
7 Measuring the Effects of Driver Distraction: Direct Driving Performance Methods and Measures

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7.1 INTRODUCTION

In modern vehicle cockpits, drivers have access to a range of entertainment, information, communication, and advanced driver assistance systems (e.g., navigation systems). Whether or not these technologies distract drivers depends in large part on the way they are designed and used. Assessment methods and metrics that are sensitive to the effects of different in-vehicle technologies on driving performance are needed to inform the safe design, deployment, and use of these devices.

Many methods and metrics are available for evaluating the impact on driving performance of driver interaction with secondary tasks. However, the selection of measurement methods for driver distraction research, as in other areas of research, should be guided by a number of general rules related to the nature of the task under study and the properties of the method itself. To be considered an appropriate measurement technique, a method must be *valid* (i.e., it measures what it claims to measure) and *reliable* (i.e., the results obtained are consistent across administrations) and have high *sensitivity* (i.e., be likely to detect the effect of an activity or technology on driving performance even when that effect is small). The results obtained must also have *external validity*; that is, they should be able to be generalized to real-world situations or to situations and individuals beyond the scope of a specific study.¹

This chapter reviews a range of assessment methods and metrics that have been used to assess the impact of distraction on driving performance. The available evidence regarding the reliability, validity, sensitivity, and generalizability of these is discussed. The focus of the chapter is on “direct” driving performance methods and metrics; that is, methods and metrics that directly assess objective measures of driving performance. Surrogate measurement methods, which simulate and assess particular aspects of the driving task (e.g., the lane change test and the visual occlusion technique), are discussed in Chapters 9 through 11 of this book.

7.2 DRIVING PERFORMANCE MEASUREMENT METHODS

7.2.1 ON-ROAD AND TEST-TRACK STUDIES

One of the most realistic, and ecologically valid, ways of measuring the potentially distracting effects of tasks that compete for the driver’s attention is to conduct an on-road study. Using this method, drivers are required to drive an instrumented vehicle on real roads for a specified period while various driving parameters are recorded using data loggers. Driving performance while engaging in a secondary task is then compared against a baseline or reference condition, such as driving when not interacting with any device.² On-road studies include naturalistic driving studies, field operational tests (FOTs), and more highly controlled on-road experiments.

FOTs and naturalistic driving studies are conducted over a period of weeks, months, or years and involve drivers driving an instrumented vehicle (sometimes their own vehicle) as part of their normal, everyday driving activity. These studies are less obtrusive than on-road experiments as they do not involve the presence of an experimenter and drivers are free to drive whenever and wherever they wish. The main difference between FOTs and naturalistic driving studies is the level of experimental manipulation involved. FOTs are designed to measure, under natural driving conditions, drivers’

interaction with one or more in-vehicle systems of interest and usually involve these systems being activated and deactivated over the course of the study. The Australian TAC SafeCar project is an example of a FOT, where drivers interacted with a suite of in-vehicle intelligent transport systems (ITS) during their everyday driving.³ In FOT studies, the effectiveness of the systems in optimizing driving performance and safety (relative to nonuse of the systems by the same drivers or relative to a control group driving vehicles not equipped with ITS technologies) is usually the main focus of research. However, naturalistic driving studies involve no experimental manipulation and simply gather, using video cameras and other on-board sensors, data on drivers' everyday driving behavior and activities, which may or may not include interaction with ITS and other technologies Original Equipment Manufacturer (OEM)-fitted, retrofitted, or nomadic). In the latter studies, the impact of everyday driver interaction with various sources of distraction on driving performance and crash risk (e.g., a mobile phone) is more the focus of research and can be observed and determined *post hoc* from analysis of the logged driving and video data. The largest naturalistic driving study conducted to date is the 100-car study (for more detail on this and other naturalistic driving studies, see Chapters 5 and 17 of this book).

On-road experiments involve relatively shorter time periods, of minutes or hours, and a higher level of experimental manipulation. The drivers follow a specified route (usually with the experimenter present) and are required to perform one or more tasks during particular segments of the drive, the timing of which is usually controlled by the experimenter.

On-road studies yield vast amounts of driving performance data under conditions that are relatively representative of actual driving. However, on-road studies, and particularly FOTs and naturalistic driving studies, are time consuming (often taking months or years to complete), are expensive to conduct, and require the storage and analysis of enormous amounts of data. In FOTs and naturalistic studies, researchers also have little or no experimental control over factors such as weather and traffic conditions. On-road experiments afford a higher level of experimental control, but the presence of the experimenter can also cause drivers to behave differently than they normally would.

Test-track studies, conducted on closed roads or dedicated test circuit, closely approximate real-world driving and have been used extensively to examine the distracting effects of secondary tasks that compete for the driver's attention.⁴⁻⁶ Here, participants are required to drive an instrumented vehicle along the test track. Information on participants' driving performance while engaging in secondary tasks is collected by a data logger or an observer, or even instrumentation embedded in the roadway. These data are compared with a baseline condition to determine the level of distraction imposed by the secondary task(s). This method approximates real driving conditions while affording the experimenter greater control over factors such as traffic signal timing (see, e.g., Ref. 7). Driving under the more controlled conditions of a test track also minimizes the safety risks associated with conducting distraction research on real roads.⁸ However, the nature of the test-track course can affect the data collected. If the course is relatively short and there is little or no traffic or obstacles on the track, then drivers may not assign as much priority to the driving task (and greater priority to the secondary task) as they would on real roads.

Drivers may, for example, spend a greater amount of time glancing away from the road than they would under real driving conditions, and this could alter the influence of the secondary task on driving performance. In addition, safety considerations make it impossible to expose drivers to demanding situations, where the consequences of driver distraction may be most critical.

7.2.2 DRIVING SIMULATORS

Driver distraction research often makes use of driving simulators, as they allow for the examination of a range of driving performance measures in a controlled, relatively realistic, and safe driving environment. Driving simulators, however, vary substantially in their characteristics, and this can affect their realism (or fidelity) and the validity of the results obtained. A distinction is often made between low-level, mid-level, and high-level driving simulators. High-level, or high-fidelity, simulators offer a realistic driving environment, complete with a vehicle cab with realistic components and layout, advanced graphics with close to a 360° field of view, and a sophisticated motion base. Mid-level simulators have a realistic cab or vehicle, large projection screens, and sometimes a simple motion base. Low-level, or low-fidelity, simulators offer less realistic driving environments and usually consist of a PC or desktop workstation and a simple buck with controls.⁹⁻¹¹

Driving simulators have a number of advantages over on-road and test-track studies. First, they provide a safe environment in which to conduct research that might be otherwise too dangerous to be conducted on-road.⁸ Although test tracks can be used to evaluate the distracting effects of in-vehicle systems on driving using single-vehicle scenarios, using multiple-vehicle scenarios in such situations is potentially hazardous. Driving simulators, in contrast, provide a safe environment for the examination of distraction issues using multiple-vehicle scenarios, where the driver can negotiate very demanding roadway situations while engaging in secondary tasks.⁸ Second, greater experimental control can be applied in driving simulators compared with on-road studies, as they allow for the type and difficulty of driving tasks to be precisely specified and any potentially confounding variables, such as weather, to be eliminated or controlled for.¹¹ Third, the cost of modifying the cockpit of a simulator to allow for the evaluation of new in-vehicle systems may be significantly less than modifying an actual vehicle.¹¹ Finally, a large range of test conditions (e.g., night and day, different weather conditions, or road environments) can be implemented in the simulator with relative ease, and these conditions can include hazardous or risky driving situations that would be too difficult or dangerous to generate under real driving conditions.¹¹⁻¹³

