Effect of Electronic Device Use On Pedestrian Safety: A Literature Review

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16. Abstract

This literature review on the effect of electronic device use on pedestrian safety is part of a research project sponsored by the Office of Behavioral Safety Research in the National Highway Traffic Safety Administration (NHTSA). An extensive literature review was conducted and summarized into three sections: pedestrian distraction, driver distraction, and pedestrian-vehicle interactions. Within each section, the findings were further divided into several subsections based on the study methodologies, such as naturalistic observations, simulation, laboratory, or crash database analysis. It was discovered that a very limited number of studies have investigated the effect of electronic device use by pedestrians and drivers on pedestrian safety. Even fewer naturalistic observation studies have been performed. Furthermore, most previous studies focus primarily on cell phone use, but the discussion regarding other types of electronic devices is missing. In conclusion, the review illustrates that there is a need to conduct naturalistic observations of the effect of electronic device use on pedestrian distraction and safety.

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EXECUTIVE SUMMARY

This literature review on the effect of electronic device use on pedestrian safety is part of a research project sponsored by the Office of Behavioral Safety Research in the National Highway Traffic Safety Administration (NHTSA). The overall project aims to quantify the risk of pedestrian crash involvement due to pedestrian and driver distraction. This literature review surveys the base of knowledge on pedestrian distraction and distraction-related crash risk in pedestrian-vehicle interactions. The review also informs the methodology in a later phase of the project during which naturalistic field observations and State crash data analyses will be used to assess the impact of electronic device use on pedestrian and driver behavior and consequent risk of crashes.

Distraction contributes to large numbers of crashes, fatalities, and injuries. NHTSA (2015) reports that 3,179 people were killed and an estimated 431,000 were injured in distraction-affected motor vehicle crashes in 2014. Distraction among pedestrians also is a contributor to pedestrian safety risk and often leads to serious injury, although the exact number of distraction-related pedestrian injuries is difficult to estimate. The United States Department of Transportation has made distracted driving a major focus by supporting and implementing a number of initiatives including setting national policies and guidelines prohibiting Federal employees from texting while driving on government business or while using government-supplied devices. Other Federal and State government agencies, as well as national safety advocacy groups, have mirrored these and other initiatives.

The growing use and influence of technology has the potential to endanger pedestrians more than in years past. In 2012, more than 1,500 pedestrians nationwide were treated in emergency rooms as a result of being injured while walking and engaged in cell phone conversations, which was more than twice the number reported in 2005, even though the total number of pedestrian injuries dropped during that time period (Nasar & Troyer, 2013). As the authors point out, however, underreporting of emergency room visits due to distracted walking is likely, so the true number of pedestrian injuries attributable to cell phone conversation-related distractions is potentially much higher than 1,500 per year. The rapid increase in reported injuries indicates pedestrians face more dangers when either they or motorists are distracted by electronic devices. However, the extent to which pedestrian safety is affected as a result of distraction among drivers and pedestrians is not well quantified through scientific study.

This literature review includes sections on distracted pedestrians, distracted drivers, and pedestrian-vehicle interactions. Summaries are provided for studies using real world naturalistic observations, simulator-based observations, and laboratory experiments in the pedestrian and driver distraction literature review. In the section on pedestrian-vehicle interactions, over 30 years of traffic conflict studies are summarized to provide the reader with an overview of the science and the engineering of intersection safety evaluations.

The central finding of this literature review is that pedestrian distraction is a real problem of which the effects can be detected in crash data, naturalistic behavioral observations, virtual environment simulator studies, and the laboratory. Distraction changes the way pedestrians walk, react, and behave, including safety-related behaviors. There are no studies showing a direct link between the behavioral effects of distraction and pedestrian crash risk.

In contrast, driver distraction is a well-studied area of behavior and the risks associated with specific distractors have been quantified, albeit with some contradictory evidence and uncertainty. Some of the research findings have been translated into laws and policies at the Federal, State, and corporate levels in the United States. Texting-while-driving bans are the most recent of these initiatives aimed at reducing the risks associated with distracted driving in general, and specifically with regard to the use of cell phones and other electronic devices.

The inclusion of traffic conflict research in this literature review represents a major addition for psychological studies of human behavior at intersections. In view of the goals for this research project—to assess the impact of joint distraction of both pedestrians and drivers as they interact—borrowing from engineering science has many advantages. For example, a review of traffic conflicts opens up a large number of safety-critical events in which the participants, pedestrians and drivers, had to engage in mild-to-severe maneuvers in order to avoid a crash. Intersection safety studies rely on the traffic conflicts approach to improve the safety of intersections through improved signage, markings, signals, and geometric design.

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BACKGROUND

In response to the high number of distraction-related injury and fatality crashes, addressing distraction is a high priority for the United States Department of Transportation (USDOT) as reflected in national policies and guidelines relating to Federal employees' texting while driving on government business or using government-supplied devices (Executive Order No. 13513, 2009); and in Federal Register notices by the National Highway Traffic Safety Administration (NHTSA) (Visual-Manual NHTSA Driver Distraction Guidelines for In-Vehicle Electronic Devices, 2012); and the Federal Motor Carrier Safety Administration (FMCSA – focused on drivers of commercial motor vehicles) (Restricting the Use of Cellular Phones, 2011). These efforts are mirrored by initiatives undertaken by other Federal and State government agencies, as well as national safety advocacy groups. Distraction contributes to large numbers of crashes, fatalities, and injuries. NHTSA (2015) reported that in 2014, there were 3,179 people killed and an estimated 431,000 injured in distraction-affected crashes. In 2014, 10% of fatal crashes, 18% of injury crashes, and 16% of all motor vehicle traffic crashes were reported as distraction-affected crashes.

However, there are limitations to collecting and reporting distraction among crash-involved drivers. The definition of distraction conditions varies among States. Some police accident reports identify distraction as a distinct reporting field while others identify distraction based upon the narrative portion of the report. The inconsistencies among police crash report forms lead to uncertainty in the reported number of distraction-affected crashes. It is certain that the number of distracted driving crashes remains underreported even when State crash report forms include a code or variable specifically designed to collect this information. Absent statements from independent witnesses, the only source of information on driver distraction is the drivers themselves and they have a vested interest in not being perceived as at-fault or inattentive.

Cell phone use while driving is of particular concern as the number of cell phones and the market share of smart phones grow annually. CTIA-The Wireless Association (2015), a wireless communications trade association, reports that in December 2014 there were 355.4 million active wireless device subscriptions in the United States, equating to 110% of the United States population. Over 1.9 trillion text messages are sent each year, equating to nearly 6,000 text messages per person per year on average. Additionally, research demonstrates that texting rates are much higher for younger people than for older adults (Smith, 2011)—people 18-24 text an average of 3,200 messages per month. In-vehicle studies show that teen drivers are distracted nearly a quarter of their time behind the wheel and that electronic devices account for the largest single category of distractions (Goodwin, Foss, Harrell, & O'Brien, 2012).

Distraction among pedestrians also is a major contributor to pedestrian safety risk and often leads to a serious injury—although the exact number of distraction-related pedestrian injuries is difficult to estimate. The growing influence of technology has the potential to endanger pedestrians more than before. In 2012, more than 1,500 pedestrians nationwide were estimated to be treated in emergency rooms as a result of distraction due to walking while engaged in cell phone conversations, which was more than twice the number in 2005, even though the total number of pedestrian injuries dropped during that time period (Nasar & Troyer, 2013). As the authors point out, however, underreporting of emergency room visits due to distracted walking is likely, so the true number of pedestrian injuries attributable to cell phone conversation-related distractions is potentially much higher than 1,500 per year. Hence, pedestrians face more dangers when either they or motorists are distracted by electronic devices. However, the extent to which pedestrian safety is impaired (or compromised) due to drivers' and pedestrians' distraction is unclear. Only one study to date has reviewed pedestrian-vehicle conflicts and the role of distraction related to device use. Brumfield and Pulugurtha (2011) observed 325 pedestrian-vehicle interactions at 7 mid-block crosswalks on the University of North Carolina, Charlotte, campus. About 18% of drivers and 29% of pedestrians were noticeably distracted (either talking on a cell phone or texting) at the point of potential conflict (vehicle and pedestrian both nearing the crosswalk). The results showed that distracted drivers were more likely to be involved in a conflict (50.9%) than were distracted pedestrians (16.8%). There are no data reported for the situation in which *both* the driver and the pedestrian were distracted. Given the study size, however, that situation would only have occurred in roughly 5% of the interactions studied, and only 17 observations would be expected. It is also worth noting that the travel speeds in this setting are likely to be low—the campus-wide speed limit is 20 mph (32.2 km/h). Actual travel speeds were not reported.

Studies of pedestrian distraction have generally been accomplished on a small scale with limited support for broader generalization to other populations and environments. For distracted walking, there is very little comparative data that can quantify the effects of any single source of distraction in relation to distraction in general. Thus, there is a strong need to understand the relationship between pedestrian safety and the use of electronic devices among drivers and pedestrians to improve safety nationwide. This reiterates the importance of this research in determining the risk associated with distraction due to electronic devices among drivers and pedestrians.

Study Objectives and Scope

This literature review is part of a larger research project to determine if electronic device use by pedestrians and drivers significantly impacts pedestrian safety. The main objective of the project is to quantify the risks faced by pedestrians as a result of electronic device use by both pedestrians and drivers. The project objectives included:

- Reviewing the literature on pedestrian and driver device use and distraction as it relates to pedestrian risk of injury or death in traffic conflicts with motor vehicles;
- Collecting naturalistic observations to quantify distraction related to driver and pedestrian use of electronic devices during pedestrian-vehicle interactions; and
- Collecting and analyzing crash report data from pedestrian-involved motor vehicle crashes to quantify the frequency and severity of crashes that involve pedestrian and driver use of electronic devices.

INTRODUCTION

With the increased use of cell phones and other electronic devices, an understanding of the relationship between safety and distracted drivers and pedestrians is needed to (a) understand the role distraction plays in pedestrian safety, and (b) identify ways to improve safety at crosswalks and mid-block crossings. A thorough literature search and review was conducted to characterize the state of knowledge on distracted walking and the risks associated with various distractor types used by both drivers and pedestrians. This information was used to develop data collection and analysis plans guiding the field research in later project tasks aimed at naturalistic observations of pedestrian and motorist interactions. In particular, the literature review helped determine the methods of identifying sources of distraction for both pedestrians and drivers, the methods of coding pedestrian behaviors in potential traffic conflict situations, and data collection protocols in a naturalistic observation study of pedestrian-vehicle conflicts.

A number of studies related to risk due to various distractor types have been conducted in recent years. A majority of the studies addressed driver distraction only. A small number of studies examined pedestrian distraction. Very few have looked at the interactions between distracted pedestrians and drivers. A few studies incorporated conflict analysis to determine the safety of pedestrians due to simultaneous distraction among drivers and pedestrians. The literature review uses the following outline to present the resources examined including publications, technical journals, conference proceedings, and government reports on:

1. ***Pedestrian Distraction*** sources and effects of distraction on pedestrians' safe navigation through the environment.

2. ***Driver Distraction*** sources and effects of distraction on driving performance and safety.

3. ***Pedestrian-Vehicle Interaction*** safety and valid engineering measurement of pedestrians and drivers interacting as pedestrians attempt to cross the street. This section includes engineering studies of pedestrian-vehicle conflict.

Within each section, the studies are further divided into several subsections based on the study methodologies, such as naturalistic observations, simulation, laboratory, or crash database analysis.

The research team used Psych Abstracts, PubMed, TRIS, and other search resources to identify candidate literature for review. The abstract from each identified source document was reviewed by three members of the research team and scored for relevance to the present effort. Articles including research methods for field data collection of distraction, pedestrian safety-related crossing behavior, and pedestrian-vehicle interactions were given preference for full document review. Also reviewed were any documents where the staff scores were split. Two rounds of additional source documents were identified based on the reference lists of the articles subjected to full document reviews. The only articles identified and then excluded from further review were those that did not address pedestrian or driver distraction, or, in the case of pedestrian-vehicle conflict studies, were duplicative of earlier documents already selected for review. A total of 118 documents were examined, of which 80 are included in the final literature review.

1. PEDESTRIAN DISTRACTION LITERATURE

The risk due to distraction among pedestrians has been studied by collecting pedestrian behavior data using a variety of observation methodologies, including naturalistic observations, computer-aided simulations, and laboratory studies (i.e., using physical environments in a non-traffic setting). The non-traffic studies are included because they provide examples of behavioral data collection methods and help to illustrate important attention-related aspects of pedestrian distraction. Additionally, several studies have investigated the pedestrian-safety impact of distraction through analysis of injury and crash data in existing databases. The following subsections describe and summarize the literature in each of the observation methodologies.

1.1 Naturalistic Observation

Naturalistic observation examines the direct (real time) or video-based (recorded) scoring of pedestrian behavior in real-world settings. This entails the observation of pedestrians walking in public spaces (in particular, crossing streets) while members of the research team record behavior and safety-related events.

Bungum, Day, and Henry (2005) observed the behaviors of 866 individuals as they walked across a 105-foot wide street near a large university in Las Vegas, Nevada. The intersection is regulated by a traffic signal with separate pedestrian signal heads, in this case a visible pedestrian walk signal accompanied by beeping sound indicating pedestrians are free to legally enter the street. The intersection features what is known as a ladder-painted crosswalk, which is a crosswalk delineated by the typical two parallel lines running the entire length of the crossing to which have been added a series of regularly spaced perpendicular lines connecting the two. The researchers defined distracted pedestrians as those wearing headphones, talking on a cell phone, eating, drinking, smoking, or talking with another pedestrian as they crossed the street. Trained observers noted pedestrian behaviors at the crosswalk including looking left and right, staying within the marked crosswalk, waiting on the curb until the signal indications turned green, and not entering the crosswalk after the pedestrian indication had switched to the orange pedestrian signal.

Operational definitions of each observed behavior helped to increase inter-observer agreement. For a person to be credited for looking left and right, a noticeable turn of the chin was required. For one to be noted for correctly waiting on the curb, both feet must have remained on the curb until the white pedestrian walk signal illuminated. Those who stepped out of the crosswalk on two or more successive steps were considered outside the marked walkway. The first person to arrive at the intersection was the one observed; if more than one observer was present, the second person was recorded by the second observer. Multiple linear regression analysis measured the statistical relationship between distracted walking and caution displayed crossing the street. After controlling for gender and whether one was walking toward or away from the observer, the results revealed that the total number of distractions was the sole significant predictor of whether or not pedestrians displayed cautionary behaviors. In particular, distraction while walking predicted the demonstration of fewer cautionary behaviors as pedestrians crossed the street; however, only 1.6% of the variance in pedestrians' demonstrations of cautious behaviors was explained by the model. This low level of predictive power may have something to do with the selection method—distracted pedestrians may be slow to enter a crosswalk after the signal changes and, thus, less likely to be selected for observation. If a tendency to "hang back" is reliably present, it may be necessary to target observations based on a selection criterion that ignores position in a group. Of course, as a strategy when distracted, hanging back may actually confer some safety to the otherwise inattentive pedestrian—placing oneself at the center of a moving group may also influence observable safety behaviors such as the ability to stay within the marked crosswalk.

Hatfield and Murphy (2007) conducted an observational field survey of 270 females and 276 males at signalized and unsignalized intersections in three suburbs of Sydney, Australia, to compare the safety of crossing behavior of male and female pedestrians using and not using a cell phone. Pedestrians were observed in triads consisting of one distracted pedestrian and two non-distracted controls. One observer recorded the behavior of all pedestrians using a cell phone, regardless of usage type (hand-held versus hands-free; conversation versus messaging). For each cell phone user, there were two control observations to provide a baseline for behavior without using cell phones: a time-matched control and a demographic-matched control. For time-matched controls, the observer recorded the behavior of the next pedestrian to pass the same point in the same direction but not using a cell phone. For demographic-matched controls, the observer recorded the behavior of a pedestrian of the same gender and approximate age as the first pedestrian but not using a cell phone.

Pedestrians were classified as starting at marked crossings, or near but not at the marked crossings (i.e., 1-10 meters distant). The observers excluded pedestrians who crossed farther than 10 meters from the marked crossing. The results showed that at signalized intersections, looking at traffic and waiting times were not associated with phone use for males but were significantly related to phone use for females. Roughly the same pattern of results was found at unsignalized crossings—looking at traffic and waiting times of females were longer when using a phone, while males showed no effect. Similarly, crossing speed of females at signalized crossings is slower when using a phone compared to time- or demographic-matched controls, while that of males was not affected. The results showed the same pattern after accounting for potential covariates including the age of the subject and whether or not they walked with a companion. Males who were texting crossed faster than time-matched controls, but that effect went away after accounting for age and companion presence. At unsignalized crossings, the effects of gender-based behavior on crossing speed were reversed; females showed no differences between cell phone users and the controls, but the male cell phone users crossed significantly slower than the controls.

Nasar, Hecht, and Wener (2008) conducted two studies to examine distraction associated with cell phone use. In the first study, observers solicited participation from 60 randomly selected passersby near the main pedestrian entrance to a large, urban, State university campus. The subjects were instructed to walk along a prescribed route, with half of them conversing on a cell phone (conversation condition), and the other half holding the phone awaiting a potential call, which never came (no conversation condition). Prior to the study, five “out-of-place” objects had been placed along the route. The participants were interviewed at the end of the route and asked to recall how many of the “out-of-place” objects they noticed. The analysis revealed that pedestrians in no conversation condition noticed significantly more objects than those in conversation condition.

