayer & Flannagan, 2011. In comparison, in the same period the number of cell phone subscriptions has grown dramatically, to over 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
using only 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, Stevenson,
McCartt, Woodward, Haworth, 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 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 hand-held devices.

Finally, it is worth noting that both studies used 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 which 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 upwards. 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, Klauer, Neale, Petersen, Lee, 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 not only provide information 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 4, in which intensive visual-manual tasks interfere with driving the most (increase of crash risk by nine times, compared to “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 (2300%) (Blanco, Bocanegra, Morgan, Fitch, Medina, et al., 2009; Blanco, Hickman, Olson, Bocanegra, Hanowski, et al., in press; Hanowski, et al., 2009). In contrast, dialing a portable cell phone increased the risk by only about three times, and conducting a conversation on a hand-held 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 four-fold 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 shows very little intrusion of auditory-vocal tasks and conversation on driving.

**Effects of contextual factors on crash risk (figure 1, box 4 - 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 driver that choose to engage in secondary tasks while driving; the time (during driving) that they decide to initiate secondary tasks; the traffic-related conditions under 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 comprises 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.** Though many critical road objects and events are expected by the driver and responded to in a more or less routine way, others are not. Studies which analyzed distraction-related crashes from national crash databases converged on two findings regarding the conditions under which drivers engage in secondary activities (Tijerina, Angell, Austria, Tan, & Kochhar, 2003).

First, drivers tend to engage in discretionary in-vehicle activities under conditions where they expect no trouble, for example: (1) In daylight, level straightaway, (2) On dry pavement, clear weather, and (3) With speed 45- 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.
Table 4. Relative Risk Odds Ratios for Crash/Near Crash for Non-Driving-Related Task Interactions (Dingus, 2009).

<table>
<thead>
<tr>
<th>Task/Interaction</th>
<th>Light Vehicle Data</th>
<th>Heavy Vehicle Data</th>
<th>Heavy Truck Driving Related</th>
</tr>
</thead>
<tbody>
<tr>
<td>Check Speedometer</td>
<td>0.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interact with Occupants</td>
<td></td>
<td>0.4</td>
<td></td>
</tr>
<tr>
<td>Talk/Listen to Hands-Free Phone</td>
<td></td>
<td>0.4</td>
<td></td>
</tr>
<tr>
<td>Look Outside Vehicle</td>
<td></td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>Passenger Interaction</td>
<td>0.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Talk/Listen to CB</td>
<td></td>
<td>0.6</td>
<td></td>
</tr>
<tr>
<td>Adjust Radio</td>
<td></td>
<td></td>
<td>0.6</td>
</tr>
<tr>
<td>Drinking Beverages</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Talk/Listen to Handheld Device</td>
<td>1.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adjust Instrument Panel</td>
<td></td>
<td>1.3</td>
<td></td>
</tr>
<tr>
<td>Eating</td>
<td>1.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Handling CD</td>
<td>2.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dialing Handheld Device</td>
<td>2.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Applying Makeup</td>
<td>3.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reaching for Object</td>
<td></td>
<td>3.1</td>
<td></td>
</tr>
<tr>
<td>Reading</td>
<td>3.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Read Book, Paperwork, Newspaper</td>
<td></td>
<td>4.0</td>
<td></td>
</tr>
<tr>
<td>Personal Grooming</td>
<td></td>
<td>4.5</td>
<td></td>
</tr>
<tr>
<td>Dialing Handheld Device</td>
<td></td>
<td>5.9</td>
<td></td>
</tr>
<tr>
<td>Use/Reach for Electronic Device</td>
<td>6.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Look at Paper Map</td>
<td>7.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Use Calculator</td>
<td>8.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reach for Moving Object</td>
<td>8.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Write on Pad/Notebook</td>
<td>8.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interact with, Look at Dispatching Device</td>
<td></td>
<td>9.9</td>
<td></td>
</tr>
<tr>
<td>Text Message on Cell Phone</td>
<td></td>
<td>23.2</td>
<td></td>
</tr>
</tbody>
</table>

Obviously, unexpected objects and events outside the vehicle may also be non-traffic-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, Gradenegger, and Kruger (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). Secondary tasks which impose high demand on the driver (or high intrusion on their driving) and which are engaged in frequently by drivers will pose a higher risk of crash than tasks which pose lower demand and are engaged in less frequently, all other things being equal (Wierwille & Tijerina, 1998).

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 pattern, 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 re-design 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 the 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 only be 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, in order to
estimate the impact on visual scanning behaviour 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, once they realize
that the traffic situation is too dangerous for the driver to engage in anything but driving.

_Distraction-countering technology and road/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 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.

