Exploring human-vehicle communication to balance transportation safety and efficiency: A naturalistic field study of pedestrian-vehicle interactions

Micah Roediger

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E. Scott Geller, Co-chair
Jeff S. Hickman, Co-chair
Charles Calderwood
Rachel A. Diana

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ABSTRACT

While driving behavior is generally governed by the nature and the driving objectives of the driver, there are many situations (typically in crowded traffic conditions) where tacit communication between vehicle drivers and pedestrians govern driving behavior, significantly influencing transportation safety. The study aimed to formalize the tacit communication between vehicle drivers and pedestrians, to inform an investigation on effective communication mechanisms between autonomous vehicle and humans. Current autonomous vehicles engage in decision making primarily controlled by on-board or external sensory information, and do not explicitly consider communication with pedestrians. The study was a within subject 2x2x2 factorial experimental design. The three independent variables were driving context (normal driving vs. autonomous vehicle placard), driving route (1 vs. 2), and narration (yes vs. no). The primary outcome variable was driver-yield behavior. Each of the ten drivers completed the factorial design, requiring eight total drives. Data were collected using a data acquisition system (DAS) designed and installed on the experimental vehicle by the Virginia Tech Transportation Institute. The DAS collected video, audio, and kinematic data. Videos were coded using a proprietary software program, Hawkeye, based on an a priori data directory. Recommendations for future autonomous vehicle research and programming are provided.
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GENERAL ABSTRACT

To improve traffic safety and efficiency, the current study examined factors of pedestrian-vehicle interactions. Driving is a dangerous endeavor for all parties, however, pedestrians are an especially vulnerable group. Many different solutions have been suggested including; education and training of road users, high visibility law enforcement, infrastructure changes, and vehicle solutions. Of all proposed, the vehicle solution, autonomous vehicles, shows great promise in improving traffic safety. Autonomous vehicles provide an opportunity for a high degree of safety, yet, inefficiencies exist. For instance, a vehicle might stop at all crosswalks regardless of pedestrian proximity. To this end, the current study was a scientific exploration of the factors relating to pedestrian-vehicle interactions. The exploratory nature of this work provided an opportunity to provide recommendations for programming of autonomous vehicles to balance safety and efficiency.
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Introduction

Pedestrian Injury and Fatality

Pedestrians worldwide face extreme danger during interactions with motor vehicles. Worldwide, more than a quarter of a million pedestrian fatalities occur annually on roadways (Global Status Report on Road Safety, 2015). The U.S. alone contributes nearly 6,000 pedestrian fatalities to the global numbers with an additional 70,000 injured annually (NHTSA, 2016). On average, pedestrian fatalities and injuries account for more than 25% of all roadway crashes, with the highest frequencies occurring in large cities and urban areas (Fatality Facts, 2016). The high number of pedestrian fatalities is linked to their extreme vulnerability as road users (Bella & Silvestri, 2015).

Pedestrian Vulnerability

Modern vehicles afford the user many protections, including safety belts, airbags, and adaptive cruise control. Thus, safety gear has provided the driver a modicum of safety not provided to pedestrians. Many researchers consider pedestrians to be the roadways most vulnerable road-user group (Rosén, Stigson, & Sander, 2011). This is due in part to a lack of pedestrian protection, but also to the vast difference in kinematics that occur when the force of a car strikes a pedestrian (Randles, Fugger, Eubanks, & Pasanen, 2001). Significant research has been dedicated to reporting "pedestrian throw distances", that is, how far the pedestrian travels following impact from a vehicle.

Estimates of pedestrian throw distances vary somewhat, but they increase rather consistently with vehicle speed. Two studies using crash-test dummies demonstrated that adult pedestrians traveled up to 38 meters (around 125 feet) when vehicle speeds reached 64 km/h (just under 40 mph; Severy, 1963; Severy & Brink, 1966). Other studies using crash-test
dummies have investigated only lower speeds and found that vehicles traveling at 40 km/h (just over 25 mph) cause adult pedestrians to travel more than 17 meters (approximately 55 feet; Stcherbatcheff, Tarriere, Duclos, Fayon, Got, & Patel, 1975). Data on real-world human-vehicle collisions, where pedestrian throw distance can be observed, are sparse. The one study reporting on real-world data used 15 videotaped pedestrian-vehicle collisions. Results mirrored the experimental data with crash-test dummies reported above (Randles, Fugger, Eubanks, & Pasanen, 2001).

**Purpose of Study**

Typical safety approaches to decrease pedestrian-vehicle collisions, consider the three “Es”: enforcement, education, and engineering (Hartman, Kweon, Lynn, & Roettig, 2007). Each approach has weaknesses, for instance, enforcement and education approaches lack clear objective impact. The engineering approach demonstrates more promise. However, the engineering approach is limited to research on infrastructure and vehicle countermeasures (e.g., safety equipment and autonomous vehicles) are not a focus. Despite their general exclusion, vehicle countermeasures have demonstrated significant improvement in safety.

Human error accounts for more than 90% of all crashes (Treat et al., 1979). Due to the ability to eliminate dangerous human errors, autonomous vehicles are one of the most promising vehicle countermeasure. As autonomous vehicles begin to replace human drivers, the frequency of crashes will presumably decrease substantially.

Reducing crashes is an important objective in transportation research. However, solely focusing on reducing crashes leads to avoidable increases in traffic congestion (Li & Sun, 2015) and harmful emissions (Pandian, Gokhale, & Ghoshal, 2009). Through research, a balance between safety and efficiency is achievable. The current study aimed to aid the balance between
safety and efficiency by investigating the tacit communication occurring between pedestrians and drivers at intersections. Understanding the tacit communication between drivers and pedestrians, future autonomous vehicles can be designed and programmed to appropriately display vehicle intentions while understanding and reacting to pedestrian behaviors. In other words, the purpose of this research was to examine and formalize the natural communication between pedestrians and drivers. Recommendations on how to leverage the formalized communication will be discussed implementation in future autonomous vehicle research.

In addition to common solutions to safety issues, the following sections describe research on pedestrians as road users – their impact, and their vulnerability. Three primary types of pedestrian research are discussed: energy economy, transportation efficiency, and road safety. Two primary factors related to pedestrian-vehicle collisions – vehicle speed and yield compliance – are emphasized due to their relevance to the current study. A comprehensive research review is summarized for each topic.

After the literature review on safety outcomes, current and alternative solutions are explored. A comprehensive literature review is provided on the most recognized solutions, referred to as, the three “Es”. Vehicle countermeasures are separated from the general engineering approach due to the focus of engineering solutions on infrastructure changes. Finally, the potential for autonomous vehicles to improve pedestrian safety is discussed, with a current limitation being an inability to adequately adapt functioning when dynamic elements are presented (i.e., pedestrians). The results from the current study provide guidance for future research.
Pedestrian Research

The vulnerable state of pedestrians has led to increased attention toward pedestrian safety from policy makers (e.g., Traffic Safety Facts, 2016). In turn, this has spurred a plethora of research aimed at building a knowledge base around pedestrians’ road use and their interaction with vehicles. Li and Sun (2016b) divided this research into three categories: 1) road safety, 2) transportation efficiency, and 3) energy economy.

Expanding on each of these categories, road safety refers to improving pedestrian-vehicle interactions to reduce injuries and fatalities. Transportation efficiency covers research aimed at reducing delays at intersections due to pedestrian-vehicle interactions. The final category, energy economy includes research on the impact of pedestrian-vehicle interactions on energy use, and emissions. Of the three types of research, the quintessential objective is safety. Thus, a majority of the research literature has focused on safety-related research.

Energy Economy

Energy-economy research has demonstrated the impact of pedestrian-vehicle interactions on the environment. Overall, the transportation sector accounts for greater than 27% of all energy consumed in the U.S. (“Overview of CMAQ Program Operations”). In addition, vehicles are responsible for 90% of carbon monoxide emission, 70% of nitrogen oxides, and 40% of hydrocarbons (Pandian, Gokhale, & Ghoshal, 2009). Three main sources that increase vehicle emissions are a vehicle being forced to stop (Rakha & Ding, 2003), wait-time (Gokhale, & Pandian, 2007), and delay (Pandian, Gokhale, & Ghoshal, 2009).

Although these figures are not specific to pedestrian-vehicle interaction, they demonstrate the overall impact of vehicles on energy consumption and harmful emissions. Furthermore, pedestrians create a distinct impact due to forcing vehicle stops, wait-time, and traffic delays (Li
Li and Sun (2014) conducted a simulation to assess the impact of pedestrian-crossing behavior on vehicle emissions and fuel consumption. Their findings concluded that a single pedestrian crossing can significantly increase carbon monoxide, nitrogen oxides, and hydrocarbon emissions. Fuel consumption was also affected with a positive correlation between pedestrian crossings and fuel consumption.

**Transportation Efficiency**

Providing for pedestrian safety is evidently related to an increase in energy consumption and harmful chemical emissions, and is also responsible for wasted man-hours. In the U.S. alone, an estimated $120 billion is expended due to extra energy consumption and wasted man-hours from traffic congestion. Pedestrians are not the sole cause of energy consumption and traffic congestion. However, interventions from research to reduce the impact of pedestrian-vehicle interactions can aid in significant monetary savings (Li & Sun, 2016b).

The main objective of research on transportation efficiency is to reduce delays, and thereby improve traffic flow. To address this issue, different areas of infrastructure need to be investigated. Lambrianidou, Basbas, and Politis (2013) investigated the impact of crossing countdown-timers on pedestrian safety and walking speed. Using behavioral observation, they found that pedestrians reacted promptly to the signals. Ultimately, this could lead to an increase in safety-related behaviors, such as waiting for the appropriate signal at an intersection.

Findings by Lipovac, Vujanic, Maric, and Nesic (2013) counter the results reported by Lambrianidou, Basbas, and Politis (2013). Specifically, Lipovac et al. (2013) coded video recordings of pedestrian behavior at an intersection before and after a countdown signal was installed and they found it had no impact on pedestrian speed. The authors concluded that
countdown signals have a positive impact on safety behavior by reducing the number of pedestrians who fail to yield to vehicles.

The length of protected turn lanes is related to traffic delays and congestion (Tian & Wu, 2006). Congestion increases at a rapid rate when turn lanes are at capacity (Zhang & Tong, 2008). When vehicles follow proper yield behavior, pedestrians are often directly responsible for preventing vehicles from continuing on their intended path and thereby severely increasing congestion (Li & Sun, 2016a).

Driver behavior has also been investigated as a contributor to traffic congestion and traffic delay. Li and Sun (2015) conducted a computer simulation study that modeled driver lane-changing behavior on multi-lane roadways around a pedestrian crossing. Results demonstrated that when drivers change lanes to avoid a pedestrian interaction vehicle speed is increased, delays are reduced, and the number of pedestrian interactions decrease.

One unfortunate issue with the simulation data is that no real-world data exist to support these findings. Even if the frequency of pedestrian-vehicle interactions were reduced in the real-world, the severity of these interactions may not be influenced. In the simulated model, vehicle speed increased and traffic flow improved. Provided this holds true, a reduction in pedestrian-vehicle interactions, pedestrian injuries and fatalities may remain unchanged, or potentially increase, due to the increase in vehicle speed (Davis, 2001).

In summary, pedestrian countdown signals appear to have a significant impact on the safety-related behavior of pedestrians, but not on reducing traffic congestion and delays. Conversely, turn-lane length is directly related to traffic congestion – as the length of turn lanes decreases – congestion increases. It has also been posited by simulation researchers that lane-
change behavior in multi-lane roadways can reduce pedestrian-vehicle interaction and in turn reduce congestion, but there is little empirical evidence to support this claim.

Road Safety

The paramount objective of research involving road users is to increase safety. When the pedestrian is the user under consideration, the primary objective is to decrease incidents of injury and fatality. Research in this area has found the two primary determinants of injury severity and fatality are vehicle speed and yield behavior. A large body of research has been conducted on both phenomena and are reviewed in the following sections.

Vehicle speed

Studies on driver behavior have investigated the impact of vehicle speed on pedestrian fatalities. This phenomenon has been most often studied in the United Kingdom (Ashton, 1980; Cuerden, Richards, & Hill, 2007; Davis, 2001; Pasanen & Salmivaara, 1993) and Europe (Anderson, McLean, Farmer, Lee, & Brooks, 1997; Hannawald & Kauer, 2004; Martin & Wu, 2018; Olszewski, Szagała, Wolański, & Zielińska, 2015; Rosén & Sander, 2009) with a few exceptions in Korea (Oh, Kang, Youn, & Konosu, 2008), China (Kong & Yang, 2010), and the U.S. (Tefft, 2013; Yaksich, 1964).

One of the earliest studies on the impact of vehicle speed on pedestrian fatalities was conducted using police data from 1958 to 1963 in St. Petersburg, Florida (Yaksich, 1964). A total of 498 pedestrian-vehicle collisions were investigated with a focus on collisions involving elderly pedestrians; however, data from all pedestrian ages were included. Yaksich (1964) reported an overall fatality rate of 10% from the 498 pedestrian-vehicle collisions. Elderly pedestrians are at higher risk of collision-related fatalities, constituting nearly half of pedestrian injuries and close to three quarters of fatalities (Yaksich, 1964).
Ashton (1980) analyzed data in the United Kingdom from 1973 to 1979. The study investigated 358 cases of pedestrian injuries. The authors reported 23% of the 358 injured pedestrians were fatalities. Of the 358 original cases, 208 had recorded values for impact speed. Ashton (1980) grouped the raw data into categories beginning at 0-10 km/h, followed by 11-20 km/h, and up to 70 or more km/h. Ashton and Mackay (1979) analyzed the speed data, adjusting for the bias in the sample to understand the relationship between impact speed and pedestrian fatalities. Unfortunately, Ashton and Mackay (1979) did not report the specific percentage of fatalities, and therefore their findings are left open to interpretation (Rosén, Stigson, & Sander, 2011).

The lack of interpretation of the raw data associated with the graphs has caused researchers to be cautious when drawing specific conclusions from the graphed data reported by Ashton and Mackay (1979). Only one attempt has been made to interpret the graphs. Reported results included 10% fatalities when a vehicle was traveling between 41-50 km/h (approximately 25-30 mph; Cuerden, Richards, & Hill, 2007). Results also demonstrated an extreme jump to 40% fatalities when a vehicle was traveling between 51-60 km/h (approximately 30-35 mph; Cuerden, Richards, & Hill, 2007).

In an effort to gain insight into the risk of a fatality based on the speed of vehicle impact, Pasanen and Salmivaara (1993) investigated 208 pedestrian injuries using the recorded vehicle speeds from Ashton (1980). A risk curve was generated using regression analysis, which indicated a striking increase in fatalities as speed increased. Fatalities reached 40% at 50 km/h and surpassed 80% at 60 km/h (Pasanen & Salmivaara, 1993).

The risk curve reported by Pasanen and Salmivaara (1993) is disputed by other authors. While discussing the study limitations, Ashton (1980) reported the data were skewed toward
more extreme cases, with high levels of severe and fatal collisions, as compared to national data. This critique was reiterated by Rosén, Stigson, and Sander (2011) who advised caution when interpreting data from the biased samples.

The critique of Pasanen and Salmivaara (1993) influenced Davis (2001) to reanalyze the data from Ashton (1980). Davis (2001) used logistic regression to analyze the data. Instead of working with the raw data, the data were weighted based on annual data representative of the United Kingdom. The representative data reported 3.5% fatalities compared to 23% in the raw data.

As would be expected, the weighted module deviated from the model on the raw data. The main difference was a reduction in fatality risk for individuals under 60 years old. The adjusted risk curve claimed only a 7% fatality risk when the vehicle was traveling 50 km/h for the 15 to 59 year-old age group (Davis, 2001). However, the risk curve for older pedestrians was comparable to the risk curve reported by Pasanen and Salmivaara (1993).

Although Davis (2001) attempted to rectify the critique of Pasanen and Salmivaara (1993), weighting the data may not adequately address the issue. When weighting data, it is important to define the weights appropriately. Ashton (1980) reported the sample over represented severe collisions, and the weights did not account for distinctions in injury types and additional factors. Fundamentally, both models have limitations due to the type of input data, and therefore, caution must be used when interpreting the models (Rosén, Stigson, & Sander, 2011). Nevertheless, these studies aid in understanding the severity of the relationship between speed and fatality.

Mirroring the research from the United Kingdom by Ashton and Mackay (1979) and Davis (2001), Tefft (2013) investigated pedestrian-vehicle collisions based on impact speed in
the U.S. Tefft (2013) using data from 1994 to 1998 as reported by the National Highway Traffic Safety Administration (NHTSA), which had been reported in a National Automotive Sampling System Pedestrian Crash Data Study (NHTSA, 2008). The analyzed data set was comprised of detailed on-site and follow-up investigations of 315 pedestrian-vehicle collisions.

Considering recommendations by Davis (2001), Tefft (2013) compared the data to national fatality statistics. As is common with similar data sets, severe and fatal collisions were over sampled. To adjust the data for biased sampling methods, the data were stratified based on injury severity and provided a weight based on a comparison with representative data at the same strata.

Based on the analysis, the risk of fatality reached 50% at speeds of 40 mph (~65 km/h) and 90% at speeds approaching 55 mph (~90 km/h). The risk reported is also substantial at speeds as low as 25 mph (40 km/h) where, on average, a fatality occurs during one in ten pedestrian-vehicle collisions (Tefft, 2013). The congruence between the findings of Tefft (2013), Davis (2001), and other authors, demonstrates the overall generalizability of the phenomenon.

Another way to examine the relationship between impact speed and the probability of a pedestrian fatality is through relative-risk functions. Several authors have reported high levels of relative risk. For example, the relative risk of a pedestrian fatality was eight times higher when a motor vehicle was traveling at 50 km/h relative to one traveling at 30 km/h. These speeds translate to roughly 30 mph compared to 20 mph (Pasanen & Salmivaara, 1993). These results were found by analyzing video data from Helsinki, Finland. The analyses were not adjusted for sampling bias.

Rosén and Sander (2009) investigated the same phenomenon using in-depth on-scene investigations from 1999 to 2007 in Germany. After adjusting for sample bias, the authors
reported five times higher risk of fatality when a driver was traveling 50 km/h (30 mph) compared to traveling 30 km/h (20 mph). They also reported the relative risk of traveling 50 km/h (30 mph) as twice as much when compared to 40 km/h, approximately 25 mph (Rosén & Sander, 2009). Comparatively, Rosén and Sander (2009) reported lower relative risk than Pasanen and Salmivaara (1993). The underlying principle continues to indicate a strong positive correlation between impact speed and the probability of a fatality from a pedestrian-vehicle collision.

Overall, estimation of risk dependent on speed can fluctuate depending on the sample, measurement type, and method of adjusting for bias. Nonetheless, the message is consistent: higher impact speeds are dangerous for pedestrians. Whenever possible, infrastructure should be designed to limit possible pedestrian-vehicle interaction when the vehicle is legally able to travel at higher speeds (Tefft, 2013).

One review of the literature conducted by Rosén, Stigson, and Sander (2011) attempted to cast doubt on the current research findings indicating a strong relationship between vehicle speed and pedestrian fatalities. The authors reviewed 11 prominent studies on risk of pedestrian fatality at different vehicle speeds. They reported most current studies over report the percentage of pedestrian fatalities due to biased samples (Rosén, Stigson, & Sander, 2011). The authors claim the over-reporting of the relationship occurs due to oversampling severe and fatal pedestrian-vehicle collisions, and simultaneously under sampling collisions resulting in minor injuries. The claim is derived from comparing the percentage of pedestrian fatalities from the reviewed papers to national data from the same year for the respective country.

Although valid and warranted, the sampling issue raised by Rosén, Stigson, and Sander (2011) is of little consequence for general conclusions. Two important points should be
considered. First, several authors performed appropriate analyses to account for oversampling of fatal and severe collisions. Second, the implication from current research is still clear and difficult to dispute—speed is a dangerous aspect of pedestrian-vehicle collisions.

To summarize the influence of impact speed on fatality and injury severity, the overall picture is clear. A high risk of fatality exists even at relatively low vehicle speeds (e.g., 25 mph). Risk continues to increase with a strong positive correlation between impact speed and pedestrian fatality. Speeds over 40 mph are extremely dangerous and risk of fatality reaches near guaranteed levels at high speeds (e.g., 55 mph). A simple solution to this issue is readily available, reduce vehicle speed during potential pedestrian-vehicle interactions to reduce the severity of injury as well as fatalities. Current research supports this conclusion, and even a low-to-moderate reduction in speed would have considerable impact on the number of fatalities (Kröyer, Jonsson, & Várhelyi, 2014).

**Yield Law and User Behavior**

Research has compiled evidence that drivers and pedestrians frequently fail to abide by laws governing yielding behavior. A major concern reported by Várhelyi (1998) is that drivers fail to adjust vehicle speed when approaching a crosswalk to account for the added danger to pedestrians. Driver and pedestrian failure to yield is related to many safety-related issues (Bertulis & Dulaski, 2013). As a general theme, researchers have concluded that yield compliance is strongly associated with pedestrian-vehicle collisions (Bella & Silvestri, 2015; Hartman, Kweon, Lynn, & Roettig, 2007; Mitman, Cooper, & DuBose, 2010). The following section provides a review of primary research on driver and pedestrian understanding of laws governing yielding behavior, as well as general trends in yield behavior.
Failure to follow the laws governing crossing behavior are considered one of the primary causes of fatal pedestrian-vehicle collisions. A mixed-method investigation of pedestrian fatalities found more than half of all pedestrian fatalities occurred when a pedestrian was crossing a road illegally (Spainhour, Wootton, Sobanjo, & Brady, 2006). The researchers concluded that this is especially dangerous because it violates driver expectations. Essentially, drivers taken by surprise often failed to avoid a collision.

