At the Forefront of HF/E

SPIDER: A Framework for Understanding Driver Distraction

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Objective: The objective was to identify key cognitive processes that are impaired when drivers divert attention from driving.

Background: Driver distraction is increasingly recognized as a significant source of injuries and fatalities on the roadway.

Method/Results: A "SPIDER" model is developed that identifies key cognitive processes that are impaired when drivers divert attention from driving. SPIDER is an acronym standing for *scanning, predicting, identifying, decision making*, and *executing a response*.

Conclusion: When drivers engage in secondary activities unrelated to the task of driving, SPIDER-related processes are impaired, situation awareness is degraded, and the ability to safely operate a motor vehicle may be compromised.

Application: The pattern of interference helps to illuminate the sources of driver distraction and may help guide the integration of new technology into the automobile.

Keywords: attention, driver distraction, situation awareness, multitasking, self-regulation

INTRODUCTION

A driver's situation awareness reflects the dynamic mental model of the driving environment, including, but not limited to, the current driving conditions; the location of other vehicles, pedestrians, and objects along the roadway; the status of any traffic lights; and the relative position along the navigated route (e.g., Durso, Rawson, & Girotto, 2007; Endsley, 1995, 2015; Horrey, Wickens, & Consalus, 2006; Kass, Cole, & Stanny, 2007). Driving is dependent upon several cognitive processes, including visual *scanning* of the driving environment for indications of threats, *predicting* and anticipating where potential threats might materialize if they are not visible, *identifying* threats and objects in the driving environment when they are in the field of view, *deciding* whether an action is necessary and what action is necessary, and *executing* appropriate *responses*—SPIDER for short (Fisher & Strayer, 2014; Strayer, in press). When drivers engage in secondary-task activities that are unrelated to the safe operation of the vehicle, attention is often diverted from driving, impairing performance on these SPIDER-related processes (Regan, Hallett, & Gordon, 2011; Regan & Strayer, 2014). Consequently, activities that divert attention from the task of driving degrade the driver's situation awareness and may compromise the ability of the driver to safely operate their vehicle.

In this article, we focus on cognitive sources of distraction (i.e., associated with the diversion of attention from driving), which are distinct from visual/structural sources of distraction (e.g., taking the eyes off the roadway); however, as discussed later, the diversion of attention can and often does alter the visual processing of the driving scene. In the following paragraphs, the effects of divided attention on driving are briefly reviewed with a particular focus on these SPIDER-related processes and how the diversion of

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attention degrades a driver's situation awareness. We also consider how self-regulatory processes may potentially complicate the relationship between driver distraction and crash risk.

Visual Scanning

Several studies have demonstrated that as secondary-task workload increases, drivers fixate more on objects immediately in front of their vehicle and less on dashboard instrumentation, side or rearview mirrors, and objects in the periphery (Cooper, Medeiros-Ward, & Strayer, 2013; Engström, Johansson, & Östlund, 2005; Harbluk, Noy, Trbovich, & Eizenman, 2007; He, Becic, Lee, & McCarley, 2011; McCarley et al., 2004; Recarte & Nunes, 2000; Reimer, 2009; Reimer, Mehler, Wang, & Coughlin, 2012; Tsai, Viirre, Strychacz, Chase, & Jung, 2007; Victor, Harbluk, & Engström, 2005). The tendency for drivers engaged in a secondary, nonvisual task to concentrate their gaze on the center of the roadway may also influence lateral lane position variation (Readinger, Chatziastros, Cunningham, Bülthoff, & Cutting 2002; Rogers, Kadar, & Costall, 2005; Wilson, Chattington, & Marple-Horvat, 2008; but see Cooper, Medeiros-Ward, & Strayer, 2013, for a different interpretation of this effect). This pattern of gaze concentration can have adverse effects on drivers' situation awareness because they may fail to scan the periphery and side mirrors for potential threats. Obviously, peripheral vision is important to safe driving, so neglecting this critical source of information is likely to increase the crash risk.