**Overview of Factors Involved in Explaining Driver Distraction**

A hybrid psychological model is presented in Figure 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 2 is on the events and processes occurring *before* any change in driving performance or an imminent crash can be observed.

**A hybrid psychological model for understanding driver distraction.** The core of Figure 2 is formed by the box labeled “Working Memory”. This refers to “the system or mechanism underlying the maintenance of task-relevant information during the performance of a cognitive task (Baddeley and Hitch, 1974; Daneman and Carpenter, 1980)” (Shah and 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).
Figure 2. Hybrid psychological model for understanding mechanisms involved in the causation of driver distraction. Meaning of abbreviations: LTM = long-term memory. S = stimulus. R = response.

Working Memory (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 containing 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.

**Working memory subdivisions.** Working memory contains: (1) The limited capacity (can hold only few elements) but very active focus of attention; (2) The less active and transient (short-duration) short-term stores, and (3) A virtually unlimited capacity, rather inactive, but long-duration long-term working memory. (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 (3 – 5) elements of unlimited duration as long as they remain in the focus. Though 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 to) and monitoring performance outcomes (e.g., determining whether one has reached the destination). When behaviour is heavily dependent on the focus, ”pure” timesharing (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 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 decays over time, with the result that their elements are permanently lost after 10 – 20 seconds, unless they are rehearsed. The stores are involved in executing routine tasks that, however, are not performed automatically (e.g., stopping when the traffic lights turn to red). These tasks also involve the coordination of the execution of lower-level schemata (low-level task management). A limited amount of “pure” timesharing is possible, when behaviour 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 timeshare tasks.

3. *Long-term working memory (LTWM)* is a construct borrowed from Ericsson & 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 (won’t get lost), though 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 behaviour is largely under control of LTWM.

**Task-relevant stimuli.** Task-relevant stimuli are non-salient stimuli that originate in the driver’s sensory buffers that have been processed by the driver to the degree that they are recognizable as task-relevant (but are not salient). 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/her conscious attention on them, and ongoing tasks must be aborted or paused (called symbols/concepts in Figure 2). On the other hand, if they represent signs, and the driver must respond to them in a more-or-less routine (though non-automatic) 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., the road ahead making turns to the right or to the left), they enter long-term working memory 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: goal setting, task (re)configuration, monitoring 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 & Shallice, 1980; Posner & Peterson, 1990; Shallice, 1982.

**Bottom-up influences.** These 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: 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, once they have occurred, though 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 working memory. 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, caused by an array of factors.

A representative set of these factors is briefly described here, using the distinction between subdivisions of working memory as an organizing framework. The factors were derived from the general psychological literature with respect to multitasking, timesharing, 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 upwards or downwards 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 of breakdown of executive control: the limited capacity of his/her 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 working memory 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., approaching 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 in order 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, a left-pointing arrow on the navigation system display is confused with an – unrelated - right-pointing arrow on a traffic sign outside the vehicle (similar responses may also be confused); or (c) **Inattentional (or change) blindness:** stimuli (or changes in
stimulus patterns) are not (consciously) perceived, though under normal circumstances they would have been perceived (Carpenter, 2002; Rensink, 2002).

3. *Level of long-term working memory:* At this level, processing is able to resist distraction to a large extent due to the high degree of automation of skill execution (Shiffrin & Schneider, 1977; Posner & Peterson, 1990; Desimone & Duncan, 1995; Theeuwes, 1996). Nonetheless, driver distraction may take on the form of (a) *Action slips* (Reason, 1990): the driver performs a behavior in association with a wrong stimulus or at the wrong time. This may be due to the driver failing 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 in order to do an errand, and, instead, drives straight home); and (b) *Crosstalk* (Hurts, 2011; Navon & Miller, 1987): 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. Though 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, versus 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 using a conceptual formula as follows:

\[
Total\ Interference = Demand + Conflict
\]

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.

In order to implement such a computational model, one needs:

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 which 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 timeshared 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 below for newer models that have the potential to compensate for this caveat.)

Also note that, whether interference among two or more timeshared tasks is observed not only depends 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 have the task stimuli presented 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, Monty, & Fisher, 1978), Moray (e.g., Moray, 1986), and Sheridan (e.g., 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, et al., 2009). The noticeability of an event is influenced by four factors: (1) top-down, (2) bottom-up, (3) workload-related, and (4) physiological factors, that is, degree of eccentricity from the centre 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, the so-called A-SA model (Wickens, McCarley, Alexander, Thomas, Ambinder, et al., 2008), in which A (attention) corresponds to SEEV, as well as to Endsley & Garland’s (2000) Level 1 Situation Awareness. This set of inter-related models may (once completed) provide a more powerful set of predictions.
about glance behavior and event responsiveness under secondary task performance than has been possible thus far.