Nasar et al. (2008) performed a second test to see whether or not pedestrians using a hand-held cell phone were more likely to display unsafe behaviors than others (i.e., pedestrians listening to iPods and pedestrians not using a cell phone or an iPod). Three observers picked a pedestrian approaching the crosswalk alone in a situation where the pedestrian might come into a potential conflict with an approaching vehicle. Each observer independently recorded the pedestrian's demographic characteristics and behaviors as they crossed the street. A total of 127 pedestrians were observed and included in the analysis. Nearly 28% of the observed pedestrians exhibited behavior judged as unsafe by the three observers. As shown in Figure 1, pedestrians who walked while using a cell phone exhibited a higher percentage of unsafe behaviors than pedestrians using an iPod or not using any distracting device. A similar result was found in pairwise comparisons, indicating there were a significantly higher proportion of unsafe behaviors exhibited by mobile phone users than the iPod group and non-distracted group.

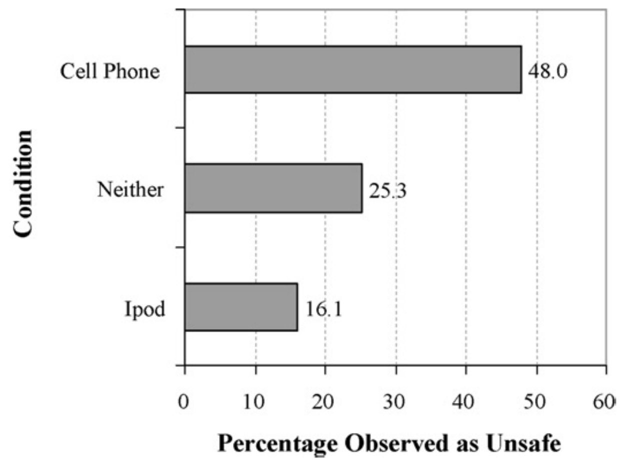

Figure 1. Percentage of Unsafe Behaviors Observed in Three Conditions From Nasar et al. (2008), Study 2.

Source: Figure 2 from Nasar et al. (2008), p 74; Reprinted with permission.

Tractinsky and Shinar (2008) compared the frequency of pedestrians using cell phones or not using cell phones bumping into an obstacle encountered while walking. A portable, horizontal, flexible aluminum rod was placed at the entrance to the main cafeteria of an Israeli university campus at seven different heights (randomized across observations). Data were collected on school weekdays over a two-month period. A total of 8,812 pedestrians were included in the analysis, 491 of whom were using a cell phone. The analysis revealed that whether a person used or did not use a cell phone while walking did not have a significant main effect on the overall probability of bumping into the rod (p=0.210). Logistic regression analyses for data obtained from each of two routes (exit and entry) found similar results—cell phone use did not have an effect on the likelihood of bumping. Further, the analysis of entry data (N=4,893) revealed that the likelihood of bumping into the rod was lower for people using cell phones than for non-users. However, as Tractinsky and Shinar point out, the low-risk situation of the study location and lack of control for people who had seen the obstacle before may prevent the result from translating to pedestrians in a traffic situation.

Hyman, Boss, Wise, McKenzie, and Caggiano (2010) conducted two studies to investigate the effects of divided attention during walking. The definition of distraction included walking while listening to an MP3 player, walking while talking on a cell phone, and walking in a pair. In the first study, the pedestrians were observed walking through the large central plaza (from which motorized vehicles are excluded) of Western

Washington University. To ensure that the pedestrians were selected without bias, the observers rotated through the participant categories (i.e., single individual with no electronics, cell phone user, music player user, pairs). They restricted observations to individuals who did not change path or condition while crossing the plaza (e.g., they excluded pedestrians who entered the plaza as a cell phone user, ended the call, and completed as a single pedestrian with no electronics in use). After applying exclusions, a total of 196 individuals were observed. The observers also recorded several outcome measures: crossing time, whether the individual stopped while crossing, the number of direction changes, whether the individual weaved, whether the individual tripped or stumbled, whether the individual was involved in a collision or near-collision, and whether the individual explicitly acknowledged other people by waving, nodding, or talking. The distraction condition affected walking behavior: cell phone users took more time (82.53 seconds) crossing the plaza compared to non-distracted single walkers (74.81 seconds) and walkers using a personal music player (73.69 seconds). Cell phone users were also more likely to weave (21.3% versus 14.0% for non-distracted single walkers), change direction (29.8% versus 4.7%), stop (4.3% versus 2.3%), or get into a near collision (4.3% versus 0.0%). Cell phone users also tended to acknowledge other people less often than non-distracted single walkers (2.1% versus 11.6%). Gender had no effect on walking speed and did not interact with the other aforementioned measures.

In their second study, Hyman et al. (2010) investigated if walking while talking on a cell phone led to inattentional blindness by placing an unusual stimulus to the side of the walking path. Inattentional blindness, as defined by Ericson, Beck, Parr, and Wolshon (2014), is “a failure to notice unexpected events due to an individual performing an attention-demanding task, even if the unexpected event occurs in the individual’s line of sight.” Hyman et al. (2010) used a brightly colored clown on a unicycle as the stimulus since he was visually noteworthy and relevant to the navigation task (i.e., in motion in the vicinity of the path that observed pedestrians were on). Interviewers asked a total of 161 individuals at the end of the path if they had seen anything unusual when crossing. If they did not mention seeing the clown, they were asked directly if they had seen the clown on the unicycle. Only 25% of the cell phone users noticed the clown. In contrast, over half of the people in the other conditions reported seeing the clown. This finding indicates inattentional blindness among cell phone users—that is they missed seeing the visually salient stimulus due to inattention caused by distraction. People walking in pairs were the most likely to see the clown, indicating that pairs may improve performance by having more observers engaged in scanning the environment.

Walker, Lanthier, Risko, and Kingstone (2012) measured cautionary behaviors exhibited by pedestrians comparing those with and without personal music devices (PMDs) at two busy crosswalks located mid-block on a two-way street on the University of British Columbia Vancouver campus. Cautionary behavior was measured as the total number of head movements (left and right) before stepping into the street, and whether or not the pedestrian slowed down or stopped before entering the crosswalk. In addition to the cautionary behavior, observers collected gender, the presence of a PMD, and the presence of other distractions (i.e., eating, drinking, on a cell phone, selecting a song on their PMD, etc.). The study’s primary author, E. Walker (personal communication, June 17, 2014), clarified that the presence of headphones in the ears of the pedestrian was used as a proxy for the presence of a PMD. The experimenters only recorded pedestrians coming from a head-on location to avoid the potential influence of walking direction on behavior. They started coding behavior when the pedestrian entered a pre-defined region until they entered the street.

For the selection of participants, each experimenter took turns identifying the first pedestrian seen entering the coding region. If pedestrians were in large groups, only the first pedestrian was coded. Pedestrians interacting with another person were excluded as well. The final analyses included 264 pedestrians after eliminating records in which the two raters disagreed on the presence of a PMD or the gender of the pedestrian. Females and males were analyzed separately using independent samples t-tests. For males, listening to PMDs did affect the cautionary behaviors significantly, t (133) =2.08, SED=0.29, p<0.05, such that males wearing PMDs looked *more* often than those without the devices. For females, there was no significant effect of PMD presence, t (127) =0.28, SED=0.33, p=0.86. In addition, there were no effects of PMD presence for females or males on the proportion of stops/slows prior to entering the crosswalk (p >0.25 for all comparisons).

Thompson, Rivara, Ayyagari, and Ebel (2013) observed crossing behaviors of a sample of 1,102 pedestrians at the 20 intersections in Seattle, Washington, with the highest number of pedestrian injuries recorded from 2009-2011. Observers used a fixed-interval selection criterion, recording data for the first person reaching the curb after a one-minute timer vibrated. Observers coded the following distractions: listening to music (headphones), hand-held cell phone, earpiece cell phone, text messaging, talking with another person, and other (carrying baby, pushing a stroller, etc.). Pedestrians with headphones in their ears connected to a device *capable* of playing music were counted as listening to music, otherwise, were coded as earpiece cell phone. Observers also recorded the direction the pedestrian walked, whether the pedestrian crossed at the crosswalk, whether the pedestrian looked left and right, and whether the pedestrian obeyed the intersection signal (if present). Time to cross was also measured from when both feet entered the street to when both feet stepped onto the opposing sidewalk. The analysis found that pedestrians who were text messaging took over half a second longer to cross each lane (0.55 s, 95% CI 0.36 to 0.75) and pedestrians who were listening to music walked faster than undistracted pedestrians by an average of 0.16s per lane. Thompson et al. (2013) also examined the association between whether or not pedestrians looked both ways and pedestrian distractions, adjusted for age and gender. The results revealed that some distractions were associated with risky pedestrian behaviors, with text messaging appearing particularly risky. Texting pedestrians were significantly more likely to cross the street without looking both ways before crossing (OR=4.00, 95% CI 2.04 - 7.84). When examining the association between distractions and crossing behaviors including looking both ways, crossing at the crosswalk and obeying the traffic signals, only text messaging and gender had a significant effect. Females were twice as likely (OR=1.52, 95% CI 1.12 – 2.05) to exhibit at least one unsafe crossing behavior in comparison to males. That is, pedestrians who were text messaging and females were more likely to exhibit unsafe crossing behavior.

1.1.1 Naturalistic Observation Summary

This review of the relatively small number of published naturalistic observation studies of pedestrian distraction provided a mix of evidence for an effect of distraction and null results where the effect of distraction was small or non-existent, or dependent on a third variable, such as gender. The findings are as follows:

- One study (Tractinsky & Shinar, 2008) found that cell phone use did not increase the likelihood of bumping into a rod placed at (or in) a cafeteria doorway.

- A study in a campus quad (where no vehicles were present) found that pedestrians using cell phones were twice as likely as all other pedestrians to fail to see a highly salient visual stimulus (a clown on a unicycle).
- Pedestrians walking a prescribed route in a campus setting, noticed significantly fewer “out of place” objects if they were engaged in a cell phone conversation while walking, than if they merely held the phone awaiting a call that never came.
- The use of personal music devices affected males but not females in the frequency of cautionary behaviors exhibited before crossing, while in another study, females showed an effect of distraction due to cell phone use, but males did not.
- The number of published studies is insufficient to enable us to determine how much of this pattern of results is due to methodological differences, how much is situational, and how much is truly due to distraction from electronic device use by pedestrians.
- A troubling methodological issue with the naturalistic observation studies has to do with selection criteria when observers are sampling from among all possible pedestrians in a traffic stream.

As stated above, the methodological differences do appear to be important, but it is difficult to identify the key difference between studies showing a small effect or no effect, and those showing obvious pedestrian issues due to distraction. For example, Tractinsky and Shinar (2008) point out that their subjects may have seen the obstacle well in advance of going through the cafeteria doors (e.g., they may have seen it while seated inside the cafeteria or during their walk approaching the doors). Another possibility is that a door is a well-expected obstacle and perhaps one that even a person operating under divided attention would (even subconsciously) spare enough processing resources to enable them to detect and avoid colliding with it—thus, a bar placed in the doorway was noticed precisely because a barrier of some type was expected.

A more problematic methodological issue with the naturalistic observation studies has to do with selection criteria when observers are sampling from among all possible pedestrians in a traffic stream. It makes sense to target the lead pedestrian for observation because that person will be least influenced by the behavior of all other pedestrians in a group. Unfortunately, it may be that the lead pedestrian is *least* likely to be distracted. This is the person most ready to cross, by definition. Those who are distracted might be expected to fail to notice any change in the signal status or in traffic conditions. They may, subconsciously, use a safety strategy adopted by prey species that travel in groups—it is safest in the middle of the herd – see Hamilton (1971) and Vine (1971) for discussions of the possible evolutionary advantages of herding behavior in prey species. Alternatively, distracted pedestrians may end up in the middle or the back of the crowd simply because they use the crowd’s movement as a cue for their own movement and so have an added latency before they start to cross the street. When groups of people cross streets, those at the back usually follow the movement of the group without checking traffic (DeVeauuse, Kim, Peek-Asa, McArthur, & Kraus, 1999). Regardless of the reason, selecting the lead pedestrian for observation may limit the number of truly distracted pedestrians observed.

Other methods that use either a random selection method (e.g., the next pedestrian arriving at the intersection after a fixed interval) or selection based on targeted features (e.g., the next female pedestrian between the ages of 18 and 25 who is/is not using a cell phone) would seem to be more promising. However, even among those studies with this type of selection criterion (i.e., random selection method or selection based on targeted features) there is a range of effects of distraction that goes from non-existent to large, statistically significant results of distraction on behavior:

- Hatfield and Murphy (2007) used random selection and found an effect of distraction for males only.
- Nasar et al. (2008) selected pedestrians before they reached the intersection—independently of their position in any group as they reached the intersection—and found that 48% of cell phone users exhibited unsafe behaviors, compared to 25.3% of undistracted pedestrians.
- Using a fixed interval selection procedure, Thompson et al. (2013) found that texting pedestrians took over a half-second longer to cross each lane than non-distracted pedestrians.

1.2 Simulation Observation

Simulation observation of pedestrian behavior uses subjects walking in a virtual environment while experimenters vary conditions, impose controlled levels of distraction levels, and record physiological and behavioral reactions to the distractors. It is widely used in studies of driver distraction to obtain detailed data that would be difficult or impossible to collect in the real world to find out the factors that might contribute to crashes. Simulator studies of pedestrian behavior are undertaken for much the same reasons as their use in measuring driver safety—the pedestrian can be put into “dangerous” situations in the virtual environment without any actual risk to the experimental subject. Simulators also provide greater control over the circumstances presented in the environment as the person is navigating through the virtual environment. For example, each subject can see the same oncoming traffic stream exactly *n* seconds after reaching a defined point in the simulated world. Simulator studies of drivers have also taken advantage of the experimenters’ ability to measure subjects’ autonomic responses and brain activity as they react to specific stimuli in the virtual world. This approach has not been used yet with respect to pedestrian simulator studies, although the pedestrian simulator studies that have been completed do include more precise measurement of behavior than is typically possible in naturalistic observation studies.

Building a theory of pedestrian risk can take these precise measurements into account when postulating what exactly pedestrians are doing (if not what they are actually thinking) as they begin to cross a busy street. Of course, the one major disadvantage when interpreting the results of simulation studies is that all of the stimuli are virtual and there is no actual risk. As such, theorists must at least consider the possibility that subjects’ reactions in these digital environments might not match their reactions in the real world—if there are no consequences of being hit by a virtual sedan, perhaps subjects are less likely to avoid it by thinking of safer actions and acting on those thoughts.

Neider, McCarley, Crowell, Kaczmarski, and Kramer (2010) conducted a study in a virtual environment with 36 participants from the University of Illinois. All participants were required to perform the road-crossing task in three conditions: no distraction, listening to music through headphones, and conversing on a cell phone using a hands-free device. The conditions were blocked and counterbalanced across 96 experimental trials (two blocks of 16 trials per condition; six total blocks per participant). Each participant received 10 familiarization trials prior to the experiment. Participants were considered as having failed to cross the street if they were “hit” by a car or if they took too long to get across (time-out). A series of measures were collected including crossing success rate, collision rate, time-out rate, and number of head turns. The analysis of success rate revealed that distractions, and particularly conversing on a cell phone, lower the percentage of successful crossings. The comparison of collision rate indicated that using a cell phone and listening to music did not increase the likelihood of being involved in a vehicle related collision. For time-out rate and overall trial duration, listening to music produced similar results as no distraction, while conversing on the cell lowered the likelihood that subjects would complete a trial within the time limit. Cell phone conversations also resulted in longer crossing times than the other two conditions. No significant differences were observed across conditions in the mean number of head turns during initiating a cross or crossing.

Two studies by Stavrinos, Byington, and Schwebel (2009, 2011) examined risky behaviors in relation to distraction due to cell phone conversations. Stavrinos et al. (2009) conducted a study of 77 children ages 10 to 11 in an immersive, interactive virtual pedestrian environment. Prior to the experiment, children completed 10 familiarization trials in the virtual environment and then completed a series of behavioral measures of attention. Then, each child was required to cross the virtual street six times while undistracted and six times while distracted by a cell phone conversation. The observers calculated four indicators of safe crossing: average start delay, average safety time, hits or close calls, and attention to traffic. Parents were required to complete a questionnaire concerning their children's cell phone use (i.e., time the children spent using a cell phone per day) and walking patterns (i.e., walking frequency and distance in various contexts, such as to parks, to school). The analysis showed that children were more likely to behave in a risky manner while engaged in a cell phone conversation than undistracted regardless of their cell phone usage and street crossing times in daily life.

Similar to the earlier study conducted with children, Stavrinos et al. (2011) also conducted two simulator studies of college students in a similar virtual environment to investigate whether college-age pedestrians would behave in a riskier manner while distracted by a cell phone conversation. First, they examined the behaviors of 108 participants from an introductory psychology course at a local university. Each participant was required to complete 12 simulated crossings in the virtual environment, which included six while distracted by a cell phone and six undistracted. The observers videotaped the trials and coded four behaviors, including time left to spare, missed opportunities, attention to traffic, and hits/close calls. The investigation of the overall significant main effect indicated that participants behaved in a riskier manner when distracted by cell phone conversations across three of the four pedestrian variables (i.e., time left to spare, missed opportunities, and hits or close calls). Results also revealed that there were no significant associations between individual difference factors and the participants' susceptibility to distraction. That is, those who used cell phones more often or those who crossed streets more frequently in the real world were as susceptible to performance decrements due to distraction in the virtual environment as were their less experienced counterparts.

In the second study, Stavrinos et al. (2011) examined the impact of particular types of distraction on pedestrian injury risk, including engaging in a cell phone conversation, engaging in a spatial task verbally by phone (the instructions were to describe sights they would see walking through their apartments), and engaging in a mental arithmetic task verbally by phone (count backwards by threes). The findings revealed a significant main effect of distraction conditions that participants were less safe under the three distraction conditions than when undistracted. The activities were all equally distracting—pairwise comparisons found no differences among the three distraction conditions in that a naturalistic cell phone conversation resulted in pedestrian behaviors as risky as the behaviors exhibited while engaging in the spatial- and arithmetic-focused conversations.