Research by Ellis, Van Houten, and Kim (2007) investigated driver yield behavior at three separate un-signalized crosswalk locations in Miami, Florida. To measure yield behavior, observers completed a behavioral checklist on the variables of interest. In this case, inter-observer reliability was 98.4%. This indicates observations between individual observers had a tendency to match. During baseline, yield percentages ranged from 21% to 34% (Ellis, Van Houten, & Kim, 2007). Following baseline, three different interventions to improve yield behavior were tested (discussed below under solutions).

Fitzpatrick, Turner, and Brewer (2007) observed motorist yield compliance across 11 sites in the U.S. Average yield compliance was just over 65%. The descriptive analysis also revealed differences among sites, with a minimum of 8% and a maximum approaching 100%.

Potential reasons for low levels of yield compliance could have been caused by a number of reasons. One possibility to consider is that drivers are in a hurry. Another explanation that has been proposed is that drivers and pedestrians do not know the traffic laws. A research report by Hartman et al. (2007) investigated yield laws in all 50 states. They suggested confusing and vague laws may limit user understanding and be a relevant factor in yield compliance.

Furthermore, Hatfield, Fernandes, Job, and Smith (2007) observed 2,854 pedestrian crossings at intersections around Australia and conducted follow-up interviews with 574
pedestrians. From the interviews, they concluded that drivers and pedestrians were often confused about who should yield. Contrary to Hartman et al. (2007), investigation into pedestrian understanding of traffic law in the U.S. demonstrates a majority of pedestrians know the laws, but many fail to abide by them (Kourtellis, Cruse, & Lin, 2015).

A large-scale study tracked the number of people following appropriate crossing behavior in eight different counties across Florida. In each county, ten survey sites were selected and observed. Across all locations, a total of 4,533 observations were made. A descriptive analysis indicated that 34% of pedestrians crossed the roadway without using a crosswalk while being within 200 feet of a crosswalk (Kourtellis, Cruse, & Lin, 2015). When surveyed before crossing, 88% of pedestrians knew the law and only a small portion (6%) failed to follow the appropriate laws (Kourtellis, Cruse, & Lin, 2015).

Similar results were found in a study conducted in Virginia. Martinez and Porter (2004) used a random stratified sample and conducted more than one thousand phone interviews with licensed drivers. They found a majority of participants answered questions about yield behavior appropriately. The percentage of questions answered correctly varied from a minimum of 63.9% to a maximum of 92% (Martinez & Porter, 2004). An example question provided asked about appropriate yield behavior when making a left turn (Martinez & Porter, 2004).

In summary, drivers and pedestrians have low levels of yielding behavior. Indeed, failing to yield when appropriate is considered one of the primary causes of pedestrian-vehicle collisions. Essentially, failure to yield when appropriate is a maladaptive behavior with negative outcomes. Research findings contradict one commonly-suggested reason for not yielding, which is a failure to understand yield law. On the contrary, pedestrians and drivers tend to know the law, but fail to follow it. A simple reminder appears to be effective in persuading pedestrians to
cross appropriately. Various solutions have been proposed to curb the problem of low yield compliance and must continue to be explored.

**Solutions**

The high risk for pedestrian-vehicle collisions has been well documented, leading researchers to search for solutions. Primary solutions typically fall into one of four categories: 1) law enforcement, 2) user education/training, 3) infrastructure, and 4) vehicle solutions. Each category reflects potential outcomes in a unique way to reduce pedestrian-vehicle collisions.

The vast majority of the safety literature refers to these categories as the three “Es”: enforcement, education, and engineering (Hartman, Kweon, Lynn, & Roettig, 2007). Law enforcement is referred to as enforcement, and user education/training is referred to as education. Finally, the last two categories, infrastructure and vehicle solutions, are commonly merged in the literature under the label of engineering solutions. For the purpose of this review, infrastructure and vehicle solutions are discussed as separate topics due to engineering or mixed interventions not including possible vehicle solutions. The primary research literature covering safety solutions is reviewed in the following sections.

**Law Enforcement (“Enforcement”)**

Research on law enforcement focuses on identifying the outcomes associated with increasing compliance with existing laws. The approach of increasing the presence of law enforcement is a policy that is often proposed to increase the frequency of driver yield behavior (e.g., Hartman et al., 2007). Law enforcement as a solution is successful in the short term, but may have limited long-term impact.

Targeted enforcement campaigns often appear extremely successful, but more detailed investigations cast doubt on their effectiveness. One prominent campaign used photographs of
pedestrian-crossing behavior and reported increases in pedestrian compliance after an increase in visible police presence (Weiner, 1968). However, in a follow-up survey after four months, levels of compliance had returned to baseline.

Another study in Seattle, Washington investigated the impact of enforcement campaigns on yield compliance. In this study, the police department provided targeted enforcement. After the study concluded, the authors were unable to provide definitive evidence of a significant increase in driver yield compliance are a function of increased enforcement (Britt, Bergman, & Moffat, 1995).

Van Houten and Malenfant (2004) investigated the impact of a high-visibility enforcement campaign across two weeks in Miami, Florida. The first week of the campaign focused solely on citing drivers who failed to yield. The results demonstrated an increase in yield compliance during the week citations were given out, but returned to baseline levels when the intervention was removed. Promising short-term results make enforcement campaigns appear beneficial at first, but without significant and lasting results, the return on investment is not positive.

Van Houten, Malenfant, Huitema, and Blomberg (2013) built on the unsuccessful enforcement campaign of Van Houten and Malenfant (2004) by increasing engineering and educational components over eight-weeks in Gainesville, Florida. They staggered each enforcement strategy and used advanced yield-warning signs, educational flyers, and advertisement to aid in increasing driver knowledge of yield law and the enforcement campaign. Yield behavior was observed and recorded by trained field observers. Marked increases of driver yield behavior occurred and steadily increased from baseline levels as more enforcement activities were introduced (Van Houten, Malenfant, Huitema, & Blomberg, 2013). On average,
yield behavior increased by nearly 40% over baseline observations. However, the researchers did not record any observations after the interventions were removed. The lack of observations over a lengthy maintenance period is a significant limitation of the study. Unfortunately, this prevents researchers from claiming any long-term impact of a campaign focusing on high-visibility enforcement.

To summarize, these studies suggest that stricter enforcement provides short-term increases in yield compliance, but is not a viable long-term solution and therefore should only be suggested as a temporary fix. Essentially, high-visibility enforcement interventions could be valuable as a short-term stopgap. For example, if an intersection or area has critical levels of pedestrian-vehicle collisions, increased police presence could be used until a more permanent solution can be implemented. Infrastructure and vehicle changes discussed in the following sections are more viable as permanent solutions.

**User Education and Training (“Education”)**

Changing the relevant behavior of drivers and pedestrians is another possible solution and has been widely recommended by researchers of yield compliance (e.g., Hartman et al., 2007; Hatfield, Fernandes, Job, & Smith, 2007). In general, most targeted educational programs have focused on young children, with educational programs that intend to reach large audiences using mass media (Martinez & Porter, 2004). This is consistent with recommendations made by researchers to target vulnerable road users. Essentially, in order to be deemed effective, educational programs need to target vulnerable road users (e.g., children and the elderly; Hartman et al., 2007).

To determine the type and the target of educational campaigns, Hartman Kweon, Lynn, and Roettig (2007) conducted a national survey of state government pedestrian coordinators. A
total of 28 pedestrian coordinators completed the survey for a response percentage of 55%. More than two-thirds of the respondents indicated the state Department of Transportation was in charge of pedestrian safety education. The primary target of respondents was young children (62%), with less than 20% targeting the elderly (Hartman et al., 2007).

Information and safety campaigns have been used frequently to increase the occurrence of safety-related behavior. Kourtellis, Cruse, and Lin (2015) studied the influence of a Florida Department of Transportation pedestrian safety-awareness campaign. They surveyed 639 pedestrians near intersections with marked crosswalks across ten counties in Florida; however, only 18% had seen messages associated with the campaign. Not only were most pedestrians unaware of the campaign, the intervention failed to produce any meaningful change in crossing behavior. When comparing those pedestrians aware of the campaign to those who were unaware, there was no difference in the percentage of individuals crossing illegally rather than in a crosswalk (Kourtellis, Cruse, & Lin, 2015).

As an alternative to a typical mass-media approach, Sarkar, Van Houten, and Moffatt (1999) suggest editing driver-training manuals to include significant portions on pedestrian-vehicle interactions. The authors noted that no driver-training manual provides information on interactions with pedestrians, as they primarily focus on knowledge of road laws. Sarkar, Van Houten, and Moffatt (1999) proposed that editing driver-training manuals would be a valuable approach to maximizing driver education. Unfortunately, this approach has yet to be tested.

Another study in Florida by Zegeer et al. (2008) investigated the impact of 14 educational campaigns implemented from 1999 to 2003. Each campaign targeted a different group, including children, the elderly, and immigrants. The materials included informational handouts, workshops, and activities. A multivariate time-series analysis demonstrated the behavior of adult
and elderly users did not change, despite the campaigns targeting adults. The only behavior-change success was with young children (Zegeer et al., 2008).

One of the most widely recognized values of educational campaigns targeting pedestrians is that they help to change child behavior and reduce negative outcomes to children. One prominent example of this research was conducted by Gates, Datta, Savolainen, and Buck (2009). A total of 16 schools were targeted in Detroit, Michigan from 2008 to 2009. Each school underwent an educational campaign to teach the children appropriate street-crossing behavior. The authors reported the children had an increase in their correct responses to a written pre and post-test by less than 25%. In addition, the overall violations of proper crossing behavior decreased less than 5% (Gates, Datta, Savolainen, & Buck, 2009). The authors concluded that, educational programs show promise at increasing comprehension and appropriate crossing behavior due to the statistical significance of their findings. However, it should be noted that a 5% change is a very small change and may not be recognized as being practically or clinically significant.

The conclusion drawn by Gates, Datta, Savolainen, and Buck (2009), that education programs are a promising way to increase pedestrian safety, is questioned in scientific works. For instance, a commentary written on popularized pedestrian-safety ideas specifically refuted claims of strong evidence for educational campaigns leading to positive behavioral change and decreased pedestrian-vehicle collisions (O’Neill, Mohan, Breen, Koonstra, Mackay, Roberts, & Ryan, 2002). The claim has been thoroughly investigated by a comprehensive review of pedestrian education programs. Duperrex, Bunn, and Roberts (2002) conducted a review of 14 articles covering randomized controlled trials of pedestrian educational programs from 1980 to 2000. The focus of the review was not on studies with children as subjects. Yet, only one article
included subjects over the age of 13. This review concluded that evidence of the success of educational campaign varied between programs. Thus, the overall evidence was weak, even for successful campaigns. The authors also made note of successful campaigns being over saturated in the literature due to publication bias (Duperrex, Bunn, & Roberts, 2002). In other words, the outlook of educational campaigns are likely even more dismal than reflected in the research literature.

A meta-analysis by Schwebel, Barton, Shen, Wells, Bogar, Heath, and McCullough (2014) included 19 articles that reported 25 studies on behavioral interventions for child pedestrian safety. The meta-analysis concluded that behavioral interventions improve children’s behavior over both the short and long-term, but they reported the evidence was weak and had significant limitations, such as the inclusion of simulation studies.

In summary, a lack of evidence exists for the efficacy of safety-related education (e.g., Zegeer et al, 2008). There is some promise for educating young children, with evidence suggesting moderate success (e.g., Gates, Datta, Savolainen, & Buck, 2009). Since children seem to be the only viable research-based target for an educational campaign, educational approaches will be very slow to have a significant impact on the vehicle-yielding issue. Although it is important to educate youth about roadway hazards, education should not be viewed as a panacea for increasing yield compliance.

**Improving Infrastructure (“Engineering”)**

Roadway design has always been considered a core component of promoting safety and limiting vehicle collisions. Unfortunately, roadway design and construction only provide minimal consideration for pedestrians, and in turn this increases the risk of pedestrian-vehicle collision (Retting, Ferguson, & McCartt, 2003). Several main factors identified as contributors to
pedestrian-vehicle collisions have readily available engineering solutions. In particular, low visibility caused by lighting conditions and pedestrians walking on roadways where no sidewalks are available are recognized as contributing factors to pedestrian-vehicle collisions (Spainhour, Wootton, Sobanjo, & Brady, 2006). A proposed solution for the former is to increase visibility by installing appropriate lighting apparatus. Of course, the latter can be solved by constructing sidewalks. More complex issues require research to identify the best solution. With this mindset, infrastructure solutions investigate the positive impact of infrastructure changes on pedestrian-vehicle outcomes.

Infrastructure solutions for pedestrian safety often use a range of outcomes to evaluate intervention impact. By far, the most popular outcome measure is pedestrian-vehicle collisions (Turner, Fitzpatrick, Brewer, & Park, 2006). Other outcome measures include driver yield behavior, pedestrian-vehicle conflict, braking distance, vehicle speed, and pedestrian behavior (Turner, Fitzpatrick, Brewer, & Park, 2006). The outcome of driver yield behavior is of primary interest for the current study and is covered in the following review of infrastructure solutions. For a comprehensive review of studies on infrastructure changes for pedestrian safety see Retting, Ferguson, and McCartt (2003).

The impact of yield signs has been thoroughly investigated. Research by Ellis, Van Houten, and Kim (2007) showed a 21% to 34% increase in yielding behavior above baseline after installation of yield signs. Four different placements of yield signs were tested: 1) directly at the crosswalk, 2) 20 feet before the crosswalk, 3) 40 feet before the crosswalk, and 4) a combination of the three sign placements. Each sign placement was systematically rotated to control for potential confounds of the site. One weakness of this study is that it did not control for potential order effects (Ellis, Van Houten, & Kim, 2007).
The study found that drivers yielding for pedestrians significantly increased under all sign placements, but some placements performed better than others. More specifically, when the sign was placed right at the crosswalk or placed at all three distances, driver yield behavior was significantly greater when compared to placing a sign far from the crosswalk. For the best placement conditions, yield behavior increased by nearly 40% over baseline. The study concluded that placing a sign that reminded drivers to yield to pedestrians is an effective prompt to increase driver yielding, especially when the sign is placed near the crosswalk (Ellis, Van Houten, & Kim, 2007).

Yield-sign distance was also investigated by Gedafa, Kaemingk, Mager, Pape, Tupa, and Bohan (2014) who tested five different treatment conditions by varying the distance of the yield sign from the crosswalk. The nearest distance to the crosswalk was 0 feet, directly at the crosswalk. The other four conditions were at 30 feet intervals (30, 60, 90, and 120 feet). A total of eight different test sites in North Dakota were tested with all five treatment conditions as well as a control period. To determine treatment effectiveness, driver yielding was measured via field observations (Gedafa et al., 2014). The research conclusions aligned with those of Ellis, Van Houten, and Kim (2007). Any yield sign demonstrated increased yielding, but the highest increase in vehicle yielding was found when a yield sign was placed directly at the crosswalk.

A different type of sign interventions was investigated by Abdulsattar, Tarawneh, McCoy, and Kachman (1996). The research team placed a sign informing drivers they must yield to pedestrians when turning. The sign was implemented at twelve marked crosswalks. To measure effectiveness, the number of pedestrian-vehicle conflicts was recorded. A pedestrian-vehicle conflict occurred anytime a pedestrian or vehicle failed to concede appropriate right-of-way (Abdulsattar, Tarawneh, McCoy, & Kachman, 1996). In this case, vehicles must always
concede right-of-way. In essence, the research team observed vehicle failure to yield, and yield compliance. The study found turning conflicts were reduced 15% to 65% by the signs, leading the authors to conclude that yield signs should be considered essential for intersections where vehicles turn across crosswalks (Abdulsattar, Tarawneh, McCoy, & Kachman, 1996).

Research has clearly demonstrated the value of placing yield signs and pedestrian markers. Huang, Zegeer, and Nossi (2000) extended their research findings on sign placement to test different sign mediums and language. They tested three sign mediums with two types of messages. The first message reminded drivers of the state law to yield. These messages were placed on an overhead sign as well as on traffic cones. The second message simply demanded drivers stop for pedestrians with the message: “Stop for Pedestrians in Crosswalk”. The three different treatments were applied in unique locations around the country in Arizona, New York, Oregon, and Washington. Each state only received one type of treatment.

The results demonstrated the legal messages on overhead signs and cones were effective at increasing yield compliance. The second message was not effective (Huang, Zegeer, & Nossi, 2000). In addition, the researchers considered the cost of each device with the signal cones being ten times cheaper than the overhead signs and concluded that signal cones are most cost effective. However, the researchers caution that engineering solutions be combined with enforcement and educational interventions for the best results (Huang, Zegeer, & Nossi, 2000).

Engineering-focused studies have investigated different types of roadway signals, including traffic lights, warning lights, and traffic-calming measures. To evaluate pedestrian-oriented traffic signals, Vasudevan, Pulugurtha, Nambisan, and Dangeti (2011) tested three different signals: 1) a pedestrian call button with activation confirmation, 2) a countdown signal with animated eyes, and 3) pedestrian activated yellow signals. Each type of signal was
implemented at select sites in Las Vegas, Nevada (Vasudevan, Pulugurtha, Nambisan, & Dangeti, 2011). To evaluate the effectiveness of the three signals, pedestrian and driver behavioral observations were recorded before and after the signals were implemented. The results indicated pedestrian yielding increased as a function of the signals. However, driver yield compliance was not significantly influenced by the signals (Vasudevan, Pulugurtha, Nambisan, & Dangeti, 2011).

**Lighting interventions.** Low visibility is an issue commonly reported in pedestrian-vehicle collisions. Nambisan, Pulugurtha, Vasudevan, Dangeti, and Virupaksha (2009) installed pedestrian-detection devices, paired with smart lighting, to increase roadway visibility. The devices were installed in Las Vegas, Nevada. Behavioral observations of pedestrian safety behavior and driver yielding were collected before and after installation. The results indicated a statistically significant increase in driver yield compliance, rising from 22% at pre-treatment to 35% during post-treatment.

Pedestrian behaviors were not as conclusive. The sample reported 100% compliance before and after the intervention for key pedestrian safety behaviors. It is unclear if significant increases would occur in samples with low levels of pre-treatment pedestrian-safety behaviors. The authors concluded that smart lighting helps to alert drivers to potential conflicts and increased yield compliance, and recommended pairing of smart lighting with other interventions (Nambisan, et al., 2009).

Foster, Monsere, and Carlos (2014) observed two intersections with a specialized alert signal – a rectangular rapid flash beacon – to determine driver yielding. A total of 62 hours of video data were recorded and analyzed for driver yield behavior. Average driver yield compliance of over 90% was reported. The authors compared situations where the beacon was
active to when it was not activated and found a reduction in yield compliance when the beacon was not active (Foster, Monsere, & Carlos, 2014). The study was limited by the fact that the beacon was active in more than 85% of all trials providing little data for comparison.

**Traffic signals.** Many studies have focused on testing the effectiveness of a single traffic intervention. These studies helped to determine if a countermeasure is effective. It is also important to study which countermeasures are most effective when compared to other countermeasures. Turner, Fitzpatrick, Brewer, and Park (2006) collected video data from 42 locations spread across seven states in the U.S. For these studies, baseline yield behavior was not established and the authors acknowledged this weakness due to the infrastructure previously being in place prior to initiation of the study. The results indicated intersections with traffic signals had the highest proportion of driver yield behavior, all exceeding 95% of pedestrian crossing events (Turner, Fitzpatrick, Brewer, & Park, 2006), and median islands had the lowest levels of drivers yielding to pedestrians (29%). In this study, sites with signs had results ranging from 20% to 91% of drivers yielding to pedestrians (Turner, Fitzpatrick, Brewer, & Park, 2006). The authors concluded that traffic signals are a valuable tool for increasing driver yielding to pedestrians reducing pedestrian-vehicle collisions (Turner, Fitzpatrick, Brewer, & Park, 2006).

**Traffic calming.** Traffic-calming measures are investigated by engineers with regard to increasing yield compliance via slowing traffic. Huang and Cynecki (2000) implemented three different traffic-calming measures: bulbouts, raised intersections, and refuge islands. A bulbout reduces the number of available lanes for drivers at an intersections, thereby reducing the distance and time a pedestrian spends in the street.

These calming measures were constructed at a total of ten sites in Massachusetts, California, Oregon, and Washington. Video data were obtained before and after the calming
measures were installed to evaluate the impact on driver yielding. The videos were then coded for driver yield compliance. Results indicate that none of the traffic calming measures had the desired effect. For some interventions, a promising increase in yield behavior was observed, but conclusions could not be drawn due to low sample sizes and non-significant differences of yielding for different traffic-calming measures. Only the bulbouts in Washington had a large enough sample size and driver yielding decreased, but the decrease was not statistically significant (Huang & Cynecki, 2000).