Predicting Hazards

Performing secondary tasks that are not related to the safe operation of a vehicle can also degrade the anticipation and prediction of hazards in the driving scene. For example, a simulator-based study by Taylor et al. (2015) examined anticipatory glances in locations where a potential hazard might present itself (e.g., a truck parked on the side of the street that obscured the view of a crosswalk where a pedestrian could appear). Drivers who were not distracted by secondary tasks were 50% more likely to make anticipatory glances toward the location of a potential hazard than drivers who were talking on a cell phone. This is an example where expectancy-driven search of the driving environment is impaired. In this respect, Taylor et al. suggested that dividing attention makes an experienced driver perform more like a novice driver. Similarly, an on-road study by Biondi, Turrill, Coleman, Cooper, and Strayer (2015) found that increases in secondary-task workload systematically impaired a driver's anticipatory glances for pedestrians, bicycles, and other vehicles as they approached intersections and crosswalks near a school zone. For example, anticipatory lateral glances decreased by 11% when drivers were talking on a cell phone and 15% when drivers interacted with a reliable voice-messaging system. This deficit in anticipatory glances was observed even when the drivers had navigated the route on several prior occasions.

The impaired visual scanning at peripheral locations and the degraded prediction of hazards at safety-critical locations are examples of bottom-up and top-down effects on driving, respectively (e.g., Bundesen, 1990). In the former case, drivers under secondary-task load tend to concentrate their gaze on the forward roadway, neglecting even salient objects in the periphery when they appear, a restriction of bottom-up visual attention. In the latter case, the diversion of attention degrades expectancy-driven top-down processing, and this degradation occurs even when there is no object in the driving environment. These two patterns of impairment document the critical role that visual attention plays in driving and how performing an attention-demanding secondary task affects both bottom-up and top-down processing of the driving environment. It is worth noting that the most frequent cause of intersection crashes is inadequate surveillance by the driver (National Highway Traffic Safety Administration, 2010). Secondary-task activities that degrade both bottom-up and top-down processing will exacerbate this source of crashes.

Identification

When drivers perform a secondary task that diverts attention from driving, the identification of objects in the line of sight can be impaired, resulting in a form of *inattentional blindness*

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(Mack & Rock, 1998; Simons & Chabris, 1999; Strayer & Drews, 2007b; Strayer & Johnston, 2001). For example, Strayer, Drews, and Johnston (2003) found that recognition memory for objects in the driving environment was reduced by 50% when the driver was talking on a hands-free cell phone. The authors of this study used an eye tracker to determine what drivers were looking at and tested only the memory for objects upon which drivers fixated. Nevertheless, the use of a cell phone cut by half what the driver noticed in the driving scene. This "look-but-fail-to-see" impairment is an obvious detriment to traffic safety (e.g., Herslund & Jorgensen, 2003).

Evidence for inattentional blindness also comes from event-related brain potentials (ERPs) obtained while participants are driving. Compared to a single-task baseline driving condition, the ERPs sensitive to contextual updating were suppressed by 50% if participants were also conversing on a cell phone (e.g., Strayer et al., 2013; Strayer, Cooper, & Drews, 2004; Strayer & Drews, 2007b). The ERP data provide direct evidence for impaired identification of events in the driving environment. Further experiments varied the safety relevance of objects in the driving scene (e.g., pedestrians, other traffic, parked cars, billboards, etc.) to see if more safety-relevant objects were prioritized; however, there was no relationship between safety relevance and susceptibility to inattention blindness (Strayer et al., 2004; see also Strayer & Drews, 2007c). While multitasking, drivers do not prioritize the processing of safety-critical information in the driving scene over the cell phone conversation. This issue is considered in greater detail when we address the role of reactive self-regulatory processes when driving under distraction.