Byington and Schwebel (2013) recorded the behavior of 92 participants crossing a street in a virtual environment. They recruited participants from an introductory psychology class at the University of Alabama at Birmingham. Each participant crossed the simulated intersection 10 times under a distraction condition and 10 times without distraction. The distraction used was an email-based “scavenger hunt” consisting of a series of messages with instructions that required subjects to search the internet and then answer a question in a reply email. Observers recorded six behavioral measures: hits/close calls, start delay, wait time, missed opportunities, looks at traffic, and eyes off road. Repeated-measures ANOVAs with condition (distracted vs. undistracted) as the independent variable and pedestrian scores as the dependent variable revealed a main effect for the distraction condition across all six pedestrian variables. This result indicates that pedestrians behave more riskily when simultaneously using the internet and crossing the street when compared with crossing the street with no distraction. Analyses of covariates showed that the main effects for distracted condition were retained across all pedestrian variables; that is, walking while engaging in mobile internet use evoked riskier behaviors than an undistracted condition regardless of randomized order, gender, ethnicity, or age. Finally, they found that pedestrian street crossing habits and mobile internet use did not affect the differential risk due to distraction—practice in the real world did not result in safer behavior in the virtual environment.

Schwebel et al. (2012) compared four distraction conditions in a semi-immersive virtual environment in which experimenters added realistic ambient and traffic noise to the otherwise low-fidelity simulated intersection displayed on computer monitors. The four distractions compared were crossing while talking on the phone, crossing while texting, crossing while listening to a personal music device, and crossing while undistracted. The experiment engaged 138 participants from an introductory psychology course. Participants completed 12 familiarization trials, after which they each completed 12 crossings in one of four randomly assigned experimental conditions. For those assigned to a distraction condition, they initially needed to cross the virtual street twice while undistracted, after which they crossed 10 times while distracted. Five indicators of safe street crossing were computed: average time left to spare, looks left and right, looks away (from the computer monitor), hits, and missed opportunities. A linear regression model comparing the groups on looks away from the street environment showed all three distracted groups (and particularly the texting group) produced more looks away than the undistracted control group. The regression models of time left to spare, looks left and right, and missed opportunities were not statistically significant. In addition, the analysis found that the participants who were distracted by music or by texting were more likely to be struck by a virtual vehicle than were the undistracted participants, but the phone conversation group was not.

1.2.1 Simulation Observation Summary

This review of simulator studies revealed the following findings:

- Texting or conversing on a cell phone while crossing can adversely impact pedestrians’ safety in a virtual environment, a finding that agrees with the results from naturalistic observations.
- Risks are minimized in the virtual environment, which is also the source of this methodology’s greatest weakness and lack of generalizability.

- The pedestrian simulation studies to date have limited the sample to young adults and children whose behavior may not be representative of pedestrians at other ages.
- The pattern of results in simulator studies is not precisely in accord with the studies using naturalistic observations in the real world. In particular, gender effects are almost entirely lacking in the simulator studies, while they appeared to be prevalent, if not universal, in the naturalistic studies. Distraction effects are comparatively larger in the simulator studies as well.

1.3 Laboratory Observation

Some studies required participants to walk in experimenter-designed trails in a laboratory or outside setting (i.e., away from vehicular traffic). This allowed the experimenters to closely observe natural behavior in a relatively safe environment. These studies are distinct from simulator studies because they do not involve a virtual environment and there is no attempt to examine traffic-related behaviors as part of the study, although "safety" of walking is measured in some studies. The reports in this category have similar advantages to the simulator studies in that the environment and the level of distraction are both under experimental control.

Lin, Goldman, Price, Sears, and Jacko (2007) examined stylus-based tapping operations on a Personal Digital Assistant (PDA) under four mobility situations: seated (baseline), slow walking on a treadmill, fast walking on treadmill, and walking through an obstacle course. Sixty-four college students served as subjects. Four variables were measured for all the mobility conditions: target selection time, error rate, task completion time, and workload. The result showed that the worst condition was walking through an obstacle course, which significantly interfered with target selection on the PDA.

Lamberg and Muratori (2012) investigated the safety impact of using cell phones while walking. At baseline, 33 participants visually located a target 8 m ahead, and then they were instructed to walk to the remembered target with vision occluded. One week later, all the participants were randomly assigned to either walk (WALK), walk while talking on a cell phone (TALK), or walk while texting on a cell phone (TEXT) toward the target with vision occluded for all the conditions. The observers measured longitudinal and lateral error for each trial. They found that walking while texting or talking on a cell phone led to gait disruptions when navigating toward a remembered target particularly while engaging in texting. Specifically, the TEXT group had a 33% reduction and the TALK group had a 16% reduction in velocity compared with baseline condition. Furthermore, the TEXT group increased 61% in lateral deviation and 13% in linear distance traveled. In contrast, the WALK group did not slow and neither the WALK nor the TALK group increased lateral deviation or linear distance traveled compared to baseline.

Bellows, Comerford, and Youmans (2012) compared the walking paths of 22 adults (11 male and 11 female) between the ages of 18 and 25 while they were simultaneously using a mobile device to send text messages (TEXT), make a phone call (CALL), or play a visuospatial game (GAME). They employed a three (send text, make call, play game) by two (male, female) quasi-experimental design with distraction as a within-subjects independent variable and gender as a between-subjects variable. All participants were exposed to each distraction condition and were required to complete a 1-foot-wide walking course with stops and step-over barriers marked out in colored tape on the floor. Movement errors were coded by the observers, including mistaken stops, failures to step over, and failure to stay within the marked path. Frequency of errors was highest in the CALL condition (mean errors = 4.09/45 s trial), followed by the TEXT condition (mean errors = 4.00/45 s trial), and lowest in the GAME condition (mean errors = 2.66/45 s trial). Note that significance tests comparing conditions were not reported. The pattern across conditions remained the same regardless of gender; however, males made more errors than females. In addition, each participant was required to complete a subjective task load index survey between each condition. The subjective task loading scores for CALL and TEXT conditions were significantly higher than for the GAME condition; however, no significant relationship between subjective workload and objective errors was found.

1.3.1 Laboratory Observation Summary

The review of laboratory studies revealed the following findings:

- The laboratory results are similar to simulation observation studies: walking while using a cell phone impacts behavior and increases the frequency of errors.
- None of the laboratory studies to date have attempted to correlate behavior in the lab to behavior or risk in the real world.

1.4 Other Data

1.4.1 Crash and Injury Databases

Some researchers have undertaken a review of distracted pedestrian-related cases from various injury and crash records databases in an attempt to identify the safety impact of distraction. These studies have the advantage of working with real-world outcomes due to distraction, but generally lack controls or exposure measures—the questions of how many pedestrians are there and what proportion of them are distracted but not injured remain unanswerable in most studies. Thus, these studies are most useful in describing the kinds of situations and distractors that have resulted in injury or death in the past so that observational studies (whether in the field or in a controlled environment) can focus on the most prevalent factors or scenarios.

Nasar and Troyer (2013) used the National Electronic Injury Surveillance System (NEISS) database to find the number of reported injuries related to cell phone use among pedestrians and drivers. NEISS, maintained by the U.S. Consumer Products Safety Commission (CPSC), collects data from a representative sample of 100 emergency rooms across the Unites States on product-related injuries. The CPSC calculates case weights to arrive at national estimates for the 3,800 eligible Emergency Departments/hospitals in the Nation. The researchers selected injury cases from 2004-2010 in which use of a cell phone was noted either for a motorized (car, motorcycle, moped, etc.) or non-motorized (pedestrian or bicyclist) party—98.2% of motorized persons were in a car and 79% of non-motorized cases were pedestrians. However, the researchers could not be certain that the motorized users were drivers, though it may be presumed that the majority were drivers. For 2009 and 2010, they examined what people were doing at the time of the injury. For pedestrians, at the time of injury, 69.5% were talking on the phone and 9.1 % were texting. For (presumed) drivers, at the time of injury, 46.6 % were reaching for the phone, 37.8% were talking, and 12.6% were texting. Note that the data do not answer the question of relative risk of the various activities since (a) the researchers cannot know how prevalent each behavior is, and (b) there may not be a direct and simple link between the distraction caused by the device and the cause of the actual injury.

A similar study by Smith et al. (2013) reviewed 2000-2011 injury data from NEISS. Two-staged screening was used to identify injuries due to cell phone use among pedestrians. First, cases were analyzed for whether they involved: distraction, any independent physical movement, and cell phone use. The researchers identified 5,754 cases meeting all three conditions. Next, they screened out cases where the injured party was using a vehicle at the time of the injury, arriving at 3,672 cases in total. The findings revealed that 78% of these patients were injured in a fall while talking on their phone. In addition, the frequency of cell phone-related injuries increased across the years both in the home and outdoor environments. Comparing the trend in cell phone connections and injuries in this case series showed that the number of injuries per cell phone connection approximately doubled over the course of the study—that is, adjusting for the increased prevalence of cell phones in the US, cell phone related emergency room visits still increased dramatically over the 12 years from 2000 to 2011.

1.4.2 Risk Modeling

Loeb and Clarke (2009) developed an econometric model of the pedestrian life-taking and life-saving effects of cell phones used by pedestrians and drivers. The dependent variable was the number of fatalities. A series of socioeconomic variables were included in the model as independent variables, such as unemployment rate, vehicle miles driven, and total population. The study used the national cell phone usage census as well as national pedestrian fatality data reported to investigate the risk associated with cell phone use, which was from a different perspective. The results showed that cell phones adversely affect pedestrian safety significantly, but that the relationship between cell phone use and safety has not been simple and straightforward over the years, since their arrival on the transportation scene. Specifically, the model showed that initially, as cell phones became more readily available, pedestrian fatalities increased. After reaching a certain critical mass of cell phones (33.292 million), the life-saving effects of cell phones overtook the life-taking effects. However, with cell phone subscribers reaching over 355 million in 2014 (CTIA, 2015), the life-taking effect surpassed the potential life-saving effect once again. Loeb and Clarke (2009) concluded that in recent years, cell phone use has had a significant and growing adverse impact on pedestrian safety. That negative impact can be expected to grow as the number of cell phone subscribers continues to increase. In part, the logic of the argument is that there is a limit to the safety improvement gained from the general ability for *someone* to call for emergency services using a cell phone. Adding more phones beyond the saturation point for that benefit does not improve safety—in other words, there are already enough cell phones in the hands of users that practically every emergency situation results in an immediate call for aid. Beyond that point, adding cell phones only serves to add to the risks, because each phone comes with a small negative impact on the safety of its user.

1.4.3 Kinematic Gait

Schabrun, van den Hoorn, Moorcroft, Greenland, and Hodges (2014) examined the kinematic gait of pedestrians when they were distracted by a cell phone while crossing a mock-up of a street in a laboratory setting. They collected the gait performance data of 26 individuals walking in a straight line in three conditions: without a cell phone, reading text on a cell phone, and typing text on a cell phone. All the participants were mobile phone users with a touch screen and had more than 3 months of daily-use experience with their phone. Each participant was required to complete three trials under each condition in a randomized order. The observers measured walking speed, stride length and frequency, deviation from path, and lateral change in the right foot position between strides for each trial. The comparison analysis found that compared to normal walking, pedestrians writing or reading text had an altered gait, walked slower, held their head in a more severely flexed position (while having greater range of motion of the head), and had shorter stride length and higher stride frequency. While writing texts, participants walked even more slowly, deviated more from the straight line path, and had less neck range of motion than when simply reading texts on the same phone. It is not clear how these kinematic changes due to distraction translate into an impact on pedestrian safety impact; however, it does seem likely that distraction, gait changes, and risk are all correlated.

1.4.4 Other Data Summary

The following findings were concluded through the review of the studies relying on other data:

- Pedestrian distraction and associated risk are difficult to study using retrospective analyses of injury databases.
- The NEISS database is useful, but lacks prevalence data to use in normalizing.
- Crash data hold the potential for quantifying the prevalence of injuries involving cell phone use or distraction in general, but rely too heavily on the self-reports of injured parties that they were distracted at the time of the incident.
- Studies relying on crash data typically have little information on pedestrian distraction.
- Pedestrian distraction leads to kinematic changes.

1.5 Summary of Pedestrian Distraction Literature

Studies have been conducted in the field or in the lab to compare behavior and risk between distracted and non-distracted pedestrians. The simulator studies show increased risky behavior for distracted pedestrians with the result that they are “hit” more often than non-distracted pedestrians, but it is difficult to determine how well those findings translate to pedestrian safety in the real world. Studies of injury and crash data similarly indicate that distraction has real-world consequences in terms of increased injury and death; however, the results are either not very specific to the type of distraction (crash data analyses) or are difficult to generalize because of the sampling frame for the databases (consumer product-related injury data). It should also be recognized that the number of documented cases each year is relatively small in comparison to total crashes.

Until very recently, crash databases failed to code specific sources of distraction, and the portion of the record describing pedestrians’ behavior or pre-crash conditions was even less specific than that for drivers. This makes it difficult to obtain sufficient behavioral data from crash databases to examine the prevalence, let alone specific contributing factors, of pedestrian distraction. Naturalistic observation studies and simulator studies provide good estimates of the size of the effect of distractors on crossing behavior. They do not, however, directly show the link to safety (in terms of crash involvement). Laboratory studies can offer a middle-ground between simulated and naturalistic observations of crossing behavior. In these studies, distraction due to electronic device use increases walking “errors” and reduces the likelihood that the pedestrian will engage in safety behaviors or notice events or stimuli in the environment. Econometric modeling points to a complex relationship between cell phones and safety with an increasing negative impact as the number of cell phones in use continues to rise beyond the critical mass needed to promote rapid emergency services notification.

Together, the results from distracted walking studies indicate that cell phones, in particular, and distraction in general are a real problem in pedestrian safety. Although the size of the pedestrian distraction problem is difficult to quantify with precision, the research indicates that the effect of any individual distraction type, including cell phones, is typically small but statistically significant. What this means is that the effects of distraction can be difficult to detect, especially, if the scale of the study is small (too few subjects/observations) or the study is subject to multiple uncontrollable factors, as might be expected in naturalistic observation situations. The research is also equivocal on the influence of a short list of likely covariates such as gender and age.

There are methodological trade-offs in researching the impact of pedestrian distraction as well. Naturalistic observation studies hold the clear advantage of directly measuring pedestrian behavior in the real world and offer at least the possibility of linking behavior to some quantifiable measure of risk. Unfortunately, the difficulty of working in the real world has limited many studies to collecting data on the lead pedestrian in a group, and thus likely missing the most distracted pedestrians. Herd behavior, in addition, may actually work in favor of the distracted pedestrian by making it safer to cross the street in the company of others who are devoting attention to the task. Other methods that use either random selection (e.g., Hatfield & Murphy, 2007) or selection based on targeted features independent of the pedestrian's position at the curb may support a more realistic assessment of pedestrian risk.

Laboratory and simulator studies have the advantage of putting task loads and environmental risks under experimental control so that they can be measured and manipulated with precision. Unfortunately, they also remove some of the motivation for subjects to consciously consider the safety of their actions as there are no real consequences for failing to successfully cross the virtual street or complete the defined route. Retrospective studies of injury and fatality data can quantify the consequences of distraction, but don't tell us anything about exposure or risk.

Note that the studies discussed in this section do not address pedestrian–vehicle interactions. These are covered in a later section of the report.

2. DRIVER DISTRACTION LITERATURE

The NHTSA-sponsored research project under which this literature review was conducted focuses not only on risk of crash involvement due to pedestrian distraction, but also on the increased crash risk to pedestrians associated with driver distraction. Naturalistic observations and simulator studies have been used extensively to investigate risk of crash involvement due to driver distraction. In addition, several studies identify the trend or proportion of crashes or injuries caused by inattentive driving through the review of national or statewide databases, and these are often updated annually. However, not many studies have focused specifically on the association between driver distraction and crash involvement with pedestrians in particular.

This section of the literature review presents a survey of relevant research going back to the earliest published studies of driver distraction and includes a sampling of a large number of recent publications. As with the section on distracted pedestrians, this section on distracted drivers includes research on naturalistic observations, simulator studies, and retrospective analyses of outcome data. As with the pedestrian distraction research, there is ample evidence of a relationship between driver distraction and safety, but quantifying the precise nature of that relationship is not simple or straightforward. For example, some of the work presented here points to the possibility that practice (or perhaps genetic factors) can help eliminate distraction and avoid any potential safety impact of driver distraction.

2.1 Naturalistic Observation

Unlike the pedestrian studies discussed in Section 1, naturalistic observations of drivers include large-scale studies using automated measurement systems. Researchers thus have the option, assuming sufficient funding, to capture multiple views and several simultaneously recorded data streams for each driver. Several studies have used an instrumented vehicle to collect naturalistic driving data to identify the relationship between distraction of drivers and driving performance.

An early study by Brown, Tickner, and Simmonds (1969) concentrated almost entirely on the attentional aspects of driving without distraction and driving while engaged in a telephone conversation. Twenty-four men ages 21-57 took part in the study, driving a 1.5-mile circuit on a closed-course test track. Observers measured four aspects of driving skill: gap judgment, success making it through the gap, speed of getting through the circuit, and measures of turning and acceleration. The telephoning task required the drivers to check the accuracy of short sentences. Audio was delivered through a loudspeaker mounted in front of the participant and the participant responded through a headset microphone. The results showed, without conversation, the time to complete the circuit and the number of gap-judgment errors were positively correlated. In contrast, when drivers were distracted by the conversation condition, circuit completion time and errors in the sentence checking task were negatively correlated, indicating that drivers slowed down under cognitive load presumably because they were trying to maintain performance on the language processing task.