Pulugurtha, Vasudevan, Nambisan, and Dangeti (2012) tested the impact of four different engineering countermeasures with a pre-treatment/post-treatment study at eight locations in Las Vegas, Nevada. The engineering countermeasures were: high-visibility crosswalks, median refuges, Danish offsets, and pedestrian channels (Pulugurtha, Vasudevan, Nambisan, & Dangeti, 2012). Trained behavioral observers measured driver yielding to pedestrians before and after the devices were installed. The results indicated high-visibility crosswalks, median refuge sites, and Danish offsets significantly increased driver yield compliance. All three countermeasures experienced compliance increases surpassing 20%, but none exceeded 25%. The authors concluded that infrastructure-based countermeasures are effective at increasing driver yield compliance (Pulugurtha, Vasudevan, Nambisan, & Dangeti, 2012).

When working to improve pedestrian safety, improvements in infrastructure are effective solutions. These solutions include traffic signals, yield signs, and traffic-calming measures. Studies report extremely promising outcomes when the infrastructure is changed to accommodate pedestrians. Although they are generally effective, infrastructure-based interventions tend to have high costs. It is also clear that funding to build new infrastructure is not always available and other solutions may be more practical.
Combining the Three “Es”: A Holistic Approach

Dunckel, Haynes, Conklin, Sharp, and Cohen (2014) implemented a large-scale holistic data-driven approach to enhance yield compliance. They first identified ten areas with high levels of pedestrian-vehicle collisions. In each area they conducted safety audits to determine the most appropriate types of engineering, education, and enforcement interventions per site.

Engineering efforts primarily focused on traffic-calming interventions. Which aimed to reduce vehicle speed. For this intervention, teams conducted pedestrian road-safety audits to determine appropriate countermeasures in each area. The teams recommended different countermeasures for improving pedestrian safety, such as: installing countdown signals, upgrading lighting fixtures to improve visibility, updating and improving sidewalks, and building fences to prevent mid-block pedestrian crossing. Unique recommendations were made for each area. A mid-block pedestrian crossing is most commonly defined as a pedestrian crossing between two marked crosswalks (Dunckel, Haynes, Conklin, Sharp, & Cohen, 2014).

Education efforts also focused on a targeted approach. By considering demographics and other person-oriented variables, the researchers were able to determine the most appropriate educational interventions for each area. For example, in one area it was determined that a high percentage of the population were originally from countries where pedestrian and vehicle traffic commingle on a regular basis. To increase yield compliance, a set of multilingual markers were placed mid-block to prompt pedestrians not to cross. In addition, a set of trained individuals intercepted individuals who attempted to cross and discussed the appropriate crossing location in the pedestrian's native language. The approach was paired with educational fliers and events hosted to improve pedestrian knowledge of appropriate crossing behavior. This is one example
of how unique educational campaigns were created based on the needs of each area (Dunckel, Haynes, Conklin, Sharp, & Cohen, 2014).

Enforcement efforts were more generalized in application across all ten areas. Many enforcement interventions focus on pedestrians or drivers. In contrast, Dunckel, Haynes, Conklin, Sharp, and Cohen (2014) worked with police officers to target drivers and pedestrians. They provided citations and warnings to individuals who failed to abide by laws governing safe yielding behavior (Dunckel, Haynes, Conklin, Sharp, & Cohen, 2014). Combining enforcement, education, and engineering, the holistic approach appeared extremely successful in the targeted areas, reducing pedestrian-vehicle collisions by 43%. In fact, despite only targeting ten areas with high incident of pedestrian-vehicle collisions, pedestrian-vehicle collisions were reduced countywide by 7% (Dunckel, Haynes, Conklin, Sharp, & Cohen, 2014).

No formal limitations were reported in the publication. The study had three primary weaknesses. First, post-treatment data were not adequately reported, despite mention of collection of post treatment data. This raises questions of the long-term effects of the holistic intervention. An important note is the study was ongoing at the time of the document and post-treatment data may be available at a later point. Second, the study did not measure driver or pedestrian yield behavior. Instead, they focused on collision reduction, which had a limited sample size and was linked to the interventions by other variables, such as yield behavior and vehicle speed. Currently, the authors are conducting follow-up research involving observations of driver yielding behavior. Third, since the holistic approach combined all three “Es” simultaneously, the individual contribution of a single “E” cannot be determined. Plus, the education component seems quite costly.
In conclusion, the holistic three “Es” approach provided several valuable takeaways. The success of the intervention shows significant promise for a holistic approach to reduce pedestrian-vehicle collisions. The main drawback of the holistic approach is the cost of implementation. It requires significant resources to be dedicated to the analysis of problem areas and to create targeted educational and engineering initiatives. The subsequent initiatives will each require significant capital investment. Due to the high cost, it is unlikely a holistic approach can be successfully implemented on a large scale.

**Vehicles Solutions**

Since the introduction of anti-lock braking systems in the late 1970s and traction-control systems in late 1980s (Gu, 2012), vehicle-safety technology has been at the forefront of innovation to improve transportation safety, including reducing pedestrian-vehicle collisions. Standard in-vehicle airbag technology is used to protect vehicle occupants. A meta-analysis of 22 studies examining fatality risk with airbags found a 22% reduction in fatalities for vehicles equipped with airbags when safety belts were worn appropriately (Høye, 2010). Recently, the concept of airbags is being expanded to protect pedestrians during pedestrian-vehicle collisions. Choi, Oh, Yun, and Park (2014) tested a new device called a pedestrian protection airbag system. The system works by deploying an external airbag to reduce the impact on the pedestrian from landing on or striking an equipped vehicle. The experiment with crash-test dummies as participants showed great promise with expected reduction between 30% and 69% of all pedestrian fatalities.

Current technology is even more advanced. A common example on vehicles today is assisted-braking technology, which begins braking when a threat is detected, even if the human operator has not engaged the brake (Bishop, 2005). Assisted braking is just one of a myriad of
technology interventions that are becoming commonplace on motor vehicles as the move toward fully autonomous vehicles continues. A number of other technologies, including lane-departure warning, lane-change support, side-collision warning, and blind-spot detection are all reviewed by Bishop (2005). These technologies are designed to aid drivers in all situations and are especially important for minimizing pedestrian-vehicle collisions. In many instances of pedestrian-vehicle collisions, drivers report not seeing the pedestrian (Retting, Ferguson, & McCartt, 2003).

Research on autonomous features revealed limitations of current technology. One of the primary concerns is that vehicle systems with autonomous features, such as braking, need to work under all speed and lighting conditions (Jermakian & Zuby, 2011). This is considered one of the key areas for improving autonomous-vehicle technology (Jermakian & Zuby, 2011). The research on autonomous vehicles has grown exponentially in recent years (Gupta, Vasardani, & Winter, 2016). As research progresses, these issues are quickly being addressed and remedied by manufacturers constructing prototypes and conducting road tests (Keferböck & Riener, 2015).

**Autonomous Vehicles**

All vehicle upgrades and technological advances hold benefits. Fully autonomous vehicles have the potential to address a plethora of major safety issues. When considering the two major issues discussed here, speed and yield compliance, autonomous vehicles are readily able to solve both. Speed can be controlled by programming maximum speeds based on geolocation and sign detection (Milanés, Naranjo, González, Alonso, & de Pedro, 2008). Autonomous vehicles also offer the opportunity for optimal yield compliance (Dickmanns, 2007).
With autonomous vehicles, pedestrian-vehicle collisions can essentially be nullified, especially considering the fact that more than 90% of traffic incidents are related to human error (Treat et al., 1979). Therefore, removing the human element should astronomically reduce the number of pedestrian-vehicle collisions. However, as mentioned previously, safety is not the only area of pedestrian-safety research, transportation efficiency is also critical. In this case, as yield compliance increases and speed decreases, delay times at un-signalized crosswalks will increase (Havard & Willis, 2012; Huang & Cynecki, 2000).

Rather than simply optimizing safety, it is necessary to also take transportation efficiency into consideration. Implementing an inefficient system would increase traffic delays and harmful emissions. Understanding how pedestrians and drivers communicate their intentions to one another is critical when balancing the important issues of safety and efficiency. Research shows that communication between pedestrians and drivers is an effective safety countermeasure (Zhuang & Wu, 2014). In general, such communication is non-verbal, such as hand signals (Zhuang & Wu, 2014), body language (Quintero, Parra, Llorca, & Sotelo, 2014), or distance to crosswalk (Crowley-Koch, Van Houten, & Lim, 2011).

To maximize safety and efficiency, autonomous vehicles must be able to assess and respond appropriately to pedestrian attempts at communication. Furthermore, they must be able to communicate the vehicle’s intentions to the pedestrian. Currently, research on autonomous vehicles is notably devoid of any consideration regarding interactions with dynamic outside forces, such as pedestrians. To illustrate this point, one of the most recent textbooks relating automated vehicles to driver safety dedicates more than 600 pages to explaining autonomous technology and its impact on safety, but said nothing about human perceptions and interaction with driverless vehicles (Watzenig & Horn, 2017).
The author's extensive literature search revealed only two documents that dealt directly with this issue. A study design proposed by Keferböck and Riener (2015) intends to study human communication with autonomous vehicles using virtual reality. The other research, a conference presentation, investigated driver behavior on a closed track with staged pedestrian crossings in Germany. Neither of these studies provided data from real-world scenarios as part of the interactions were staged. Thus, the current study was designed to formalize pedestrian and driver communication by studying naturalistic pedestrian-vehicle encounters. The results will be used to provide recommendations for further study of autonomous vehicles.

Methodology

Design

This study followed a three-way factorial design to explore tacit communication between vehicles and pedestrians during high-density pedestrian traffic. Each of the three variables from the three-way factorial had two levels, providing a 2x2x2 full factorial study design. The three independent variables were: 1) driving context, 2) driving route, and 3) narration. The two levels of driving context were driving an unmodified vehicle, and driving while the vehicle was equipped with a three signs reading "self-driving vehicle". Driving route includes one route primarily covering un-signalized crosswalks, while the second rout primarily covered signalized crosswalks. The narration condition included driving the vehicle with no special instructions and driving the vehicle while performing a think-aloud protocol. A graphic representation of the study design is depicted in Figure 1.

Experimental Equipment

The field study used a 2008 Cadillac STS. Data collection occurred via access to the Controller Area Network (CAN bus) and a data-collection instrument for naturalistic driving data.
collection, known as a mini-data acquisition system (mini DAS, visual provided in Figure 2). The CAN bus is the car’s central computer and provides the ability to tap into turn-signal use, accelerator pressing, brake pressing, and vehicle speed. The mini DAS is a compact data-collection instrument for driving research. It attaches easily to the vehicle windshield (a photo of the mini DAS attached to the experimental vehicle is provided in Figure 3) providing continuous forward video of the roadway, along with video of the driver via an internal facing camera (a photo of the two views is provided for reference in Figure 4).

On top of these two streams of video the mini DAS collects: audio recording, global position (GPS), accelerometer, gyroscope, and magnetometer. Furthermore, the system is capable of flagging events of interest by pressing a button on the mini DAS or by pressing a button via the proprietary software called Soley.

**Participants**

A total of 11 drivers were recruited – six females and five males. Due to an equipment failure, one female driver had incomplete data and therefore the final sample consists of five females and five males. The drivers were recruited by gender to account for possible gender differences in driving behavior.

**Recruitment**

Participants were recruited from the Center for Applied Behavior Systems (CABS), a research center in the Department of Psychology at Virginia Tech. The experimenter met with CABS members and provided information about participation. Recruitment followed a script provided in Appendix A.
Compensation

Participants received research credit for their participation. One hour of research credit was awarded for completing the prescreening, regardless of selection in the study. Participants received an additional 1.5 hours of research credit for each driving session, up to a maximum of eight driving sessions. This compensation allowed for half an hour of travel to and from the driving site, half an hour for preparation and instruction, and half an hour of driving. No participants selected to withdraw, which was voluntary and acceptable at any time.

Procedures

Participant screening. Individuals who consented to participate completed a screening form and vision test to ensure they met the study inclusion criteria. The participants were required to meet all of the criteria listed on the screening form provided in Appendix B. Appropriate vision was tested using a standard Snellen eye chart. Corrected/uncorrected vision of 20/40 in each eye was required to participate. After the vision screening, participants were given a paper and pencil survey that included demographic questions and basic driving history of recent moving violations and crash history (see Appendix C for a copy of the demographic survey).

Practice Drive

Before conducting the experimental driving sessions, participants drove the experimental vehicle near the experimental driving routes. The practice route is provided in Appendix D. The practice drive was an opportunity to become more comfortable driving the experimental vehicle.

Data Collection Sessions

Each participant drove in eight driving sessions, one session for each level of the 2x2x2 design. Ordering effects were minimized by having all participants drive both routes under each
driving context without performing the think-aloud protocol. More specifically, the first four
drives comprised no narration with the routes and driving context randomized. Then, the driver
performed the same order for the routes and driving context while performing the narration
protocol. This selection was made because performing without the think-aloud protocol is
unlikely to affect performance in the think-aloud protocol. However, if the think-aloud protocol
had been introduced first, the participants may have experienced a carryover into the other
drives.

For the duration of each driving session, the participant was accompanied by the
experimenter. At the beginning of each session, the experimenter oriented the participant to basic
vehicle-specific elements adjustable for comfort and safe operation of the vehicle. These features
include the mirrors, seat, and steering wheel. Prior to each drive, the experimenter informed the
participant to refrain from electronic device use and follow all traffic laws (e.g., safety-belt use
while driving), including obeying all traffic signs (e.g., following posted speed limits). To begin
the drive, the experimenter instructed the participant to drive a predetermined route. Necessary
information and instructions regarding the experimental conditions was provided. Upon
completion of a route, the participant was offered a short break before resuming to complete the
experimental session.

**Driving context.** The variable of driving context had two levels and each participant
drove under both contexts crossed with all other independent variables. For the first level
participants drove the vehicle with no modification. In the second level, participants drove the
vehicle with signage on each side door and the front hood that read “self-driving vehicle”. This
manipulation provided the research team the ability to investigate differences between actions
toward vehicles that were believed to be autonomous. See Figure 5 for a photograph of the
experimental vehicle equipped with signs. The related instructions for participants are provided in Appendix E.

**Driving Route.** Each participant drove two different routes per condition of the other variables. The two routes were designed to encompass different areas with different types of crosswalks. The first route included areas on a university campus near classroom buildings and high traffic areas between classroom buildings. This route was characterized by a large number of crosswalks where pedestrians primarily have the right-of-way (i.e., crosswalks without signals).

The second route included areas immediately beyond the university campus and was characterized by crosswalks where vehicles primarily have the right-of-way (i.e., signaled crosswalks). Both routes were designed to provide a large number of opportunities to interact with pedestrian crossings (See Appendix F for the two experimental routes).

**Narration.** While driving, participants were either given no special instructions or they were given instructions to follow a think-aloud protocol (Charters, 2003). During the think-aloud protocol, participants provided narration of whatever they were thinking about while reacting to the external stimuli. The think-aloud instructions requested the participants to verbalize whatever came into their mind when their driving was influenced by outside factors. For example, if the driver altered his/her behavior in response to a pedestrian entering the roadway, s/he was requested to talk through the decision. The think-aloud protocol provided a small window into the participant’s decision-making processes during pedestrian interactions (Charters, 2003).

**Data Retrieval**

Prior to each driving session, the DAS was inspected to ensure all sensors were working properly. At the end of the day the hard drives were returned to the Virginia Tech Transportation
Institute (VTTI) and the data were downloaded to a secure server. Each file on the hard drive was inspected to verify the data had been collected.

**Data Reduction**

**Quality control.** To maintain quality control, the data were reviewed in Hawkeye, a proprietary data-reduction software that syncs video and audio data with measures from the CAN bus and was used to verify correct synchronization of video-to-sensor and auditory data. See Figure 6 for an example of the Hawkeye data-reduction window. The quality-control protocol ensured the data coded for analysis were collected properly.

**Operationalization for events of interest.** An event of interest was operationally defined for two categories of crosswalk users: pedestrians and human-propelled vehicles. The operational definition for pedestrians: an event begins when a pedestrian is less than or equal to ten feet from a crosswalk while the experimental vehicle is approximately 50 feet from the crosswalk; the event stops when the vehicle has passed the crosswalk. The operational definition for human-propelled vehicles: an event begins when a human-propelled vehicle is less than or equal to 30 feet from a crosswalk while the experimental vehicle is approximately 50 feet from the crosswalk; the event stops when the vehicle has passed the crosswalk.

To arrive at the operational definitions provided for the study, the start and end-point triggers of an event of interest were defined. In this case, the start trigger was defined for two different groups who regularly cross the road. The first group consisted of pedestrians. The second group consisted of a pedestrian crossing while operating a human-propelled vehicle (e.g., a pedal cyclist or skateboard).

To determine the activator for an event, each definition was based on the crosswalk user having a realistic ability of reaching the crosswalk during the time it would take the experimental
vehicle to come to a complete stop under normal driving conditions. Creating an event start activator for this definition required defining an interaction distance where the experimental vehicle had a reasonable ability to stop and the pedestrian or human propelled vehicle had a reasonable chance of entering the crosswalk before the experimental vehicle passes. For human-propelled vehicles, pedal cyclists were able to achieve the greatest speed and were used as a benchmark.

To determine the distance of the experimental vehicle from a crosswalk, the distance it would take the vehicle to come to a complete stop was calculated. This distance was calculated by taking the total distance it would take the vehicle to make a complete stop and adding the distance the car would travel during a standardized amount of time to represent human reaction time. This calculation was made by the following formula: \[ d_{stop} = \frac{v_0^2}{2g} + d_{reaction}. \]

The formula for \( d_{stop} \) was \( d_{stop} = \frac{v_0^2}{2g}. \) Where \( d_{stop} \) was the stopping distance, \( v_0 \) was the initial velocity in f/s, \( g \) was the constant acceleration due to gravity, and \( \mu \) was the coefficient of friction (Parker, 2004). The formula for \( d_{reaction} \) was \( d_{reaction} = v_0 \cdot t_{reaction}. \) Where \( d_{reaction} \) represented reaction distance and \( t_{reaction} \) the reaction time in seconds.

The equation for stopping distance was simplified using the constant .9 in place of \( \mu \) for friction under normal conditions (Parker, 2004) and 32 feet per second for gravity \( (g) \). It was simplified as \( d_{stop} = \frac{v_0^2}{2 \cdot 32 \cdot 0.9} = \frac{v_0^2}{57.6}. \) The equation for reaction distance was simplified using the constant .75 seconds for reaction time based on research by Mohebbi, Gray, and Tan (2009). Thus, \( d_{reaction} = v_0 \cdot 0.75 \).

To compute the distance for our operational definition, plug in the maximum speed of our vehicle to determine the upper-bound stopping distance. In this case, the highest speed limit
during either route is 25 miles per hour or 36.67 feet per second. 
\[ V_0 = \frac{36.67^2}{57.6} = \frac{1344.69}{57.6} = 23.4 \] feet. Adding the stopping distance to the distance the vehicle will travel during driver reaction time provided the total stopping distance. Here, 
\[ d = .75(36.67) = 27.5 \] feet. The final step involved adding the stopping distance to the reaction distance for a total of 50.9 feet. For convenience in identification this was rounded to 50 feet.

To determine the upper-bound distance a pedestrian can be from the crosswalk to be considered having a realistic ability to enter the crosswalk during the time it takes the experimental vehicle to stop was determined by multiplying the normal walking speed of a pedestrian by the time it takes a car to stop. The time it will take the car to stop from initial breaking was calculated using the formula 
\[ V_0 = \frac{2d}{2v + V_0} \] In this instance, \( t \) was stopping time, \( v \) was the final velocity or 0, \( V_0 \) was our initial velocity (36.67 feet per second), and \( d \) was the stopping distance (23.4 feet).

To solve for stopping time, the required values are plugged into the formula 
\[ \frac{2(23.4)}{0 + 36.67} = \frac{46.8}{36.67} = 1.3 \] seconds. To calculate the total time the reaction time of .75 seconds was added, for a total rounded stopping time of 2.1 seconds. To determine the distance from a crosswalk for a pedestrian the total vehicle stopping time was multiplied by the normal walking speed of a pedestrian. The normal walking speed of a pedestrian of 1.4 meters per second was used which converts to 4.6 feet per second (Browning, Baker, Herron, & Kram, 2006). Multiplying 2.1 by 4.6 yielded a distance of 9.7 feet. For convenience this was rounded to ten feet.

The procedure for pedestrians was repeated for human-propelled vehicles using pedal cyclists as a benchmark due to their increased capacity for speed. The estimate of the average
pedal cyclist speed of 15.5 kilometers per hour was used (Copenhagen City of Cyclists: Bicycle
Account, 2012). The speed of 15.5 kilometers per hour was converted to 14.1 feet per second.
Multiplying 14.1 by 2.1 is 29.6 feet. This was rounded to 30 feet for convenience.

Thus, for pedestrians, the operational definition for an event starting was a pedestrian
who was less than or equal to ten feet from a crosswalk while the experimental vehicle was
approximately 50 feet from the crosswalk. For human-propelled vehicles, the operational
definition for an "event start" was a human-propelled vehicle that was less than or equal to 30
feet from a crosswalk while the experimental vehicle was approximately 50 feet from the
crosswalk.