Decision Making

Drivers must evaluate several sources of information when making a driving maneuver. When motorists divert attention from driving, they often fail to fully evaluate the alternative sources of information in the driving environment. For example, Cooper, Vladisavljevic, Medeiros-Ward, Martin, and Strayer (2009) examined the decisions when drivers changed lanes in low-, medium-, and high-density traffic. Compared to conditions of undivided attention, when drivers were talking on a cell phone, they were 11% more likely to make unsafe lane changes (e.g., cutting off the driver in the adjacent lane or failing to use their turn signal), and this impairment grew as the driving demands (e.g., traffic density) increased. Similarly, Cooper and Zheng (2002) used a gap acceptance task to study decision making when drivers were making left-turn maneuvers with oncoming traffic. When motorists were listening and responding to verbal messages, they misjudged the gap separating oncoming vehicles and their speed, and this finding was most apparent on wet roadways. Horswill and Mckenna (1999) also found that secondary-task distractions impaired dynamic decision making. In these studies, divided attention led to unsafe decision making that increased the risk of a crash.

Execution of a Response

A hallmark signature of divided attention is the slowing of reaction time to imperative events in the driving environment. In this context, when something in the driving environment requires a response (e.g., initiating a braking response to a child in the street), those reactions are often delayed (for a meta-analysis, see Caird, Willness, Steel, & Scialfa, 2008; Horrey & Wickens, 2006). Moreover, the effect of secondary-task load on brake reaction time is magnified as the perceptual load in the driving environment increases, as is the case when traffic density increases (Strayer, Drews, & Johnston, 2003). Secondary tasks, such as a cell phone conversation, tend to positively skew the reaction time distributions, so that the late responses are particularly delayed (Ratcliff & Strayer, 2014). These changes in the reaction time distribution have been modeled using a continuous form of the random walk (i.e., a diffusion process) and are indicative of a reduction in the accumulation of evidence supporting a corrective action to avoid a crash. As such, the delayed reactions under secondary-task load are thought to reflect the combined effects of impaired scanning, predicting, identification, and decision making. The magnitude of the delay in reaction time varies with the complexity of the secondary

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task and ranges from 10% to 20% for cell phone conversations (e.g., Strayer et al., 2003) to 40% for more complex interactions, such as sending short message service or text messages using voice commands (e.g., Strayer, Cooper, Turrill, Coleman, & Hopman, 2015). Delayed reactions caused by secondary-task interactions increase both the likelihood and severity of crashes (Brown, Lee, & McGehee, 2001).

Situation Awareness

A driver's situation awareness reflects the mental model of the driving environment (e.g., Durso et al., 2007; Endsley, 1995, 2015; Horrey et al., 2006; Kass et al., 2007). In this context, working memory has been shown to play a critical role in the driver's situation awareness, and secondary tasks (e.g., cell phone conversations) that place demands on working memory also degrade the driver's situation awareness (e.g., Johannsdottir & Herdman, 2010; Heenan, Herdman, Brown, & Robert, 2014). Situation awareness is informed and updated by the SPIDER-related processes (i.e., scanning, predicting, and identifying) and facilitates expectancy-based processing of the driving scene. Among other things, drivers need to be aware of other vehicles, pedestrians, bicycles, and objects in their vicinity and to update that information over time as they change their relative positions. When the SPIDER-related processes are impaired by the performance of a secondary task that is unrelated to driving, the awareness of this important information in the driving environment begins to degrade over time. For example, has a bicyclist changed position since the driver last attended to him or her, and if so, what corrective actions need to be taken by the driver to avoid a crash? What is the current speed limit and how fast is the driver going relative to the posted speed? What is the status of the traffic light, and can the driver make it through the intersection without stopping?

SPIDER uses an information-processing approach to help us understand driver distraction and is consistent with the 70-year literature on attention that establishes that performance is degraded when attention is diverted to an unrelated secondary task (Strayer & Drews, 2007a). It is noteworthy that the first three processing operations in SPIDER (i.e., scanning, predicting, and identification) are similar to Endsley's (1995) three levels of situation awareness. Scanning is related to Level 1 situation awareness (i.e., perception of the elements in the current situation), predicting is related to Level 3 situation awareness (i.e., prediction of future status), and identification is related to Level 2 situation awareness (i.e., comprehension of current situation). Impaired situation awareness plays a causal role in making good decisions and responses quickly and accurately. Fisher and Strayer (2014) found that even a small decrease in the likelihood that a driver successfully completes one of the SPIDER-related activities cascades throughout the system to compromise the driver's situation awareness. In essence, the modeling showed that a distracted driver is a less situationally aware driver. In this context, even small lapses in situation awareness can lead to poor performance (Endsley, 1995).