Green, Hoekstra, and Williams (1993) collected driving condition data using an instrumented vehicle for a sample of eight participants during baseline conditions (no distraction) and while engaging in a conversation using a cell phone. Further, a route guidance system provided turn-by-turn directions on “navigation” trials. Participants drove a specified route and were instructed to make a cell phone call using the car-phone provided by the experimenters. To complete this task, the participant needed to turn on the phone, dial, and then engage in a conversation involving either listening/deciding (e.g., hearing descriptions and choosing a restaurant); talking (e.g., describing what you did last weekend); or producing a list (e.g., listing the names of as many fruits as you can). Each participant made 12 calls, including three initial practice calls while parked and the remainder while driving on a 50-mph (80.5 km/h) U.S. route and a 65-mph (104.6 km/h) interstate route. The instrumented vehicle collected lane tracking, steering wheel position, speed, accelerator pedal angle, road scene video, driver view video, and audio. The results showed no main effect of distraction on average speed, but the standard deviation of speed varied significantly across the three conditions (baseline, navigation, and phone). The speed standard deviations increased by about 50% for both the navigation and phone condition versus baseline. Lateral position was not affected by distraction, but the standard deviation of lateral position was significantly affected by distraction. The standard deviation of steering wheel angle, however, showed that the phone condition had much greater variability than either of the other two conditions—perhaps not surprising given that subjects had to turn on and manually dial the phone. It is not clear how such changes in variability translate to safety outcomes; however the data indicate an effect of distraction on precision and stability of control inputs.

Klauer, Dingus, Neale, Sudweeks, and Ramsey (2006) calculated the relative near-crash/crash risk associated with driving drowsy and driving distracted using naturalistic driving data from two reduced databases: the 100-car instrumented vehicle study database and the baseline database. The baseline database was created by stratifying the entire dataset based upon the number of crashes, near-crashes, and incidents in which each vehicle was involved, and then randomly selecting 20,000 6-second segments from the 6.3 terabytes of driving data. Driver inattention was defined as: driver engagement in secondary tasks, driver drowsiness, driving-related inattention to the forward roadway, or non-specific eye glance away from the forward roadway. Secondary tasks were categorized into three levels: complex, moderate, and simple. The complex secondary tasks are those that require either multiple steps, multiple eye-glances away from the forward roadway, and/or multiple button presses. Moderate secondary tasks are defined as tasks that require, at most, two glances away from the roadway and/or at most two button presses. Simple secondary tasks are those that require none or one button press and/or one glance away from the forward roadway. The researchers computed odds ratios for each type of inattention and for duration of glances away front-forward view. The results showed that engaging in complex secondary tasks increases near-crash/crash risk three times above the baseline value. Engaging in moderately complex secondary tasks was shown to double the risk.

Young, Salmon, and Cornelissen (2012) used an instrumented vehicle to explore the nature of errors made by drivers when distracted versus not distracted. Twenty-three drivers ages 19-51 took part in the study. The driving route comprised an 8.7-km urban route in the suburbs surrounding the Monash University Clayton Campus in Australia. The test route contained 11 intersections with a combination of fully signalized, partially signalized, unsignalized traffic controls, and 50-, 60-, 70-, and 80-km/h speed zones. The test was performed at off-peak times for traffic volume. The participants were required to drive the test route twice, once undistracted (baseline) and once while distracted (performing a visual detection task). Vehicle control-related data and eye tracking data were collected while drivers drove the instrumented vehicle. Drivers made a total of 268 errors (11.7 per driver on average) when distracted and 182 errors (7.9 per driver) when not distracted. Generalized estimating equation modeling indicated that drivers were 48% more likely to make an error when distracted than when not distracted. The model also demonstrated that distracted drivers were significantly more likely to exceed the speed limit, activate their indicator too early, and accelerate too fast. The odds of making a line excursion and traveling too fast for a turn did not differ significantly across the distracted and undistracted conditions. In addition, distracted drivers were significantly more likely to violate the road rules and make misjudgment and overreaction errors (e.g., accelerating too fast) than undistracted drivers. Comparing the types of errors made, however, Young et al. (2012) found that drivers made the same types of errors in the two conditions, just more of them when distracted.

More recent large-scale naturalistic driving studies have provided researchers with the data necessary to calculate the risk associated with use of electronic devices while driving. Klauer et al. (2014) used the 100-Car Naturalistic Driver Study and Naturalistic Teen Driving Study datasets to identify distraction-related crashes and near-crashes and compared driver activities in the periods immediately preceding those adverse events to randomly selected control periods. They calculated at-fault crash risk related to various secondary tasks (including electronic device use) in both datasets to obtain estimates of distraction-related crash risk separately for teens and adults. Table 1 displays the odds ratios calculated for each of the secondary tasks examined for novice and experienced drivers. The odds ratios shown in the table can be interpreted as a measure of relative risk with higher odds ratios indicating an increased risk of that factor being implicated as a crash causation factor. Values at or below 1.0 indicate no increased risk (or potentially reduced risk). For novice drivers (ages 16.3 – 17.0 who had a driver's license for 3 weeks or less at the beginning of the study), dialing or reaching for a cell phone and texting all lead to significantly increased crash risk, as did reaching for an object other than a cell phone, looking at a roadside object, and eating. Among experienced drivers (ages 18 -72 years), only dialing a cell phone resulted in significantly increased crash risk.

Table 1. Odds Ratios Measuring Crash Risk Associated With Secondary Tasks for Novice and Experienced Drivers from Klauer et al. (2014).

Task	Novice Drivers	Experienced Drivers
	Odds Ratio (95% CI)	
Using cell phone		
Texting or using Internet	3.87 (1.62–9.25)	NA†
Dialing	8.32 (2.83–24.42)	2.49 (1.38–4.54)
Talking	0.61 (0.24–1.57)	0.76 (0.51–1.13)
Reaching for phone	7.05 (2.64–18.83)	1.37 (0.31–6.14)
Reaching for object other than cell phone	8.00 (3.67–17.50)	1.19 (0.61–2.31)
Looking at roadside object	3.90 (1.72–8.81)	0.67 (0.37–1.22)
Adjusting controls for radio or HVAC	1.37 (0.72–2.61)	0.53 (0.30–0.94)
Adjusting controls other than those for radio or HVAC	2.60 (0.89–7.65)	0.64 (0.15–2.65)
Eating	2.99 (1.30–6.91)	1.26 (0.74–2.15)
Drinking nonalcoholic beverage	1.36 (0.31–5.88)	0.44 (0.16–1.22)

* The analysis of the 100-Car Naturalistic Driving Study involving experienced adult drivers was based on 518 crashes and near-crashes for which the driver was at fault or partially at fault and 16,614 control periods. The analysis of the Naturalistic Teenage Driving Study was based on 167 crashes and near-crashes for which the driver was at fault or partially at fault and 5238 control periods. CI denotes confidence interval, and NA not applicable.

† Texting, accessing the Internet, or both rarely occurred during the data-collection period in the 100-Car Study, so this task could not be appropriately evaluated with the use of the data from this study.

Source: Table 2 from Klauer et al. (2014); Reprinted with permission.

Fitch et al. (2013) investigated the risk of safety-critical events associated with three types of cell phone use: hand-held (HH), partial hands-free (PHF), and integrated hands-free (IHF). In this study, a safety-critical event refers to crashes, near-crashes (requiring a rapid evasive maneuver to avoid a crash), and crash-relevant conflicts (which were less severe than the near-crash events, but more severe than “normal driving”). The naturalistic driving study engaged 204 drivers for an average of 31 days each.

Table 2 presents the rate ratios associated with various cellphone use activities. In the table, an asterisk indicates significance (different from a risk of 1.0) at the $p<.05$ level. As seen in Table 2, the significant effects of cell phone use on safety-critical event risk are all associated with hand-held phone use manual manipulation, but not necessarily with conversation using a cell phone. Visual-manual interaction with the phone as part of a call or when texting are clear risk factors. This implicates dialing or answering a hand-held phone as one likely risk factor associated with every call.

Table 2. Safety-Critical Event Risk Associated With Three Types of Cell Phone Use From Fitch et al. (2013).

SUBTASK	Rate Ratio	Lower Confidence Limit (LCL)	Upper Confidence Limit (UCL)	p-value
Cell Phone Use – Collapsed		0.96	1.81	.0917
Visual-Manual	2.93*	1.90	4.51	<.0001
Call-Related Visual-Manual	3.34*	1.76	6.35	.0003
Text-Related Visual-Manual	2.12*	1.14	3.96	.1840
Talking/Listening	0.84	0.55	1.29	.4217
Talking/Listening HH	0.84	0.47	1.53	.5764
Talking/Listening PHF	1.19	0.55	2.57	.6581
Talking/Listening IHF	0.61	0.27	1.41	.2447
HH Cell Phone Use (Collapsed)	1.73*	1.20	2.49	.3400
PHF Cell Phone Use (Collapsed)	1.06	0.49	2.30	.8780
IHF Cell Phone Use (collapsed)	0.57	0.25	1.31	.1859

Source: Adapted from Table 1 from Fitch et al. (2013). Adapted with permission.

2.1.1 Naturalistic Observation Summary

- Naturalistic driving studies are in agreement that distraction increases the frequency of driving errors and risk of a crash or near-miss.
- Recent naturalistic driving studies have supported calculation of crash-causation risk ratios for specific distractors, including cell phone use.
- It is likely that future analyses arising from more recent naturalistic observation studies (specifically, the Strategic Highway Research Program—SHRP2) will provide greater detail about the nature and consequences of driver distraction.
- Pedestrian-vehicle crash risk will be difficult to estimate even from the larger pool of naturalistic observations in the SHRP2 study.

2.2 Simulation Observation

Simulation studies of driver distraction, like those studying pedestrian distraction, have the advantage of bringing the environment and the distracting stimuli under experimenter control. These studies also support a large number of dependent variables that can be measured with greater precision than is typical for the behavioral measurements taken in naturalistic settings. There is a significant number of relevant simulator studies. In the following subsections on simulation observation, the literature has been divided into categories to make the significant number of studies more accessible.

Studies addressing response time and performance of distracted drivers are presented in the first category (subsection 2.2.1). These studies document the basic effects of distraction on performance in the simulated driving environment. The articles cited here focus almost entirely on the distracting effects of cell phones. The next subsection (2.2.2) discusses studies comparing the effects of cell phone-related distraction and alcohol intoxication. The last subsection (2.2.3) discusses distraction and its effect on visual information processing. Another set of relevant simulator studies addresses age and practice effects. These are included in a separate section (section 2.5) of this literature review due to the potentially important implications of their findings for interpreting all of the simulation-based studies.

2.2.1 Response Time and Driving Performance Literature

McKnight and McKnight (1993) observed a 25-minute video driving sequence containing 45 highway traffic situations of which participants were expected to respond by manipulation of an instrumented vehicle. Measurements were taken under five conditions of distraction, including placing a cell phone call, carrying on a casual cell phone conversation, carrying on an intense cell phone conversation, tuning a radio, and no distraction. A total of 150 drivers took part in the test, including 45 young, 56 middle-age, and 49 older drivers. The video was recorded through the windshield of a moving automobile and was played back on a 50-inch screen rear-projection television. Participants were required to observe the driving scenes and to use the vehicle controls to respond to the evolving scenes the same way as they would when driving their cars. Performance was scored in terms of whether or not subjects responded to each of the situations they encountered. A repeated-measures ANOVA showed that the combined scores across the four distractions and each of the four distractions differed significantly from the no-distraction condition. All of the distractions led to significant increases in the proportion of situations to which subjects failed to respond, as shown in Figure 2. In particular, intense phone conversations and radio tuning yielded the greatest increases in failure to respond to the driving scene. There were no significant differences among the individual distraction conditions. Interpretation of these results is limited because the sole outcome measure was whether or not drivers responded—drivers may have chosen not to respond rather than failing to respond because of distraction.

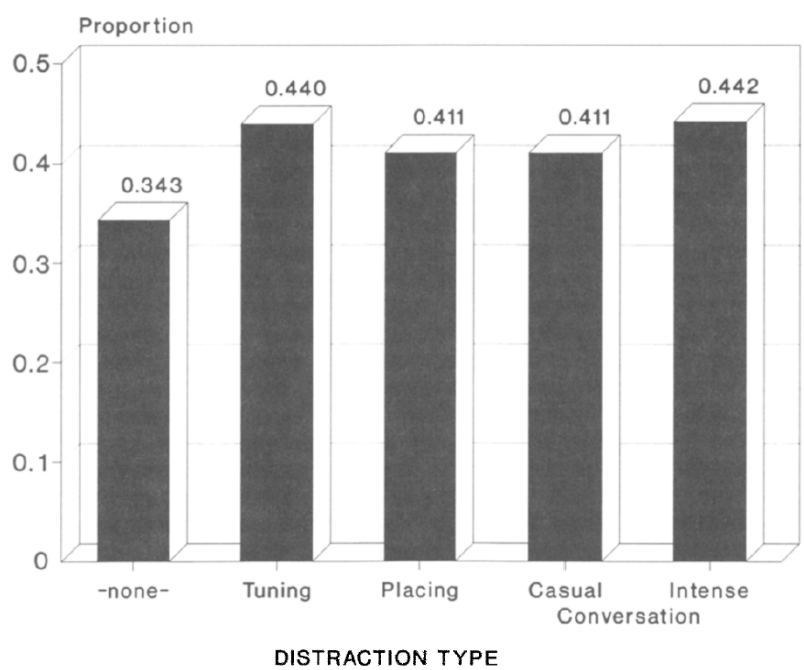

Figure 2. Proportion of subjects failing to respond to highway traffic situations: Total sample from McKnight and McKnight (1993).

Source: Figure 1 from McKnight and McKnight (1993), p. 262; Reprinted with permission.

Strayer and Johnston (2001) conducted dual-task studies to assess the effect of cell phone conversations on driver performance. The first experiment compared the effects of hand-held and hands-free cell phone conversations on a simulated driving task. They also included a control group who listened to the radio while performing the driving test. Subjects' probability of detecting and reaction time to a red-light stimulus was measured in a between-groups comparison. Forty-eight undergraduates from the University of Utah were randomly assigned to the three conditions. The results showed that hand-held and hands-free cell phones resulted in equivalent dual-task deficits. When combining the data of two phone conditions, the data demonstrated that the phone conversation slowed the response time to simulated traffic signals significantly, as well as increased the probability of missing these signals, while listening to a book on tape did not impair the performance significantly.

In the second experiment, they sought to localize the sources of cell phone interference on driving. Twenty-four University of Utah undergraduates took part in the experiment. Participants were required to perform a simulated pursuit tracking driving task on both an easy, predictable course, and a difficult, unpredictable course. Participants completed each course in single-task mode as well as in two dual-task conditions involving the use of a cell phone. One of the dual-task conditions was a shadowing task while participants repeated words that the experimenter read to them over a hand-held cell phone. The other dual-task condition was a word-generation task with the participant required to generate a new word that began with the last letter of the word read by the experimenter. The results showed that tracking errors increased when participants used the cell phone to perform the active, attention-demanding word-generation task but not when they performed the shadowing task.

Lin and Chen (2006) investigated the effect of three types of distractions related to use of a hands-free phone on driving performance. Twelve drivers, aged 21 to 29 participated. Each participant completed four sessions, including one under baseline condition (drive only) and three under differing types of distraction (casual conversion, number guessing, and two-digit number addition). Participants were required to maintain a specified following distance behind a lead vehicle in the virtual environment and to brake when the brake lights of the lead vehicle came on. The results showed that both the means and the standard deviations of driving speed, headway, brake reaction time, and number of collisions were significantly affected by distraction. Only lateral position was unaffected by distraction. A further analysis revealed that driving speed was highest in the driving only condition. For headway, the number-guessing and number-adding conditions resulted in significantly longer headways than the other conditions (casual conversation or driving-only). Brake reaction time in distracted conditions was significantly longer than in the driving-only condition. In particular, the casual talking condition had the longest braking reaction time. The results also showed that the number of collisions in adding and guessing tasks differed from baseline condition but collisions in the casual talking were no different than baseline. In general, the study concluded that driving performance was adversely affected by verbal distraction, and the impairment of driving performance depended on the nature of the verbal distractor.

Schattler, Pelleriot, McAvoy, and Datta (2006) compared driving performance while not distracted (control scenario) versus while engaged in hand-held cell phone conversations. Thirty-seven drivers, ages 18 to 65 participated by driving in a simulated environment. In the conversation condition, participants answered one or more questions presented using a cell phone—the conversation lasted to the end of the route.

Participants who followed different routes in the control and test conditions were excluded, leading to a total of 32 participants in the study—25 of whom followed the designated route. The conversation and control scenarios were compared for overall driver performance scores, speed profiles, lateral displacement, and traffic crashes. The chi-square (χ^2) test of significance was used to evaluate driver performance scores for all 32 drivers, for the 25 drivers who followed the designated route, and for the seven remaining drivers who followed the same, non-designated route in both conditions. They found that conversing on cell phones degraded driver ability to respond and drive appropriately on the simulated road network. That is, distracted drivers were more likely to make errors, such as swerving, driving on the sidewalk, overturning, etc. However, when the performance scores of the group of seven drivers who followed the straight path were analyzed independently, no significant differences were found between the control and conversation conditions. This lack of a difference between conditions was most likely due to the relatively simple path and minimal driver response required along the straight-line path. A paired t-test of average speed indicated that drivers drove significantly slower while engaged in a cell phone conversation than when undistracted. The z-test for proportions was performed to determine whether differences were significant in the percentage of time subject vehicles were traveling with improper lateral placement (i.e., traveling outside of the lane, swerving, or overturning) during the control and conversation conditions. The results showed that the percentage was higher for the conversation condition than the control. The increased occurrence of improper lateral placement probably was attributable to drivers' being able to steer with only one hand, as opposed to two, while operating a hand-held cell phone.