The event-stop activator was considered the moment when the experimental vehicle
could no longer interact with any pedestrian or human-propelled vehicle. The event stop
occurred once the experimental vehicle passed the crosswalk. Thus, the final operational
definitions were: 1) for pedestrians: an event began when a pedestrian is less than or equal to ten
feet from a crosswalk while the experimental vehicle is approximately 50 feet from the
crosswalk, and the event stopped when the vehicle passes the crosswalk, and 2) for human-
propelled vehicles: an event begins when a human-propelled vehicle is less than or equal to 30
feet from a crosswalk while the experimental vehicle is approximately 50 feet from the
crosswalk, and the event stops when the vehicle passes the crosswalk.

**Event-of-interest flagging.** Events of interest were flagged by the experimenter during
driving sessions (as described above, using the button on the DAS or the button in Soley). Flags
were applied when an event occurred based on the operational definition provided. In an effort to
make the definition more applicable during driving sessions, the vehicle distance from the
crosswalk (50 feet) was converted to car lengths. Since the car is 16.7 feet long, it equates to 2.99
car lengths. This was rounded to three car lengths for ease of implementation during driving sessions. The distance between the pedestrians and the crosswalk is about one car length. Flagged events were reviewed in Hawkeye for further analysis.

**Flag Validation.** The data set included valid (true positives) and invalid (false positives) flags. To verify flags, the experimenter reviewed each flagged event. Events that fit the operational definition were considered valid flags, and events that did not match were considered invalid. Invalid flags (false positives) were excluded from additional data reduction.

**Event coding.** Valid events were marked and inserted into the DB2 database. A guide was used when evaluating event start (See Appendix H). Each event had a defined beginning and endpoint based on the definition outlined in the methodology. The data reductionists used the Hawkeye software to select and code each event following the reduction protocol outlined in the data directory, that is, a document that provides a systematic walkthrough for coding events.

Coding reliability was checked with a sample of 100 events randomly selected and coded by two independent data reductionists. Reliability was coded as a percent-agreement statistic (Lombard, Snyder-Duch, & Bracken, 2002) where the number of exact agreements was divided by the total number of events coded for reliability. Event reliabilities ranged from a low of 56% to a high of 100% agreement. The percent agreement for each variable can be found in Table 1. In general, 80% is an accepted cut-off for acceptable reliability (Neuendorf, 2002). In some cases, lower reliability is acceptable for exploratory research (Lombard, Snyder-Duch, & Bracken, 2002). Nearly all variables (43/45) had reliability over 80%.

In this data set, each variable with low percent agreement was investigated for issues related to the reductionist training. The variable with the lowest percent agreement (56%) was pedestrian path obstruction allowed for multiple selections. In this case, a majority of cases with
disagreement were due to the coding of a pedestrian as a path obstruction when a pedestrian was in the opposite side of the path, but not necessarily obstructing the path. When another pedestrian as a path obstruction was removed from the coding scheme, percent agreement of this variable increased to 84%.

The only other variable with an interrater agreement below 80% was pedestrian assertiveness. By nature, this variable was subjective due to it being an evaluation made by the data reductionist of the pedestrian assertiveness. In general, the cases with disagreement were within one level on the scale provided which indicated disagreement was not extreme (e.g., rater one selected 5 and rater two selected 6). Since the low interrater agreement did not appear to be due to training it was not modified in any way before analysis.

Data Directory. The data directory (See Appendix I) was adapted for the current study from previous human-machine interaction research performed by the Virginia Tech Transportation Institute (VTTI). Current a-priori variables were included based on guidance from research covering pedestrian and driver behavior. Overall, the data directory separated questions based on two primary categories of variables – fixed and flexible. Fixed variables were stable throughout the event or captured only at the event start. Examples of fixed variables included (but were not limited to): infrastructure, vehicle speed at event start, posted speed limit, and weather. Flexible variables could change throughout the event or were unique to a single pedestrian, such as pedestrian assertiveness, pedestrian and driver gestures, and pedestrian demographic variables. Data reductionists were instructed to transcribe the driver’s verbal utterance relating to the study. Throughout coding, an issue with sound quality prevented accurate transcription of driver utterances.
The research literature was searched for relevant factors for variable coding. The primary outcome of interest was driver-yield behavior. The data directory included a measure of driver-yield behavior relating to each event. The following variables were investigated as predictors of driver yield compliance. Different types of infrastructure are discussed throughout the literature as impacting driver and pedestrian behavior. For example, Turner, Fitzpatrick, Brewer, and Park (2006) investigated factors related to driver-yield compliance and found more travel lanes were associated with lower-yield compliance. The current study included VTTI’s standard roadway and infrastructure variables that are collected across studies at VTTI. These variables covered how travel was divided, the number of contiguous travel lanes, the number of through travel lanes, and who had the right-of-way. The current study coded for the presence of a bicycle lane as research previously demonstrated a positive correlation between bicycle lanes and reductions in pedestrian-vehicle interactions (Cloutier, Lachapelle, Amours-Ouellet, Bergeron, Lord, & Torres, 2017).

Infrastructure also included traffic-control measures, such as yield signs. The literature reviewed in this paper provides an in-depth examination of the benefit provided by yield signs on driver compliance (e.g., Ellis, Van Houten, & Kim, 2007). Based on the demonstrated effect revealed in the research literature, the coding scheme included questions on traffic control relating to drivers and pedestrians. These questions covered yield signs, stop signs, and traffic lights.

Related to infrastructure, speed limits have been demonstrated to have higher driver-yield compliance when the speed limit is lower (Turner, Fitzpatrick, Brewer, & Park, 2006). Therefore, the current coding scheme included the posted speed limit. The speed limit is divided into three categories for ease of coding, 15, 25, and 35 mph. These three speed limits cover all
roads driven during the experimental test routes. Not only are posted speed limits associated with yield compliance, the vehicle speed was also directly associated with yielding. Research has shown an indirect relationship between vehicle speed yield compliance (Katz, Zaidel, & Elgrishi, 1975; Schroeder & Rouphail, 2011). As such, vehicle speed was coded at event start.

In general, VTTI coding schemes include variables relating to environmental conditions. For example, the weather and lighting conditions were coded. The current study also collected these two factors as they may be related to visual obstructions. In addition, research by Bradbury, Stevens, Boyle, and Rutherford (2012) found that pedestrians were two times more likely to wait at an intersection when weather is clear compared to rainy. The presence of parked vehicles has also been linked to pedestrian-vehicle interactions (Cloutier, Lachapelle, Amours-Ouellet, Bergeron, Lord, & Torres, 2017). In crash-scene investigations, the driver often reports failing to observe the pedestrian as the main reason for the pedestrian-vehicle collision (Retting, Ferguson, & McCartt, 2003). As such, visual obstructions impacting the driver were included as a fixed variable in the data directory.

One of the most prominent variables covered in research on pedestrian and driver yield behavior is related to distances. For pedestrian decision making, this distance is called gap acceptance (Koh & Wong, 2014). Essentially, pedestrians evaluate the distance rather than the time to collision (Brewer, Fitzpatrick, Whitacre, & Lord, 2006; Schmidt & Färber, 2009). This was incorporated into the data directory as the distance the vehicle was from the crosswalk. When considering the driver, the distance the pedestrian was to the crosswalk was collected as a possible predictor of yield behavior. Evaluation of distance was based on subjective perspective. To ensure data quality, distance was converted to a categorical variable and a guide was provided for the data reductionists to review (See Appendix J). In addition to the distance to the crosswalk,
the number of pedestrians in the crosswalk, and the number of waiting pedestrians were coded. These variables were included due to current research demonstrating a relationship between the number of waiting pedestrians and vehicle yield compliance (Brosseau, Zangenehpour, Saunier, & Miranda-Moreno, 2013; Katz, Zaidel, & Elgrishi, 1975).

Demographic and person-oriented variables have also been investigated by researchers and demonstrated a relationship between pedestrian-oriented variables and yield compliance. The current study included gender (Bradbury, Stevens, Boyle, & Rutherford, 2012), age (Avineri, Shinar, & Susilo, 2012; Chai, Shi, Wong, Er, & Gwee, 2016), color of clothing (Harrell, 1993; Spainhour, Wootton, Somanjo, & Brady, 2006), pedestrian assertiveness (Harrell, 1993; Mitman, Cooper, & DuBose, 2010), and pedestrian activities (e.g., cell-phone use; Cooper, Schneider, Ryan, & Co, 2012; Hatfield & Murphy, 2007).

Pedestrians and drivers likely use the variables described above as cues for yielding. However, the current study aimed to investigate how pedestrians and drivers directly communicate. Few studies have measured methods of direct communication between pedestrians and drivers. It is recognized that no standard mode of communication exists for pedestrians-driver communication. A study by Crowley-Koch, Van Houten, and Lim (2011) investigated the impact of a raised hand or an extended arm. Both signals were effective in increasing driver yield. Zhuang and Wu (2014) investigated four different types of hand gestures and found when pedestrians raised their hand palm outward driver yield compliance tripled compared to no signal. Research has also shown eye contact (Fisher & Garay-Vega, 2012) and smiling (Guéguen, Eyssartier, & Meineri, 2016) influence increased driver yield behavior. The current study integrated the research findings and collected both types of pedestrian and driver communication – facial and hand signals.
Amendments. The data directory only included one amendment to include an observation of the hand position of the driver during the event. This variable was included after a driver made a comment about intentionally altering his/her hand position to influence the pedestrian’s perception of the vehicle.

Independent Variables

Driving context. Driving context was a dichotomous variable with two levels. The first level had participants drive the vehicle with no modification. For the second level, participants drove the vehicle while it was marked with a sign indicating “self-driving vehicle”.

Driving Route. The route driven by participants was a dichotomous variable with two levels. The first level (Route 1) covered areas on a university campus, while the second level (Route 2) included areas immediately beyond the university campus near local businesses.

Narration. The independent variable of narration was a dichotomous variable with two conditions. For condition one, participants were not given any specific instructions on narrating their actions. In the second condition, participants were asked to follow a think-aloud protocol.

Analysis

A descriptive analysis was performed to reveal information on the nature of events. The descriptive analysis also provided information about the frequency of tacit communication between drivers and pedestrians. The descriptive analysis was conducted using the SPSS software. Regression analyses were performed to identify the predictors of driver yield behavior. Due to the nested data structure, an unconditional-means model was run, which provided evidence that a multilevel logistic regression analysis was appropriate. The lme4 package from the software R was used for all regression analyses.
Results

Results are reported for the descriptive analysis and regression models. The descriptive analysis detailed pedestrian demographics and influences of experimental conditions on pedestrian and driver behavior. The regression analyses identified predictors of driver yield behavior.

Data cleaning

A total of 1,808 events were completely coded. Several variables of interest were investigated for low-frequency counts to ensure appropriate inference could be made from the data. The first was the pedestrian type. This variable was coded into multiple categories, in the data only the categories pedestrian and bicyclist were reported. A total of 29 events were reported for a bicyclist. As this type of pedestrian was fundamentally different in behavior, the bicyclists were excluded from analysis. Next, the variables yield behavior, pedestrian path, and right-of-way were investigated for low frequencies. For yield behavior, all categories other than driver yields and driver fails to yield were excluded due to extremely low sample sizes. For pedestrian path, only pedestrians attempting to enter the roadway were included, and was represented by the variable categories – roadway and crosswalk. Finally, the right-of-way reported was used as a check, and only instances where the pedestrian or the vehicle had the right-of-way were included. For the above reasons, an additional 41 events were removed from further investigation. Overall, a total of 70 events were removed from further analysis resulting in a total sample of 1,738 cases.

Descriptive analysis

For interpretability, the variables were divided into three primary categories: 1) event context, 2) driver behavior, and 3) pedestrian behavior. Event-context variables were variables
occurring in the environment and not directly related to the behavior of the driver or a pedestrian (e.g., number of contiguous travel lanes). Driver or pedestrian behavior variables were directly related to actions taken by the driver or pedestrian, respectively. Descriptive statistics for continuous variables are reported in Table 2 and distribution plots are provided in Figure 7-10. The frequencies and percentages for event context, driver behavior, and pedestrian behavior categorical variables are reported in Tables 3, 4, and 5, respectively.

**Event context.** Primarily, events occurred under normal weather conditions. This can be seen by the high number of events with clear/partly cloudy weather (93.3%) and the high number of events during daylight (95.1%). Most events occurred on roads with a speed limit of 25 miles per hour (75.9%), simple two-way traffic (59.8%), one contiguous travel lane (93.6%), one through-travel lane (94.6%), and no bicycle lane (75.3%). No traffic control was applicable to the experimental vehicle (58.0%); however, more than a third of the events occurred with a yield sign (36.0%). Events occurred almost exclusively without a traffic control signal for pedestrians (99.6%). In most events pedestrians had the right-of-way (92.4%).

The experimental vehicle was typically traveling straight (92.3%) either 0-15 feet (52.7%) or 15-30 feet (41.2%) from the crossing. Driver vision was obstructed in nearly half of all events (44.8%). The drivers’ path was not obstructed in more than half of all events (51.5%). The most common path obstructions for drivers were pedestrians (34.7%) and other vehicles (19.1%). An opposing vehicle was reported as traveling in the other lane during 21.6% of all events. For a majority of events (60.0%) the experimental vehicle had not stopped or slowed before the start of the event.

The variable for the number of pedestrians in the crossing was continuous with a mean of 0.96 and standard deviation of 1.37. This variable had a skewness measure of 2.19, indicating it
was highly skewed right (Joanes & Gill, 1998). The variable for the number of pedestrians near the crossing (within 10 feet) was continuous with a mean of 1.49 and a standard deviation of 1.50. This variable was highly skewed right with a skewness of 2.22 (Joanes & Gill, 1998). The pedestrian being coded in the video was generally either in the crosswalk (36.9%) or within 5 feet of the crosswalk (38.0%). For the pedestrian position, more than half of the pedestrians were approaching the curb to cross (51.0%). The intended pathway for most pedestrians was a crosswalk (93.6%); in only a few events the pathway was a roadway without a crosswalk (6.4%). For a majority of events the pedestrian path was not obstructed (81.8%). The most common pedestrian-pathway obstruction was a non-experimental vehicle (16.3%). Another pedestrian was available for coding in nearly half of the events (49.7%).

**Driver behavior.** During most events, the driver yielded to the pedestrian (89.0%); the other 11% were failure to yield events. At event start, the vehicle speed ranged from 0.00 to 58.56 km/h (mean = 20.56 km/h, SD = 8.94). The range is equivalent to 0.00 to 36.39 mph. The skewness was -0.14, approximating a symmetric distribution (Joanes & Gill, 1998). In reaction to the pedestrian, most drivers continued, but decelerated (41.8%) or came to a complete stop (23.8%). The facial expression made by drivers was typically eye glance (90.6%). During most events the driver made no hand signal (87.3%). For events where a driver made a hand signal, the most common types were waving through (7.9%) and waving with palm outward (4.1%). Drivers' hand placement on the steering wheel was most commonly the top of the wheel (45.2%) or bottom of the wheel (51.2%).

**Pedestrian behavior.** Most pedestrians made no reaction to the approaching vehicle (71.1%). The most common reactions were interrupting walking, then continuing (10.9%) and continuing, but accelerating (6.1%). The color of clothing worn by pedestrians covered a wide
range, but most commonly pedestrians wore dark clothes (41.3%). More than half of pedestrians were male (59.6%) and over a third were female (38.0%). Nearly all pedestrians fit the age category encompassing non-elderly adults (97.0%). Very few pedestrians fit the category of dependency (0.9%).

Pedestrian phone use was relatively low; more pedestrians were looking at or manipulating phone controls (8.1%) compared to talking on the phone (2.6%). The headphone category was difficult to code due to video quality and distance of pedestrians from vehicles. Nearly a third of all events were coded as unable to determine (30.8%), and nearly two thirds were coded as no headphones (65.7%). More than three quarters (77.7%) of pedestrians were only carrying a backpack. Very few pedestrians were reported eating (0.6%) or jogging (0.5%). The most common activity from the variable "other pedestrian activities" was talking to someone in person (8.5%).

More than one third (34.3%) of all pedestrians clearly made no facial expression toward the experimental vehicle and more than half made eye contact (56.8%). Most pedestrians (81.6%) made no hand signal toward the experimental vehicle. The most common hand signal made by pedestrians was a wave palm outward (8.6%). The mean pedestrian assertiveness was 4.30 with a standard deviation of 1.76 and skewness of -0.39. This approximates a symmetric distribution (Joanes & Gill, 1998).

Driving context. Events within the driving context were split with just over half of the events occurring when the sign was placed on the car (51.2%) and just under half when the sign was not on the car (48.8%). The independent variable of driving context was investigated for influence on driver or pedestrian behavior using the Chi-Square test for independence between the driving context and each behavioral variable of interest. The results of the Chi-Squared tests
are reported in Table 6. Of the variables investigated, only the position of the drivers’ hands on
the wheel (χ² (2, n = 1,738) = 41.7, p< .05) and driver waving pedestrians through (χ² (1, n = 1,738) = 4.2, p< .05) were significant. No dependence was detected between the driving context
and yield behavior (χ² (1, n = 1,738) = 1.4, p> .05). All other behavioral variables, including all
pedestrian behavior variables, investigated were non-significant indicating no interdependence in
the data.

Narration. Events within the narration condition were split with just over half of events
occurring when the participant was thinking-aloud (50.6%) and just under half when the
participant was not (49.4%). The driver yield behavior was independent from the narration
condition (χ² (1, n = 1,738) = 0.1, p> .05). Driver eye contact had a significant Chi-Square test,
indicating dependence with the narration condition (χ² (1, n = 1,738) = 7.8, p< .05). All other
behavioral variables were found to be non-significant, the full results of the Chi-Square tests are
in Table 7.

Driving route. Events occurred more frequently when participants were driving the route
primarily on the university campus with unsignalized intersections (64.0%) compared to the
route primarily focused in a city region with signalized intersections (34.0%). A Chi-Square test
was run to test if yield behavior was independent from the driving route. The test indicated no
dependence in the data (χ² (1, n = 1,738) = 0.1, p> .05). No theoretical reason was established for
a possible relationship between driving route and driver or pedestrian behavior. Therefore, no
Chi-Square tests of independence were conducted for these variables.

Regression analysis

The regression analysis tested for the variables of interest that predicted driver yield
behavior. Due to the large sample size (n=1,738) statistical significance of predictor variables
was not of particular interest. Instead, the odds ratio estimate determined the predictor variables for substantive interpretations. Odds ratio estimates are a common measure of effect size used in regression analysis with a binary dependent variable (Chen, Cohen, & Chen, 2010).

Based on research by Chen, Cohen, and Chen (2010), when the outcome of interest has around a 10% occurrence, the odds ratio estimate equivalent of large and medium effect sizes are 4.1387 and 2.4972, respectively. This is calculated to have a general approximation to a Cohen’s $d$ of 0.8 and 0.5 which is a large and medium effect size, respectively (Cohen, 1992). A small effect size, Cohen’s $d$ of 0.2 (Cohen, 1992) is approximated with an odds ratio estimate of 1.4615 (Chen, Cohen, & Chen, 2010). Only medium and large effect sizes will be interpreted as promising for future research.

All models were designed for the binary outcome variable driver yield behavior. The variable was coded as either “Driver yields” or “Driver fails to yield”. The Chi-Square test of independence for all independent variables (driving context, narration, and driving route) indicated no dependence between driver yield behavior and the independent variables. Due to the independence, the variables were collapsed for the regression analysis. A Chi-Square test of independence was run to test for independence between driver gender and yield behavior. The test indicated no dependence in the data ($\chi^2 (1, n = 1,738) = 0.6, p > .05$). The non-significant result suggested excluding the variable for driver gender from the predictive models. The regression models were specified as follows.

**Unconditional means model.** Due to the nature of the data collected, events were nested within drivers, an unconditional means model was run to test if a significant portion of variance in the outcome variable was due to the grouping variable. In this case, the grouping variable was the driver. The model was specified as only the grouping variable as a random effect regressed
on the dependent variable. The model results are provided in Table 8. From this model, the variance of the random effect, 0.6058, was used to calculate a residual intraclass correlation (ICC). The residual ICC value is considered the proportion of residual variance attributed to driver effects (Wynants, Timmerman, Bourne, Van Huffel, & Van Calster, 2013). The formula for the residual ICC is the variance of the group-level intercept divided by the variance of the group-level intercept plus the error term (variance at the individual level). The variance of the driver divided by the variance of the driver plus the error. However, when the outcome variable is binary, the error term is not defined and a fixed parameter must be used instead. The fixed parameter is \( \frac{\hat{y}^2}{3} \) (Wynants et al., 2013).

Calculating the residual ICC from the random effects variance component in the unconditional means model provides us with the calculation \( \frac{0.6058}{0.6058 + \frac{\hat{y}^2}{3}} \). The calculation resulted in a residual ICC value of .1555. This value is interpreted as the driver-level variance accounting for 15.55% of the overall variance. In other words, 84.45% of all variance was due to event-level effects and 15.55% was due to driver-level variance. Although more than 80% of the variance was due to event-level effects, the residual ICC of .1555 attributed to driver-level effects exceeds the general cut off of .12 for using a multilevel analysis (James, 1982). A visual depiction of the driver-level variance can be seen in Figure 6. Thus, the following regression models were run as multilevel models, the driver was included as a level-two random effect.