Self-Regulation

The relationship between driver distraction and crash risk is complicated by how and when drivers choose to engage in a secondary nondriving activity. All other things being equal, it is reasonable to assume that activities that degrade a driver's situation awareness will increase the risk of a crash. But drivers may attempt to self-regulate their nondriving activities to periods when they perceive the risks to be lower. Following Braver, Gray, and Burgess (2007), we suggest that there are two forms of self-regulation in driving: *proactive* and *reactive.* An example of the proactive self-regulation is when a driver decides to place a call or send a text when stopped at a traffic light. Even with proactive self-regulation, the degraded situation awareness often persists after the interaction has terminated (e.g., Strayer et al., 2015). By contrast, reactive self-regulation refers to situations when a driver moderates his or her usage in real time based upon driving difficulty or perception of driving errors. An example of reactive self-regulation is when the driver terminates his or her call when the demands of driving increase.

Reactive self-regulation depends upon drivers being aware of their driving errors and

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adjusting their behavior accordingly. As mentioned earlier, Strayer et al. (2004) found no relationship between safety relevance of objects in the driving environment and susceptibility to inattention blindness, casting doubt on reactive self-regulation based on this source of information. More recently, Sanbonmatsu, Strayer, Biondi, Behrends, and Moore (in press) found that a driver's ability to reactively self-regulate his or her multitasking behavior was limited by the same factors that caused the driver to be distracted in the first place. In their study, they found a positive correlation between the self-awareness of driving errors and actual driving errors when drivers were not talking on a cell phone. By contrast, a negative correlation was found between the self-awareness of driving errors and actual driving errors when drivers were talking on a cell phone. Alarmingly, the cell phone drivers who made the most errors were blithely unaware of their driving impairments; hence any reactive self-regulatory behavior would appear to be minimal at best (see also Horrey, Lesch, & Gabaret, 2009).

Finally, it is often difficult to establish when a behavior is a form of adaptive self-regulation or, instead, a by-product of the diversion of attention from driving. This distinction has been a cause of some confusion in the literature. For example, as mentioned earlier, drivers maintain lane position better when they are engaged in an attention-demanding secondary task, such as talking on a cell phone. Are these drivers self-regulating by working harder to stay in their lane? We think that this is an unlikely interpretation of the data. Instead, Medeiros-Ward, Cooper, and Strayer (2014) suggested that complex skilled behaviors, like driving an automobile, are supported by a hierarchical control network that coordinates the interaction between automatic encapsulated routines and limited capacity attention (see also Logan & Crump, 2011). These authors found that when participants drove on a predictable section of roadway, diverting attention from driving improved lane maintenance, whereas attending to driving degraded lane maintenance. By contrast, when unpredictable gusts of wind were added to the scenario, diverting attention from driving degraded lane maintenance, whereas attending to driving improved lane maintenance. Interpreting the lane maintenance data using hierarchical control theory provides a framework for determining when a behavior is a form of self-regulation and when it is a by-product of the diversion of attention from driving. In the current case, the improvement in lane maintenance behavior appears to be a by-product of the diversion of attention rather than an increase in self-regulation.

Driver Distraction and Crash Risk

It is notoriously difficult to determine the crash risk associated with driver distraction. There are a variety of methods for studying driver behavior, each with strengths and weaknesses. Some are used primarily in experimental research (e.g., test track, instrumented vehicle, and driving simulation) whereby the primary goal is to understand basic mechanisms underlying driving behavior. Other methods are used in a nonexperimental context (e.g., epidemiological, observational, naturalistic) whereby a primary goal is to gain a better understanding of the determinants of crash risk. There is good agreement in the research using the experimental approach; however, there appears to be less agreement with the correlational approach (e.g., epidemiological studies report that the odds ratio for a crash is 4 times higher when drivers are using a cell phone [e.g., Redelmeier & Tibshirani, 1997; McEvoy et al., 2005], whereas estimates from naturalistic studies suggest that the odds ratio for talking on a cell phone is often not different from and sometimes below 1.0 [e.g., Klauer et al., 2014]). However, the validity of these naturalistic studies has recently been called into question (Knipling, 2015).