Models of Task Interruption/Resumption and Goal Activation

Trafton, Altmann, Brock, & 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 working memory. Executive attention can increase an item’s level of activation by rehearsal or attending 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 like driving has been suspended, it must acquire new activation in order to become retrievable through priming.

Thus, the theory predicts that an interrupted driver must have “access to” contextual cues in order 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 utilizing lag periods which makes 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/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 which 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 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, b; 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 which 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 before, 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 (2001); and Tsimhoni and Liu (2003).

**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. Though many of these models focus on Box 5 in Figure 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.

Crash databases may underestimate the size of the distraction problem, because drivers will often hide the fact that they were distracted or 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, Perez, & Dingus, 2005).

Finally, the NHTSA-program known as “Advanced Collision Avoidance Technologies” (ACAT) 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 due to driver distraction.

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\(^1\) SOAR is a formalism based on a cognitive architecture created for modeling different aspects of (intelligent) human behavior (Laird, Rosenbloom, & Newell, 1987).
Final Note

Even with the extensive work done in modeling over the last 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. It can be done 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 5, derived largely from the work of Angell et al. (2006), provides a convenient summary and key references for many methods that are currently used in observing or eliciting distractions. The methods are described in terms of the conditions under 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 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 tradeoffs. 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 benchtop simulation - , then testing may best start out using 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 which are regulated by government entities (see also Driver Metrics Workshop, 2006; Rupp, 2010).

The distraction observation and elicitation protocols in Table 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:
Table 5. Distraction Observation and Elicitation Methods.

<table>
<thead>
<tr>
<th>Method</th>
<th>Use conditions and environments</th>
<th>Associated Guidelines</th>
<th>Driver Performance Correlates</th>
<th>Simplicity / Cost</th>
<th>Does Method Provide for Comparisons against Baseline Data?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static (&quot;No Load&quot;) Task Time Measurement</td>
<td>Laboratory / Static / Tests the distracting task only</td>
<td>“15-sec rule” (Green, 1999)</td>
<td>Has been related to changes in eye glance patterns and speed – for visual-manual tasks only</td>
<td>Very simple / Very low</td>
<td>Not applicable – Static method</td>
</tr>
<tr>
<td>(Society of Automotive Engineers, 2004)</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Occlusion Method</td>
<td>Laboratory / Static / Tests distracting task only</td>
<td>20-sec Total Shutter Open Time (Society of Automotive Engineers, 2004); ISO standard approved</td>
<td>Has been related to changes in eye glance patterns, lane position, and speed – for visual-manual tasks only</td>
<td>Relatively simple / Low</td>
<td>Not applicable – Static method</td>
</tr>
<tr>
<td>(International Standards Organization, 2007)</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Benchtop Peripheral Detection Task</td>
<td>Laboratory / Static / Tests the distracting task combined with the Peripheral Detection Task</td>
<td>Not applicable</td>
<td>Has been related to event detection, but predictive validity is too low to recommend – see instead Peripheral Detection Task imposed on driving scene below</td>
<td>Relatively simple / Low</td>
<td>Not applicable – Static method</td>
</tr>
<tr>
<td>Modified Sternberg Task Using Road Sign</td>
<td>Laboratory / Static / Tests the distracting task combined with the memory task</td>
<td>Not applicable</td>
<td>Related to event detection on-road for both visual-manual tasks and auditory-vocal-cognitive tasks</td>
<td>Relatively simple / Low</td>
<td>Not applicable – Static method</td>
</tr>
<tr>
<td>Stimuli (Sternberg, 1969)—similar to</td>
<td></td>
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<tr>
<td>Peripheral Detection Task, but with memory</td>
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<tr>
<td>load component</td>
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<tr>
<td>Lane Change Test</td>
<td>Laboratory / Simulator dynamic / Tests the distracting task combined with the Lane Change Task</td>
<td>ISO standard approved</td>
<td>Direct comparisons difficult, due to 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</td>
<td>Simplicity depends on simulator / Moderate to high depending on simulator</td>
<td>Simulator baseline driving</td>
</tr>
</tbody>
</table>
Table 5 (part 2)