The use of driving simulators as research tools does, however, have a number of disadvantages. First, data collected from a driving simulator generally include the effects of learning to use the simulator and may also include the effects of being directly monitored by the experimenter.² Second, driving simulators, particularly high-fidelity simulators, can be very expensive to install and manage and require a higher level of expertise to operate than other equipment used to measure driver distraction (e.g., surrogate measures such as visual occlusion goggles or the lane change test), particularly because they also often require the experimenter to operate peripheral equipment such

as eye tracking systems.¹¹ Simulator discomfort is another problem encountered with simulators and is particularly common among older drivers and females, who experience higher dropout rates than younger, male drivers.^{8,14,15} In addition, simulator discomfort can undermine driving performance and confound the measurement of distraction-related performance decrements.¹⁶ However, one of the most problematic aspects of driving simulator research that has major implications for driver distraction research is the effect of the simulator on drivers' priorities in relation to the performance of primary (i.e., driving) and secondary tasks. The cognitive resources that drivers devote to the primary and secondary tasks while in the simulator may differ significantly from those deployed on actual roads because driving errors in the simulator do not have serious consequences.⁸ Thus, drivers may glance away from the road for a greater length of time when dialing a phone in the simulator than they would in the real world because they know their safety will not be compromised. This is a contentious issue in driving simulator research and raises the question as to how valid are driving simulators as tools for conducting driver distraction research.

7.3 SIMULATOR FIDELITY AND VALIDITY

7.3.1 FIDELITY

As discussed earlier, a simple description of driving simulators places them on a continuum that ranges from low to high fidelity. Fidelity refers to the level of realism inherent in the virtual world. The closer a simulator approximates real-world driving, in terms of the design and layout of controls, the realism of the visual scene, and its physical response characteristics, the greater fidelity it is reported to have.^{9,13} Numerous dimensions of fidelity have been proposed, many of which relate to the simulator's technical or physical characteristics, but these characteristics may not necessarily correspond to the degree to which the simulator replicates the driving experience.

Rehmann et al.¹⁷ proposed that there are four interrelated dimensions of simulator fidelity: equipment fidelity, environmental fidelity, objective fidelity, and perceptual/psychological fidelity. Equipment fidelity refers to the degree to which the simulator replicates the appearance and feel of the real-world system, in terms of the layout of the vehicle cockpit and the size, shape, color, and position of the vehicle/system controls. Environmental fidelity concerns the extent to which the simulator replicates motion and visual cues, and other sensory information from the real-world environment. Objective fidelity refers to the degree to which a simulator replicates its real-world counterpart in terms of dynamic cue timing and synchronization (e.g., timing of the visual cues matching steering inputs). The fourth dimension, perceptual or psychological fidelity, is concerned with the degree to which the driver perceives the simulation to be a believable reproduction of the real driving task, and the degree to which the driver's pattern of interaction with the driving environment and system controls corresponds to real-world driving.¹⁷ Simulator fidelity is a complicated issue with many factors to consider, and simulators cannot always be accurately described using a three-tier classification system of low, medium, and high fidelity.

The level and type of fidelity required by a simulator depends on the type of research being conducted. It has been suggested that higher fidelity levels are required for research where the results of the simulation are used to draw conclusions about real-world driving performance, as when assessing whether interaction with an in-vehicle device distracts drivers.¹³ In terms of the specific aspects of simulator fidelity that are most important for distraction research, little research exists that can be used to guide this decision. However, knowledge regarding what driving performance measures are affected by distraction can provide some useful insights into what aspects of simulator fidelity might be important. For example, distraction, particularly visual distraction, has been shown to affect drivers' ability to maintain lateral position.^{18,19} In turn, a lack of motion and visual cues has been shown to affect the precision of lateral position control to a greater extent in simulators than actual vehicles, because the absence of visual and kinesthetic feedback leads to a decreased ability to select appropriate steering corrections.^{11,20} Thus, it appears that environmental fidelity, and the precise replication of motion and visual cues in particular, is important for the accurate measurement of the effects of distraction on lateral control. Distraction has also been shown to affect drivers' visual scanning patterns and their ability to detect events occurring in the periphery,^{18,21} suggesting that a display screen with a wide field of view is important to be able to capture the effects of distraction on the detection of objects or events occurring in the driver's peripheral field of view. A simulator's fidelity can thus affect how sensitive it is to the effects of distraction. This issue is explored further in Sections 7.3.3, 7.4, and 7.5.

The location of the in-vehicle system under evaluation, relative to the driver and the roadway, and the type and layout of its controls are also important. The location of the system in the simulated vehicle and its visual angle from the road should match precisely its placement in real vehicles because its distance from the forward view directly contributes to the degree of distraction it imposes on drivers. For example, a study on monitor location within the vehicle revealed that as the downward viewing angle of the display increased, the drivers' ability to detect that they were closing in on a lead vehicle decreased.²² In addition, the types of controls used and their layout should be consistent across the simulated and real systems. Discrepancies in the location and design of the in-vehicle system between simulated and real vehicles may lead drivers to interact with the system differently in the simulator and, thus, lead to driving performance being differentially affected across the simulated and real-world environments.

These are but a few examples of simulator fidelity dimensions that may be important for distraction research. It is likely that there are many more aspects that are important for this type of research. Identifying the specific aspects and levels of simulator fidelity that are required for distraction assessment should be a focus of further research.

7.3.2 VALIDITY

Simulator validity typically refers to the degree to which behavior in a simulator corresponds to behavior in real-world environments under the same conditions.^{10,20} The validity of a simulator can be affected by its level of fidelity. This, and the following, section will explore the issue of simulator validity and its relationship to fidelity.

The best method for determining the validity of a simulator is to compare driving performance in the simulator to driving performance in real vehicles using the same driving tasks.²⁰ A number of studies have examined driving simulator validity and have generally found good correlations between simulated driving performance and driving performance on real roads.^{10,18}

There are two types of validity: absolute validity and relative validity. If the numerical values for certain tasks obtained from the simulator and actual vehicles are identical or near identical, absolute validity is said to have been achieved.^{9,23} Relative validity is achieved when driving tasks have a similar affect (e.g., similar magnitude and direction of change) on driving performance in both the simulator and real vehicles.²³ Although limited, research has generally found that simulators demonstrate good *relative* behavioral validity for many driving performance measures, although *absolute* validity has rarely been demonstrated.^{9,11,20,23–25}

7.3.3 RELATIONSHIP BETWEEN SIMULATOR FIDELITY AND VALIDITY

High-fidelity simulators offer a more realistic driving environment and generally support greater validity than lower-fidelity simulators; however, they can be much more expensive to build and operate than lower-fidelity simulators and can be less sensitive to the effects of distraction.¹⁸ An important consideration for simulator users is whether the increased costs of high-fidelity simulators are offset by their greater validity and whether the decreased validity of low-fidelity simulators is offset by their greater sensitivity.