Future Research

Cognitive control has emerged as an important individual difference in the attention literature (Engle & Kane, 2015). For example, Sanbonmatsu, Strayer, Medeiros-Ward, and Watson (2013) found that individuals scoring lower in working-memory capacity and higher in sensation seeking and impulsivity were more likely to engage in multitasking activities. This relationship accounted for 25% of the variance

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between individuals. Future research will benefit from incorporating the individual-differences approach to better understanding how the SPIDER-related processes affect driving behavior.

Another line of future work would use the SPIDER framework to derive quantitative predictions concerning the impact of different sources of distraction. In particular, different sources of distraction may have unique signatures of impairment in the SPIDER framework. Research to dissociate the differential effects is ongoing (e.g., Strayer et al., 2013, 2015; Strayer, Turrill, Coleman, Ortiz, & Cooper, 2014) and may help guide the integration of new technology into the automobile.

CONCLUSIONS

Driver distraction is caused by the diversion of attention away from activities critical for safe driving toward activities that are either less critical or unrelated to driving. We developed a SPIDER model of driver distraction that describes how several cognitive processes are impaired when drivers perform a concurrent secondary task that is unrelated to driving. Drivers who are distracted tend to fixate on the forward roadway more often and scan the periphery less often, are less likely to anticipate and predict potential hazards in the driving environment, often fail to identify objects in their line of sight, make poorer decisions, and are slower to take evasive action when it is needed. The SPIDER-related processes are an important source of information supporting the driver's situation awareness.

Concurrent performance of activities unrelated to driving that degrade the driver's situation awareness are likely to increase crash risk. However, the relationship is complicated by how and when drivers choose to engage in these secondary-task activities. With proactive self-regulation, drivers decide in advance if and when to engage in an activity (e.g., dial or text at a traffic light). But there is little evidence that drivers can effectively self-regulate based on the real-time demands of driving—in fact, the more that a driver is distracted, the less capable he or she is of engaging in this self-regulatory behavior. Additional research on drivers' self-regulation will be important in understanding the risks associated with secondary-task interactions in the vehicle.

KEY POINTS

- The objective was to identify key cognitive processes that are impaired when drivers divert attention from driving.
- A "SPIDER" model is developed that identifies key cognitive processes that are impaired when drivers divert attention from driving. SPIDER is an acronym standing for *scanning, predicting, identifying, decision making*, and *executing a response*.
- When drivers engage in secondary activities unrelated to the task of driving, SPIDER-related processes are impaired, situation awareness is degraded, and the ability to safely operate a motor vehicle may be compromised.

REFERENCES

Biondi, F., Turrill, J. M., Coleman, J. R., Cooper, J. M., & Strayer, D. L. (2015). Cognitive distraction impairs driver's anticipatory glances: An on-road study. In D. V. McGehee, J. D. Lee, & M. Rizzo (Eds.), *Driving Assessment 2015: International Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design* (pp. 23–29). Iowa City: Public Policy Center, University of Iowa.

Braver, T., Gray, J., & Burgess, G. (2007). Explaining the many varieties of working memory variation: Dual mechanisms of cognitive control. In A. R. A. Conway, C. Jarrold, M. J. Kane, A. Miyake, & J. N. Towse (Eds.), *Variation in working memory* (pp. 76–106). New York, NY: Oxford University Press.

Brown, T. L., Lee, J. D., & McGehee, D. V. (2001). Human performance models and rear-end collision avoidance algorithms. *Human Factors*, *43*, 462–482.