Drews, Yazdani, Godfrey, Cooper, and Strayer (2009) investigated the impact of text messaging on driving performance. Forty undergraduate students, aged 19 to 23 participated. Participants were required to drive under both single-task (driving only) and dual-task (driving while texting) conditions in a high-fidelity driving simulator. The drivers were instructed to respond to any text messages received during the session. A lead car was set to brake at random intervals during the trials. Braking reaction time, crashes, lane crossings, lane reversals, and gross lateral displacement were measured. Drews et al. (2009) found that text messaging while driving adversely impacted driving performance. In particular, driving while texting increased reaction time, following distance, and lane tracking errors. A total of seven simulated collisions were observed—driving while texting accounted for 86% of them.

2.2.2 Talking Versus Drinking Literature

Burns, Parkes, Burton, Smith, and Burch (2002) studied the impairment of simulated driving performance due to hands-free and hand-held phone conversations in comparison to the performance due to alcohol impairment. Twenty drivers aged 21 to 45 took part in the simulated study. Test route included multiple conditions (e.g., motorway with moderate traffic, car following, curving road, and dual carriageway with traffic lights) and drivers drove under conditions of no-alcohol or with alcohol intake calculated to be equivalent to a .08 grams per deciliter (g/dL) blood alcohol concentration (BAC). There were three conversation conditions: no cell phone (control), hands-free cell phone, and hand-held cell phone. The phone conversations in the control condition were while seated in a waiting area. Burns et al. (2002) measured absolute speed, speed maintenance, lane position maintenance, and reaction time and errors in response to warnings for each route. The results showed a tendency for drivers to slow down when talking on hand-held or hands-free phones, while alcohol had the opposite effect. The standard deviation of speed and speed error measures indicated that drivers had significantly poorer speed control when using the hand-held phone than during the other conditions. Reaction times were significantly slower for drivers using phones in comparison to when they had alcohol. For errors in response to warnings, the drivers missed significantly more warnings when they were using a phone. There were also significantly fewer warnings missed by the drivers when they had alcohol in comparison to when they were using the hands-free phones. The phone users were also responding to the wrong warnings more often than the alcohol drivers. The study confirmed that alcohol impairs driving performance in the simulated environment and found that speed control and reaction time were impaired more by using a phone than by having a positive blood alcohol level equivalent to .08 BAC. A later study by Strayer, Drews, and Crouch (2006) compared relative impairment associated with conversing on a cell phone while driving versus driving with a BAC of .08. Forty adults ages 22 to 34 participated in the experiment. The conditions were: single-task baseline driving, driving while intoxicated at a measured BAC of .08 g/dL, driving while conversing on a hand-held cell phone, and driving while conversing on a hands-free cell phone. A series of dependent variables were measured, as shown in Table 3. During simulated driving sessions, participants followed a pace car and reacted to simulated braking events by the lead vehicle. Strayer et al. (2006) found that performance in cell phone and alcohol conditions differed significantly from each other, leading them to conclude that alcohol and cell phone conversations were affecting different aspects of driving performance, and that both conditions impaired drivers' performance in some ways. When drivers were conversing on a cell phone, they were involved in more simulated rear-end collisions, reacted to vehicles braking in front of them 9% slower, and increased the following distance by 24%, relative to baseline. In addition, compared with baseline, it took 19% longer for participants who were talking on a cell phone to recover the speed that was lost during braking. By contrast, when participants were intoxicated, there were no differences compared to baseline on these performance variables. The driving performance decrements associated with hand-held and hands-free cell phone conversations were not significantly different.

Table 3. Means and Standard Errors for Alcohol, Baseline, and Cellphone Conditions From Strayer et al. (2006).

	Alcohol	Baseline	Cell Phone
Total accidents	0	0	3
Brake reaction time (ms)	779 (33)	777 (33)	849 (36)
Maximum braking force	69.8 (3.7)	56.7 (2.6)	55.5 (3.0)
Speed (mph)	52.8 (2.0)	55.5 (0.7)	53.8 (1.3)
Mean following distance (m)	26.0 (1.7)	27.4 (1.3)	28.4 (1.7)
SD following distance (m)	10.3 (0.6)	9.5 (0.5)	11.8 (0.8)
Time to collision (s)	8.0 (0.4)	8.5 (0.3)	8.1 (0.4)
Time to collision < 4 s	3.0 (0.7)	1.5 (0.3)	1.9 (0.5)
Half recovery time (s)	5.4 (0.3)	5.3 (0.3)	6.3 (0.4)

Source: Table 1 from Strayer et al. (2006), p. 387; Reprinted with permission.

2.2.3 Visual Field Effects Literature

Atchley and Dressel (2004) examined functional field of view under cognitive load using the Useful Field of View (UFOV) test and compared performance under conversation and non-conversation conditions. Functional field was defined as that portion of a person's full visual field from which they can process information. The experimental setup did not involve simulated driving; however, the experiment mimics some aspects of the driving task—in particular, the ability to detect and react to visual stimuli presented simultaneously in the center and periphery of a subject's visual field under varying cognitive load. The primary UFOV visual task was a two-item delayed match-to-sample discrimination of stimuli presented in the center of the visual field. Presentation times were varied based on subjects' errors and correct responses on the primary visual discrimination task (simple condition) or on the discrimination and secondary visual detection tasks (two complex conditions). In the complex conditions, a second visual task was added to the primary task trials in which the subjects had to report the location of a simultaneously presented icon that could appear at any of eight locations in the visual periphery; complexity of this secondary task varied based on the presence or absence of distractor stimuli in the periphery. Twenty-one undergraduate students from the University of Kansas, Lawrence, participated in the study and performed the simple and complex visual tasks under two auditory conditions: conversation versus no-conversation while experimenters measured the presentation time required to maintain 75% accuracy on the visual tasks. The first experiment studied the conversation condition in which subjects used hands-free cell phones to listen to an audio presentation of a moderate frequency word and were required to respond with a word that began with the final letter of the presented word. Visual task thresholds increased significantly in the conversation condition in comparison to the no-conversation condition. In a second experiment, the same methods were used with the exception that subjects were instructed to provide a different word each time they encountered the same letter prompt as in the prior trial. In both experiments, presentation time increased with both visual task complexity and under cognitive load from the conversation task, with conversation requiring roughly a four-fold increase in visual presentation time. A significant interaction of the visual task complexity and conversation presence/absence indicated that the subjects' functional visual task threshold diminished under the cognitive load induced by the verbal task. Atchley and Dressel (2004) concluded that the same effect would likely be demonstrated when people drive while having a cell phone conversation—that the conversation would tend to reduce a driver's functional field of view causing them to react more slowly (or not at all) to objects in their periphery.

Laberge, Scialfa, White, and Caird (2004) compared driver reactions to pedestrians appearing in a virtual environment among three groups of drivers: driving alone, driving while talking with a passenger, and driving while talking over a hands-free cell phone. Eighty college students from the University of Calgary ages 18 to 27 performed in two driving scenarios: easy—a residential area with little traffic, and difficult—an urban area with increased traffic and a visually complex background. Two driving events were added, one time each, at random in the simulated driving tasks: intersection traffic signal indication change and pedestrian incursion. Each participant was randomly assigned to the cell phone, passenger, or driving alone condition. Laberge et al. (2004) recorded lane maintenance, speed maintenance, perception response time (PRT) to driving events, and subjective perceptions of workload. For the pedestrian event, swerving and braking responses were analyzed. For the traffic signal event, accelerating, braking, and release of the accelerator were analyzed. No significant differences in lane or speed maintenance were found between drivers who were driving alone and drivers who were distracted by hands-free phone conversations. Follow-up *t*-tests showed that whether the driver was talking with a passenger or talking over a cell phone, the PRT was significantly slower than when the drivers were not distracted by conversation.

Haque and Washington (2013) compared the reaction times of young drivers responding to traffic events that occurred at different points in a driver's field of view. Thirty-two licensed drivers 21 to 27 years old drove two simulated routes: one route in the Central Business District (CBD) and the other one was in a hypothetical suburban area. The speed limit was mostly 40 km/h in the CBD and varied from 50 to 60 km/h in the suburban area. Three distraction conditions were presented to each participant on both routes: baseline (no phone conversation), hands-free phone conversation, and hand-held phone conversation. Reaction times were calculated for each participant during two traffic events presented at a random time during each simulated drive (a lead vehicle braking suddenly and a pedestrian entering a zebra crossing from a footpath). The results showed that reaction times to a pedestrian entering a zebra crossing from the footpath were 42% and 41% higher than baseline when drivers were distracted by a hands-free and hand-held phone conversation, respectively. No significant differences were found among distraction conditions in participants' reactions to the lead vehicle braking. The results indicated that distraction due to cell phone conversations impaired the driving performance of young drivers in response to a traffic event in their peripheral but not central vision. A further statistical analysis revealed that the reaction times of provisional license holders were about twice as long as those of full licenses holders.

2.2.4 Simulation Observation Summary

The majority of the simulator studies discussed in this section indicate that talking or texting while driving degrades driver perception and performance, as summarized in Table 4.

Table 4. Summary of Findings From Simulator-Based Studies of Driver Distraction.

Study	Study Variable	Findings
Response Time and Driving Performance		
McKnight & McKnight, 1993	Placing a cell phone call, carrying on a casual cell phone conversation, carrying on an intense cell phone conversation, tuning a radio	Distractions led to significant increases in the proportion of situations to which subjects failed to respond. There were no significant differences among the individual distraction conditions.
Strayer & Johnston, 2001	Hand-held and hands-free cell phone	The results showed that hand-held and hands-free cell phones resulted in equivalent dual-task deficits. Phone conversation impaired the performance significantly.
Lin & Chen, 2006	Hands-free cell phone	Driving performance was adversely affected by verbal distraction, and the impairment of driving performance depended on the nature of verbal distractor.
Schattler et al., 2006	Hand-held cell phone	Conversing on cell phones degraded driver ability to respond and drive appropriately on the simulated road network.
Drews et al., 2009	Texting	Text messaging while driving adversely impacted driving performance.

Study	Study Variable	Findings
Talking Versus Drinking		
Burns et al., 2002	Driving while conversing on a cell phone (hand-held and hands-free) and driving with a BAC of .08	Alcohol impairs driving performance, while speed control and reaction time were impaired more by using a cell phone than by alcohol intoxication.
Strayer et al., (2006)	Driving while conversing on a cell phone (hand-held and hands-free) and driving with a BAC of .08	Alcohol and cell phone conversations both impaired drivers' performance but in dissimilar ways. The driving performance decrements associated with hand-held and hands-free cell phone conversations were not significantly different.
Visual Field Effects		
Atchley & Dressel, 2004	Hands-free cell phone	Driving while holding a cell phone conversation reduced drivers' functional field of view causing them to react more slowly (or not at all) to objects in the periphery.
Laberge et al., 2004	Talking with a passenger and hands-free cell phone	Talking with a passenger or talking over a hands-free cell phone significantly slowed drivers' response times to the sudden appearance of a pedestrian.
Haque & Washington, 2013	Hands-free and hand-held cell phone	Cell phone conversations increased the reaction time of young drivers in response to a pedestrian entering a crossing in their peripheral visual area, but did not affect reaction time to a central visual stimulus of the lead vehicle braking.

Just two of the simulator studies examined the effect of driver distraction on risk associated with pedestrians crossing the virtual roadway. In both studies, conversation proved to be a significant distractor, leading to longer reaction times in response to pedestrians entering the roadway. Haque and Washington (2013) compared drivers' reaction times to pedestrians and a lead vehicle braking event and found that conversation as a distractor had a much larger effect on reaction times to pedestrians than to the braking event of a lead vehicle. This difference is ascribed to inattention to peripheral visual events—a narrowing of the visual field under distraction.

Drivers in the virtual environment show some evidence of compensating under cognitive loads by adjusting speed and following distance; however, it is clear that whatever compensatory adjustments are happening, they are incomplete or not entirely effective. As noted for simulator studies of pedestrian behavior, it is possible that subjects involved in a driving simulator study relax their behavior and become more tolerant of errors and delays in comparison to how they might drive in the real world. Evidence for this relaxed approach to simulated driving comes in the form of a large number of crashes in the virtual world compared to what would be expected or tolerable in an afternoon of driving. Thus, one of the key strengths of simulator-based studies may also present their greatest barrier to generalization—the virtual world is zero risk.

2.3 Crash and Injury Data

Statewide and national databases, including the Fatality Analysis Reporting System (FARS), the National Automotive Sampling System (NASS) Crashworthiness Data System (CDS), and NASS General Estimates System (GES), have been essential sources for information on contributing factors and consequences of distracted driving. However, data limitations with respect to recording driver distraction events exist in each of these databases, as indicated in the Traffic Safety Facts (NHTSA, 2015).

One primary limitation is that police accident reports (PARs) vary across jurisdictions and create inconsistencies in reporting. Some PARs identify distraction as a distinct reporting field, while others are based on the narrative portion of the reports. For example, Mynatt and Radja (2013) reviewed driver distraction crash data in the National Motor Vehicle Crash Causation Survey (NMVCCS), NASS GES, and NASS CDS and found that in the records for the same vehicles, a distraction had been coded in the NMVCCS twice as often as in the NASS CDS and 2.5 times more often than in the NASS GES. These results indirectly imply that driver distraction may be underreported in the FARS and NASS GES data.

The studies presented in this section are retrospective analyses using these existing databases to identify the principal factors associated with distracted driving-involved crashes. While FARS is a standardized dataset across all States, the focus is on fatal crashes and consequently the small number of total cases can limit the ability to generalize to the broader scope of all crashes, or all pedestrian-involved crashes at any severity level. In addition, FARS analysts ultimately rely on the PAR as the source of information about suspected driver distraction. In a pedestrian-vehicle fatal collision, the driver is more likely to survive than the struck pedestrian, and thus a FARS case noting that the driver was distracted will be rare because that annotation would rely primarily on the driver's own self-report (other sources may include witness statements or officer judgment).

Wang, Knipling, and Goodman (1996) reviewed 1995 data from NASS CDS with an emphasis on the Driver Distraction/Inattention to Driving (DD/ID) variable that was added to the dataset that year. Table 5 presents the weighted percentage involvement for each data element of the DD/ID variable as defined in the 1995 dataset—the driver distraction codes have changed at least twice since that first year. It was estimated that 14.9% of drivers and 25.6% of crashes in 1995 involved driver inattentiveness as a contributing factor. A bivariate comparison of driver inattention-related factors to other crash variables revealed that distraction played its largest role in rear-end and single vehicle crashes. It should be noted that even though the NASS CDS dataset is carefully coded based on experts' post-crash investigations, it still relies on police reports of crashes as a triggering event and thus would result in underestimating the contribution of distraction to crashes because of under-reporting. CDS investigators also must rely in some portion on self-reports by drivers and other crash-involved parties; a circumstance that also limits the completeness and reliability of data on distraction.

Table 5. Percentage of CDS Crashes Involving Inattention/Distraction Related Crash Causes From Wang et al. (1996).

Data Element			% of Drivers	% of Crashes
Distraction and Inattention Involved	Sleepy/fell asleep		1.5%	2.6%
	Distracted	Distracted by other occupant [specified]	0.9%	1.6%
		Distracted by moving object in vehicle [specified]	0.3%	0.5%
		Distracted while dialing, talking, or listening to cellular phone [location and type of phone specified]	0.1%	0.1%
		Distracted while adjusting climate controls	0.2%	0.3%
		Distracted while adjusting radio, cassette, CD [specified]	1.2%	2.1%
		Distracted while using other device/object in vehicle [specified]	0.1%	0.2%
		Distracted by outside person, object, or event [specified]	2.0%	3.2%
		Eating or drinking	0.1%	0.2%
		Smoking-related	0.1%	0.2%
		Distracted/inattentive, details unknown	1.5%	2.6%
		Other distraction [specified]	1.3%	2.2%
	Looked but did not see		5.6%	9.7%
	Subtotal of Distracted/Inattentive		**14.9%**	**25.6%**
Unknown/no driver present			38.5%	46.0%
Attentive/not distracted			46.6%	28.4%

Source: Adapted from Table 1 from Wang et al. (1996); Adapted with permission from the Association for the Advancement of Automotive Medicine.

Another early study (Stutts, Reinfurt, Staplin, & Rodgman, 2001) reviewed 1995-1999 data from NASS CDS to identify the most common sources of distraction. They estimated an annual average of 284,000 distracted drivers in crashes over the 5-year study period, which accounted for 8.3% of all drivers. Table 6 shows the weighted percentages of drivers' codes for each distraction type coded in the CDS database. Since there is a small number of raw cases for certain categories, "using device/controls integral to vehicle" and "adjusting climate controls" were combined into a single "vehicle/climate control" category. "Talking or listening on cellular phone" and "dialing cellular phone" were combined into a single "using/dialing cell phone" category. According to the data, the most frequently reported source of distraction for crash-involved drivers was outside persons, objects, or events (29.4%), while using or dialing cell phone only accounted for an average of 1.5% of total crashes over the 5 years. The findings are valuable to showcase the major sources of distraction; however, it should be noted that cell phones have become more widespread since the period covered in this study. The increasing prevalence of cell phones is discussed later in this section.

Table 6. Yearly Trends in Specific Driving Distractions Based on Weighted CDS Data From Stutts et al. (2001).