Several driving simulation studies have examined how the level of fidelity of a simulator affects driving performance and the validity of the results obtained. Early research suggested that the presence of a moving base and higher image resolution may increase the absolute validity of driving simulators.^{10,20,25} For example, the performance of certain driving tasks, such as speed control and lane-keeping performance, are less precise in low-fidelity, fix-based simulators than in high-fidelity, motion-based simulators or real vehicles, because of the absence of haptic and motion cues.^{11,20,25} However, some recent research has found that lower-fidelity simulators demonstrate levels of validity comparable to those of their higher-fidelity counterparts.^{11,18}

A study conducted by Reed and Green¹¹ assessed the validity of a low-cost driving simulator, in high- and low-fidelity mode, for use in measuring the distracting effects of using a mobile phone. The simulator used was the Driver Interface Research Simulator located at the University of Michigan Transportation Research Institute (UMTRI). This comprised a 1985 Chrysler Laser with an instrumented steering wheel and brake and accelerator pedals. The visual scene was projected onto a screen that gave a 22 × 33 degree field of view. Participants were tested under two fidelity conditions: high and low. In the high-fidelity mode, the visual scene included a colored, textured background and roadside objects, whereas in low-fidelity mode, the scene was black with white road edge and center lines.

Twelve participants drove an instrumented car along a freeway route and a simulated highway route while periodically dialing a mobile phone. Measures of lane position, speed, steering wheel angle, and throttle position were recorded and compared for the simulator and actual driving conditions. Results revealed that only one significant difference was found between fidelity conditions: the effect of visual

fidelity on the standard deviation of steering wheel angle was in the opposite direction for males and females. Given the lack of differences observed between the two fidelity conditions, the validity of the simulator was evaluated for the high-fidelity condition only. When the simulator and on-road results were compared, it was found that mean speeds were similar in the simulator and instrumented vehicle; however, lane keeping was less precise in the simulator than in the instrumented vehicle. More specifically, the variation in lane position was twice as large in the simulator as in the instrumented vehicle under the phone task condition, which may reflect drivers' tendency to be less cautious about making driving errors in the simulator because the consequences for doing so are far less severe than those in actual vehicles. Reed and Green concluded that the simulator demonstrated good absolute validity for speed measurements and good relative validity for the effects of the phone task on lane keeping.

More recently, a study by Engström et al.,¹⁸ conducted as part of the HASTE project, compared the effects of visual and cognitive demand on driving performance in a range of test environments, including static and moving-base simulators. The fixed-base simulator was the Volvo Technology (VTEC) simulator located at Volvo Technology Corporation in Sweden. This simulator comprises a Volvo S80, with a 135° horizontal field of view without rear projection. The moving-base simulator was the Swedish National Road and Transport Research Institute (VTI) simulator, located in Lidköping, Sweden, which is a high-fidelity, dynamic simulator. The VTI simulator consists of a Volvo 850 vehicle and a 120° visual view with no rear projection. Drivers drove along a motorway in either the fixed- or moving-base simulator, once while performing no secondary task and once while performing either a surrogate visual IVIS task (the arrows task) or a surrogate cognitive-auditory IVIS task (the Auditory Continuous Memory Task). The difficulty level of the surrogate tasks was varied during the drive. Results revealed that the effects of visual and cognitive load on driving were largely consistent across the static and moving-base (dynamic) simulators. One point of difference was that the effect of the surrogate tasks on lateral vehicle control was greater in the fixed-base than in the moving-base simulator, which suggests that the lower-fidelity simulator may have been less valid but more sensitive.

It is important to note that although the aforementioned research is promising in terms of the ability of a low-fidelity simulator to accurately measure the effects of driver distraction on driver performance, demonstrating that one simulator's being valid for the assessment of a particular driving task does not assure that all simulators will be equally valid. In general, the validity of simulator results will depend on the degree to which the simulator replicates the confluence of driving and in-vehicle task demands that occur in actual driving situations. The absolute degree of simulator fidelity may be less important than its specific characteristics. It is recommended that the validity of individual simulators be established separately for each driving situation they are used for.¹³

7.4 THE RELATIONSHIP BETWEEN SENSITIVITY AND TEST METHODS

A general finding that has emerged from driver distraction and workload research is that the different assessment methods or test environments demonstrate varying

levels of sensitivity to the effects of secondary tasks. In particular, a number of studies have shown that as the realism of assessment methods or test environments increases, the less sensitive they become to the effects of secondary tasks on driving performance. Sensitivity refers to the ability to detect even small changes in driving performance due to, in this case, the performance of a secondary activity. Blaauw²⁰ demonstrated that a fixed-base driving simulator was able to differentiate between experienced and inexperienced drivers on secondary tasks with greater sensitivity than an instrumented vehicle during an on-road test. Reed and Green¹¹ also found that the effects of dialing a mobile phone on lane-keeping performance were more pronounced in a low-cost driving simulator than on the road. Age effects on lane-keeping performance while performing the concurrent dialing task were also of a greater magnitude in the simulator than in the on-road test.

More recently, the results of the CAMP Driver Workload Metrics project revealed that the laboratory tests generally generated larger or more discernable effects than the test-track or on-road tests, and for some driving measures, effects were observed in the laboratory tests that were not observed in the on-road and test-track studies. For example, a number of event detection measures in the laboratory were capable of discriminating between the effects of high- and low-workload auditory-vocal tasks on driving, whereas these measures were not able to distinguish between the effects of high- and low-workload tasks on driving on the test track. The effect sizes found in the on-road and test-track studies were largely comparable across tasks and driving performance measures.²⁶

The studies conducted as part of the HASTE project also revealed differences in the discriminability of test environments; however, the results were more diverse. These studies examined the effects of surrogate and actual in-vehicle tasks on driving performance in the laboratory, in a range of driving simulators and on real roads. Overall, the results revealed that, in line with the CAMP results, the effects of the surrogate visual and cognitive in-vehicle tasks were generally larger in the laboratory than in the driving simulators or the on-road tests. The effect sizes found in the driving simulator and on-road studies were, however, largely comparable across the driving performance measures examined. One difference that was observed across the field and simulator trials was that physiological workload and steering activity was higher in the field than in the simulators, which the authors believed reflected an increase in effort and a lower error tolerance in real traffic, possibly due to the increased risk associated with this environment.¹⁸

The relative sensitivity or discriminability of testing environments was more varied when drivers interacted with actual in-vehicle systems (navigation and traffic information systems). In contrast to the CAMP project results, both the on-road tests and the driving simulators demonstrated larger effect sizes than the laboratory results. However, the effects of the actual in-vehicle systems on driving performance were larger in the simulator compared with the on-road tests.²⁷ It is not clear why these discrepancies across the studies occurred, but they may relate to the different secondary tasks used.