Bundesen, C. (1990). A theory of visual attention. *Psychological Review*, *97*, 523–547.

Caird, J. K., Willness, C. R., Steel, P., & Scialfa, C. (2008). A meta-analysis of the effects of cell phones on driver performance. *Accident Analysis & Prevention*, *40*, 1282–1293.

Cooper, J. M., Medeiros-Ward, N., & Strayer, D. L. (2013). The impact of eye movements and cognitive workload on lateral position variability in driving. *Human Factors*, *55*, 1001–1014.

Cooper, J. M., Vladisavljevic, I., Medeiros-Ward, N., Martin, P. T., & Strayer, D. L. (2009). Near the tipping point of traffic stability: An investigation of driving while conversing on a cell phone in simulated highway traffic of varying densities. *Human Factors*, *51*, 261–268.

Cooper, P. J., & Zheng, Y. (2002). Turning gap acceptance decision-making: The impact of driver distraction. *Journal of Safety Research*, *33*, 321–335.

Durso, F., Rawson, K., & Girotto, S. (2007). Comprehension and situation awareness. In F. T. Durso, R. Nickerson, S. T. Dumais, S. Lewandowsky, & T. Perfect (Eds.), *The handbook of applied cognition* (2nd ed., pp. 163–194). Chichester, UK: Wiley.

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Endsley, M. R. (1995). Towards a theory of situation awareness in dynamic systems. *Human Factors*, *37*, 32–64.

Endsley, M. R. (2015). Situation awareness misconceptions and misunderstandings. *Journal of Cognitive Engineering and Decision Making*, *9*, 4–32.

Engle, R. W., & Kane, M. J. (2015). Executive attention, working memory capacity, and a two-factor theory of cognitive control. *Psychology of Learning and Motivation*, *44*, 145–199.

Engström, J., Johansson, E., & Östlund, J. (2005). Effects of visual and cognitive load in real and simulated motorway driving. *Transportation Research: Part F*, *8*, 97–120.

Fisher, D. L., & Strayer, D. L. (2014). Modeling situation awareness and crash risk. *Annals of Advances in Automotive Medicine*, *5*, 33–39.

Harbluk, J. L., Noy, Y., Trbovich, P. L., & Eizenman, M. (2007). An on-road assessment of cognitive distraction: Impacts on drivers' visual behavior and braking performance. *Accident Analysis & Prevention*, *39*, 372–379.

He, J., Becic, E., Lee, Y., & McCarley, J. S. (2011). Mind wandering behind the wheel: Performance and oculomotor correlates. *Human Factors*, *53*, 13–21.

Heenan, A., Herdman, C. M., Brown, M. S., & Robert, N. (2014). Effects of conversation on situation awareness and working memory in simulated driving. *Human Factors*, *56*, 1077–1092.

Herslund, M. B., & Jorgensen, N. O. (2003). Looked-but-failed-to-see-errors in traffic. *Accident Analysis & Prevention*, *35*, 885–891.

Horrey, W. J., Lesch, M. F., & Garabet, A. (2009). Dissociation between driving performance and drivers' subjective estimates of performance and workload in dual-task conditions. *Journal of Safety Research*, *40*, 7–12.

Horrey, W. J., & Wickens, C. D. (2006). Examining the impact of cell phone conversations on driving using meta-analytic techniques. *Human Factors*, *48*, 196–205.

Horrey, W. J., Wickens, C. D., & Consalus, K. P. (2006). Modeling drivers' visual attention allocation while interacting with in-vehicle technologies. *Journal of Experimental Psychology: Applied*, *12*(2), 67–78.

Horswill, M. S., & Mckenna, F. P. (1999). The effect of interference on dynamic risk-taking judgments. *British Journal of Psychology*, *90*, 189–199.

Johannsdottir, K. R., & Herdman, C. M. (2010). The role of working memory in supporting drivers' situation awareness for surrounding traffic. *Human Factors*, *52*, 663–673.

Kass, S. J., Cole, K. S., & Stanny, C. J. (2007). Effects of distraction and experience on situation awareness and simulated driving. *Transportation Research Part F: Traffic Psychology and Behaviour*, *10*, 321–329.