**Prediction Model One.** Following from the above analysis, the model used driver yield behavior as the dependent variable in a logistic multilevel model that included the driver as a level-two random effect. The predictor variables were selected based on relevance to the analysis and a category frequency cutoff criteria to ensure possible predictive value. For the first prediction model, categorical variables were selected based on having at least 5% of the data in a
minimum of two categories. When applicable, for any category below a minimum of 2% of overall data categories were recoded to combine categories. Category combination was only conducted if a meaningful comparison was created. When a meaningful comparison was not created, the variable was inserted as is. For the first prediction model, the following description indicates how each variable was handled. A summary of the variables included in the first prediction model can be found in Table 9 and a full explanation of each variable and selection is provided in Appendix K.

The first prediction model was estimated using the \texttt{lme4} package running in the software \texttt{R} to perform a logistic multilevel model. This model is often known as a generalized linear mixed effect model. To predict driver yield behavior, the driver was treated as a random intercept effect. Fixed effects were included for the continuous variables vehicle speed, number of pedestrians in the path, and number of pedestrians near the path. Since repeated measures were collected for each driver, the continuous variables were person-mean centered by subtracting the mean of the driver from each score for that driver (Ohly, Sonnentag, Niessen, & Zapf, 2010). Person-mean centering controls for driver-level variance in the interpretation of the results (Enders & Tofighi, 2007).

Fixed effects were included for the categorical variables event history, speed limit, visual obstruction, traffic control, right-of-way, vehicle distance to crossing, pedestrian distance to crossing, pedestrian position, pedestrian path, pedestrian reaction, driver reaction, pedestrian clothing, pedestrian gender, phone use, pedestrian facial expression, pedestrian assertiveness, driver facial expression, opposing vehicle, factors affecting pedestrian path, and factors affecting driver path. Categorical variables were dummy coded so each categorical response was compared to a reference category.
Due to oversaturation the outcome of the first prediction model was not interpreted. In this case, the first prediction model had 59 predictor variables with a sample size of 1,738 and was inadequate to estimate the model. Oversaturation was indicated by large standard errors of estimates as well as failure to converge. In addition, it was not possible to calculate the Hessian matrix due to small frequencies in some categories. To handle these issues, the number of predictors was reduced in the following model. The results of the first prediction model can be found in Appendix L.

**Prediction Model Two.** To ameliorate the issues from the initial model, the second prediction model followed more stringent inclusion criteria, thereby reducing the overall number of variables in the model. The following steps were taken to reduce the number of predictor variables. First, if a variable had less than 5% in each category it was removed or recoded. Second, the correlation matrix from the first prediction model was investigated. Any predictor that correlated 0.7 or higher with another variable was removed. A summary of the variables included in the model is provided in Table 10 and a detailed explanation is provided in Appendix M.

The second prediction model was estimated using the *lme4* package (Bates, Maechler, & Bolker, 2012) running in the software R to perform a logistic multilevel model. This model is often known as a generalized linear mixed-effect model. To predict driver yield behavior, the driver was treated as a random intercept effect. Fixed effects were included for the continuous variables: vehicle speed, number of pedestrians in the path, and number of pedestrians near the path. Since repeated measures were collected for each driver, the continuous variables were person-mean centered by subtracting the mean of the driver from each score for that driver (Ohly, Sonnentag, Niessen, & Zapf, 2010). Person-mean centering controls for driver-level
variance in the interpretation of the results (Enders & Tofighi, 2007). Fixed effects were included for the categorical variables event history, visual obstruction, traffic control, right-of-way, vehicle distance to crossing, pedestrian distance to crossing, phone use, pedestrian facial expression, pedestrian assertiveness, driver facial expression, opposing vehicle, factors affecting pedestrian path, and factors affecting driver path. Categorical variables were dummy coded so each categorical response was compared to a reference category. A complete list of the categorical variables and the reference categories for the second prediction model can be found in Table 11.

The results of the second prediction model are depicted in Table 12. When the variance for the random effect was compared between the prediction model and the unconditional means model an increase from 0.61 to 1.45 was revealed. In cases where all predictors were continuous and the person-mean was centered, the variance would be expected to decrease as predictors are added. Under these circumstances, an increase in variance may indicate the multilevel model is misspecified (Snijders & Bosker, 1994). However, the current model included more categorical variables than continuous variables. Categorical variables cannot be person-mean centered and since the within-person variance in the categorical predictors cannot be controlled in the model, it is added to the random-effect variance (Snijders & Bosker, 1994). To test this assumption, two models adding a single predictor to the unconditional means model were run. The first included only the continuous person-mean centered variable number of pedestrians near the crossing. As would be expected, this model demonstrated a decrease in variance, with a reported estimate of 0.60, which was down from 0.61 in the unconditional means model. The second included only the categorical variable pedestrian face. This model showed an increase in random effects variance from the unconditional means model from 0.61 to 0.69. The combination of these two
models provided evidence the increase in variance was due to the addition of categorical predictors rather than model misspecification.

Interpretation of the odds ratio estimates from model two are as follows. An odds ratio estimate greater than one indicates an increase in odds while an odds ratio estimate less than one indicates a decrease in odds. For all subsequent odds ratio estimates greater than one are interpreted as an increase in the likelihood of failing to yield. To aid in clear interpretation of odds ratio estimates less than one they will be converted to the odds ratio estimate for individuals yielding. In this case one is divided by the odds ratio estimate to provide the likelihood the driver will yield. Exact odds ratio estimates are provided in parentheses after interpretation. Calculations converting odds ratio estimates less than one are provided when appropriate.

Based on the reported odds-ratio estimates, results indicated six categorical predictors were comparable to a large effect. The predictors that demonstrated a large effect were: 1) traffic-control stop sign compared to no traffic control, 2) driver making eye contact compared to no eye contact, 3) a factor affecting the driver's path compared to no path impairment, 4) pedestrian distance to crossing 0 feet compared to in the crossing, 5) pedestrian distance to crossing 0-5 feet compared to in the crossing, and 6) pedestrian distance to crossing 5-10 feet compared to in the crossing.

When a stop sign was present for the driver, the driver was more than 16 times more likely to yield compared to when no traffic control was present (Odds ratio estimate = 1/0.06 = 16.67). When a driver was looking at a pedestrian the driver was 50 times more likely to yield compared to when the driver did not look (Odds ratio estimate = 1/0.02 = 50). When the driver's path was obstructed, the driver was more than six times more likely to yield to the pedestrian compared to when the driver's path was not obstructed (Odds ratio estimate = 1/0.16 = 6.25). The
final three large effects were the dummy coded variables for pedestrian distance to the crossing. When a pedestrian was 0 feet away from the crossing, the driver was 16 times more likely to fail to yield compared to when the pedestrian was in the crossing (Odds ratio estimate = 16.32). When the pedestrian was 0-5 feet away from the crossing, the likelihood of the driver failing to yield was 16 times higher compared to when the pedestrian was in the crossing (Odds ratio estimate =16.03). When a pedestrian was 5-10 feet away from the crossing, the driver was 76 times more likely to fail to yield compared to when the pedestrian was in the crossing (Odds ratio estimate = 76.02).

A total of three predictors were equivalent to a medium effect. The predictors that demonstrated a medium effect were: 1) pedestrian making eye contact compared to no eye contact, 2) a vehicle traveling in the opposing lane compared to no vehicle, and 3) a factor affecting the pedestrian’s path compared to no path impairment. When a pedestrian was making eye contact the driver failing to yield was more than three times more likely to fail to yield compared to when the pedestrian was not making eye contact with the driver (Odds ratio estimate = 3.31). When a vehicle was in the opposing lane, the vehicle was nearly three times more likely to yield to the pedestrian compared to when no vehicle was in the opposing lane (Odds ratio estimate = 1/0.35 = 2.86). When the pedestrian's path was obstructed, the driver was nearly four times more likely to fail to yield compared to when the pedestrian's path was not obstructed (Odds ratio estimate = 3.85).

The odds-ratio estimates for continuous predictors indicate that no continuous predictors were large or medium effects. Continuous variable odds ratio estimates are multiplicative, but even when a 30 unit increase above the person mean is considered for vehicle speed, the odds ratio estimate is less than a small effect (Odds ratio estimate = 1.01^{30} = 1.35).
Discussion

The field study aimed to provide a starting point for understanding the tacit communication between drivers and pedestrians to inform the development of autonomous vehicles. The main types of communication investigated were facial expressions and hand signals. For either group, facial expressions beyond eye contact were very uncommon. Eye contact was coded as looking at the other party, not necessarily a mutual gaze. Drivers nearly always made eye contact with the pedestrian (90.6%). However, just over half of pedestrians made eye contact with the driver (56.8%). In terms of autonomous vehicles, if pedestrians do not look at the vehicle, a visual stimulus will not be enough to indicate the autonomous vehicles’ intentions to the pedestrian. It would be advisable to include an auditory signal for instances where the autonomous vehicle is not stopping for the pedestrian.

The hand signals made by drivers and pedestrians tended to fall into different categories. In general, pedestrians only waved palm (8.6%) outward. The claiming or granting of yield behavior was not explicitly coded for and should be considered in future research. Drivers provided two common hand signals, waving pedestrians through or waving palm outward. Again, detailed inference on the meaning of this difference would be an inferential leap without appropriate data.

The comparison of pedestrian and driver behavior related to the driving context provided some interesting results. Here, the drivers were aware the vehicle was marked with a sign reading “self-driving vehicle” during which the drivers altered their visible behavior. The changes in steering wheel hand position toward the bottom and a reduction in waiving pedestrians through can be interpreted as participant attempts to conform to the study expectations. The history of demand characteristics in psychology is well documented, as
participants bring their own perspectives to the experiment. The classic definition of this type of participant behavior is considered the “good participant role” (Orne, 1962). In this role, participants often attempt to conform to the experimental expectancy to “do a good job” or “not ruin the study” (Orne, 1962). Despite the changes in visible behavior, the safety criterion, yielding behavior, was not impacted by the sign condition.

Another interesting finding was that pedestrians did not change any of their behavior when interacting with the vehicle when it was marked as a “self-driving vehicle”. One possible explanation is due to the lack of pedestrian eye gaze at the experimental vehicle, with just over half of all participants looking at the vehicle during the pedestrian-vehicle interaction. However, this explanation is improbable since pedestrian eye gaze was not different between the two driving contexts. Rather it is more likely the majority of pedestrians’ behavior did not change in response to the autonomous vehicle due to other factors, such as knowing they have the right-of-way. Other probable explanations are that pedestrians who fail to look are simply not attending to factors beyond the self, or just following the crowd. A complete lack of pedestrian behavior change when the “self-driving vehicle” sign was equipped needs to be considered in future autonomous vehicle research and programming.

During driving sessions the experimenter noticed some pedestrians had extreme reactions to the vehicle when it was equipped with the “self-driving vehicle” sign. These included a pedestrian starting to walk into the crosswalk, followed by quickly returning to the curb. The pedestrian then circled behind the vehicle to cross. Such pedestrian behavior was not visible in the video data, due to a limited field of view. In addition, extended eye gaze for a small portion of pedestrians was noticed and reported by the video reductionists. However, the behavior of
extended eye gaze was not explicitly coded and a more complete investigation could measure eye gaze time.

The comparison of pedestrian and driver behavior between the narration conditions provides an interesting and relevant finding for future think-aloud protocol in driving context. In the current study, driver eye glance toward the pedestrian was influenced by the narration condition. Past research would suggest the decrease in eye gaze is due to an increase in driver cognitive load, as the result of controlled and automatic information processing (Shiffrin & Schneider, 1977). Driving is well established as an automated cognitive task (Drews, Pasupathi, & Strayer, 2008) and distraction arises when the automated processing is interrupted by increased cognitive load from outside factors (Strayer & Johnston, 2001). A classic example of distraction from increased cognitive load was established by Strayer, Drews, and Johnston (2003) where the effect of hands-free cell phone conversations impaired the participants’ ability to react in a driving simulation when a vehicle braked in front of them.

Think-aloud protocols still provide an avenue for valuable research on pedestrian-vehicle interaction. The evidence from the current study suggests this protocol should be explored cautiously in more controlled settings where driver distraction does not have the possibility for serious negative outcomes. A driving simulator (e.g., Strayer, Drews, & Johnston, 2003) provides a means for conducting think-aloud protocols in a safe controlled environment.

The finding of less eye contact by drivers to pedestrians can also be connected to past research roadway eye glance for drivers talking on a hands-free cellphone. The general finding indicates that drivers spend more time looking at the roadway when talking on a hands-free cellphone compared to a baseline measure (Olson, Hanowski, Hickman, & Bocanegra, 2009). The overall conclusion is usually this presents a protective effect on crash risk by reducing eye
glance away from the roadway. This conclusion is also supported by direct analysis of crash and safety critical event risk while talking on a hands-free cellphone (Olson, Hanowski, Hickman, & Bocanegra, 2009). However, due to the cognitive demands of talking on a hands-free cellphone it is likely the increase in forward roadway gaze is a cognitive resource saving strategy (National safety council, 2012).

In the current study, the eye gaze was not measured, however, the decrease in eye contact with pedestrians suggests the cognitive distraction from the narration condition is providing a similar result based on cognitive brain function and cognitive task switching costs. The past studies have indicated the increased forward roadway looking related to a reduction in risk. The important difference between past literature and the current study is the focus on pedestrian interactions where attending to non-forward roadway stimuli is critical in safe vehicle operation. More specifically, it is critical for drivers to attend to pedestrians who are approaching the roadway to avoid any potential safety critical events.

A residual ICC value of .1555 from the unconditional means model points to a relationship between yield behavior and individual differences. The current study did not measure individual difference as this was not the purpose. However, this suggests a need for future research to explore a wide range of individual differences, from personality factors and driver history to driving capabilities.

An additional take-away from the 15.55% of all variance being related to driver level effects is the influence on statistical power for future studies. In general, power analyses assume detecting an effect across all variance. However, studies investigating individual differences in yield behavior are looking for a proverbial needle in a haystack. Or in this case an effect in 15.55% of total variance. During study design, the influence proportion of variance attributed to
driver level effects on statistical power need to be considered when determining an appropriate study sample size.

From the predictive model the odds ratio estimates for pedestrian distance to the crossing mirrors the findings of Koh and Wong (2014). Koh and Wong reported a decrease in yielding behavior as pedestrian distance increased. The current study found a mirroring result. The take away from this finding is that the effect of pedestrian distance on driver yield behavior indicates drivers are making a judgment as to when it is safe to proceed, even if a pedestrian is approaching the curb. The rest of the odds ratio estimates equivalent to large and medium effect sizes provide new findings for consideration. Another pedestrian behavior, the pedestrian making eye contact with the vehicle is equivalent to a medium effect size. This provides an interesting avenue for future research to investigate the intention of eye contact made by pedestrians as an indicator of intention to cross. No specific claims as to the pedestrian intention based on eye contact from this study. The predictive model also indicates driver eye contact with the pedestrian is an important factor. In this case when a driver looked at a pedestrian they were 50 times more likely to yield compared to when they did not look. This provides empirical support for drivers self-report of not seeing the pedestrian after a pedestrian-vehicle collision (Retting, Ferguson, & McCartt, 2003). The model does not indicate if pedestrians use the driver's gaze as an indicator for crossing or not.

The predictive model also goes beyond pedestrian and driver behavior and indicates four different situational factors provide differentiating influences on driver yield behavior. First, when a stop sign is present the driver is much more likely to stop for pedestrians. This is very possibly due to the influence of the legal requirement for vehicles to stop. Second, when a vehicle is traveling in the opposing lane the driver is more likely to yield to a pedestrian. Further
research is needed to determine the underlying explanation. The following two explanations should be considered for research. 1) The finding could indicate a descriptive social norm associated with another vehicle stopping for a pedestrian, and 2) it could indicate pedestrian location as a pedestrian may have entered the crosswalk on the far side. The third and fourth situational factors to consider are path obstructions for the pedestrian and driver. In this case, a driver path obstruction is related to yielding. Conversely, a pedestrian path obstruction is related to failing to yield.

The findings from the predictive model that did not contribute large or medium effect sizes are of equal interest. The effect size for a yield to pedestrians sign did not even qualify as a small effect. This finding runs counter to a large body of research on yielding behavior related to yield signs (e.g., Ellis, Van Houten, & Kim, 2007). Ellis, Van Houten, and Kim (2007) reported significant increases in driver yielding to pedestrians after a yield sign was installed. The results from their study and the broader literature have been short-term, between subject field studies. In contrast, the current study was a longitudinal within subject design.

This suggests that yield signs may not be as effective at increasing yielding behavior as indicated by previous research. The discrepancy warrants further research to test if yield signs provide long-term improvement in driver yield behavior. A replication of the study by Ellis, Van Houten, and Kim (2007) with a longer withdraw period would provide a clearer picture of the impact of yield signs on driver behavior.

Another finding counter to previous research is the odds ratio estimate for vehicle speed indicates it is not a predictor of yielding. Past research by Betulis and Dulaski (2014) provided evidence that yielding behavior significantly decreases with increases in vehicle speed. In the predictive model, vehicle speed was person-mean centered which controls for driver effects. The
significant findings of past research when driver effects were not controlled taken with the non-significant findings when driver effects were controlled suggests vehicle speed alone is not the variable of interest. Rather vehicle speed is an indicator of an underlying individual difference between drivers.

The variable pedestrian assertiveness was also not equivalent to a large or medium effect size. This finding is counter to past research which indicates an increase in yielding when pedestrian assertiveness increases (Harrell, 1993; Mitman, Cooper, & DuBose, 2010). The counter findings may be due to the low reliability indicating the variable was not properly coded. If this is the case future research should further develop the theoretical conceptualization of pedestrian assertiveness and operationally define clear behavioral indicators. Alternatively, the variable may not be as pertinent as past research suggests considering reports do not indicate the operational definition (Mitman, Cooper, & DuBose, 2010) or it is based on the distance to the crosswalk (Harrell, 1993).

Moreover, the vehicle distance also did not contribute a meaningful effect. This may be due to the categorization of the variable for coding purposes. A more precise measurement of vehicle distance should be investigated before any conclusions are made. Interestingly, the pedestrian behavior variables of phone use and eye contact did not contribute meaningful effects to the model. Failure to predict yield behavior from the pedestrian behavior variables indicates drivers may not be using these indicators as primary factors in their yield decision. It is possible that a decision is made before such indicators are fully processed. However, this conclusion requires further investigation into the driver's and pedestrian's decision making processes.

The current study was designed as part one of a two part study on autonomous vehicles interactions with pedestrians. The second stage will be the programing of an autonomous vehicle
to test recommendations provided by present findings. Based on the results discussed above, the following study recommendations are made. To optimize the efficiency of the autonomous vehicle strategy four stages should be considered for implementation. In stage one, the vehicle would be programmed to stop anytime a pedestrian was detected to maximize safety. In stage two, the vehicle would be programmed to stop anytime a pedestrian-vehicle interaction might occur based on the speed and distance of each party leading to an intersection. In stage three, the vehicle would be programmed to have the vehicle stop or slow depending on potential interaction between the vehicle and pedestrian. In this way modulating the speed may decrease the amount of time spent by the vehicle during the interaction by avoiding a complete stop. In the fourth stage, path obstruction situational variable will be added to the programming. Here, the vehicle can be instructed react to path obstructions. More specifically, proceed when the pedestrian path is obstructed and stop when the vehicle path is obstructed or another vehicle has also stopped.

A few additional notes on the second part of the experiment that need to be addressed are ensuring safety of pedestrians, experimental design, and outcomes of interest. To address the safety issue in naturalistic settings, it will be important to program a failsafe during all stages. The failsafe could be an override programmed into all stages to force stop the vehicle anytime a pedestrian would be at risk of causing a safety critical event. Overall experimental design is not directly recommended, however, many runs with each programming stage counterbalanced to control for ordering effects should be considered. As for outcome variables, it is critical to test the efficiency and safety of each stage. Evaluating the safety of each program could be accomplished by measuring the number of safety critical events. The efficiency of each
programming stage could be assessed by the total time spent on the route, or the time spent stopping for pedestrians.

**Limitations**

The current study had limitations that need to be considered when interpreting the results. The limitations include shortcomings in the experimental equipment, uncontrollable nature of external factors, and the subjectivity of video ratings with categorical variables. These limitations represent minor consideration with the experimental equipment, study design, and potential for human error.

The experimental equipment provided a restricted field-of-view and limited video and sound quality. In some circumstances, the limited field-of-view would not show the pedestrian for the full event thereby preventing coding of pedestrian behavior or communication attempts. The video field-of-view did not always represent the drivers’ field-of-view. Although overall video quality was good, the resolution made it difficult to properly code nuanced variables. The variables for pedestrian facial expressions and headphone use were most affected. The sound equipment also limited the outcome of the experiment. In part, the study was designed to gain an understanding of the drivers’ cognitive processes occurring during pedestrian-vehicle interactions through a think-aloud procedure. The microphone did not adequately record the audio for content analysis. In all likelihood, the failure to adequately record verbal utterances was likely due to the participants’ utterance volume rather than an equipment failure. However, this limitation should be considered for future research using this equipment.

The overall study design focused on creating a naturalistic driving environment for the participants to interact with pedestrians. As a general rule, field studies lack controls available in laboratory research (Vanhove & Harms, 2015). For instance, other non-experimental vehicles
would stop for pedestrians; thereby, limiting the participant’s opportunities to interact with the pedestrians. In this study, sample size was sufficiently large for pedestrian-vehicle interactions. Furthermore, the value added by naturalistic observation of the phenomenon would not be easily replicated in a laboratory setting.