<table>
<thead>
<tr>
<th>Method</th>
<th>Use conditions and environments</th>
<th>Associated Guidelines</th>
<th>Driver Performance Correlates</th>
<th>Simplicity / Cost</th>
<th>Does Method Provide for Comparisons against Baseline Data?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual Peripheral Detection Task superimposed on driving scene (e.g., real driving, simulated driving (Martens and van Winsum, 2000), or driving video (Angell, Young et al., 2002)</td>
<td>Laboratory / Simulator dynamic / Tests the distracting task combined with the Peripheral Detection Task and simulated driving</td>
<td>May be included in ISO Preliminary Work Item below</td>
<td>Has been related to event detection on the road – for visual-manual tasks and for auditory-vocal-cognitive tasks</td>
<td>Simplicity depends on simulator / Moderate to high depending on simulator</td>
<td>Simulator baseline driving</td>
</tr>
<tr>
<td>Head-mounted Peripheral Detection Task, or tactile/auditory Peripheral Detection Task (Engstrom, Aberg, et al, 2005)</td>
<td>Laboratory / Simulator dynamic / Test track / Tests the distracting task combined with the Peripheral Detection Task and driving</td>
<td>ISO Preliminary Work Item now underway</td>
<td>Assesses effects of task demands on selective attention (cognitive processes / central and executive attention)</td>
<td>Relatively simple / Low to high depending on testing environment that is used</td>
<td>May be possible to obtain baseline driving data depending on the testing environment that is used</td>
</tr>
<tr>
<td>&quot;Static&quot; Load &amp; Enhanced Static Load Method &amp; variants (Young &amp; Angell, 2003; Young, Aryal, et al, 2005; Young, Angell, et al, 2009)</td>
<td>Laboratory / Simulator dynamic / Test track / Tests the distracting task combined with the Peripheral Detection Task and driving</td>
<td>Not applicable (though permitted as a method from which to obtain glance data under Alliance Guidelines [V 2.1] (Driver Focus-Telematics Working Group, 2006)</td>
<td>Yields glance data and event detection/response measures, as well as task completion time measures under attention load (or divided attention conditions); has been validated to road data</td>
<td>Relatively simple / Low to high depending on testing environment that is used</td>
<td>May be possible to obtain baseline driving data depending on the testing environment that is used</td>
</tr>
<tr>
<td>Simulator Evaluation</td>
<td>Laboratory / Simulator dynamic / Tests the distracting task combined with simulated driving</td>
<td>Not applicable</td>
<td>Depends on the fidelity of the simulator, the demands of primary driving task used, and task types tested</td>
<td>Simplicity depends on simulator / Moderate to high depending on simulator</td>
<td>Simulator baseline driving</td>
</tr>
<tr>
<td>Test Track Evaluation</td>
<td>Test track / Dynamic / Tests the distracting task combined with driving and other tasks (optional)</td>
<td>“Alliance Guidelines” (Driver Focus-Telematics Working Group, 2006)</td>
<td>Varying levels depending on any additional tasks present.</td>
<td>Complexity depends on test conditions / Moderate to high</td>
<td>Test track baseline driving</td>
</tr>
</tbody>
</table>
Table 5 (part 3).

<table>
<thead>
<tr>
<th>Method</th>
<th>Use conditions and environments</th>
<th>Associated Guidelines</th>
<th>Driver Performance Correlates</th>
<th>Simplicity / Cost</th>
<th>Does Method Provide for Comparisons against Baseline Data?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Naturalistic Evaluation</td>
<td>Public roads / Dynamic / Tests the distracting task combined with driving</td>
<td>“Alliance Guidelines” (Driver Focus-Telematics Working Group, 2006)</td>
<td>Driver performance extracted directly but may be subject to high levels of noise due to the uncontrolled driving conditions; noise can be reduced by careful route selection</td>
<td>Complex / High</td>
<td>Relative comparisons can be made to normal driving during the experiment</td>
</tr>
<tr>
<td>Naturalistic Driving</td>
<td>Public roads / Dynamic / Tests the distracting task combined with driving at driver’s pace</td>
<td>None currently</td>
<td>Driver performance extracted directly. Since drivers select which tasks to do and when, requires large scale data collection to achieve sufficient experimental power</td>
<td>Complex / High</td>
<td>With sufficiently large-scale studies (hundreds of driver-years of data) inferences of risk can be developed.</td>
</tr>
</tbody>
</table>
1) Methods where a task is examined with little or no driving context
   a) Task Completion Time – length of time taken to complete the distracting task under 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.\(^2\)
   d) Subjective Measures – driver prompts to assess their perception of their cognitive load while completing a distracting task (e.g., Endsley 2004).

2) Methods where 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 sec is sometimes used as an upper threshold (Driver Focus-Telematics Working Group, 2006).