Klauer, S. G., Guo, F., Simons-Morton, B. G., Ouiment, M. C., Lee, S. E., & Dingus, T. A. (2014). Distracted driving and risk of road crashes among novice and experienced drivers. *New England Journal of Medicine*, *370*, 54–59.

Knipling, R. R. (2015). Naturalistic driving events: No harm, no foul, no validity. In D. V. McGehee, J. D. Lee, & M. Rizzo (Eds.), *Driving Assessment 2015: International Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design* (pp. 196–202). Iowa City: Public Policy Center, University of Iowa.

Logan, G. D., & Crump, M. J. C. (2011). Hierarchical control of cognitive processes. In B. Ross (Ed.), *The psychology of learning and motivation* (Vol. 54, pp. 1–27). Burlington, MA: Academic Press.

Mack, A., & Rock, I. (1998). *Inattentional blindness*. Cambridge, MA: MIT Press.

McCarley, J. S., Vais, M., Pringle, H., Kramer, A. F., Irwin, D. E., & Strayer, D. L. (2004). Conversation disrupts scanning and change detection in complex visual scenes. *Human Factors*, *46*, 424–436.

McEvoy, S. P., Stevenson, M. R., McCartt, A. T., Woodward, M., Haworth, C., Palamara, P., & Cercarelli, R. (2005). Role of mobile phones in motor vehicle crashes resulting in hospital attendance: A case-crossover study. *British Medical Journal*, *331*, 428–433.

Medeiros-Ward, N., Cooper, J. M., & Strayer, D. L. (2014). Hierarchical control and driving. *Journal of Experimental Psychology: General*, *143*, 953–958.

National Highway Traffic Safety Administration. (2010). *Crash factors in intersection-related crashes: An on-scene perspective*. Retrieved from http://www-nrd.nhtsa.dot.gov/Pubs/811366.pdf

Ratcliff, R., & Strayer, D. L. (2014). Modeling simulated driving with a one-boundary diffusion model. *Psychological Bulletin and Review*, *21*, 577–589.

Readinger, W. O., Chatziastros, A., Cunningham, D. W., Bülthoff, H. H., & Cutting, J. E. (2002). Gaze-eccentricity effects on road position and steering. *Journal of Experimental Psychology: Applied*, *8*, 247–258.

Recarte, M. A., & Nunes, L. M. (2000). Effects of verbal and spatial-imagery tasks on eye fixations while driving. *Journal of Experimental Psychology: Applied*, *6*, 31–43.

Redelmeier, D. A., & Tibshirani, R. J. (1997). Association between cellular-telephone calls and motor vehicle collisions. *New England Journal of Medicine*, *336*, 453–458.

Reimer, B. (2009). Impact of cognitive task complexity on drivers' visual tunneling. *Transportation Research Record: Journal of the Transportation Research Board*, *2138*, 13–19.

Reimer, B., Mehler, B., Wang, Y., & Coughlin, J. F. (2012). A field study on the impact of variations in short-term memory demands on drivers' visual attention and driving performance across three age groups. *Human Factors*, *54*, 454–468.

Regan, M. A., Hallett, C., & Gordon, C. P. (2011) Driver distraction and driver inattention: Definition, relationship and taxonomy. *Accident Analysis & Prevention*, *43*, 1771–1781.

Regan, M. A., & Strayer, D. L. (2014). Towards an understanding of driver inattention: Taxonomy and theory. *Annals of Advances in Automotive Medicine*, *58*, 5–13.

Rogers, S. D., Kadar, E. E., & Costall, A. (2005). Gaze patterns in the visual control of straight-road driving and braking as a function of speed and expertise. *Ecological Psychology*, *17*, 19–38.

Sanbonmatsu, D. M., Strayer, D. L., Biondi, F., Behrends, A. A., & Moore, S. M. (in press). Cell phone use diminishes self-awareness of impaired driving. *Psychonomic Bulletin & Review*.