A number of explanations exist for why less realistic test environments, such as low-fidelity simulators, provide larger secondary task effects than on-road or test-track tests. First, drivers' priorities and attention/effort allocation in laboratory tasks

and simulators may differ from real-world driving environments because the risk of injury or property damage is absent in these environments. Thus, drivers may be less concerned about missing hazardous events or drifting from their lane in laboratory and simulator tests because the consequences for doing so are far less severe than they are on real roads, or even test tracks. Second, task effects may not be as apparent in on-road and test-track environments because of the greater amount of “measurement noise” present (e.g., uncontrolled variables such as traffic density or weather conditions). Finally, the lack of vestibular and tactile cues or feedback in laboratory and simulator tests may make driving more demanding, leading to less spare capacity and, consequently, larger effects of secondary tasks. In particular, the lack of feedback may reduce drivers’ ability to choose appropriate steering corrections when they deviate from their correct lane position, resulting in the observed larger lane-deviation effects.^{11,26}

The ability of laboratory and simulator tests to detect small effects is further enhanced by the relatively low cost of testing. The relatively low cost of low-fidelity and laboratory tests makes it possible to collect data from many more participants than would be possible in a high-fidelity simulator. As a consequence the statistical power of comparisons is much greater.

Until the exact nature of this trend is better understood, system designers should not rely solely on laboratory tests to evaluate the safety implications of in-vehicle systems. Rather, it is advisable to include them to initially highlight potential problems with systems, or as part of a batch of evaluation tests that also include on-road or simulator trials.

7.5 FIDELITY, VALIDITY, SENSITIVITY, AND COST TRADE-OFFS

Choosing which method to use when evaluating an in-vehicle system is often a trade-off between level of fidelity, validity, sensitivity, and cost. On-road studies, for example, offer the greatest level of fidelity and external validity. They are, however, expensive and time consuming to conduct and do not offer the same level of experimental control as a driving simulator or laboratory tests, and thus may be less sensitive. One promising trend to emerge from the literature is that low-fidelity simulators offer a similar level of sensitivity and validity as high-fidelity simulators for evaluating the effects of secondary tasks on driving performance. Low-fidelity simulators can, thus, be used by in-vehicle system designers to evaluate the impact of in-vehicle systems on driving performance, without sacrificing any sensitivity to system effects and without incurring the high setup and operating costs associated with high-fidelity simulators. However, no simulator, regardless of its level of fidelity, can completely replicate driving in the real world. In distraction research, the different attention allocation policies and patterns of secondary task interaction used by drivers in simulated and real driving environments is of particular concern. Thus, although simulators offer a relatively inexpensive test environment for initial assessment of the distracting effects of a device, in-vehicle devices should also be evaluated in an on-road setting before final decisions are made regarding its suitability for use while driving.

7.6 MEASURES OF DRIVING PERFORMANCE

Choosing appropriate driving performance measures or variables, which are compatible with the measurement technique(s) being used and sensitive to the particular aspect of distraction being evaluated, is just as important as using appropriate measurement methods. Ideally, the selection of driving performance measures should be based on a consideration of the type of system being evaluated and theories or previous research findings regarding how certain tasks influence driver behavior. In turn, the selection of assessment methods will often be informed by the particular driving performance measures being examined. A deliverable from the European Aptive Integrated Driver-vehicle Interface (AIDE) project (Deliverable 2.2.1) provides a comprehensive review of driving performance measures that can be used in the evaluation of in-vehicle systems.²⁸ A brief review of some of the most common driving measures that have been used in distraction research is provided in the following section along with example research findings.

7.6.1 LONGITUDINAL CONTROL

A range of longitudinal control measures can be examined in distraction research. Two of the most common include measures of speed and following distance. These are discussed in Sections 7.6.1.1 and 7.6.1.2.

7.6.1.1 Speed

The relationship between speed and crashes is widely recognized in the road safety community, and as such, speed is a commonly used dependent variable in transportation human factors research, including driver distraction research. A number of speed-related measures can be calculated, including mean and 85th percentile speed, maximum speed, and the standard deviation, or variability, of speed. Several on-road and simulator studies have found that drivers display greater variation in driving speed and throttle control when using a mobile phone, and this has been demonstrated for hands-free as well as handheld phones.^{5,11,29} It has also been shown that drivers display a tendency to reduce their speed when talking on a mobile phone, which is believed to be a form of behavioral adaptation to reduce primary task demand or increase the safety margin.^{29,30} In a driving simulator, Srinivasan and Jovanis¹² found that mean speeds were lower when drivers manually operated a route navigation system. Operating a CD player while driving can also result in reduced simulated driving speeds³¹; however, the use of voice inputs to operate CD players has been shown to reduce the likelihood of traveling at speeds that are considered to be too low.³²

7.6.1.2 Vehicle Following (Headway)

Vehicle following, or headway, measures are also commonly employed in driver distraction research. Several specific vehicle following measures have been commonly used, including mean headway (distance or time based), minimum headway, and standard deviation of headway. Headway is an indication of the safety margin

that drivers are willing to accept, and thus, short headways are often interpreted as being indicative of degraded driving performance and a measure of high secondary task load.

A number of studies have, however, found that drivers tend to adopt longer headways when interacting with secondary tasks, particularly visual tasks.^{19,33,34} In a simulator study, Greenberg et al.¹⁹ found that drivers increased their headway when engaging in a visual secondary task and that this effect was particularly pronounced for older drivers. Also, as part of the HASTE project, Östlund et al.³⁴ found in a series of laboratory, simulator, and on-road studies that both time and distance headway increased when drivers were performing a visual surrogate IVIS task, but not during cognitive IVIS operation.

7.6.2 LATERAL CONTROL

Lateral control measures commonly examined in distraction research include lane keeping and steering measures. These are discussed in Sections 7.6.2.1 and 7.6.2.2.

7.6.2.1 Lane Keeping

Lane keeping, or lateral position, refers to the position of a vehicle on the road in relation to the center of the lane in which the vehicle is traveling. Decrements in lateral position control are used as a measure of secondary task load when evaluating the effects of in-vehicle systems on driving performance. The most commonly used lateral position metrics are mean lane position, standard deviation of lane position, and number of lane exceedences (LANEX).

Research suggests that drivers' ability to maintain their lateral position on real or simulated roads is adversely affected when performing secondary tasks, particularly tasks requiring large amounts of visual attention.¹⁸ Drivers make a greater number of lane position deviations and exceedences while dialing or talking on either a handheld or a hands-free mobile phone, even when driving on straight roads with little traffic.^{5,11} Research also suggests that drivers make a greater number of lane deviations and exceedences when manually entering details into a route guidance system or when following navigation instructions presented visually, rather than through voice guidance.^{35,36} Tuning the radio, interacting with a CD player, or listening to radio broadcasts can also degrade driving performance, as measured by lane position deviation.^{31,37,38}

An interesting finding with respect to lateral control is that moderate levels of cognitive load have been shown to lead to more precise lateral control, by reducing lane-keeping variation. Visual load, in contrast, has been shown to increase lane-keeping variation.^{18,19}

7.6.2.2 Steering Wheel Metrics

Measures of steering wheel movement have been used extensively in many forms of driving research. These include standard deviation of steering wheel angle, steering wheel reversal rate, steering wheel angle high-frequency component (HFC), steering wheel action rate, and steering entropy (less predictable steering behavior).³⁴ In driver distraction and workload research, steering wheel movements are considered

to be an indicator of secondary task load. When driving under normal conditions (i.e., when not performing a secondary task), drivers will make a number of small corrective steering wheel movements to maintain lateral position. When engaging in a secondary task, however, particularly a visual-manual task, drivers will often make a number of large and abrupt steering wheel movements to correct heading errors.