Driver Distraction	1995 (N=322K)	1996 (N=279K)	1997 (N=182K)	1998 (N=371K)	1999 (N=265)	Overall (N=1,420K)
Outside person, object, event	28.1[1] (6.9)[2]	35.1 (4.7)	35.4 (6.4)	19.8 (5.5)	34.3 (4.1)	29.4 (2.4)
Adjusting radio/cassette/CD	14.1 (1.6)	4.7 (1.5)	0.4 (0.3)	23.5 (12.5)	5.7 (2.4)	11.4 (3.7)
Other occupant	11.8 (1.7)	12.8 (4.3)	10.6 (5.6)	7.5 (2.4)	12.7 (3.0)	10.9 (1.7)
Moving object in vehicle	3.5 (2.5)	6.2 (3.1)	2.5 (1.0)	2.2 (1.0)	7.6 (4.0)	4.3 (1.6)
Other device/object	---[3]	2.6 (1.1)	4.1 (2.5)	5.3 (3.2)	2.7 (1.2)	2.9 (0.8)
Vehicle/climate controls[4]	4.1 (1.2)	1.6 (0.9)	3.4 (1.0)	2.4 (1.4)	2.7 (0.8)	2.8 (0.6)
Eating, drinking	1.8 (0.6)	1.3 (0.5)	0.3 (0.2)	1.6 (0.7)	3.3 (1.8)	1.7 (0.3)
Using/dialing cell phone[5]	1.2 (0.6)	2.8 (1.7)	3.5 (1.4)	0.3 (0.1)	0.8 (0.7)	1.5 (0.5)
Smoking related	1.6 (0.9)	0.5 (0.4)	1.6 (0.5)	0.01 (0.01)	1.2 (0.7)	0.9 (0.2)
Other distraction	17.1 (6.0)	19.7 (3.0)	35.0 (7.2)	35.3 (9.4)	21.9 (5.7)	25.6 (3.1)
Unknown distraction	16.7 (7.5)	12.9 (3.1)	3.0 (2.0)	2.1 (0.9)	7.2 (2.3)	8.6 (2.7)

[1] Column percent
[2] Standard error
[3] Variable not available in 1995
[4] Combination of using device/controls integral to vehicle and adjusting climate controls
[5] Combination of talking or listening on cellular phone and dialing cellular phone

Source: Table 3 from Stutts et al. (2001), p. 11; Reprinted with permission.

NHTSA (Singh, 2010) conducted the NMVCCS between 2005 and 2007 to collect on-scene information on crash causes, including driver distraction. Two aspects of distracted driving were investigated: distraction from sources within the vehicle (e.g., conversing on a phone) and non-driving cognitive activities (e.g., thinking about financial problems). A descriptive analysis of a weighted estimate of 2,188,970 crashes and 3,889,775 drivers revealed that distraction from internal sources was a more prevalent form of inattention than non-driving cognitive activities. Among internal sources of distraction, conversing with a passenger (about 16%) was the most frequently recorded factor. Cell phone use (conversing on the phone, dialing or hanging up, and texting) was the second most frequently recorded factor and accounted for about 3.4% of distraction-related crashes due to internal sources of distraction.

NHTSA (2015) presents analyses of distracted driving-affected fatal crashes based on 2014 FARS data. For this analysis, a distraction-affected crash is any crash in which a driver was identified as distracted at the time of the crash. Beginning in 2010, the FARS definitions for distraction changed to match those in the NASS General Estimates System (NASS GES). For both systems, when looking at distraction-affected crashes, the driver is identified as “Yes-Distracted,” “No-Not distracted,” or “Unknown if distracted.” If the driver is identified as distracted, additional codes are entered to specify the source of distraction. In 2014, there were 29,989 fatal crashes, 2,955 (10%) of which were distraction affected. Of those distraction-affected crashes, 385 (13%) were cell phone related—amounting to 1.3% of all fatal crashes. This may be an underestimate given the restrictive definition for distraction-affected crash. Based on a companion analysis of NASS GES data, NHTSA estimates that approximately 8% of distraction-affected injury crashes and 7% of distraction affected property-damage-only crashes involved cell phone use as the distraction type. Over all crash severity levels, NHTSA estimates that in 2014 cell phones contributed to 69,000 crashes, amounting to an estimated 1.1% of all crashes.

2.3.1 Crash and Injury Data Summary

- Studies of national databases have revealed that distracted driving is a major contributor to crashes.
- Early studies indicated that cell phones and other electronic devices were not a big factor.
- More recent analyses indicate that cell phones are a factor in about 1.1% of all crashes, 7% of all distraction-affected crashes, and 13% of all distraction-affected fatal crashes. This is a clear pattern of overrepresentation of cell phone involvement as a distractor in fatal crashes.
- NMVCCS data indicates that cell phones are second only to conversations with another vehicle occupant in contributing to distraction-affected crashes.
- For recent years, the results of analyses of national databases agree well with the more detailed information from naturalistic driving studies.

2.4 Other Data

Two studies used cell phone call records and personal post-crash interview data to establish a relationship between crash risk and cell phone use.

Redelmeier and Tibshirani (1997) calculated relative risk of a crash when a cell phone was used versus not used. The researchers selected participants based on people who came into a collision reporting center in Toronto, Canada. Collision reporting centers allow people involved in non-injury crashes to complete an official crash report with the help of trained personnel. They excluded from the analysis anyone who did not own a cell phone or did not have available billing records from their cell phone service provider. A total of 699 drivers involved in property-damage-only (PDO) crashes were included in the study. Cell phone records for the day of the crash and for the week prior to the crash were acquired. The study used five different time-based control conditions: day before, workday, weekday, maximal use day, and matching prior day. Relative risk was calculated based on a case-crossover analysis where the event was compared to other randomly selected time periods for the same person. The analysis revealed a roughly four-fold increase in risk of crash associated with cell phone use while driving. No significant difference was found between hands-free and hand-held cell phones; however, the study is somewhat biased in that only drivers who consented to participate were included in the analysis. The most likely result, then, is a probable underestimation of the impact of cell phone use on crash risk. Also, it must be noted that hands-free cell phone technology in the mid-1990s was vastly different from what is currently available with modern vehicle-integrated systems or third-party wireless interfaces, which may be a factor in the efficacy of this particular data from 1997.

Similarly, McEvoy et al. (2005) conducted a retrospective study of the cell phone use of 456 drivers involved in a crash between 2002 and 2004 and seen in a hospital emergency department. They assessed phone records for participants during a defined "hazard period", which was within 10 minutes prior to a crash that resulted in a hospital stay. The analysis compared the records of cell phone use in the hazard period to the same person's cell phone use during driving times at control periods (similar time periods 1-day, 3-days, and 7-days prior to the crash). If there was a hands-free device in the vehicle, regardless of its use during both periods, this was considered hands-free phone use. The results showed that about 9% of participants had used a cell phone in the hazard period. Approximately 3% of participants had used a cell phone during control periods. Of the 40 participants who had used a phone in the hazard period, 89% of participants had a hands-free phone. It was concluded that cell phone use increases crash risk roughly three-fold. However, the researchers did not collect information on the type of hands-free technology participants were using. More recent naturalistic driving studies (e.g., Fitch et al. [2013] as discussed in Section 2.1) have made the distinction between hands-free cell phone use when the phone functions are integrated into the vehicle (e.g., voice-based dialing or contact selection through the audio system in the vehicle) versus when they are a function of the phone itself (i.e., when using the phone in speaker mode).

None of the retrospective studies have compared manual versus voice dialing; however, manual manipulation of a hand-held phone (or, perhaps, a hands-free phone that still requires some manual manipulation) has been identified as a risk factor in naturalistic driving studies. With the availability of naturalistic driving study data from large-scale data collection efforts, the utility of the retrospective analysis methodology has waned. It is unlikely that more studies will be performed using this method because of the costs and the uncertainty involved in linking crash events to cell phone activity as well as the need to infer usage modes based on the phone's capabilities (or post-event interviews).

2.4.1 Other Data Summary

- Distracted driving is a major contributor to crashes; however, at least in early studies, cell phones and other electronic devices were not considered a big factor.
- Using hands-free cell phones was not shown as safer than using hand-held cell phones based on retrospective analyses. The conversation itself appears to be the major source of distraction.
- Retrospective analysis using cell phone records and crash data have been eclipsed by the more reliable data from large-scale naturalistic driving studies, in which cell phone use and its association with crash or near-crash events can be observed directly.

2.5 Experience, Practice Effects, and "Supertaskers"

The data on the negative effects of distraction are not unequivocal. For a distractor to have an effect on driving safety, first it must actually *be* distracting to the driver. That is, the driver must focus some portion of his or her attention and processing resources (perceptual or cognitive) on the source of distraction. Second, for the distraction to have a negative effect on safety, the total task demands in the driving situation must exceed the driver's ability to safely cope with them. That is, there must be some increase in the probability of an error or delayed response that, coupled with events in the driving environment, result in an adverse event (a crash or a measurable near-miss). From the collection of simulator studies, it was observed that drivers under increased cognitive load (e.g., while conversing) compensate by reducing speed and increasing following distance—at least in the simulated environment. It makes intuitive sense that older drivers—those with many years' experience—might have developed skills and conscious strategies for safe driving that would work to reduce the risk of driving while using a cell phone or engaging with other distractors. Novice drivers, who are generally young, can be expected to have faster reflexes than older drivers, but would also be expected to have less well-trained reactions to traffic situations. They too may have adopted conscious strategies to improve safety even when distractors are present. Younger people are also more experienced using cell phones than are older people, especially if the distracting activity is texting.

Simulator studies are ideally suited to get at the differences among subjects based on experience and practice because the experiment can include multiple trials and the experimenter has precise control over the presentation of stimuli in the virtual environment. There are a small number of studies that have looked at age, experience, and practice effects in distracted driving. Their results are somewhat surprising.

Strayer and Drews (2004) compared two age groups of drivers on performance in single-task (driving only) and dual-task (conversation on a hands-free phone while driving) conditions. Twenty older drivers (ages 65 to 74) and twenty young drivers (ages 18 to 25) took part in the study. Participants were required to follow a pace car driving in the right-hand lane of the highway in a virtual environment. The researchers examined four parameters related to the reaction to the braking pace car: brake onset time, following distance, speed, and half-recovery (i.e., the time for participants to recover 50% of the speed that was lost during braking). The analysis indicated significant main effects of age as well as task load (driving alone versus driving plus conversation). However, the interaction between age and task load was not significant, indicating that driving while engaging in a hands-free conversation did not distract one age group of drivers more than the other. Older drivers did have slower reaction times, larger following distances, slower speeds, and slower recovery to their prior speed than younger drivers, but the conversation-related decrements were roughly the same for older and younger drivers. The data also showed that drivers engaged in hands-free cell phone conversations had 18% slower braking onset, 12% larger following distances, and took 17% longer to recover speed lost due to braking, as shown in Table 7.

Table 7. Driving Performance Measures as a Function of Age and Single- Versus Dual-Task Conditions From Strayer and Drews (2004).

	Younger Adults		Older Adults	
	Single Task	Dual Task	Single Task	Dual Task
Brake onset time (ms)	780 (49)	912 (83)	912 (49)	1086 (83)
Following distance (m)	22.7 (3)	26.4 (2)	37.1 (3)	40.7 (2)
Driving speed (mph)	63.3 (2)	62.1 (1)	52.4 (2)	53.7 (1)
½ Recovery time (s)	4.6 (0.4)	5.9 (0.4)	6.4 (0.4)	7.0 (0.4)

Note. Standard errors are presented in parentheses.

Source: Table 2 from Strayer and Drews (2004), p. 644; Reprinted with permission.

Shinar, Tractinsky, and Compton (2005) compared performance among three groups of drivers—novice, experienced, and older—in three conditions: no distraction and two conversation conditions (math and Q&A). In the math conversation condition, participants were required to mentally solve multiple-operation arithmetic in sequence on a string of single-digit numbers and provide the answer. In the Q&A conversation condition, participants were required to answer a series of questions based on circumstances/interests stated in a prior intake questionnaire. During the two conversation conditions, participants responded to questions delivered through a dedicated speaker installed in the simulated vehicle. Each participant took part in five sessions over 14 days. Sessions contained three 9-minute blocks of driving divided into three 3-minute segments. The three distraction conditions were presented in randomized order across the 3-minute segments so that each 9-minute block contained each condition once. Three driving tasks (maintain constant 50 mph [80.5 km/h], maintain constant 65 mph [104.6 km/h], and follow a virtual vehicle whose speed varied between 50 mph and 65 mph) changed in each block and the order was counterbalanced across participants. The researchers took dependent measures including average speed, speed variance, average lane position, lane position variance, steering variability, and crashes. The results showed that there was no practice effect under the distraction condition at the 50 mph speed. However, in the 65 mph speed condition, there was a general practice effect on speed. A practice effect on the math distraction problem was evidenced by a speed reduction on early trials that gradually disappeared, as shown in Figure 3. Interestingly, when drivers were distracted by conversations, they drove faster than when not distracted. Speed variance decreased over time for all age groups, and the differences between age groups also diminished over time, as shown in Figure 4.

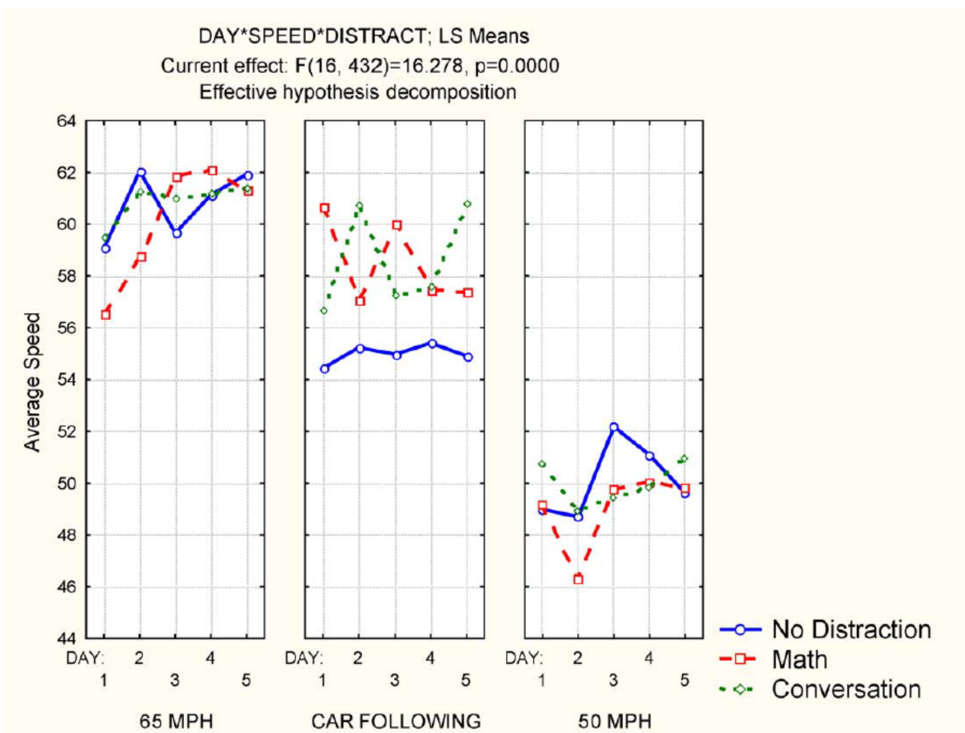

Figure 3. The Effects of Distraction, Practice, and Required Speed on the Drivers' Average Speed From Shinar et al. (2005).

Source: Figure 1 from Shinar et al. (2005), p. 318: Reprinted with permission.

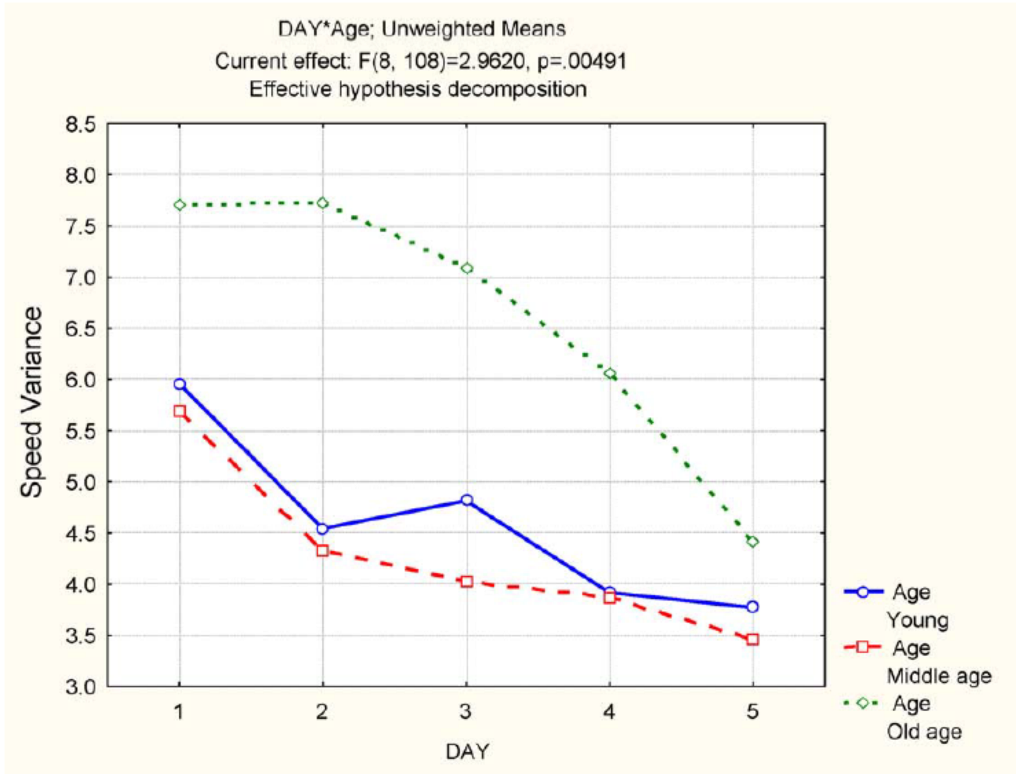

Figure 4. The Effects of Practice and Age on the Driver's Speed Variance From Shinar et al. (2005).