Finally, the issue of human error and subjective coding should be considered a limitation of the study. Reliability for the variables of interest met acceptable levels; however, the use of human coders led to creating artificial categorical variables that more detailed computer software could have avoided. A prime example of this artificial categorization is for vehicle distance to the crossing. This variable was selected because of the low effect size estimate from the predictive multilevel logistic regression for vehicle distance to the crossing. Past research suggests distance is a critical factor in yield behavior (e.g., Schmidt & Färber, 2009). If the variable had been more precisely recorded, the result may have been different.

The limitations in the study need to be considered when drawing conclusions from the results. In this study, appropriate measures were taken to consider the limitations during study design as well during interpretation of the results. Moreover, the study was designed to be exploratory in nature and future research is needed to further investigate the findings.

**Future Research**

The study raises many interesting empirical questions that warrant further exploration. One such question is to investigate the process of communication between the driver and the pedestrian. The current study found pedestrians only using one hand signal – a wave palm outward. This could indicate only one message is intended from the communication, or the single type of hand signal could be used for multiple types of messages. For example, this message could indicate claiming the right-of-way, gratitude to the driver for stopping, or a simple
acknowledgment they were going to walk. However, drivers used more than one type of hand signal to communicate with pedestrians. An in depth investigation into the process of the communication could aid in understanding how drivers and pedestrians use tacit communication during pedestrian-vehicle interactions.

One avenue readily available for studying the process of tacit communication would be a detailed qualitative analysis of the rich video data collected in this study. Researchers could undertake a qualitative analysis by watching a subset of events and writing a detailed description of the event encompassing the communication between pedestrians and drivers. Researchers could take a driver or pedestrian-centered approach. In a driver-centered approach, a team of researchers could video participants in a naturalistic driving environment and have the participant watch their video while describing the reasoning for his/her actions. To study the phenomenon while focusing on the pedestrian perspective, researchers could interview pedestrians after they were observed crossing during a potential pedestrian-vehicle interaction. The pedestrian perspective would be especially important for understanding the pedestrian’s communication intention.

Qualitative video analysis would also provide an avenue for investigation into many other interesting questions. For instance, do social norms (Cialdini & Goldstein, 2004) influence pedestrian or driver behavior? Consider the example of a vehicle stopping in the opposing lane for a pedestrian to cross, but the driver in the experimental vehicle has no path obstruction. Will the driver of the experimental vehicle follow suit and also stop, or will s/he continue without stopping for the pedestrian?

Future research should also aim to improve on the limitations of the current study. One of the primary limitations is the limited field of view provided by the mini DAS. To remedy this
issue, future research could focus on including more cameras with higher resolution. Another option would be to include additional instruments, such as radar and LiDAR. Radar is a well-known tool that sends out electromagnetic waves to detect objects. LiDAR is less well known, but performs object and speed detection using light waves (Chillemi, 2015). The use of radar and LiDAR would provide 360-degree sensing capabilities with automated detection of motion and closing distance.

To ameliorate the issue of data being derived from subjective video ratings, deep learning algorithms could be introduced to code and analyze video data of pedestrian-vehicle interactions. One such technique—convolutional neural networks—provides promising results in large-scale video classification (Karpathy, Toderici, Shetty, Leung, Sukthankar, & Fei-Fei, 2014). However, they require large amounts of input and extensive training for sufficient accuracy (Karpathy et al., 2014). Such techniques provide great value in autonomous vehicle research. These techniques have already been implemented to teach an autonomous vehicle to drive based on the steering-wheel angle of human drivers (Du, Guo, & Simpson, 2017).
References


Table 1. Coding reliability for all variables in ascending order

<table>
<thead>
<tr>
<th>Variable</th>
<th>Reliability</th>
<th>Variable</th>
<th>Reliability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pedestrian assertiveness</td>
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<td>Traffic control</td>
<td>98</td>
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<tr>
<td>Pedestrian facial expression</td>
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<td>Vehicle position</td>
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<td>Driver facial expression</td>
<td>82</td>
<td>Pedestrian reaction</td>
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<tr>
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<td>83</td>
<td>Other Pedestrian activities</td>
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<tr>
<td>Factor affecting pedestrian path</td>
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<td>Yield</td>
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<td>Pedestrian hand signals</td>
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<td>Pedestrian headphone use</td>
<td>86</td>
<td>Driver hand signals</td>
<td>99</td>
</tr>
<tr>
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<td>Driver hand position</td>
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<td>Factor affecting driver path</td>
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<td>Variable</td>
<td>Frequency (%)</td>
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<td>---------------</td>
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</tr>
<tr>
<td>1. Weather</td>
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<td>8. Traffic control</td>
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<td>49 (2.8)</td>
<td>Yield to pedestrian sign</td>
<td>626 (36.0)</td>
</tr>
<tr>
<td>Mist/Light rain</td>
<td>19 (1.1)</td>
<td>Stop sign</td>
<td>91 (5.2)</td>
</tr>
<tr>
<td>Raining</td>
<td>8 (0.5)</td>
<td>Red light</td>
<td>2 (0.1)</td>
</tr>
<tr>
<td>Snowing</td>
<td>40 (2.3)</td>
<td>Green light (solid)</td>
<td>3 (0.2)</td>
</tr>
<tr>
<td>2. Lighting</td>
<td></td>
<td>9. Pedestrian signal</td>
<td></td>
</tr>
<tr>
<td>Daylight</td>
<td>1653 (95.1)</td>
<td>No signal</td>
<td>1731 (99.6)</td>
</tr>
<tr>
<td>Dawn</td>
<td>3 (0.2)</td>
<td>Walk</td>
<td>3 (0.2)</td>
</tr>
<tr>
<td>Dusk</td>
<td>51 (2.9)</td>
<td>Countdown clock</td>
<td>1 (0.1)</td>
</tr>
<tr>
<td>Darkness, lighted</td>
<td>24 (1.4)</td>
<td>Do not walk</td>
<td>3 (0.2)</td>
</tr>
<tr>
<td>Darkness, not lighted</td>
<td>7 (0.4)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Speed limit</td>
<td></td>
<td>10. Right of way</td>
<td></td>
</tr>
<tr>
<td>Drillfield (15 mph)</td>
<td>404 (23.2)</td>
<td>Experimental vehicle</td>
<td>132 (7.6)</td>
</tr>
<tr>
<td>Other town roads (25 mph)</td>
<td>1320 (75.9)</td>
<td>Pedestrian</td>
<td>1606 (92.4)</td>
</tr>
<tr>
<td>Patrick Henry Drive (35 mph)</td>
<td>14 (0.8)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Traffic flow</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No lanes</td>
<td>43 (2.5)</td>
<td>Vehicle straight</td>
<td>1605 (92.3)</td>
</tr>
<tr>
<td>Simple 2-way traffic</td>
<td>1039 (59.8)</td>
<td>Vehicle straight, from stop</td>
<td>3 (0.2)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>at signalized intersection</td>
<td></td>
</tr>
<tr>
<td>Divided (median strip or barrier)</td>
<td>250 (14.4)</td>
<td>Vehicle preparing to turn</td>
<td>86 (4.9)</td>
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<tr>
<td>One-way traffic</td>
<td>404 (23.2)</td>
<td>across traffic</td>
<td>4 (0.2)</td>
</tr>
<tr>
<td>Unknown</td>
<td>2 (0.1)</td>
<td>Vehicle preparing to turn</td>
<td>17 (1.0)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>with traffic</td>
<td></td>
</tr>
<tr>
<td>5. Number of contiguous lanes</td>
<td></td>
<td>Vehicle turning across traffic</td>
<td>2 (0.1)</td>
</tr>
<tr>
<td>One lane</td>
<td>1627 (93.6)</td>
<td>Other</td>
<td>1 (0.1)</td>
</tr>
<tr>
<td>Two lanes</td>
<td>99 (5.7)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Three or more lanes</td>
<td>12 (0.7)</td>
<td>0 feet</td>
<td>70 (4.0)</td>
</tr>
<tr>
<td>6. Number of through lanes</td>
<td></td>
<td>0-15 feet</td>
<td>916 (52.7)</td>
</tr>
<tr>
<td>No through lanes</td>
<td>59 (3.4)</td>
<td>15-30 feet</td>
<td>716 (41.2)</td>
</tr>
<tr>
<td>One through lane</td>
<td>1644 (94.6)</td>
<td>30+ feet</td>
<td>36 (2.1)</td>
</tr>
<tr>
<td>Two through lanes</td>
<td>33 (1.9)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Three or more through lanes</td>
<td>2 (0.1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Bicycle Lanes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No bicycle lane</td>
<td>1308 (75.3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bicycle lane near</td>
<td>150 (8.6)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bicycle lane far</td>
<td>29 (1.7)</td>
<td></td>
<td></td>
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<tr>
<td>Bicycle lane on both sides</td>
<td>251 (14.4)</td>
<td></td>
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Table 3. Frequency and percent of categorical variables relating to the event context (continued)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Frequency (%)</th>
<th>Variable</th>
<th>Frequency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>13. Visual obstruction</td>
<td></td>
<td>17. Pedestrian distance</td>
<td></td>
</tr>
<tr>
<td>No obstruction</td>
<td>960 (55.2)</td>
<td>0 feet</td>
<td>217 (12.5)</td>
</tr>
<tr>
<td>Vision obstructed</td>
<td>778 (44.8)</td>
<td>0-5 feet</td>
<td>660 (38.0)</td>
</tr>
<tr>
<td>Vehicle stopped right</td>
<td>212 (12.2)</td>
<td>5-10 feet</td>
<td>210 (21.1)</td>
</tr>
<tr>
<td>Vehicle stopped left</td>
<td>289 (16.6)</td>
<td>10+ feet</td>
<td>10 (0.6)</td>
</tr>
<tr>
<td>Vehicle moving right</td>
<td>21 (1.2)</td>
<td>In crosswalk</td>
<td>641 (36.9)</td>
</tr>
<tr>
<td>Vehicle moving left</td>
<td>198 (11.4)</td>
<td>18. Pedestrian position</td>
<td></td>
</tr>
<tr>
<td>Buildings, billboards, other roadway infrastructure</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trees, vegetation</td>
<td>126 (7.2)</td>
<td>Waiting on curb to cross</td>
<td>158 (9.1)</td>
</tr>
<tr>
<td>Other</td>
<td>53 (3.0)</td>
<td>In roadway, crossing (before vehicle trajectory)</td>
<td>112 (6.4)</td>
</tr>
<tr>
<td>Unknown</td>
<td>4 (0.2)</td>
<td>In roadway, crossing (in vehicle trajectory)</td>
<td>581 (33.4)</td>
</tr>
<tr>
<td>14. Factor affecting the drivers path</td>
<td></td>
<td>19. Pedestrian pathway</td>
<td></td>
</tr>
<tr>
<td>Path not obstructed</td>
<td>895 (51.5)</td>
<td>Crosswalk</td>
<td>1626 (93.6)</td>
</tr>
<tr>
<td>Path obstructed</td>
<td>843 (48.5)</td>
<td>Roadway (no crosswalk)</td>
<td>112 (6.4)</td>
</tr>
<tr>
<td>Pedestrian</td>
<td>603 (34.7)</td>
<td>20. Factors affecting pedestrians path</td>
<td></td>
</tr>
<tr>
<td>Vehicle</td>
<td>332 (19.1)</td>
<td>Path not obstructed</td>
<td>1422 (81.8)</td>
</tr>
<tr>
<td>Construction</td>
<td>2 (0.1)</td>
<td>Path obstructed</td>
<td>316 (18.2)</td>
</tr>
<tr>
<td>Other</td>
<td>2 (0.1)</td>
<td>Vehicle</td>
<td>283 (16.3)</td>
</tr>
<tr>
<td>15. Vehicle traveling in opposing lane</td>
<td></td>
<td>21. Another pedestrian to code</td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>1363 (78.4)</td>
<td>Apparent urgency</td>
<td>14 (0.8)</td>
</tr>
<tr>
<td>Yes</td>
<td>375 (21.6)</td>
<td>Traveling with companion</td>
<td>36 (2.1)</td>
</tr>
<tr>
<td>16. Event history</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>1,043 (60.0)</td>
<td>No</td>
<td>875 (50.3)</td>
</tr>
<tr>
<td>Stopped or slowed for vehicle</td>
<td>330 (19.0)</td>
<td>Yes</td>
<td>863 (49.7)</td>
</tr>
<tr>
<td>Stopped or slowed for infrastructure</td>
<td>182 (10.5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>183 (10.5)</td>
<td></td>
<td></td>
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</table>
Table 4. Frequency and percent of categorical variables relating to driver behavior

<table>
<thead>
<tr>
<th>Variable</th>
<th>Frequency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Driver yield behavior</td>
<td></td>
</tr>
<tr>
<td>Yield</td>
<td>1546 (89.0)</td>
</tr>
<tr>
<td>Fails to yield</td>
<td>192 (11.0)</td>
</tr>
<tr>
<td>2. Driver reaction</td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>201 (11.6)</td>
</tr>
<tr>
<td>Continue, but accelerate</td>
<td>78 (4.5)</td>
</tr>
<tr>
<td>Continue, but decelerate</td>
<td>726 (41.8)</td>
</tr>
<tr>
<td>Comes to a complete stop</td>
<td>413 (23.8)</td>
</tr>
<tr>
<td>Interrupted driving, then continues</td>
<td>319 (18.4)</td>
</tr>
<tr>
<td>Other</td>
<td>1 (0.1)</td>
</tr>
<tr>
<td>3. Driver facial expression</td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>156 (9.0)</td>
</tr>
<tr>
<td>Facial communication</td>
<td>1582 (91.0)</td>
</tr>
<tr>
<td>Smile</td>
<td>29 (1.7)</td>
</tr>
<tr>
<td>Frown</td>
<td>1 (0.1)</td>
</tr>
<tr>
<td>Raised eyebrows</td>
<td>1 (0.1)</td>
</tr>
<tr>
<td>Head nod</td>
<td>10 (0.6)</td>
</tr>
<tr>
<td>Eye contact</td>
<td>1574 (90.6)</td>
</tr>
<tr>
<td>4. Driver hand signal</td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>1517 (87.3)</td>
</tr>
<tr>
<td>Waves through</td>
<td>138 (7.9)</td>
</tr>
<tr>
<td>Other wave</td>
<td>83 (4.8)</td>
</tr>
<tr>
<td>Wave with palm out</td>
<td>72 (4.1)</td>
</tr>
<tr>
<td>Waves through</td>
<td>138 (7.9)</td>
</tr>
<tr>
<td>Two finger wave</td>
<td>7 (0.4)</td>
</tr>
<tr>
<td>Thumbs up</td>
<td>3 (0.2)</td>
</tr>
<tr>
<td>Other</td>
<td>1 (0.1)</td>
</tr>
<tr>
<td>Unable to determine</td>
<td>1 (0.1)</td>
</tr>
<tr>
<td>5. Driver hand position</td>
<td></td>
</tr>
<tr>
<td>Top of wheel</td>
<td>785 (45.2)</td>
</tr>
<tr>
<td>Side of wheel</td>
<td>64 (3.7)</td>
</tr>
<tr>
<td>Bottom of wheel</td>
<td>889 (51.2)</td>
</tr>
<tr>
<td>Variable</td>
<td>Frequency (%)</td>
</tr>
<tr>
<td>----------------------------------------------</td>
<td>---------------</td>
</tr>
<tr>
<td>1. Pedestrian reaction</td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>1236 (71.1)</td>
</tr>
<tr>
<td>Continue, but accelerate</td>
<td>106 (6.1)</td>
</tr>
<tr>
<td>Continue, but decelerate</td>
<td>48 (2.8)</td>
</tr>
<tr>
<td>Begin walking from stationary</td>
<td>101 (5.8)</td>
</tr>
<tr>
<td>Interrupted walking, then continues</td>
<td>190 (10.9)</td>
</tr>
<tr>
<td>Interrupted walking, then abort</td>
<td>38 (2.2)</td>
</tr>
<tr>
<td>Other</td>
<td>19 (1.1)</td>
</tr>
<tr>
<td>2. Pedestrian clothing color</td>
<td></td>
</tr>
<tr>
<td>Black</td>
<td>718 (41.3)</td>
</tr>
<tr>
<td>White</td>
<td>225 (12.9)</td>
</tr>
<tr>
<td>VT bright</td>
<td>71 (4.1)</td>
</tr>
<tr>
<td>VT dull</td>
<td>159 (9.1)</td>
</tr>
<tr>
<td>Colored bright</td>
<td>170 (9.8)</td>
</tr>
<tr>
<td>Colored dull</td>
<td>266 (15.3)</td>
</tr>
<tr>
<td>Unable to determine</td>
<td>78 (4.5)</td>
</tr>
<tr>
<td>Other</td>
<td>51 (2.9)</td>
</tr>
<tr>
<td>3. Pedestrian gender</td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>660 (38.0)</td>
</tr>
<tr>
<td>Male</td>
<td>1036 (59.4)</td>
</tr>
<tr>
<td>Unable to determine</td>
<td>42 (2.4)</td>
</tr>
<tr>
<td>4. Pedestrian age</td>
<td></td>
</tr>
<tr>
<td>Middle</td>
<td>1685 (97.0)</td>
</tr>
<tr>
<td>Older</td>
<td>45 (2.6)</td>
</tr>
<tr>
<td>Unable to determine</td>
<td>8 (0.5)</td>
</tr>
<tr>
<td>5. Pedestrian dependency</td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>1724 (99.2)</td>
</tr>
<tr>
<td>Disabled</td>
<td>9 (0.5)</td>
</tr>
<tr>
<td>Accompanying child</td>
<td>1 (0.1)</td>
</tr>
<tr>
<td>With pet</td>
<td>2 (0.1)</td>
</tr>
<tr>
<td>Other</td>
<td>1 (0.1)</td>
</tr>
<tr>
<td>6. Pedestrian phone use</td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>1443 (83.0)</td>
</tr>
<tr>
<td>Listening or talking</td>
<td>45 (2.6)</td>
</tr>
<tr>
<td>Looking and/or manipulating controls</td>
<td>141 (8.1)</td>
</tr>
<tr>
<td>Unable to determine</td>
<td>108 (6.2)</td>
</tr>
<tr>
<td>Other</td>
<td>1 (0.1)</td>
</tr>
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</table>
Table 6. Results of Chi-Square tests between the driving context condition and behavioral variables

<table>
<thead>
<tr>
<th>Driving context</th>
<th>Vehicle without sign</th>
<th>Vehicle with sign</th>
<th>$\chi^2$(df)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Driver yield behavior</td>
<td>Yield</td>
<td>763</td>
<td>783</td>
</tr>
<tr>
<td></td>
<td>Failure to yield</td>
<td>86</td>
<td>106</td>
</tr>
<tr>
<td>Driver hand position</td>
<td>Top of wheel</td>
<td>446</td>
<td>339</td>
</tr>
<tr>
<td></td>
<td>Side of wheel</td>
<td>36</td>
<td>28</td>
</tr>
<tr>
<td></td>
<td>Bottom of wheel</td>
<td>367</td>
<td>522</td>
</tr>
<tr>
<td>Driver eye contact</td>
<td>Yes</td>
<td>769</td>
<td>805</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>80</td>
<td>84</td>
</tr>
<tr>
<td>Driver wave through</td>
<td>Yes</td>
<td>79</td>
<td>59</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>770</td>
<td>830</td>
</tr>
<tr>
<td>Driver wave palm outward</td>
<td>Yes</td>
<td>34</td>
<td>38</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>815</td>
<td>851</td>
</tr>
<tr>
<td>Driver reaction</td>
<td>No reaction</td>
<td>88</td>
<td>113</td>
</tr>
<tr>
<td></td>
<td>Continue, but accelerate</td>
<td>34</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td>Continue, but decelerate</td>
<td>367</td>
<td>359</td>
</tr>
<tr>
<td></td>
<td>Comes to complete stop</td>
<td>214</td>
<td>199</td>
</tr>
<tr>
<td></td>
<td>Interrupted driving, then continued</td>
<td>146</td>
<td>173</td>
</tr>
<tr>
<td>Pedestrian eye contact</td>
<td>Yes</td>
<td>482</td>
<td>505</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>367</td>
<td>384</td>
</tr>
<tr>
<td>Pedestrian wave palm outward</td>
<td>Yes</td>
<td>72</td>
<td>77</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>777</td>
<td>812</td>
</tr>
<tr>
<td>Pedestrian reaction</td>
<td>No reaction</td>
<td>601</td>
<td>635</td>
</tr>
<tr>
<td></td>
<td>Continue, but accelerate</td>
<td>54</td>
<td>52</td>
</tr>
<tr>
<td></td>
<td>Continue, but decelerate</td>
<td>20</td>
<td>28</td>
</tr>
<tr>
<td></td>
<td>Begin walking from stationary</td>
<td>59</td>
<td>42</td>
</tr>
<tr>
<td></td>
<td>Interrupted walking, then continued</td>
<td>91</td>
<td>99</td>
</tr>
<tr>
<td></td>
<td>Interrupted walking and aborted</td>
<td>14</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>Other</td>
<td>10</td>
<td>9</td>
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### Table 7. Results of Chi-Square tests between the narration condition and behavioral variables