7.6.3 EVENT DETECTION AND REACTION TIME MEASURES

Event detection and reaction time metrics have become increasingly popular in in-vehicle system research and evaluation, primarily because of the relationship between these measures and risk of crash involvement. A range of event detection and response time measures can be examined, including number of missed/detected events, number of incorrect responses made, and response time and distance (e.g., distance from event when detected).

Drivers' ability to detect and react to external events or objects has been shown to be impaired by the use of in-vehicle devices, particularly when these devices are complex. A number of studies have found that using either a handheld or hands-free phone can increase drivers' reactions to hazards and common road events (e.g., traffic light changes) by up to 30%.^{29,34,39-41} In a driving simulator study, Srinivasan and Jovanis¹² found that drivers' reaction times to vehicles crossing their path or to traffic light changes increased when they were listening to navigation instructions from a route guidance system that issued turn-by-turn navigation instructions. Accessing and reading e-mails using a voice-based in-vehicle e-mail system while driving has also been found to increase drivers' reaction times to a braking lead vehicle by up to 30% in a simulated driving environment.⁴²

7.6.4 GAP ACCEPTANCE

Negotiating gaps in traffic is a complex task requiring considerable visual guidance and attention. Gap acceptance measures that have been used in distraction research include number of collisions initiated and size of gaps accepted. Research shows that when using in-vehicle devices such as a mobile phone, drivers tend to accept shorter gaps in traffic when turning than when not using a phone.⁴³ A test-track study by Cooper and Zheng⁴ also found that when using a mobile phone, drivers do not consider weather or road surface conditions when making a decision to turn across oncoming traffic. In particular, when using the phone and the road surface was wet, drivers initiated twice as many collisions as when not using the phone.

7.6.5 SUBJECTIVE MENTAL WORKLOAD

Subjective, or self-reported, workload measures require the participant to rate his/her perceived level of workload shortly after completing a task. Several simple subjective mental workload scales have been developed to measure an individual's perceived workload. Some of the main scales used in the driving domain include the NASA Task Load Index (NASA TLX), the Subjective Workload Assessment Technique (SWAT), the Modified Cooper Harper Scale (MCH), and the Rating Scale Mental Effort (RSME). The NASA TLX and SWAT scales are multidimensional scales

designed to address several different dimensions of workload, such as performance and mental effort. However, ratings from the subscales are frequently combined in an equally weighted average.⁴⁴ Another multidimensional workload scale that has recently been developed to assess the level of workload associated with in-vehicle tasks is the Driving Activity Load Index (DALI). The DALI is a modified version of the NASA TLX that has been specifically tailored to the assessment of in-vehicle systems/tasks in the automotive environment and has been validated as part of the AIDE project.⁴⁵ The MCH and RSME scales, in contrast, are unidimensional scales that rely on just one dimension (e.g., invested effort) to assess workload. Subjective mental workload measures are appealing because of their low cost, ease and speed of administration, and the fact that they are nonintrusive. Subjective assessment techniques do have a number of drawbacks, however, including participants forgetting aspects of their performance posttrial and difficulties in determining whether participants are reporting overall workload levels averaged over the entire task or to specific peaks in workload.⁴⁶ The reader is referred to Stanton et al.⁴⁶ for more detail on subjective workload measures.

Research has demonstrated that using a mobile phone of any type to talk, dial, or answer while driving on real roads results in increased workload and greater levels of frustration, particularly when the conversation is complex or highly emotional.^{6,47} Entering destination details into a route guidance system while driving also increases drivers' subjective workload, particularly if the system is operated manually rather than through voice activation.^{12,36} Finally, accessing and reading e-mail using an in-car e-mail system, even when it is voice activated, has been found to increase drivers' subjective workload, and this increase is further heightened as the system becomes more complex.⁴²

7.6.6 CHOOSING DRIVING PERFORMANCE MEASURES

Driver distraction is a multidimensional construct, which means that no single driving performance measure will capture all the effects of distraction. A large number of driving measures exist, making it difficult to know which ones to include in an evaluation. Of course, the decision regarding which set of measures to use should be guided by the specific research question under examination. However, recent research offers insights into what measures are most appropriate for particular evaluations.

A number of on-road and simulator studies, for example, have found that visual and cognitive distraction differentially affect different driving performance measures.^{18,19,21} Specifically, visual distraction has a greater effect on lateral control measures, whereas cognitive distraction affects visual scanning behavior to a greater degree than visual distraction. Thus, the type of competing task being assessed should guide measurement selection. The HASTE and CAMP projects have also attempted to identify a set of valid and reliable driving measures that should be used when assessing distraction.^{24,26} Although this research offers some guidance regarding what driving performance measures to use, there does not exist a universally agreed set of driving performance measures to use in distraction evaluations. All researchers and system evaluators can do is use a range of driving measures that are valid, reliable, and sensitive to the type of distraction being evaluated.

Another challenge in relation to driving performance measures is the absolute versus relative interpretation of evaluation results. Driving performance measures do not always have a monotonic relationship with safety or crash risk, and this makes absolute interpretation of the effects of distraction on driving performance difficult (see Chapter 4 for further discussion of the nonlinear relationship between driving performance and crashes). For example, if engagement in a secondary activity increases the standard deviation of lateral position by a certain amount, this does not mean that crash risk will be increased; crash risk may increase, remain unchanged, or decrease, depending on the prevailing driving conditions at the time. An absolute interpretation of driving performance results requires a clear relationship between the driving performance measure in the test environment and the consequences for safety outcomes *and* a clear criterion for determining what a safe system is. The challenges associated with defining an “acceptable” level of driving performance and establishing performance criteria are discussed in Section 7.7.

7.7 REFERENCE TASKS AND PERFORMANCE CRITERIA

When evaluating the effect of in-vehicle systems on driving performance, researchers sometimes employ a reference task. A reference task is a task that is used as a benchmark for defining the maximum level of secondary task demand that is deemed acceptable for a driver to cope with when driving.⁴⁸ Driving performance when performing the reference task is compared with driving performance while interacting with the in-vehicle device under examination. If the level of driving performance when concurrently performing the secondary task under evaluation is poorer than that associated with concurrent performance of the reference task, then the secondary task is deemed to be unsafe to perform while driving. Currently, there is no single agreed “best” or standardized reference task to use when evaluating in-vehicle systems. Nor is it always clear what constitutes an “acceptable” level of driving performance degradation. The development of standard reference tasks that can be used in the evaluation of in-vehicle systems is the focus of a Preliminary Work Item currently being developed by Sub-Committee 13 of Technical Committee 22 of the International Organization for Standardization (ISO).