Sanbonmatsu, D. M., Strayer, D. L, Medeiros-Ward, H., & Watson, J. M. (2013). Who multi-tasks and why? Multi-tasking ability, perceived multi-tasking ability, impulsivity, and sensation seeking. *PLOS ONE*, *8*, e54402.

Simons, D. J., & Chabris, C. F. (1999). Gorillas in our midst: Sustained inattentional blindness for dynamic events. *Perception*, *28*, 1059–1074.

Strayer, D. L. (in press). Attention and driving. In J. Fawcett, E. F. Risko, & A. Kingstone (Eds.), *The handbook of attention* (pp. 423–442). Cambridge, MA: MIT Press.

Strayer, D. L., Cooper, J. M., & Drews, F. A. (2004). What do drivers fail to see when conversing on a cell phone? In the

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Proceedings of the Human Factors and Ergonomics Society 48nd Annual Meeting (pp. 2213–2217). Santa Monica, CA: Human Factors and Ergonomics Society.

Strayer, D. L., Cooper, J. M., Turrill, J. M., Coleman, J. R., & Hopman, R. J. (2015). *The smartphone and the driver's cognitive workload: A comparison of Apple, Google, and Microsoft's intelligent personal assistants*. Washington, DC: AAA Foundation for Traffic Safety.

Strayer, D. L., Cooper, J. M., Turrill, J., Coleman, J., Medeiros-Ward, N., & Biondi, F. (2013). *Measuring cognitive distraction in the automobile*. Washington, DC: AAA Foundation for Traffic Safety.

Strayer, D. L., & Drews, F. A. (2007a). Attention. In F. Durso, R. Nickerson, S. Dumais, S. Lewandowsky, & T. Perfect (Eds.), *Handbook of applied cognition* (2nd ed., pp. 29–54). West Sussex, UK: Wiley.

Strayer, D. L., & Drews, F. A. (2007b). Cell-phone induced inattention blindness. *Current Directions in Psychological Science*, *16*, 128–131.

Strayer, D. L., & Drews, F. A. (2007c). Multi-tasking in the automobile. In A. Kramer, D. Wiegmann, & A. Kirlik (Eds.), *Applied attention: From theory to practice* (pp. 121–133). New York, NY: Oxford University Press.

Strayer, D. L., Drews, F. A., & Johnston, W. A. (2003). Cell phone induced failures of visual attention during simulated driving. *Journal of Experimental Psychology: Applied*, *9*, 23-52.

Strayer, D. L., & Johnston, W. A. (2001). Driven to distraction: Dual-task studies of simulated driving and conversing on a cellular phone. *Psychological Science*, *12*, 462–466.

Strayer, D. L., Turrill, J., Coleman, J., Ortiz, E., & Cooper, J. M. (2014). *Measuring cognitive distraction in the automobile: II. Assessing in-vehicle voice-based interactive technologies*. Washington, DC: AAA Foundation for Traffic Safety.

Taylor, T., Roman, L., McFeaters, K., Romoser, M., Borowsky, A., Merritt, D. J., Pollatsek, A., Lee, J. D., & Fisher, D. L. (2015). *Cell phone conversations impede latent hazard anticipation while driving, with partial compensation by self-regulation in more complex driving scenarios*. Amherst: Arbella Insurance Human Performance Lab, University of Massachusetts.

Tsai, Y., Viirre, E., Strychacz, C., Chase, B., & Jung, T. (2007). Task performance and eye activity: Predicting behavior relating to cognitive workload. *Aviation, Space, and Environmental Medicine*, *5*, B176–B185.

Victor, T. W., Harbluk, J. L., & Engström, J. A. (2005). Sensitivity of eye-movement measures to in-vehicle task difficulty. *Transportation Research Part F: Traffic Psychology and Behavior*, *8*, 167–190.

Wilson, M., Chattington, M., & Marple-Horvat, D. E. (2008). Eye movements drive steering: Reduced eye movement distribution impairs steering and driving performance. *Journal of Motor Behavior*, *40*, 190–202.

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