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<th>Narration</th>
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<th></th>
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<tbody>
<tr>
<td></td>
<td>No think-aloud</td>
<td>Think-aloud</td>
<td>$\chi^2$(df)</td>
<td></td>
</tr>
<tr>
<td>Driver yield behavior</td>
<td>Yield</td>
<td>762</td>
<td>784</td>
<td>0.1(1)</td>
</tr>
<tr>
<td></td>
<td>Failure to yield</td>
<td>97</td>
<td>95</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Top of wheel</td>
<td>377</td>
<td>408</td>
<td>1.1(2)</td>
</tr>
<tr>
<td>Driver hand position</td>
<td>Side of wheel</td>
<td>33</td>
<td>31</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bottom of wheel</td>
<td>859</td>
<td>879</td>
<td></td>
</tr>
<tr>
<td>Driver eye contact</td>
<td>Yes</td>
<td>795</td>
<td>779</td>
<td>7.8(1)*</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>64</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Driver wave through</td>
<td>Yes</td>
<td>63</td>
<td>75</td>
<td>0.9(1)</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>796</td>
<td>804</td>
<td></td>
</tr>
<tr>
<td>Driver wave palm outward</td>
<td>Yes</td>
<td>30</td>
<td>42</td>
<td>1.8(1)</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>829</td>
<td>837</td>
<td></td>
</tr>
<tr>
<td>Driver reaction</td>
<td>No reaction</td>
<td>93</td>
<td>108</td>
<td>3.7(4)</td>
</tr>
<tr>
<td></td>
<td>Continue, but accelerate</td>
<td>45</td>
<td>34</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Continue, but decelerate</td>
<td>367</td>
<td>359</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Comes to complete stop</td>
<td>204</td>
<td>209</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Interrupted driving, then continued</td>
<td>150</td>
<td>169</td>
<td></td>
</tr>
<tr>
<td>Pedestrian eye contact</td>
<td>Yes</td>
<td>496</td>
<td>491</td>
<td>0.6(1)</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>363</td>
<td>388</td>
<td></td>
</tr>
<tr>
<td>Pedestrian wave palm outward</td>
<td>Yes</td>
<td>69</td>
<td>80</td>
<td>0.6(1)</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>790</td>
<td>799</td>
<td></td>
</tr>
<tr>
<td>Pedestrian reaction</td>
<td>No reaction</td>
<td>630</td>
<td>606</td>
<td>6.1(6)</td>
</tr>
<tr>
<td></td>
<td>Continue, but accelerate</td>
<td>50</td>
<td>56</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Continue, but decelerate</td>
<td>23</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Begin walking from stationary</td>
<td>45</td>
<td>56</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Interrupted walking, then continued</td>
<td>81</td>
<td>109</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Interrupted walking and aborted</td>
<td>20</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Other</td>
<td>10</td>
<td>9</td>
<td></td>
</tr>
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</table>
Table 8. Results of the unconditional means model

<table>
<thead>
<tr>
<th>Fixed effects</th>
<th>Estimate</th>
<th>Standard error</th>
</tr>
</thead>
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<tr>
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<td>Random effect</td>
<td>Variance</td>
<td>SD</td>
</tr>
<tr>
<td>Driver</td>
<td>0.61</td>
<td>0.78</td>
</tr>
<tr>
<td>Variable</td>
<td>Changes</td>
<td>Min 2&gt;.05</td>
</tr>
<tr>
<td>-----------------------------------------</td>
<td>----------</td>
<td>-----------</td>
</tr>
<tr>
<td>1. Event history</td>
<td>None</td>
<td>Yes</td>
</tr>
<tr>
<td>2. Speed limit</td>
<td>None</td>
<td>Yes</td>
</tr>
<tr>
<td>3. Traffic flow</td>
<td>None</td>
<td>Yes</td>
</tr>
<tr>
<td>4. No. contiguous lanes</td>
<td>None</td>
<td>Yes</td>
</tr>
<tr>
<td>5. No. through lanes</td>
<td>None</td>
<td>No</td>
</tr>
<tr>
<td>6. Visual obstructions</td>
<td>Combined</td>
<td>Yes</td>
</tr>
<tr>
<td>7. Weather</td>
<td>Combined</td>
<td>No</td>
</tr>
<tr>
<td>8. Light</td>
<td>Combined</td>
<td>No</td>
</tr>
<tr>
<td>9. Traffic control</td>
<td>Combined</td>
<td>Yes</td>
</tr>
<tr>
<td>10. Pedestrian signal</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>11. Right of way</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>12. Vehicle position</td>
<td>Combined</td>
<td>Yes</td>
</tr>
<tr>
<td>13. Vehicle distance</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>14. Pedestrian distance</td>
<td>Combined</td>
<td>Yes</td>
</tr>
<tr>
<td>15. Pedestrian position</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>16. Pedestrian path</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>17. Pedestrian reaction</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>18. Driver reaction</td>
<td>Combined</td>
<td>Yes</td>
</tr>
<tr>
<td>19. Pedestrian clothing</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>20. Pedestrian gender</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>21. Pedestrian age</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>22. Pedestrian dependency</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>23. Phone use</td>
<td>Combined</td>
<td>Yes</td>
</tr>
<tr>
<td>24. Headphone use</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>25. Carrying items</td>
<td>Combined</td>
<td>Yes</td>
</tr>
<tr>
<td>26. Eating</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>27. Jogging</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>28. Other activities</td>
<td>Combined</td>
<td>Yes</td>
</tr>
<tr>
<td>29. Pedestrian facial expression</td>
<td>Combined</td>
<td>Yes</td>
</tr>
<tr>
<td>30. Pedestrian hand signal</td>
<td>Combined</td>
<td>Yes</td>
</tr>
<tr>
<td>31. Driver facial expression</td>
<td>Combined</td>
<td>Yes</td>
</tr>
<tr>
<td>32. Driver hand signal</td>
<td>Combined</td>
<td>Yes</td>
</tr>
<tr>
<td>33. Opposing vehicle</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>34. Factors affecting pedestrian path</td>
<td>Combined</td>
<td>Yes</td>
</tr>
<tr>
<td>35. Factors affecting driver path</td>
<td>Combined</td>
<td>Yes</td>
</tr>
<tr>
<td>36. Another pedestrian to code</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Variable</td>
<td>Changes</td>
<td>All &gt; 5%</td>
</tr>
<tr>
<td>-----------------------------------</td>
<td>---------</td>
<td>----------</td>
</tr>
<tr>
<td>1. Event history</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>2. Speed limit</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>3. Visual obstructions</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>4. Traffic control</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>5. Right of way</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>6. Vehicle distance</td>
<td>Combined</td>
<td>Yes</td>
</tr>
<tr>
<td>7. Pedestrian distance</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>8. Pedestrian position</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>9. Pedestrian path</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>10. Pedestrian reaction</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>11. Driver reaction</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>12. Pedestrian clothing</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>13. Pedestrian gender</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>14. Phone use</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>15. Pedestrian facial expression</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>16. Driver facial expression</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>17. Opposing vehicle</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>18. Factors affecting pedestrian path</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>19. Factors affecting driver path</td>
<td>No</td>
<td>Yes</td>
</tr>
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</table>
Table 11. Reference category for each categorical variable in prediction model

<table>
<thead>
<tr>
<th>Categorical predictor</th>
<th>Reference Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Event history</td>
<td>None</td>
</tr>
<tr>
<td>2. Visual obstructions</td>
<td>None</td>
</tr>
<tr>
<td>3. Traffic control</td>
<td>None</td>
</tr>
<tr>
<td>4. Right of way</td>
<td>Pedestrian right-of-way</td>
</tr>
<tr>
<td>5. Vehicle distance</td>
<td>0-15 feet from crosswalk</td>
</tr>
<tr>
<td>6. Pedestrian distance</td>
<td>In crosswalk</td>
</tr>
<tr>
<td>7. Phone use</td>
<td>None</td>
</tr>
<tr>
<td>8. Pedestrian facial expression</td>
<td>None</td>
</tr>
<tr>
<td>9. Driver facial expression</td>
<td>None</td>
</tr>
<tr>
<td>10. Opposing vehicle</td>
<td>None</td>
</tr>
<tr>
<td>11. Factors affecting pedestrian path</td>
<td>None</td>
</tr>
<tr>
<td>12. Factors affecting driver path</td>
<td>None</td>
</tr>
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</table>
Table 12. Model two results

<table>
<thead>
<tr>
<th>Fixed effects</th>
<th>Odds ratio</th>
<th>Estimate</th>
<th>Standard error</th>
<th>Z-score</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>0.15</td>
<td>-1.91</td>
<td>0.69</td>
<td>-2.77</td>
<td>0.01</td>
</tr>
<tr>
<td>Vehicle speed</td>
<td>1.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.93</td>
<td></td>
</tr>
<tr>
<td>Event history - stopped for infrastructure</td>
<td>0.47</td>
<td>-0.75</td>
<td>0.40</td>
<td>-1.88</td>
<td></td>
</tr>
<tr>
<td>Event history - stopped for vehicle</td>
<td>0.72</td>
<td>-0.33</td>
<td>0.44</td>
<td>-0.75</td>
<td></td>
</tr>
<tr>
<td>Event history - stopped for pedestrian</td>
<td>0.49</td>
<td>-0.71</td>
<td>0.46</td>
<td>-1.55</td>
<td></td>
</tr>
<tr>
<td>Visual obstruction - Obstructed</td>
<td>0.80</td>
<td>-0.22</td>
<td>0.24</td>
<td>-0.92</td>
<td></td>
</tr>
<tr>
<td>Traffic control - yield to pedestrian</td>
<td>0.97</td>
<td>-0.03</td>
<td>0.25</td>
<td>-0.12</td>
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</tr>
<tr>
<td>Traffic control - stop sign</td>
<td>0.06</td>
<td>-2.81</td>
<td>0.87</td>
<td>-3.21</td>
<td></td>
</tr>
<tr>
<td>Right of way - pedestrian</td>
<td>2.28</td>
<td>0.82</td>
<td>0.39</td>
<td>2.12</td>
<td></td>
</tr>
<tr>
<td>Vehicle distance - 15+ feet away</td>
<td>0.66</td>
<td>-0.42</td>
<td>0.26</td>
<td>-1.62</td>
<td></td>
</tr>
<tr>
<td>Number of pedestrians in path</td>
<td>0.98</td>
<td>-0.02</td>
<td>0.09</td>
<td>-0.27</td>
<td></td>
</tr>
<tr>
<td>Number of pedestrians near path</td>
<td>1.02</td>
<td>0.02</td>
<td>0.08</td>
<td>0.31</td>
<td></td>
</tr>
<tr>
<td>Pedestrian distance - 0 feet away</td>
<td>16.32</td>
<td>2.79</td>
<td>0.55</td>
<td>5.09</td>
<td></td>
</tr>
<tr>
<td>Pedestrian distance - 0-5 feet away</td>
<td>16.03</td>
<td>2.77</td>
<td>0.52</td>
<td>5.38</td>
<td></td>
</tr>
<tr>
<td>Pedestrian distance - 5-10 feet away</td>
<td>76.02</td>
<td>4.33</td>
<td>0.55</td>
<td>7.82</td>
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</tr>
<tr>
<td>Phone use - using</td>
<td>1.34</td>
<td>0.30</td>
<td>0.39</td>
<td>0.75</td>
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</tr>
<tr>
<td>Phone use - unable to determine</td>
<td>2.18</td>
<td>0.78</td>
<td>0.50</td>
<td>1.57</td>
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<tr>
<td>Pedestrian facial expression - eye contact</td>
<td>3.31</td>
<td>1.20</td>
<td>0.36</td>
<td>3.35</td>
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</tr>
<tr>
<td>Pedestrian facial expression - unable to determine</td>
<td>0.49</td>
<td>-0.72</td>
<td>0.71</td>
<td>-1.01</td>
<td></td>
</tr>
<tr>
<td>Pedestrian assertiveness</td>
<td>1.10</td>
<td>0.09</td>
<td>0.07</td>
<td>1.40</td>
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<tr>
<td>Driver facial expression - eye contact</td>
<td>0.02</td>
<td>-3.97</td>
<td>0.34</td>
<td>-11.64</td>
<td></td>
</tr>
<tr>
<td>Vehicle in opposing lane - yes</td>
<td>0.35</td>
<td>-1.06</td>
<td>0.38</td>
<td>-2.77</td>
<td></td>
</tr>
<tr>
<td>Factor affecting pedestrian path - path obstruction</td>
<td>3.85</td>
<td>1.35</td>
<td>0.38</td>
<td>3.57</td>
<td></td>
</tr>
<tr>
<td>Factor affecting driver path - path obstruction</td>
<td>0.16</td>
<td>-1.82</td>
<td>0.32</td>
<td>-5.77</td>
<td></td>
</tr>
<tr>
<td>Random effect</td>
<td>Variance</td>
<td>SD</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Driver</td>
<td>1.45</td>
<td>1.21</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

*Indicates an effect that is not a meaningful comparison
Figure 1. Graphical representation of the 2x2x2 study design.
Figure 2. Photograph of the mini data acquisition system.
Figure 3. Photograph of mini DAS attached to experimental vehicle windshield.
Figure 4. Photograph of forward roadway and internal camera view provided by the mini DAS.
Figure 5. Photograph of the experimental vehicle equipped with signs.
Figure 6. Example photograph of the Hawkeye data reduction window.
Figure 7. Histogram of number of pedestrians in the crossing
Figure 8. Histogram of number of pedestrians near the crossing
Figure 9. Histogram of number of vehicle speed
Figure 10. Histogram of number of pedestrian assertiveness
Figure 11. Caterpillar plot of driver ordered by random effect for driver
Appendix A

Recruitment Script (PowerPoint)
Project Purpose

- The purpose of this project is to gather information about how vehicles communicate with external forces in their surroundings. You will be driving a study vehicle on public roads while vehicle and surrounding information is recorded with telematics, sound, and video recording equipment.

Eligibility

- Must have a valid U.S. driver’s license at the time of participation.
- Must be 18 years or older.
- Must drive at least twice per week.
- Must be a U.S. citizen or permanent resident (green card holder able to work anywhere in the U.S. with no restrictions).
- Must be able to read, write, and speak English comfortably. If the screener finds during the phone interview, the caller is struggling with their ability to communicate fluently in English or has a speech impediment (i.e. stuttering), then the screener will avoid scheduling this person.
- Cannot have a history of neck or back conditions, which still limit their ability to participate in certain activities.
- Cannot have a history of brain damage from stroke, tumor, head injury, recent concussion, or disease or infection of the brain.
- Cannot have a current heart condition which limits their ability to participate in certain activities.
- Cannot have a current respiratory disorder/disease or disorder/disease requiring oxygen.
Eligibility, cont

- Cannot have current problems with motion sickness, inner ear problems, dizziness, vertigo, or balance problems.
- Cannot have uncontrolled diabetes.
- Must not have had any major surgery within the past 6 months (including eye procedures).
- Cannot currently be taking any substances that may interfere with driving ability (cause drowsiness or impair motor abilities).
- Must have normal or corrected to normal vision in both eyes.
- Must be able to drive without sunglasses or without lenses that darken inside a vehicle.
- Must have normal or corrected to normal hearing in both ears.
- Must be able to drive an automatic transmission without assistive devices/special equipment.
- Must not have been convicted of more than two driving violations in the past 3 years.
- Must not have been convicted of an injurious accident (driving violation) in the past 3 years.
- Allow VTII permission to use the digital video including my image for research purposes outside the study, such as a conference presentation.

Procedures

- Fill out a brief demographics questionnaire
- Drive preplanned practice route
- Drive a preplanned test route for a maximum of 45 minutes at a time.
  - There will be two driving sessions, the 2nd driving session approximately 2 weeks after the completion of the first driving session.
- You must follow all rules of the roadway and refrain from cell phone use during all scheduled drives
Risks

- The risk of a crash normally present while driving a vehicle on public roads at posted speeds with varying traffic patterns and density.
- Any risk present when driving a new and unfamiliar vehicle.
- If you have had previous eye injuries or surgeries you are at an increased risk of further eye injury by participating in a study where risks, although minimal, include the possibility of collision and airbag deployment.
- Possible fatigue due to longer driving segments.
- Participants who have had previous neck/spine injuries and/or surgeries are at an increased risk of further neck/spine injury by participating in this study where risks, although minimal, include the possibility of whiplash.
- Please be aware that events such as equipment failure, stray or wild animals entering the road, pedestrians, and weather changes may require you to respond accordingly.
- If you are pregnant you should talk to your physician and discuss this consent form with them before making a decision about participation.

Precautions for your safety

- The study will be conducted on pre-determined roads with which the experimenter is familiar with.
- You will be instructed to drive a practice route to become familiar with the vehicle (to reduce the risk of driving an unfamiliar vehicle).
- An experimenter will be present in the passenger seat of the vehicle. However, as long as you drive the research vehicle, it remains your responsibility to drive in a safe and legal manner.
- The experimenter will monitor your driving and will ask you to stop if he or she feels that the risks are too great to continue.
- If any of the tasks make you uncomfortable or prevent you from safely operating the vehicle, inform the experimenter and do not perform the task.
- You are encouraged to take breaks as needed. You may withdraw from the study at any time. If you wish to withdraw the experimenter will provide return transportation.
Precautions for your safety

- The experimenter will be monitoring your speed, lane position, and following distance to any vehicle in front of you (lead vehicle). You will be instructed to maintain a 3-second headway to the vehicle in front of you. This headway allows you plenty of time to reach if the lead vehicle brakes or changes lanes.
- You will be required to wear the lap and shoulder belt restraint system while in the car.
- The vehicle is equipped with a driver’s side and passenger’s side airbag supplemental restraint system, fire extinguisher, and first-aid kit. The experimenter has a cell phone.
- In the event of a medical emergency, or at your request, VTI staff will arrange medical transportation to a nearby hospital emergency room.
- All data collection equipment is mounted such that, to the greatest extent possible, it does not pose a hazard to you in any foreseeable case.
- The experiment will not be run during hazardous road conditions, including wet or icy conditions.

Statement of liability

- In the event of a crash or injury in an automobile owned or leased by Virginia Tech, the automobile liability coverage for property damage and personal injury is provided. The total policy amount per occurrence is $2,000,000. This coverage (unless the other party was at fault, which would mean all expense would go to the insurer of the other party’s vehicle) would apply in case of a crash for all volunteers and would cover medical expenses up to the policy limit. For example, if you were injured in an automobile owned or leased by Virginia Tech, the cost of transportation to the hospital emergency room would be covered by this policy.
- Participants in a study are considered volunteers, regardless of whether they receive payment for their participation; under state law, worker’s compensation does not apply to volunteers; therefore, if not in the automobile, the participants are responsible for their own medical insurance for bodily injury. Appropriate health insurance is strongly recommended to cover these types of expenses. For example, if you were injured outside of the covered automobile, the cost of transportation to the hospital emergency room would be covered by your insurance.
Benefits

- While there are no direct benefits to you from this research, you may find the experiment interesting. No promise or guarantee of benefits is made to encourage you to participate. Participation in this study will contribute to the improvement of understanding human vehicle interaction.

Extent of Anonymity and Confidentiality

- The data gathered in this experiment will be treated with confidentiality. Shortly after participation, your name will be separated from your data. A coding scheme will be employed to identify the data by participant number only (e.g., Participant No. 1).

- It is possible the Virginia Tech Institutional Review Board (IRB) may view this study’s collected data for auditing purposes. The IRB is responsible for the oversight of the protection of human subjects involved in research.

- VTTI will store your identifiable data on a secure VTTI server.

- A dataset may also be made publicly available. The public dataset will be de-identified and will not contain any information that might lead to the identification of an individual participant; thus, no audio or video will be stored or uploaded to the public use dataset.

- Qualified external researchers will be provided with identifiable data under the terms of a data sharing agreement or contract that at a minimum provides the participant with the same level of confidentiality and protection provided by the consent form.
Compensation

- You will be compensated with 1 hour of research credit for each hour of participation. If the session ends early for any reason, you will be paid the rate of 1 credit per hour, rounded to the nearest ½ hour (minimum of ½ credit).

Freedom to Withdraw

- As a participant in this research, you are free to withdraw at any time without penalty. If you choose to withdraw, you will be compensated for the portion of time of the study for which you participated. Furthermore, you are free not to answer any question or respond to experimental situations without penalty. If you choose to withdraw during the study session, please inform the experimenter of this decision and he/she will drive you back to the building.
Approval of Research

— Before data can be collected, the research must be approved, as required, by the Institutional Review Board for Research Involving Human Subjects at Virginia Polytechnic Institute and State University. You should know that this approval has been obtained and is valid until the date listed at the bottom of this page.
Participant's Responsibilities

- To wear your lap and shoulder belt restraint system while in the vehicle.
- To notify research staff if you encounter any difficulties of any type.
- To maintain safe operation of the instrumented vehicle at all times.
Appendix B

Participant Screening Form

Participant ID:

Study overview:

“The current study is being run by Virginia Tech Transpiration Institute to investigate how humans communicate with and interpret communication from motor vehicles. Ultimately, the results of this experiment will help to guide the programming and design of autonomous vehicles. As a participant you will drive our instrumented vehicle on preplanned routes in Blacksburg, VA. The research vehicle is equipped with data collection equipment which records audio and video data while you drive. Each study session will last approximately 1 hour. During all driving sessions you will be accompanied by a researcher and are expected to follow all instructions”.