Source: Figure 4 from Shinar et al. (2005), p. 320; Reprinted with permission.

As shown in Figure 4, in general, the practice effect was age-related, with older drivers showing a different pattern than middle-age and young (novice) drivers. As shown in Figure 3, over the course of five exposures to the simulated environment, there was no difference in performance between the non-distracted and distracted conditions. Interestingly, some drivers experienced no performance impairments due to distraction even upon their first exposure to the simulator.

A similar result was found by Watson and Strayer (2010). They tested 200 University of Utah undergraduate students in a driving simulator using a variant of the operation span (OSPAN) task. OSPAN has a main task of memorizing items and recalling them in correct order, while simultaneously solving a distractor problem. The researchers compared single task (driving only) and dual task (driving while performing a demanding auditory version of the OSPAN task) conditions. In the aggregate, they found that the dual task condition slowed reaction time, increased following distance during driving, and reduced both recall and math performance on the OSPAN task. However, when they looked at the individual data, they found five participants (out of 200) who showed no decrement in performance on either the driving or the OSPAN task under dual task conditions. These individuals had faster reaction times, closer following distances, better memory performance, and better math performance than the remaining participants and, more importantly, their performance was the same in the single- and dual-task conditions. Watson and Strayer (2010) called these individuals "supertaskers" to reflect the fact that they show no performance decrement when multi-tasking.

Sanbonmatsu, Strayer, Medeiros-Ward, and Watson (2013) examined the relationship between personality and individual differences in multi-tasking ability. They found that multi-tasking ability as measured by the OSPAN task was not positively correlated with multi-tasking activity or cell phone use while driving. In contrast, multi-tasking and cell phone use while driving were positively correlated with perceived multi-tasking ability. Hence, people who believe that they were good as opposed to bad at multi-tasking were more likely to engage in multiple tasks simultaneously and to use a cell phone while driving. The authors proposed that "supertaskers" were consciously aware of their ability and took advantage of it. They did not posit a mechanism for this awareness, nor were they able to make a distinction between people who "knew" versus "thought" they possessed a particular ability.

2.5.1 Experience, Practice Effects, and "Supertaskers" Summary

- In some experiments virtually all subjects experienced practice effects sufficient to eliminate the performance decrements associated with multi-tasking over a small number of trials.
- In some experimental settings, there are a small percentage of subjects who perform equally well under distraction and non-distraction conditions without any practice.
- There have not been enough studies to rule out some obvious and less important explanations for "supertaskers". These are discussed further below.

The existence of practice effects in simulator studies is not surprising—it is an unfamiliar environment and the experimental situations are artificial. Even experienced drivers, using a cell phone, or doing both simultaneously, might need some exposure to the virtual environment and the novel tasks (such as OSPAN) used in the experiment. What *is* surprising is that there are some people who perform equally well under distraction and non-distraction conditions. These findings are relatively new and there have not been enough studies to rule out some obvious and less important explanations. For example, perhaps "supertaskers" are actually performing below their full capacity in the non-distracted conditions and thus, by comparison, they look like superb multi-taskers in the distracted conditions because their performance does not degrade further. Sanbonmatsu et al. (2013) looked at whether OSPAN performance was *positively* correlated with multi-tasking ability, not whether the "supertaskers" were "coasting" during the non-distracted conditions. Some discussion has centered on whether the "supertaskers" are taking advantage of transfer effects from, for example, past videogame playing; however, this seems unlikely to be a complete explanation because the supertaskers do not self-report higher levels of experience on these other tasks than non-supertaskers. Another possible explanation is that the distraction tasks in the dual task condition are simply not that difficult. As a result, some portion of the population will be able to quickly master the task and show no performance decrement in a dual-task situation. This is one possible explanation for why practically everyone in the Shinar et al. (2005) study showed no dual-task performance decrement by the end of only five sessions. Additionally, it is likely that some humans have extraordinary abilities with respect to multi-tasking. This is almost certainly true as the expectation for any human trait is that it will follow a distribution (e.g., a normal distribution) within the population. In this respect, "supertaskers" might perform at the high end of the distribution of human multi-tasking abilities, just as Watson, Strayer, and their colleagues have proposed. In combination with the idea that different studies used different levels of difficulty in the multi-tasking conditions, the innate superiority of a small segment of the population would also explain why "supertaskers" look like a rare phenomenon in some experiments and yet are easily developed over five exposures in others.

2.6 Driver Distraction Summary

A variety of studies have established a relationship between cell phone use while driving and crash risk. While risk seems to be well defined in some of the studies, there is equivocal data comparing across naturalistic driving studies and simulator studies. The simulator studies generally found a large effect of distraction due to conversations while the more recent naturalistic driving studies generally found no effect of talking on a cell phone, but found large effects of visual-manual interaction with the devices.

Reports from simulator studies would seem to indicate that perhaps drivers can become used to the distraction due to cell phone use and, at least partially, mitigate the risk behaviorally by driving more slowly and following at a greater distance. Furthermore, there appears to be a small subset of the population who may not suffer any performance decrement under dual-task conditions that combine driving with some form of distractor task, including various levels of conversation. We don't know yet what accounts for the phenomenon, but the possibility exists that "supertaskers" are merely people who had a lot of practice with cell phone use while driving prior to their entry into the simulator studies. It is also possible that some superiority in multitasking can be learned and transferred from other activities to the driving task, or even learned during the experiment.

With the exception of a small number of visual field perception studies, the research on risks associated with driver distraction does not address the interaction between distracted pedestrians and drivers. Section 3 of this report, Pedestrian-Vehicle Interaction, specifically discusses this issue.

3. PEDESTRIAN-VEHICLE INTERACTION

A very limited number of studies have investigated the safety of pedestrians due to simultaneous distraction among drivers and pedestrians. This section discusses the literature available on pedestrian-vehicle interactions.

3.1 Naturalistic Observation Literature

Cooper and Schneider (2012) examined the frequency of specific behaviors at intersections near transit facilities in the Bay Area of San Francisco. The target behaviors were: (a) pedestrians crossing the roadway while using a mobile device, such as a cell phone, (b) pedestrians crossing a signalized intersection against a red light, (c) bicyclists running a red light at a signalized intersection, and (d) motorists turning right on red without stopping. A total of 1,144 pedestrians, 557 bicyclists, and 2,267 drivers were observed. The data showed that only 8% of pedestrians used mobile devices while crossing, but the proportion ranged from less than 3% to more than 18% at specific study sites. Approximately 27% of the 478 drivers who arrived at a red light and were turning right failed to stop before turning. This study gives some basic prevalence data for a specific set of intersections and people, but does not address the interactions among the various types of persons (pedestrians, bicyclists, and drivers). The presence of electronic distractors among pedestrians in this study does not necessarily translate into any safety consequences or increased risk of a crash, and the researchers did not examine distraction among the other two road user types.

3.1.1 Naturalistic Observation Summary

- The naturalistic, behavioral literature on pedestrian-driver interactions and risk is new and, to date, does not directly address distraction as a factor in determining risk.

3.2 Traffic Conflict Definition and Collection

Very few behavioral studies in the psychological literature of pedestrian safety have made use of the term "traffic conflict", but it has become an important concept in engineering studies of pedestrian safety. This section consists of a primer on the various definitions of traffic conflict, with special attention to pedestrian-vehicle conflicts. In site-specific engineering studies where crashes are rare events, studying safety is difficult because of the lack of event data. In particular, sites with a low frequency of crashes will, when treated with a safety countermeasure, still have a low frequency of crashes. It can take many years of aggregate data to quantify the benefits of any particular treatment. Safety engineers faced with site-specific safety concerns often examine surrogate measures of safety, in particular traffic conflicts, to identify the source of safety issues and candidate countermeasures to address any safety problem. An early study by Older and Spicer (1976) discussed the use of conflict analysis for road safety research. The definition of a conflict used in the study was as follows:

> *A traffic conflict is a situation involving one or more vehicles where there is imminent danger of a collision if the vehicle movements remain unchanged. A conflict can usually be recognized by the occurrence of an evasive maneuver by one or more of the vehicles, the maneuver being either braking or change of lane (weaving).* (p. 336)

A conflict classification based on the severity of the evasive action was employed, as shown in Table 8. Older and Spicer (1976) used a paired-team approach to collect conflict data in the field and test the inter-rater reliability. The result showed that trained personnel reached a level of approximately 80% agreement. Importantly, comparisons between crashes and conflicts showed a significant strong correlation with crashes occurring at similar times, on days when traffic flows were reasonably consistent.

Table 8. Conflict Severity Classification From Older and Spicer (1976).

Conflict Severity	Grade	Definition
Slight	1	Precautionary braking or lane change (e.g., for vehicle waiting to enter junction) or other anticipatory braking or lane change when risk of collision minimal.
	2	Controlled braking or lane change to avoid collision but with ample time for maneuver.
Serious	3	Rapid deceleration, lane change, or stopping to avoid collision resulting in a near miss situation (No time for steady controlled maneuver).
	4	Emergency braking or violent swerve to avoid collision resulting in a very near miss situation or minor collision.
	5	Emergency action followed by collision.

Source: Adapted from Table 1 from Older and Spicer (1976), p. 338; Adapted with permission.

A study by Migletz, Glauz, and Bauer (1985) compared conflicts to historic crash records to determine when and where traffic conflicts sufficed as a surrogate measure for safety. They collected traffic conflict, crash, and volume data at 46 urban intersections in four cities in the greater Kansas City metropolitan area. Intersections were categorized based on whether or not they were signalized, and then were stratified by intersection traffic volumes. Migletz et al. (1985) defined conflicts as

> *A traffic event involving two or more road users, in which one user performs some atypical or unusual action, such as a change in direction or speed that places another user in jeopardy of a collision unless an evasive maneuver is undertaken.* (p. 1)

Average daily conflicts were compiled by type of conflict for each type of intersection. They performed correlation and rank correlation analyses on the conflict and crash data and found that crash-conflict correlation was significant in three out of eight cases (i.e., same direction accidents at signalized high volume intersections, opposing left turn crashes at signalized high volume intersections, and through cross traffic crashes at unsignalized low volume intersections). Hence, traffic conflict was an acceptable surrogate for these types of crashes since they could be used to produce accurate estimates of crashes. In addition, they demonstrated that the studies could use conflict data when there were insufficient crash data to produce an estimate. In addition, by broadening the definition of conflict to include all road users, Migletz et al. (1985) helped in the effort to apply the traffic conflict methodology to studies of pedestrian-vehicle and bicycle-vehicle crash risk.

Hyden (1987) conducted a thorough review of the development of the traffic conflict method for traffic safety evaluation in Sweden. Based on observations, Hyden found that there was a minimum time at which a road user will make the decision to take evasive action (brake or swerve). That appeared to be at 1.5 seconds before the collision would occur, which was considered the time to crashes (TA[1]) measured at the point when the evasive maneuver began. Hyden trained field observers to judge a 1.5 seconds TA and compared their

[1] Here TA was used to define “time to crash.” In the Hyden (1987) study, accident was used rather than crash.

judgments made in real-time against a videotaped record of the same events. Overall, field observers tended to overestimate the TA value at short intervals and underestimate the TA value at long intervals. However, in judging pedestrian-vehicle conflicts, observers' real-time judgments were not statistically different from measured values based on video post-analysis. Hyden concluded that real-time observations using trained coders were sufficiently accurate to support valid conflict analysis. False alarms were rare and misses were spread equally across all values of TA. Hyden also concluded that the most severe conflicts resulted in the highest levels of inter-rater agreement.

In 1988, Van Houten explored the effects of advance stop lines and signs on pedestrian safety. Conflicts were used as the surrogate measure for crashes. Pedestrian-vehicle conflicts were classified into three types according to the motorist behaviors:

- *Type 1:* A motorist had to engage in abrupt audible braking, had to change lanes abruptly to avoid striking a pedestrian, or a pedestrian had to jump to avoid being struck by a vehicle.
- *Type 2:* A motorist who failed to yield to a pedestrian passed within less than one lane's distance from the pedestrian but did not qualify as a type 3 conflict.
- *Type 3:* A vehicle passed in the immediately adjacent lane to the left of a vehicle that had yielded to a pedestrian who was crossing the street. (Van Houten, 1988, p. 247)

Gårder (1989) provided two standard definitions of conflicts. One definition was developed by participants at a 1977 international workshop on traffic conflicts:

> *A traffic conflict is an observable situation in which two or more road users approach each other in space and time to such an extent that there is a risk of collision if their movements remain unchanged.* (Gårder, 1989, p. 437)

The second is the definition adopted by the Department of Traffic Planning and Engineering in Lund, Sweden:

> *A serious conflict occurs when two road-users are involved in a situation where a collision would have occurred within 1.5 seconds, if both road-users had continued with unchanged speeds and directions. The time is calculated from the moment one of the road-users starts braking or swerving to avoid the collision.* (Hyden, 1977)

Gårder used the same training and evaluation process as Hyden and achieved similar results in terms of inter-rater agreement and accuracy. Approximately 80% of the traffic situations were judged correctly by observers in real time.

Parker and Zegeer (1989) developed a manual to guide engineers observing conflicts in the field. They defined conflicts as "an event involving two or more road users, in which the action of one user causes the other user to make an evasive maneuver to avoid a collision" (p. 4). Although no specific definition was provided in the manual regarding pedestrian-vehicle conflicts, the manual includes a brief example of pedestrian-vehicle conflict situations.

Abdulsattar, Tarawneh, McCoy, and Kachman (1996) defined pedestrian-vehicle conflicts as “any evasive action taken by a pedestrian, or a group of pedestrians, while crossing within a marked crosswalk, to avoid a turning vehicle” (p. 38). It included any pedestrian hesitation in response to a vehicle in the travel line and pedestrian refusal to cross by returning to the curb. They also considered the event as a conflict when a pedestrian was in the crosswalk trying to finish crossing and a turning vehicle occupied the crosswalk within 20 feet of the pedestrian. The observers measured conflict when a turning vehicle and a pedestrian were at the crosswalk at the same time. They classified conflicts into two categories based on the location of the pedestrian in the crosswalk:

- Type A conflicts occurred when the pedestrian was in the half of the crosswalk outside the path of the turning vehicle; and
- Type B conflicts occurred when the pedestrian was in the half of the crosswalk within the path of the turning vehicle.

Hakkert, Gitelman, and Ben-Shabat (2002) tested a new pedestrian crossing warning flasher at uncontrolled intersections in Israel using conflict data. Pedestrian-vehicle conflicts were defined as an abrupt change of course or speed by either the pedestrian or the vehicle in order to avoid a collision. Five observers were present at each site: two observers were responsible for speed and traffic counting, one observer was responsible for recording reactions of vehicles, one observer was responsible for recording pedestrian reactions, and the fifth observer was responsible for counting conflicts. The conflicts were counted within the crosswalk area. The crosswalk area included the crosswalk zone and the road areas 5-30 meters before and beyond the crosswalk zone.

Bechtel, Macleod, and Ragland (2004) used pedestrian-vehicle conflicts as a surrogate measure for crashes to investigate the safety effect of pedestrian scramble signals. They defined conflicts as a situation where “a pedestrian or vehicle taking sudden evasive action to avoid a vehicle-pedestrian collision that would have occurred had the users’ paths remained unaltered” (p. 22).

A similar definition of conflicts was used in a study by Eccles, Tao, and Mangum (2004), stating that “conflict was an interaction between a vehicle and a pedestrian in which either a pedestrian or a vehicle takes evasive action, such as weaving, braking, or running, to avoid a collision” (p. 38). They also emphasized that a collision had to be imminent to be considered a conflict.

Van Houten, Retting, Farmer, and Van Houten (2007) and Van Houten, McCusker, Huybers, Malenfant, and Rice-Smith (2007) defined pedestrian-vehicle conflicts as “(a)ny situation in which the driver engaged in abrupt braking or either the driver or pedestrian took sudden evasive action to avoid a collision” (p. 87). Van Houten, Retting, et al. (2007) collected data at intersections with a leading pedestrian interval signal. Two observers independently scored pedestrian behavior and pedestrian-vehicle conflicts. The number of conflicts between pedestrians and turning vehicles was scored separately for pedestrians leaving the curb just before the start of the walk indication, at the start of the walk indication, during the remainder of the walk cycle, and during the “don’t walk” signal. The distance covered by the pedestrian when conflict occurred was also scored. Van Houten, McCusker, et al. (2007) used a similar method to analyze pedestrian-vehicle conflicts at crosswalks with advance yield markings and fluorescent yellow-green signs. Data collection was divided into five sessions, with each session consisting of 20 pedestrian crossings while vehicles were present. Marks were placed on the curb at 3 meter intervals. Observers also recorded how far in advance of the crosswalk motorists stopped for pedestrians. Two observers worked independently at each site and had a high level of inter-rater agreement (100% of conflicts were scored identically).