A number of different reference or criterion tasks have been used previously in driver distraction research. One approach is to assume that the criterion task is no task. Here, any driving performance degradation deriving from interaction with a competing secondary task is regarded as an unacceptable level of degradation. Several studies examining mobile phone use have compared phone use while driving with simply driving while engaging in no secondary task (e.g., Ref. 8; see also Ref. 49). However, a number of researchers have questioned whether driving on its own is a suitable reference activity when comparing secondary tasks. It is possible that just driving is too stringent a benchmark given that most secondary tasks can be expected to impose at least some additional demand on drivers. This is a particularly important argument when the IVIS task replaces one that is currently performed in the car through a different means, such as navigation with a paper map.³⁵

The Alliance of Automobile Manufacturers (AAM) in the United States has included, in their guidelines, time-based criteria stating that visual-manual tasks

performed while the vehicle is in motion should require no more than 20 s total glance time and that single-glance durations should not exceed 2 s. In-vehicle tasks that comply with these criteria are considered safe to perform while driving. Data from the 100-car study provide support for the 2 s criterion. Klauer et al.⁵⁰ found that single-glance durations of greater than 2 s increased near-crash/crash risk by at least two times, whereas glance durations of less than 2 s were not associated with increased crash risk. However, there is a lack of evidence to support the criterion that tasks requiring less than 20 s total glance time can be safely performed while driving.⁵¹

Some studies examining the distracting effects of mobile phones have used manual radio tuning (e.g., tuning into a specified radio station using buttons, dial, or toggle switch) as a reference task, claiming that if using a mobile phone degrades driving performance to a comparable or lower degree than tuning a radio, then it is an acceptable task to perform while driving. The AAM also advocates the use of manual radio tuning as a criterion task against which to compare telematics device use. The adoption of the radio tuning task as a benchmark is based on the assumption that tuning the radio imposes only a moderate and socially accepted level of risk, and its impact on driving is reasonably well understood. Research suggests, however, that even radio tuning can degrade driving performance to an extent that safety may be compromised.^{38,52} The type of host radio device used when performing the radio-tuning task can have a profound influence on the degree of workload deriving from performance of the task. Several studies, for example, have examined the effects of the radio-tuning task on driving performance using a continuous tuning dial rather than the preset buttons found on many modern radio systems. Use of this type of interface is likely to require a greater amount of time to tune a station than simply pressing a preset button. Similarly, radio control position and display size can have substantial effects on the demands of radio tuning, making it surprisingly difficult to ensure uniform implementation of this reference task. This may have the effect of increasing the distracting effects of the radio-tuning task and, thus, may lead to erroneous conclusions regarding the acceptability of performing certain secondary tasks while driving. More generally, a visual-manual reference task may affect driving performance in a quite different manner than a cognitively demanding task. A cognitive task, for example, might not degrade lane position maintenance to the same degree as a given reference task, but it might undermine event detection to a much greater degree. As a consequence, comparisons to a single-reference task can underestimate the safety consequences of distracting tasks.

Other studies have compared the effects of using mobile phones with driving under the influence of alcohol. Burns et al.²⁹ compared the driving impairment caused by using handheld and hands-free mobile phones to that caused by having a blood alcohol concentration (BAC) over the U.K. legal alcohol limit (80 mg/100 mL or 0.08). Twenty participants were tested using the Transport Research Laboratory (TRL) advanced driving simulator. Drivers' reaction times to hazards were, on average, 30% slower when conversing on a handheld mobile phone than when driving under the influence of alcohol. Drivers also demonstrated reduced speed control when using a mobile phone, but not when under the influence of alcohol. However, drivers' standard deviation of lane position when they were under the influence of alcohol was significantly higher than when they were talking on the phone or when

driving with no phone or alcohol. The authors concluded that certain aspects of driving are impaired to a greater extent when using a mobile phone than when driving while intoxicated.²⁹

Strayer et al.⁵³ also compared, using a driving simulator, the driving performance of mobile phone users with drivers who were intoxicated by alcohol (BAC of 0.08) to establish a benchmark for assessing the relative risks of phone use while driving. They found that although the impairments associated with mobile phone use may be as great as driving with a BAC of 0.08, the exact nature of these impairments differed across the two conditions. When using the mobile phone, drivers were involved in more rear-end collisions, their reaction times to a lead braking vehicle were reduced, and their following distance variability increased by 24%. When intoxicated, drivers displayed a more aggressive driving style. They followed the pace car at a closer distance than they did in the baseline condition, and they braked with 23% more force than they did in either the mobile phone or baseline conditions.

A number of problems have been identified with using alcohol intoxication as a benchmark for establishing the risks associated with various distracting tasks. First, although both alcohol and mobile phone use have been shown to impair driving performance, they have been shown to affect different driving performance measures—or to affect the same driving performance measures to different degrees or even in the opposite direction—suggesting that the mechanisms underlying degraded driving performance differ between the two forms of impairment. Second, distraction tends to be relatively transient (i.e., lasting only as long as the driver is engaging in the distracting activity), whereas alcohol impairment persists over prolonged periods of time (i.e., usually over the entire length of a drive). Consequently, the time frame for exposure to risk is relatively greater for alcohol impairment than for impairment deriving from distraction. It is important to note that this issue is relevant to all reference tasks, not just alcohol. Selecting a reference task that is as similar as possible to the task under evaluation in terms of its duration and the mechanisms by which it affects driving is fundamental for obtaining valid results.

Some researchers have suggested that a more appropriate reference task may be an alternative application of the particular secondary function under evaluation. For example, finding a point of interest on a paper map may be used as a reference task against which to compare the effect of an in-vehicle route guidance task.²⁶ One problem with this approach is that the alternative application of the task may itself impose a high level of demand on the driver and, as such, would not be deemed an “acceptable” benchmark against which the task of interest is compared. Another problem is that for some new tasks, such as iPod interactions, there is no alternative application of the task because the device is so novel.

It is clear that the development of distraction reference tasks is in its infancy, and as such, there is no universally agreed “best” reference task against which to compare the effects of new in-vehicle systems. It is likely that the most appropriate reference task will differ depending on the type of in-vehicle system and, hence, the specific type of distraction being evaluated (e.g., a reference task that imposes visual-manual load on the driver when evaluating a visual-manual task). Ideally, a reference task is one that is unambiguously defined, is repeatable across different test environments, and induces distraction in a manner similar to the task under evaluation.

7.8 CONCLUSION

This chapter has provided a review of the various methods, driving performance measures, and reference tasks that can be used to directly assess the effects of secondary tasks on driving performance. The performance of secondary tasks has a wide range of effects on driving performance, and a number of methods and driving performance measures exist to quantify these effects. Each of the assessment methods has advantages and disadvantages. Deciding which method to use is often a trade-off between cost, validity, and experimental control. Driving simulators, for example, provide a safe and controlled environment for conducting distraction research and evaluation; however, they lack the realism that on-road evaluations offer, particularly if they are lower-fidelity devices.