\(^2\) The so-called “occlusion method” was pioneered by Senders, Kristofferson, Levison, Dietrich, and Ward (1966) in the context of measuring the visual load of the primary driving task.
• 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 due to drivers glancing at the task; a limit of 20 sec is sometimes used as an upper threshold (Driver Focus-Telematics Working Group, 2006).

e) Peripheral Detection Task (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 drivers are at maintaining lateral control of the vehicle while completing a distracting task.

h) Longitudinal control – how effective drivers are 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 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, & Rice, 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/system for purposes of human factors evaluations.

3) Examine the available guidelines (Driver Focus-Telematics Working Group, 2006; The Commission of the European Communities, 2007) 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:
   
   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, re-design tasks, and implement re-designs 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/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 below.

**Standards and guidelines.** Automakers and makers of nomadic devices can use guidelines and recommendations to design systems with minimum distraction-potential (Driver Focus-Telematics Working Group 2006; The Commission of the European Communities 2007). Currently 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; “Alliance”) took these voluntary guidelines a step further by signing a “Letter of Commitment” to the National Highway Traffic Safety Administration (NHTSA). In this letter, participating automakers
established that their new products would meet the Alliance guidelines, and provided a timeline and terms for verifying this.

“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, anti-lock 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


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 its principles, the “Alliance Guidelines” allow for completion of a visual occlusion test (which is performed in static conditions and should be completed within 15 seconds of total shutter open time, that is, “The 15-second Rule”; Green, 1999), a static divided attention test (where a primary task closely mimics the visual demands of driving and the secondary task of interest is performed concurrently), or on-road/test-track/simulator testing of the task while the participant drives the test vehicle. Practitioners are directed to Table 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 on the field. There is, however, some experimental evidence of potential benefits from lockouts. For example, Donmez, Boyle, & 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).

While 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 enacted as widespread policy. Furthermore, the sale and distribution of jamming devices is 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 above, 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, Weiss, et al., 2003), these systems are still under development. Some benefits have been observed in experimental settings (Donmez, Boyle, Lee, & McGehee, 2006; Donmez, Boyle, et al., 2006; Engström & Victor, 2009; Victor, Harbluk, 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 the 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 hand-held phone but not a hands-free
phone), certain technologies (e.g., display devices over 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 US laws that address driver distraction:

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
once 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
currently too early to determine the extent to which these laws will be effective.

**Training and education.** There are two different aspects of training and education to
mitigate and manage distraction. First, there is a question if 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, Lesch, 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 develop 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. While much progress has been made in the last 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 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. Below, lessons learned will be summarized for three types of stakeholder.

Designers of devices that may be used in a moving vehicle typically must deliver designs and prototypes under a combination of economic and political constraints. For these stakeholders, guidelines, standards, measurement methods, and legislation are all important topics. Currently, 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 additional research directed towards 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. While in many cases this reduction does not result in any negative consequence, inattention to the forward roadway comes at the expense additional crash risk. They should also understand that while 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 to 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 different 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 will be summarized.

Distraction in the context of “connected vehicle” ecosystems. There is currently an increasing trend towards connecting vehicles with each other and with the road infrastructure through wireless means (e.g, the Connected Vehicles initiative in the US: 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 parent’s cell phones or compile them for review on a website (Farmer, Kirley, & McCartt, 2010; McGehee, Raby, 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 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 distraction-like behaviors (e.g., real-time eyes-off-road assessment) become available. For example, in the US, 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). While 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 driver’s eyes off the road for substantial periods of time. 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 towards 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 where the cause of a crash was unclear? Could they be deemed responsible for crashes based on 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.** While recent efforts by the US and other governments to bring driver distraction to the forefront (e.g., [http://www.distraction.gov](http://www.distraction.gov)) have provided more drivers with information about the issue, it 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 based on 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 Manufacturer’s 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. Though not specifically aimed at avoiding driver distraction, its guidelines apply to manufacturers and retailers of electronic devices which, if used or designed inappropriately, may be distracting to the driver.

The philosophy of Vision Zero includes two principles: (1) Safety responsibility must be shared by road system designers and individual drivers, and (2) 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, multi-stakeholder-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](http://www.dot.gov/affairs/2010/dot9910.htm)). Therefore, driver distraction is receiving world-wide 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 towards 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 validate brain activation models. As the required equipment evolves and becomes more durable, it could be expected that these systems will 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 datasets (e.g., of naturalistic driving), will provide a full view of the driving behaviors of thousands of drivers. Careful observation of these datasets (e.g., the SHRP2 NDS; 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 over the next several years in order to advance knowledge in the field of distraction and improve the safety of drivers. These questions include:

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 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 which are useful in managing and mitigating any negative effects of distracting behaviors. What is known
about distraction has changed considerably in the last decade, and very likely will do so again over decades to come.
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