Benekohal, Medina, and Wang (2007) described conflicts as the situation where a "pedestrian was in the crosswalk and the motorist did not yield as required" (p. 12). Requirement to yield was based on whether the pedestrian was already in the crosswalk. That is, motorists were required to yield when pedestrians were in the crosswalk. They classified conflicts in the following three groups:

- *Non-severe conflicts:*
  - A pedestrian crosses the road halfway and waits in the center of road or in the opposing lane of traffic as vehicles pass.
  - A pedestrian steps in the crosswalk, hesitates to continue crossing, and comes back to curb.
  - A pedestrian rushes or runs to finish crossing due to an approaching vehicle that is slowing down.
- *Severe conflicts caused by motorists:*
  - A pedestrian is waiting in the middle of the road (with no raised median) and vehicles keep passing in both directions.
  - A pedestrian suddenly aborts crossing, runs back to curb.
  - A pedestrian runs to finish crossing and approaching vehicle doesn't seem to have slowed down significantly.
  - Motorist suddenly changes lanes to go around the pedestrian.
- *Severe conflicts caused by pedestrians:*
  - A pedestrian forces motorist to suddenly yield by stepping on the road.
  - A pedestrian runs to cross the street and causes motorists to suddenly stop or slow down.
  - A pedestrian tries to cross a four-lane street right after getting off the bus, and stops in front of the bus or causes other motorists to suddenly stop or yield. (p. 13)

Clark, Hummer, and Dutt (2007) evaluated the effectiveness of fluorescent yellow-green pedestrian warning signs in reducing pedestrian-vehicle conflicts. Conflict was defined as the event "when a pedestrian or bicyclist was in the roadway and an oncoming motorist was close to the crossing area (within 20 m), thus requiring evasive action such as vehicle braking, swerving, or on the part of the pedestrian, running to avoid a collision" (p. 41). They classified conflicts into the following types: braking conflict, weaving conflict, running conflict, and close-call conflict.

Kaparias, Bell, Biagioli, Bellezza, and Mount (2014) presented a new behavioral analysis technique for vehicle-pedestrian interactions. They classified events into the following types:

- *Steady Car-Pedestrian:* These events involved a four-wheeled vehicle that was already traveling at a steady pace at the time of interaction with a pedestrian.

- *Effective Shared Space:* These events occurred in situations where vehicles appeared to be static or traveling slower than pedestrians, while pedestrians were also in the road space. This type of interaction occurred most commonly in three circumstances:
    - When a traffic signal changed, a vehicle began to pull way but pedestrians were still in the road space and had not yet finished crossing.
    - When a vehicle traveled around a sharp corner while a pedestrian was crossing the road.
    - When there was a slow moving queue of vehicles and a pedestrian attempted to walk between them to cross the road. (p. 4)

They graded interactions in three severity levels based on pace and direction changes. Pedestrians' pace changes were graded on a 4-point scale: (1) returns to curb; (2) stops temporarily waiting for the vehicle to pass; (3) accelerates to pass before the vehicle; and (4) continues at the same pace. Vehicles' pace changes were graded on a 3-point scale: (1) slows and stops; (2) slows without stopping; and (3) continues full speed. Changes in direction were similarly graded for pedestrians: (0) returns to pavement; (1) deviates to avoid vehicle, and (2) continues along path and for vehicles: (1) deviates to avoid pedestrian; and (2) continues along intended path. The vehicles' acceleration patterns were also graded: (0) no change in speed; (1) waits for pedestrians to clear before accelerating; and (2) accelerates as soon as pedestrians cross the vehicle's intended path.

3.2.1 Traffic Conflict Definition and Collection Summary

- Several studies have confirmed that traffic conflicts were as accurate as crashes to predict safety effectiveness when there was insufficient crash data.
- Engineering researchers have been using traffic conflicts as a common surrogate measure for crashes since the 1970s.
- After appropriate training, observers could identify traffic conflicts and reach a high level of inter-rater agreement.
- These studies standardized pedestrian-vehicle conflicts and described the collection of conflict data in the field in detail, which provides meaningful guidance on collecting naturalistic data for the purpose of this research project.

3.3 Conflict and Risk Assessment

Very few publications have examined pedestrian-vehicle conflicts in a way that supports risk assessment modeling. This is important because it goes beyond the site-specific nature of a typical engineering-focused conflict analysis to provide a more general approach to safety and pedestrian-vehicle interactions. A good tool for comparing safety among a group of intersections is the Pedestrian Intersection Safety Index (Ped ISI).

Zegeer et al. (2006) developed the Ped ISI based on intersection rating and avoidance maneuvers. They studied 69 sites in three cities: Miami, Philadelphia, and San Jose, and collected and analyzed crash data for each site. However, there were only 33 pedestrian crashes reported during the study period for the 69 sites, which was insufficient to be used as an index for developing the Ped ISI. They observed 911 motorist conflicts or avoidance maneuvers and 184 pedestrian conflicts or avoidance maneuvers from the video tapes. In addition, they invited experts (e.g., engineers, planners, and bike-pedestrian coordinators) to rate each location in a web-based survey that included intersection description and video. On average, each site received 62 ratings. The final Ped ISI equation was developed with the dependent variables (behavioral data and rating) along with site variables.

In a follow-up report to Zegeer et al. (2006), Carter, Hunter, Zegeer, Stewart, and Huang (2006) produced guidance on how to develop and use the Ped ISI. In the study, they provide a clear definition of conflict between motorist and non-motorist: "a sudden interaction between a bicycle or pedestrian and motor vehicle such that at least one of the parties had to suddenly change speed or direction to avoid the other" (p. 14). The maneuvers that occurred during conflicts could be hard braking or swerving, jumping out of the way, etc. In addition, they distinguished between conflicts and avoidance maneuvers. Avoidance maneuvers were considered as "any change in direction or speed caused by an interaction between parties," which can be slowing, soft stopping, or non-sudden changes in direction.

To date, only one study has directly examined pedestrian and driver distraction in the context of a conflict analysis (Brumfield, Pulugurtha, Maradapudi, & Miatudila, 2011). Observers recorded pedestrian and motorist yielding behaviors as well as conflicts between road users at seven marked mid-block crosswalks at the University of North Carolina Charlotte campus. The study examined three types of distractions: talking on cell phone, texting, and other. The "other" category included distractions such as eating, listening to an iPod, putting on makeup, reaching for an object, talking to a passenger, or anything else that had obvious control of the driver's attention. This study did not distinguish hands-free and hand-held cell phone use because only a few drivers were observed to be clearly distracted by a hands-free device. Pedestrian-vehicle conflicts were defined as "when either [the] vehicle or the pedestrian had to abruptly change their path or speed of travel to avoid [a] collision with the other road user" (p. 4). In the study, six types of conflicts were noted:

- Vehicle braking suddenly or swerving to avoid hitting a pedestrian.
- Pedestrian jumping forward or back to avoid being struck by a vehicle.
- Pedestrian entering the crosswalk and stepping back because the vehicle did not yield.
- The oncoming vehicle changing lanes so that the vehicle could proceed without reducing speed.
- Pedestrian becoming trapped on a crosswalk because the oncoming vehicle did not yield.
- Vehicle running close to a pedestrian walking in a crosswalk.

Observers noted only the first pedestrian-vehicle interaction. The data showed that 64% of drivers yielded to pedestrians and approximately 20% of pedestrian-vehicle interactions resulted in a conflict. In addition, 18% of drivers and 29% of pedestrians were noticeably distracted when crossing the crosswalks. Of the distracted drivers and pedestrians, 16% of pedestrians and 9% of drivers were talking on a cell phone, and 7% of pedestrians and 3% of drivers were texting. There was a significant difference on yield rate to pedestrians between distracted drivers and undistracted drivers, with distracted drivers yielding 5% of the time, and undistracted drivers yielding 77% of the time. Higher frequencies of pedestrian-vehicle conflicts associated with distracted drivers were observed. The distracted drivers conflicted with a pedestrian 54% of the time, as compared to 13% of the time for undistracted drivers. By contrast, distraction among pedestrians did not result in a significant increase in conflicts. Distracted pedestrians conflicted with a vehicle in 21% of events, as compared to 17% for undistracted pedestrians. However, the researchers reported qualitative observations saying that distracted pedestrians were more aggressive and more careless than undistracted pedestrians.

3.3.1 Conflict and Risk Assessment Summary

- To date, only one study directly examined the risk due to pedestrian and driver distraction using conflict analysis. The study was limited to one college campus.
- Pedestrian Intersection Safety Index (Ped ISI) will be a useful tool for field data collection. Specifically, Ped ISI can be used to characterize and compare the safety of intersection crossing locations. For use in naturalistic observations of pedestrians, for example, it would be useful to know ahead of time which locations pose the greatest safety risk based on their design and level of use.

3.4 Summary of Pedestrian-Vehicle Interaction

Because of the limited availability of pedestrian crash data and the insufficient sample size of the crash data for most studies of pedestrian safety at intersections, engineers have developed the traffic conflict method to provide a surrogate safety measure. As may be seen from the cited examples, there are many competing definitions of “conflict,” but they all generally focus on the interaction of two road users in which at least one member of the pair changes course or speed in response to an imminent collision. The traffic conflict method has been applied to a wide range of traffic safety situations, including pedestrian-vehicle interactions at intersections. Relevant examples are cited here because they point the way to a reliable method for coding pedestrian-vehicle interactions that correlates well with crash frequency. At least with respect to “severe” conflicts, the number of conflicts is predictive of the number of crashes, as shown in Figure 5 from Older and Spicer (1976). Unfortunately, the literature on traffic conflicts does not include many validation studies demonstrating, for example, the correlation between conflicts and crashes. Hyden (personal communication, January 31, 2014) stated that the relationship between the frequency of serious conflicts and crashes is “strong” since a serious conflict is essentially a near-crash condition and logically could be expected to show a relationship to crash frequency.

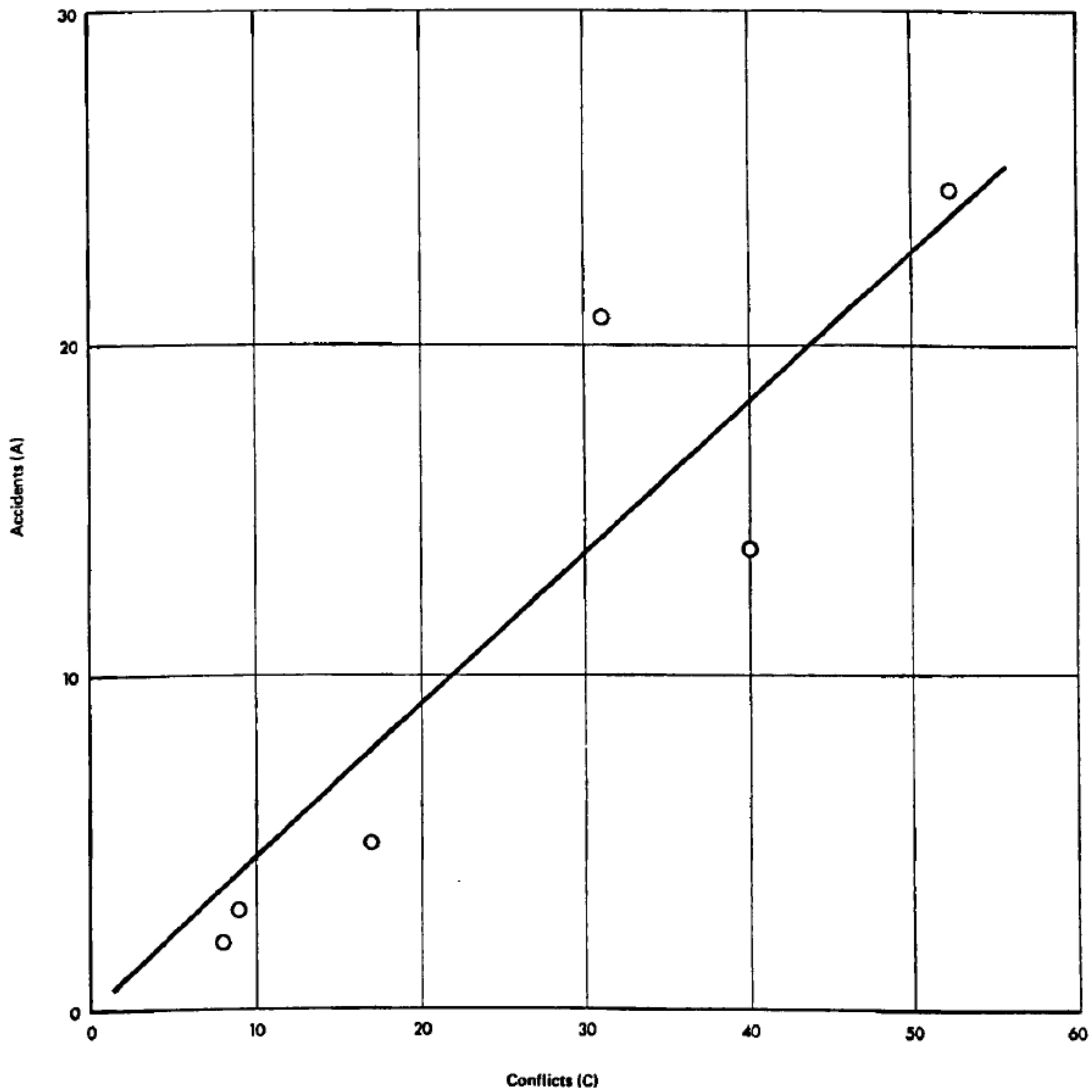

Figure 5. Number of injury crashes (accidents) and serious conflicts at six intersections from Older and Spicer (1979).

Source: Figure 3 from Older and Spicer (1979), p. 341; Reprinted with permission.

Only one study has used the pedestrian-vehicle conflict method in an examination of pedestrian and driver distraction (Brumfield et al., 2011). This study has limitations due to its campus setting, low speed limits, and focus on mid-block crossings. However, the Brumfield study has many of the features planned for the field data collection phase of the project for which this literature review was conducted. Based on the published work using field observations, observers can accurately code the presence of a conflict as well as its severity. Inter-rater agreement as high as 100% was reported after moderate amounts of training. Validation against post-analysis of video tapes shows that observers also reached a high level of accuracy.

Another useful tool coming from this area of research is the Ped ISI. By rating intersections based on field observations, researchers are able to pre-identify a set of locations most likely to have a high frequency of pedestrian-vehicle conflicts. This proved useful in selecting sites for our own field data collection later in this project.

4. OVERALL SUMMARY

A thorough and targeted literature review was conducted in order to accomplish three goals:

1) To characterize the pedestrian distraction problem, especially, as it relates to pedestrian use of electronic devices while crossing streets.
2) To examine the likely interface between pedestrian and driver distraction as both road users try to navigate through intersections.
3) To inform our own field data collection methodology based on the successes and failures of prior research.

Inconsistencies exist among the results of the various studies. Most of the published studies indicate some impact of distraction on pedestrians and/or drivers. However, the studies found small levels of pedestrian distraction often not directly linked to crash risk. Driver distraction has been extensively studied in naturalistic and simulated environments. While there is general agreement that distraction causes changes in drivers' responses, some recent studies indicate that performance decrements due to distraction may actually disappear with practice (at least in the limited case of distraction due to talking on a cell phone; practice effects related to dialing or texting have not been studied).

Also note, a limited number of studies address distraction as a factor in pedestrian-vehicle interactions. Engineering studies using conflict analysis generally have focused on behaviors related to evading collisions rather than the precursor behaviors of the road users (driver and pedestrian alike), including distracting behaviors.

Predominately, the majority of studies have used simulation or laboratory experiments versus naturalistic observations to investigate the potential risks associated with distraction. However, the virtual environment and designed trials through a laboratory space may disrupt the automatic nature of driving or walking. In addition, obvious differences exist between the virtual environment and the real world as the "crash" frequency (and lack of injuries or fatalities, of course) in simulator studies showed. As noted in the earlier discussions of simulator studies, the removal of real risk may alter the subconscious reactions of research subjects so much so that any insights gained from such studies must be validated with real world observations when feasible. Specifically, it may be that research subjects sitting in a simulator may tolerate risks of a virtual collision that they would never tolerate when driving on a real road in a real car. While there are no actual comparative studies of cell phone use in simulated versus real walking or driving, the distraction caused by cell phones and other devices may be larger in a simulator study simply because of the virtual nature of the risks in the virtual environment. If so, reliance on simulator studies alone could lead to overestimation of cell phone-related distraction's impact on safety.

Crash data analyses of the impact of distraction on safety are also limited. The NASS CDS dataset is perhaps the best resource for this type of study among drivers because it uses a well-trained set of data collectors to ensure standardized information, and it includes very detailed coding of distractor types. For pedestrians, CDS is not as useful. Other data sources, including emergency department and hospital admissions and phone records can bolster our knowledge of how big a role distraction plays in injury crashes, but these sources generally do not provide a good measure of exposure. Further, it can be difficult to infer specific details of the injured persons' interaction with the distractor.

In contrast, naturalistic observation studies of pedestrians can provide a reliable estimate of exposure (such as the prevalence of electronic device use among pedestrians), but may be less reliable in estimating risk because very few pedestrian-vehicle interactions result in a crash. The expectation in any brief study of the types reported here is that there would be no pedestrian-involved crashes and, were one to occur, that lone data point would not be useful in any analysis. Rather, it would call a halt to data collection as the research team rendered aid as needed.

The traffic conflict method has considerable promise to allow naturalistic observation studies to collect surrogate measures of crash risk. The method is well developed and accepted in the engineering world, but has yet to see much use in behavioral analysis. It represents an improvement over previous behavioral studies in that it has the potential to help link pedestrian and driver distraction to increased risk of a traffic conflict.

The literature review helped identify gaps in the existing body of knowledge, including:

- A very limited number of studies have investigated pedestrian safety due to electronic device use by drivers or pedestrians. Even fewer naturalistic observation studies have been performed.
- Most previous studies focus primarily on cell phone use, but the discussion regarding other types of electronic devices is missing (e.g., tablets, mp3 players).

This review illustrates there is a need to conduct naturalistic observation of the effect of electronic device use on pedestrian distractions and safety.

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