One promising finding that has emerged from driving simulation research is that lower-fidelity simulators offer similar levels of sensitivity and validity as high-fidelity simulators for evaluating the impact of distraction on driving performance. This suggests that system designers can, therefore, use lower-fidelity simulators to evaluate the impact of in-vehicle systems on driving performance, without sacrificing sensitivity and without incurring the high costs associated with high-fidelity simulators.

There are still a number of areas of distraction assessment that require further development or understanding, particularly in relation to the relative sensitivity of test environments and reference tasks. First, a number of studies have found that, paradoxically, the more realistic is a test method or environment, the less sensitive it is to the effects of secondary tasks on driving performance. The mechanisms underlying this trend are not currently understood, and as such, system designers should not rely solely on one assessment method to evaluate the safety implications of in-vehicle systems. Second, it is important that appropriate reference tasks be developed to provide a benchmark against which the impact on driving performance of in-vehicle tasks can be established. Appropriate reference tasks are ones that are unambiguously defined, are repeatable across different test environments, and impose a similar type of demand or distraction as the task under evaluation.

Finally, there is currently little consensus regarding which assessment method or driving performance measures should be used for the evaluation of particular tasks. As such, in the past, evaluation studies tended to use a large range of methods and driving measures. Efforts are under way in a number of projects (e.g., HASTE, AIDE, and CAMP), however, to define a set of assessment methods and driving measures that can be used to assess different categories of in-vehicle systems. The outputs of these projects should be closely monitored.

Given the high rate at which technologies are proliferating the vehicle market, it is important that a set of standardized assessment methods and reference tasks, which are valid, reliable, inexpensive, and sensitive, are identified to inform the safe design and use of these systems. The remaining chapters in this section discuss the various surrogate methods that are being used to evaluate the potentially distracting effects of in-vehicle systems.

REFERENCES

1. Kantowitz, B.H., Selecting measures for human factors research, *Human Factors* 34, 387–398, 1992.
2. NHTSA, *Internet Forum on Driver Distraction* [On-line], available at www.nrd.nhtsa.dot.gov/departments/nrd-13/driver-distraction/welcome.htm, accessed on November 10, 2006.
3. Regan, M.A., Young, K.L., Triggs, T.J., Tomasevic, N., Mitsopoulos, E., Tierney, P., Healy, D., Tingvall, C., and Stephan, K., Impact on driving performance of intelligent speed adaptation, following distance warning and seatbelt reminder systems: key findings from the TAC SafeCar Project, *IEE Proceedings Intelligent Transport Systems* 153 (1), 51–62, 2006.
4. Cooper, P.J. and Zheng, Y., Turning gap acceptance decision-making: the impact of driver distraction, *Journal of Safety Research* 33 (3), 321–335, 2002.
5. Green, P., Hoekstra, E., and Williams, M., *On-the-Road Tests of Driver Interfaces: Examination of a Route Guidance System and a Car Phone*, University of Michigan Transport Research Institute, Washington, D.C., 1993.
6. Harbluk, J.L., Noy, Y.I., and Eizenman, M., *The Impact of Cognitive Distraction on Driver Visual Behaviour and Vehicle Control*, Report No. TP No. 13889 E, Road Safety Directorate and Motor Vehicle Regulation Directorate, Ottawa, Canada, 2002.
7. Hancock, P.A., Simmons, L., Hashemi, L., Howarth, H., and Ranney, T., The effects of in-vehicle distraction on driver response during a crucial driving maneuver, *Transportation Human Factors* 1 (4), 295–309, 1999.
8. Goodman, M.J., Bents, F.D., Tijerina, L., Wierwille, W., Lerner, N., and Benel, D., *An Investigation of the Safety Implications of Wireless Communication in Vehicles*, Report No. DOT HS 808-635, U.S. Department of Transportation, National Highway Traffic Safety Administration (NHTSA), Washington, D.C., 1997.
9. Godley, S.T., Triggs, T.J., and Fildes, B.N., Driving simulator validation for speed research, *Accident Analysis and Prevention* 34 (5), 589–600, 2002.
10. Kaptein, N.A., Theeuwes, J., and van der Horst, R., Driving simulator validity: some considerations, *Transportation Research Record* 1550, 30, 1996.
11. Reed, M.P. and Green, P.A., Comparison of driving performance on-road and in a low-cost simulator using a concurrent telephone dialling task, *Ergonomics* 42 (8), 1015–1037, 1999.
12. Srinivasan, R. and Jovanis, P.P., Effect of in-vehicle route guidance systems on driver workload and choice of vehicle speed: Findings from a driving simulator experiment, In *Ergonomics and Safety of Intelligent Driver Interfaces*, Noy I.A. (Ed.) Lawrence Erlbaum Associates, Inc., Mahwah, NJ, 1997, pp. 97–114.
13. Triggs, T.J., Driving simulation for railway crossing research, In *Seventh International Symposium on Railroad-Highway Grade Crossing Research and Safety—Getting Active at Passive Crossings*, Monash University, Clayton, Australia, 1996.
14. Hein, C.M., Driving simulators: six years of hands-on experience at Hughes Aircraft Company, In *Proceedings of the Human Factors and Ergonomics Society 37th Annual Meeting*, Seattle, Washington, 1993, pp. 607–611.
15. Johnson, D.M., *Introduction to and Review of Simulator Sickness Research*, Report No. Research Report 1832, U.S. Army Research Institute-Rotary Wing Aviation Research Unit, Fort Rucker, AL, 2005.
16. Bittner, A.C., Gore, B.F., and Hooey, B.L., Meaningful assessments of simulator performance and sickness: can't have one without the other, In *Proceedings of the Human Factors and Ergonomics Society 41st Annual Meeting*, Santa Monica, CA, 1997.
17. Rehmann, A.J., Mitman, R.D., and Reynolds, M.C., *A Handbook of Flight Simulation Fidelity Requirements for Human Factors Research*, Report No. DOT/FFF/CT-TN95/46,

- U.S. Department of Transportation, Federal Aviation Administration, Atlantic City, NJ, 1995.
18. Engström, J., Johansson, E., and Ostlund, J., Effects of visual and cognitive load in real and simulated motorway driving, *Transportation Research Part F: Traffic Psychology and Behaviour* 8 (2), 97–120, 2005.
 19. Greenberg, J., Tijerina, L., Curry, R., Artz, B., Cathey, L., Grant, P., Kochlar, D., Kozak, K., and Blommer, M., Evaluation of driver distraction using an event detection paradigm, *Journal of the Transportation Research Board* No 1843, 1–9, 2003.
 20. Blaauw, G.J., Driving experience and task demands in simulator and instrumented car: a validation study, *Human Factors* 24, 473–486, 1982.
 21. Recarte, M.A. and Nunes, L.M., Mental workload while driving: effects on visual search, discrimination and decision making, *Journal of Experimental Psychology: Applied* 9, 119–137, 2003.
 22. Asoh, T., Kimura, K., and Ito, T., JAMA's Study on the location of in-vehicle displays. Paper 2000-01-C010, In *SAE Conference Proceedings*, 2000, pp. 37–42.
 23. Harms, L., Experimental studies of dual-task performance in a driving simulator—the relationship between task demands and subjects' general performance, *IATSS Research* 16 (1), 35–41, 1992.
 24. Carsten, O.M.J., Groeger, J.A., Blana, E., and Jamson, A.H., *Driver Performance in the EPSRC Driving Simulator (LADS): A Validation Study*. Final report for EPSRC project GR/K56162, Leeds University, Leeds, UK, 1997.
 25. McLane, R.C. and Wierwille, W.W., The influence of motion and audio cues on driver performance in an automobile simulator, *Human Factors* 17, 488–501, 1975.
 26. Angell, L.S., Aufflick, J.L., Austria, P.A., Kochhar, D.S., Tijerina, L., Biever, W., Diptiman, D., Hogsett, J., and Kiger, S., *Driver Workload Metrics Project: Task 2 Final Report*, National Highway Traffic Safety Administration, Washington, D.C., 2006.
 27. Johansson, E., Carsten, O., Janssen, W., Jamson, S., Jamson, H., Merat, N., Östlund, J., Brouwer, R., Mouta, S., Harbluk, J., Anntila, V., Sandberg, H., and Luoma, J., *Validation of the HASTE Protocol Specification*. HASTE Deliverable 3, available at http://www.its.leeds.ac.uk/projects/haste/downloads/Haste_D3.pdf, accessed on October 31, 2006.
 28. Johansson, E., Engström, J., Cherri, C., Nodari, E., Tofferi, A., Schindhelm, R., and Gelau, C., *Review of Existing Techniques and Metrics for IVIS and ADAS Systems*. AIDE Deliverable D2.2.1, available at http://www.aide-eu.org/res_sp2.html, accessed on March 24, 2006.
 29. Burns, P.C., Parkes, A., Burton, S., Smith, R.K., and Burch, D., *How Dangerous is Driving with a Mobile Phone? Benchmarking the Impairment to Alcohol*, TRL Report 547, TRL Limited, 2002.
 30. Haigney, D., Taylor, R.G., and Westerman, S.J., Concurrent mobile (cellular) phone use and driving performance: task demand characteristics and compensatory processes, *Transportation Research Part F* 3, 113–121, 2000.
 31. Jenness, J.W., Lattanzio, R.J., O'Toole, M., and Taylor, N., Voice-activated dialing or eating a cheeseburger: which is more distracting during simulated driving? In *Human Factors and Ergonomics 46th Annual Meeting*, 2002, pp. 592–596.
 32. Gartner, U., König, W., Wittig, T., and Bosch, R., *Evaluation of Manual vs. Speech Input when Using a Driver Information System in Real Traffic*, available at http://ppc.uiowa.edu/driving-asse...nt%20Papers/02_Gartner_Wittig.html, accessed on February 10, 2003.
 33. Hjälm Dahl, M. and Varhelyi, A., Speed regulation by in-car active accelerator pedal—effects on driver behaviour, *Transportation Research Part F* 7 (2), 77–94, 2004.
 34. Östlund, J., Carsten, O., Merat, N., Jamson, S., Janssen, W., and Brouwer, R., *Deliverable 2—HMI and Safety-Related Driver Performance*. HASTE Project. Report No. GRD1/2000/25361 S12.319626, Institute for Transport Studies, Leeds, UK, 2004.

35. Dingus, T., McGehee, D., Hulse, M., Manakkal, N., Mollenbauer, M., and Fleischman, R., *Travtek Evaluation Task C3—Camera Car Study*, Performance and Safety Sciences, Inc., Iowa City, 1995.
36. Tijerina, L., Parmer, E., and Goodman, M., Driver workload assessment of route guidance system destination entry while driving: a test track study, In *Proceedings of 5th ITS World Congress*, Seoul, Korea, 1998, p. 8.
37. Jancke, L., Musial, F., Vogt, J., and Kalveram, K.T., Monitoring radio programs and time of day effect simulated car-driving performance, *Perceptual and Motor Skills* 79, 484–486, 1994.
38. Wikman, A., Nieminen, T., and Summala, H., Driving experience and time-sharing during in-car tasks on roads of different width, *Ergonomics* 41 (3), 358–372, 1998.
39. Brookhuis, K.A., de Vries, G., and de Waard, D., The effects of mobile telephoning on driving performance, *Accident Analysis and Prevention* 23 (4), 309–316, 1991.
40. Strayer, D.L. and Johnston, W.A., Driven to distraction: dual-task studies of simulated driving and conversing on a cellular telephone, *Psychological Science* 12 (6), 462–466, 2001.
41. Tokunaga, R.A., Hagiwara, T., Kagaya, S., and Onodera, Y., Effects of conversation through a cellular telephone while driving on driver reaction time and subjective mental workload, In *Transportation Research Board 79th Annual Meeting*, Washington, D.C., USA, 2000, p. 14.
42. Lee, J.D., Caven, B., Haake, S., and Brown, T.L., Speech-based interaction with in-vehicle computers: the effect of speech-based e-mail on drivers' attention to the roadway, *Human Factors* 43, 631–640, 2001.
43. RoSPA, *Mobile Phones and Driving: A Literature Review*, The Royal Society for the Prevention of Accidents, Birmingham, UK, 1997.
44. Nygren, T.E., Psychometric properties of subjective workload measurement techniques: implications for their use in the assessment of perceived mental workload, *Human Factors* 33 (1), 17–33, 1991.
45. Pauzié, A., Manzano, J., and Dapzol, N., Driver's behavior and workload assessment for new in-vehicle technologies design, In *Proceedings of the 4th International Driving Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design*, Stevenson, Washington, 2007.
46. Stanton, N.A., Salmon, P.M., Walker, G.H., Baber, C., and Jenkins, D.P., *Human Factors Methods. A Practical Guide for Engineering and Design*, Ashgate, Hampshire, UK, 2005.
47. Matthews, R., Legg, S., and Charlton, S., The effect of cell phone type on drivers subjective workload during concurrent driving and conversing, *Accident Analysis and Prevention* 35, 441–450, 2003.
48. ISO/WD 26022, Road vehicles—ergonomic aspects of transport information and control systems—Simulated lane change test to assess in-vehicle secondary task demand, International Organization for Standardization (ISO), 2007.
49. Young, K., Regan, M., and Hammer, M., *Driver Distraction: A Review of the Literature*, Report No. 206, Monash University Accident Research Centre, Clayton, Australia, 2003.
50. Klauer, S.G., Dingus, T.A., Neale, V.L., Sudweeks, J.D., and Ramsey, D.J., *The Impact of Driver Inattention on Near-Crash/Crash Risk: An Analysis Using the 100-Car Naturalistic Driving Study Data*, Virginia Tech Transportation Institute, Blacksburg, VA, 2006.
51. Transport Canada, *Strategies for Reducing Driver Distraction from In-Vehicle Tele-matics Devices: A Discussion Document*, Transport Canada, Ottawa, Canada, 2003.
52. Briem, V. and Hedman, L.R., Behavioural effects of mobile telephone use during simulated driving, *Ergonomics* 38, 2536–2562, 1995.
53. Strayer, D.L., Drews, F.A., and Crouch, D.J., A comparison of the cell phone driver and the drunk driver, *Human Factors* 48 (2), 381, 2006.

DRIVER DISTRACTION

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and Mitigation*

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