“The Expectations in this study include the following:

- Maintain safe vehicle operation at all times (e.g., follow laws, posted signs, wear safety belt, and refrain from cell phone use)
- Drive the study vehicle on preplanned routes
- Commit to three separate driving sessions.”

“Will you agree to participate in this study” Yes• No•

If no, “thank you for your time”

If yes, “I’m going to ask you a few questions to determine your eligibility to participate in the study. Your responses on the screening form will be destroyed if you do not meet the eligibility requirements. This form will be saved if you meet the eligibility requirements; however, only an anonymous participant ID will be used and not your name or other identifying information.”
Entry Criteria: If answer to “no”, please read, “thank you for your time, you do not meet the eligibility criteria to participate in this study.”

1. “Do you have a valid U.S. driver’s license at the time of participation”. Yes • No •
2. “Are you 18 years or older.” Yes • No •
3. “Are you U.S. citizen or permanent resident (green card holder).” Yes • No •
4. “Do you regularly drive at least twice a week.” Yes • No •
5. “Can you read, write, and speak English comfortably.” Yes • No • If the screener finds during the phone interview, the caller is struggling with their ability to communicate fluently in English or has a speech impediment (i.e. stuttering), then the screener will avoid scheduling this person.

If answer to “yes”, please read “thank you for your time, you do not meet the eligibility criteria to participate in this study.”

6. “Do you have a history of neck or back conditions, which still limit their ability to participate in certain activities.” Yes • No •
7. “Do you have a history of brain damage from stroke, tumor, head injury, recent concussion, or disease or infection of the brain.” Yes • No •
8. “Do you have a current heart condition which limits their ability to participate in certain activities.” Yes • No •
9. “Do you have a current respiratory disorder/disease or disorder/disease requiring oxygen.” Yes • No •
10. “Have you had an epileptic seizure or lapse of consciousness within the past 12 months.”
   Yes • No •

11. “Have you had, on average, more than one migraine or severe headache per month during
    the past year.” Yes • No •

12. “Do you have current problems with motion sickness, inner ear problems, dizziness,
    vertigo, or balance problems.” Yes • No •

13. “Do you have uncontrolled diabetes.” Yes • No •

14. “Did you have had any major surgery within the past 6 months (including eye
    procedures).” Yes • No •

15. “Are you currently be taking any substances that may interfere with driving ability (cause
    drowsiness or impair motor abilities).” Yes • No •

If answer to “no”, please read “thank you for your time, you do not meet the eligibility
criteria to participate in this study.”

16. “Do you have normal or corrected to normal vision in both eyes.” Yes • No •

17. “Do you have normal or corrected to normal hearing in both ears.” Yes • No •

18. “Can you drive an automatic transmission without assistive devices/special equipment.”
    Yes • No •

If answer to “yes”, please read “thank you for your time, you do not meet the eligibility
criteria to participate in this study.”
19. “Have you been convicted of more than two driving violations in the past 3 years.” Yes• No•

20. “Have you have been convicted of an injurious accidents (driving violation) in the past 3 years.” Yes• No•

If answer to “no”, please read “thank you for your time, you do not meet the eligibility criteria to participate in this study.”

21. “Will you allow VTTI permission to use the digital audio and video including my image for research purposes outside the study, such as a conference presentation.” Yes• No•
Appendix C

Demographics Form

Please indicate your age in exact years (e.g., 18, 19, 20, etc.)

____________

Please indicate your gender

- Male
- Female
- Prefer not to answer

Have you received any moving violations in the last 12 months?

- Yes (if yes how many__________)
- No

Have you been involved in a motor vehicle crash in the last 12 months?

- Yes
- No

If yes were you at fault?

- Yes
- No

If yes please describe the incident below.
Appendix E

Instructional Scripts

**Instructional Script A:**
During our drive today you should listen to the experimenter for route guidance while obeying all traffic rules, regulations, and signs. This includes maintaining safe vehicle operation at all time and wearing safety belts. In addition, refrain from cell phone use during the duration of the drive.

**Instructional Script B:**
During our drive today you should listen to the experimenter for route guidance while obeying all traffic rules, regulations, and signs. This includes maintaining safe vehicle operation at all time and wearing safety belts. In addition, refrain from cell phone use during the duration of the drive.

During the drive, please try to narrate any actions you perform that are influenced by outside factors. More specifically, if you alter driving behavior to accommodate a pedestrian explain what you did and why in as much detail as possible. For example, if a pedestrian steps in to the street and you subsequently slow down, you may say I noticed one pedestrian stepping into the roadway on the passenger side and I felt I needed to slowly press the break, decreasing my speed, to avoid making contact with the pedestrian. Safe driving takes precedence over any of these instructions. If you, at any time, feel unsafe or uncomfortable narrating while driving, please focus on the safe operation of the vehicle and prohibit narration until you feel safe and comfortable again.
Instructional Script C:

During our drive today you should listen to the experimenter for route guidance while obeying all traffic rules, regulations, and signs. This includes maintaining safe vehicle operation at all time and wearing safety belts. In addition, refrain from cell phone use during the duration of the drive.

This vehicle has several signs that read, “Self-driving vehicle”. This vehicle is not self-driving and does not have any self-driving features. It will not steer, brake, accelerate or initiate any other driving functions unless you perform those function. You will be responsible for steering, braking, accelerating, and obeying all traffic rules, regulations, and signs.
Appendix F

Experimental Route #1
Experimental Route #2
Appendix H

Valid Event Identification Guide

A valid event starts when:

A) A pedestrian is less than or equal to 10 feet from a crosswalk while the experimental vehicle is approximately 50 feet from the crosswalk

B) A human propelled vehicles is less than or equal to 30 feet from a crosswalk while the experimental vehicle is approximately 50 feet from the crosswalk. The most common instances are bicycles and skateboards, but the category extends to any augmented transportation.

Events stop when:

A&B) when the vehicle has passed the crosswalk.
Pedestrian event start from left hand side
Pedestrian event start from the right hand side
Human propelled vehicle event start from the left hand side. The car distance here is about 60-70 feet. However, from the left hand side the human propelled vehicle leaves the camera view at 50 feet. We need to keep our eye out for possible human propelled vehicle events from the left. However, they should be rare.

Human propelled vehicle event start from the right hand side.
Appendix I

Data Directory

Open Hawkeye

Choose collection - Comm. of Auto Vehicles

Type in the file ID to the load trip bar and select load trip

File ID is found in the Data Reduction Log Spreadsheet in the google team drive

After the video loads check under control info to verify the file ID

In Hawkeye on left side there is a panel it has all of the possible data windows

  Under Collected open Video and open all options (there should be two)
  Under Collected open Audio and open all options (should be one, “wave”)
  Under Demuxed open Vehicle Can_1 open Vehicle Speed

In Hawkeye press select

  Chose an un-coded event, make sure to verify the time stamps

Double click “comm” in the annotations box under question code

Answer the questions according to this data dictionary.

Make sure to save often.

&***&***Any event with more than one pedestrian: all other pedestrians need to be coded in the excel file found here

\vti.ad.vt.edu\Data\Projects03\451478\Drop Boxes\Misc

****Data Reduction Log is used to store and keep track of when an event has been coded
**Coding Spreadsheet for Pedestrians** is used to code additional pedestrians during an event beyond the first pedestrian.

In the spreadsheet code all checkbox questions as 1 for yes and 0 for no. If you need to code as “other”, “unknown” or “unable to determine” put that code into the first cell and describe in notes.

**Driver & Pedestrian question reduction:**

**Page ONE**

1. **EventHistory.** Did any of the following occur before the current event? Code as none unless the experimental vehicle did not have time to return to normal travel.
   - (0) None
   - (1) Vehicle stopped/slowed for infrastructure
   - (2) Vehicle stopped/slowed for non-experimental vehicle
   - (99) Other *(describe in “Notes”)*

2. **SpeedLimit.** What is the speed limit on the current road?
   - (1) 15 mph (Drillfield)
   - (2) 25 mph (other town roads)
   - (3) 35 mph (Patrick Henry drive)

3. **TrafficFlow.** How is travel divided?
   - (0) No lanes
   - (1) Not divided – simple 2-way traffic way
   - (2) Not divided – center 2-way left turn lane
   - (3) Divided (median strip or barrier)
(4) One-way traffic – two lanes one for each direction of travel

(88) Unknown

4. ContiguousTravelLanes (#). **How many lanes for same direction travel were available?**

(0) 0

(1) 1

(2) 2

(3) 3+

(88) Unknown

5. ThroughTravelLanes (#) - **How many lanes for same direction travel were available?**

(0) 0

(1) 1

(2) 2

(3) 3+

(88) Unknown

6. Bicyclelane. **Was a lane available for bicycle travel?**

(0) No bicycle lane

(1) Bicycle lane near – a bicycle lane adjacent to experimental vehicle

(2) Bicycle lane far – a bicycle lane on the side of the road not being traveled by the experimental vehicle

(3) Bicycle lane on both sides

7. VisualObstructions. **What environmental factors impaired the driver’s ability to see a possible pedestrian interaction? (Check all that apply)**
(0) No obstruction
(1) Stopped vehicle right
(2) Stopped vehicle left
(3) Moving vehicle right
(4) Moving vehicle left
(5) Building, billboard, or other roadway infrastructure design features
(6) Trees, crops, vegetation
(99) Other (describe in “Notes”)

(88) Unknown whether vision was obstructed

8. Weather. What type of weather is applicable to the experimental vehicle at event start?

(1) Clear/partly cloudy
(2) Overcast
(3) Mist/Light Rain
(4) Raining
(5) Snowing
(6) Fog
(99) Other

88) Unable to determine (describe in "Notes") – Cannot tell from the video due to poor video quality, missing video, misaligned video, etc.

9. Lighting. What type of ambient lighting is applicable to the experimental vehicle at event start?

(1) Daylight
(2) Dawn

(3) Dusk (low light)

(4) Darkness (lighted)

(5) Darkness (not lighted)

(88) Unknown (describe in "Notes") – Cannot tell from the video due to poor video quality, missing video, misaligned video, etc.

10. TrafficControl. **What type of traffic control is applicable to the experimental vehicle at event start?**

(0) None

(1) Yield to pedestrian sign

(2) Yield to traffic sign

(3) Stop sign

(4) Red light

(5) Yellow light

(6) Green light (solid)

(7) Green light (arrow)

(99) Other (describe in "Notes")

11. PedestrianSignal. **What type of signal is applicable to the pedestrian at event start?**

(0) No signal

(1) Walk – a steady walking person

(2) Countdown clock – a steady upraised hand (and/or walking person) with numerical countdown, or numerical countdown alone
(3) Warning do not start walking - a flashing upraised hand (signifying do not start walking, but if already started, then finish crossing)

(4) Do not walk – a steady upraised hand

(99) Other (describe in "Notes")

(88) Unable to determine (describe in "Notes") – Cannot tell from the video due to poor video quality, missing video, misaligned video, etc.

12. RightofWay. **Who has the right-of-way for the impending encounter?** Right-of-way (ROW) is related to the upcoming encounter (i.e., if both parties proceed, who will have the ROW). For example, if pedestrian will be in crosswalk when the vehicle approaches, pedestrian has ROW. If there is no crosswalk and the pedestrian is not in the roadway at the point of encounter, the vehicle has ROW.

(1) Experimental vehicle

(2) Pedestrian

(3) Undefined – there is no rule to determine who has right-of-way

(88) Unable to determine (describe in "Notes") – Cannot tell from the video due to poor video quality, missing video, misaligned video, etc.

13. VehiclePosition. **What type of scenario is the current or impending experimental vehicle pedestrian encounter?**

(1) Vehicle straight – Vehicle proceeding straight

(2) Vehicle straight, from stop – Vehicle transitions from being stopped to continue straight ahead through one or more crosswalks

(3) Vehicle preparing to turn across traffic – Vehicle is waiting or beginning to turn across traffic

(4) Vehicle preparing to turn with traffic – Vehicle is waiting or beginning to turn with traffic
(5) Vehicle turning across traffic – Vehicle turning across traffic
(6) Vehicle turning with traffic – Vehicle turning with traffic
(7) Vehicle in parking lot, exiting – Vehicle exiting parking lot
(8) Vehicle in parking lot, entering – Vehicle entering parking lot
(9) Vehicle in parking lot, traveling through – Study vehicle travels through a parking lot and/or parking garage where there is a variety of pedestrian pathways available and pedestrian(s) present.
(99) Other (describe in "Notes") – Other scenario not listed above (enter description in Notes variable)
(88) Unable to determine (describe in "Notes") - Cannot tell from the video due to poor video quality, missing video, misaligned video, etc.

14. VehicleSpeed. How fast is the vehicle traveling at the start of the event?

15. VehicleDistance. How far away is the vehicle from the crosswalk at event start?

(0) 0 feet
(1) 0-15 feet
(2) 15-30 feet
(3) 30+ feet

16. PedinCrosswalk. How many pedestrians were in the crosswalk at event start?

17. PedNearCrosswalk. How many pedestrians were within 0-10 feet of the crosswalk at event start?

18. PedDistance. How far away is the nearest pedestrian from the crosswalk at event start?

(0) 0 feet - Record 0 feet if the pedestrian is waiting at the edge of the crosswalk to enter
(1) 0-5 feet - Record 0-5 feet if the pedestrian is within 0-5 feet, but is not waiting

(2) 5-10 feet

(3) 10+ feet

(4) In crosswalk

Page TWO

19. UtteranceCoding. Transcribe any verbal comments or utterance made by the driver that relate to the current protocol. Make sure to transcribe word for word. In addition, these utterances may occur slightly before or after a defined event.

20. Coached. Did the participant receive any coaching for the think-aloud protocol?

Page THREE

21. Notes. Any unusual circumstances or factors that affected the coding of these variables and additional comments regarding what was observed during this reduction

Page FOUR

22. PedNum. Number each pedestrian starting at 001 restart the count within each event

23. Yield. Who yielded during the interaction?

(1) Experimental vehicle - Experimental vehicle lets the pedestrian cross completely with no confusion about who is yielding

(2) Vehicle fails to yield - Vehicle continues when it should have yielded without any yield behavior by the pedestrian (i.e., waving the car on)

(3) Pedestrian - Pedestrian yields the right of way via communication

(4) Pedestrian attempts to yield, but vehicle yields - Pedestrian makes an attempt to yield, but ultimately the vehicle yields
(5) Vehicle attempts to yield, but pedestrian yields - Vehicle makes an attempt to yield, but pedestrian ultimately yields

24. PedType. What category does the target pedestrian best fit?

(1) Pedestrian

(2) Bicycle

(3) Skateboard

(4) Other human propelled vehicle

25. PedPosition. What is the pedestrian’s position at start of possible interaction for pedestrian interaction?

(1) Approaching curb to cross

(2) Waiting on curb to cross

(3) In roadway, crossing (before vehicle trajectory) – at this point, if the pedestrian stops and vehicle continues, there will be no vehicle conflict with pedestrian path

(4) In roadway, crossing (in vehicle trajectory) – at this point, if the pedestrian stops and vehicle continues, there will likely be conflict between vehicle path and pedestrian

(5) In roadway, crossing (after vehicle trajectory) – at this point, if the pedestrian stops and vehicle continues, there will be no vehicle conflict with pedestrian path

(6) Walking on sidewalk, other path (not crossing street) – pedestrian is walking in the vicinity of the vehicle, but is not crossing or intending to cross the street

(99) Other (describe in "Notes")

(88) Unable to determine (describe in "Notes") – Cannot tell from the video due to poor video quality, missing video, misaligned video, etc.

26. PedPath. What is the pedestrian’s intended path at start of possible interaction?
(1) Crosswalk

(2) Roadway (no crosswalk) – includes walking across roadway without a crosswalk and in a parking lot, not on an intended or marked path

(3) Sidewalk or other path (not roadway) – includes walking on a sidewalk or in a parking lot on an intended or marked path (such as a crosswalk)

(99) Other (describe in "Notes")

(88) Unable to determine (describe in "Notes") – Cannot tell from the video due to poor video quality, missing video, misaligned video, etc.

27. PedReaction. What is the type of reaction (task change) that occurred by the pedestrian in response to the experimental vehicle? Code reactions that occur anywhere during the event. If multiple reactions occur, select the first reaction and select other and describe the first reaction and any additional reactions. When describing multiple use the definitions provided in this coding question whenever possible.

(0) None - the pedestrian did not have any noticeable change

(1) Continue walking but accelerate or change path – the pedestrian accelerated noticeably or changed their path to increase distance from the experimental vehicle (includes going from walking to jogging)

(2) Continue walking but decelerate – there was a noticeable decrease in pace, but the pedestrian did not quit walking (includes going from jogging to walking)

(3) Begin walking from stationary

(4) Interrupted walking then continue – the pedestrian stopped but then continued walking while the experimental vehicle was approaching or passing by
(5) Interrupted walking and abort – includes stopping (not walking or waiting until experimental vehicle passed by) or retreating

(99) Other (describe in "Notes")

28. DriverReaction. What is the type of reaction (task change) that occurred by the driver in response to the pedestrian? Code reactions that occur anywhere during the event. If multiple reactions occur, select the first reaction and select other and describe the first reaction and any additional reactions. When describing multiple use the definitions provided in this coding question whenever possible.

(1) Continues but accelerates or change path – the driver accelerated noticeably or changed their path to increase distance from the pedestrian

(2) Continues but decelerates – there was a noticeable decrease in speed, but the vehicle did come to a complete stop

(3) Comes to a complete stop

(4) Interrupted driving then continue – the driver stopped but then continued while the pedestrian was approaching

(99) Other (describe in "Notes")

29. PedClothing. What color of clothing was the pedestrian wearing?

(1) Black

(2) White

(3) VT Bright

(4) VT Dull

(5) Colored Bright

(6) Colored Dull
(99) Other

(88) Unable to determine

30. PedGender. **What is the pedestrian’s gender?**

(1) Male

(0) Female

(88) Unable to determine (describe in "Notes")

31. PedAge. **What age group does the pedestrian best fit?**

(1) Young – Child or teenager (not young adult), appears to be a minor (under 18 years old)

(2) Middle – Others not clearly child or elderly, includes college students

(3) Older – Includes the elderly (with or without some apparent or likely age-related visual, hearing, and/or physical limitations) (in general, about 65 years old or more)

(88) Unable to determine (describe in "Notes") – Only code if video does not provide a clear view (head is mostly covered, etc.), otherwise make your best guess about the pedestrian’s age category

32. Dependency. **What is the pedestrian’s situation regarding someone else’s dependency on them or their own vulnerability?** If multiple occurs code as other.

(0) None

(1) Disabled - includes walker, wheelchair, cane, other assistive devices

(2) Accompanying child - includes holding hand or otherwise guiding, pushing stroller, even, child being carried, leading or following child(ren) when staying together appears to be an objective

(3) Pregnant

(4) Guiding or assisting elderly or disabled
(5) With pet - includes walking on or off leash, or holding

(6) Alcohol or drugs - appears to be under the influence of alcohol or other drugs

(7) Exhibiting horseplay – includes aggressive or risky behavior

(99) Other (describe in "Notes")

(88) Unable to determine (describe in "Notes") – Cannot tell from the video due to poor video quality, missing video, misaligned video, etc.

33. Phone Use. **What type of phone use is occurring if any by the pedestrian?**

(0) None

(1) Listening or talking - including Bluetooth (but no headphones), activities that divert attention from surroundings or influence walking/crossing pattern

(2) Looking and/or manipulating controls – includes reading texts, dialing, texting, or otherwise operating phone with fingers

(99) Other (describe in "Notes")

(88) Unable to determine (describe in "Notes") – Cannot tell from the video due to poor video quality, missing video, misaligned video, etc.

34. Headphones. **Is the pedestrian using headphones of any type?**

(0) None

(1) Earbuds

(2) Over ear headphones

(99) Other (describe in "Notes")

(88) Unable to determine (describe in "Notes") – Cannot tell from the video due to poor video quality, missing video, misaligned video, etc.

35. Carrying. **Is the pedestrian carrying anything?**
(0) Nothing

(1) Backpack/bag

(2) Food or drink

(3) Both - code both if the pedestrian is carrying both food/drink and a bag

(99) Other

36. EatDrink. Is the pedestrian eating or drinking?

(0) No eating or drinking

(1) Eating or drinking

37. Jogging. Is the pedestrian running for exercise?

(0) Not jogging

(1) Jogging

38. OtherPedActivities. Is the target pedestrian doing any of the following actions?

(0) None

(1) Looking at personal item – includes items on the body or being held, other than phone (such as newspaper, object in purse)

(2) Talking to someone in person

(3) Gesturing or interacting– includes interacting with a person (other than talking) or object not on one's person other than the experimental vehicle, pointing at an object, waving to someone, etc.

(99) Other (describe in "Notes")

(88) Unable to determine (describe in "Notes") – Cannot tell from the video due to poor video quality, missing video, misaligned video, etc.
39. PedFacial. What facial gesture(s) if any did the pedestrian make toward the driver?

(Check all that apply)

(1) None
(1) Eye contact
(1) Smile
(1) Head nod
(99) Other (describe in "Notes")

(88) Unable to determine (describe in "Notes") – Use when a gesture appears, but it is unclear.

40. PedHand. What hand gesture(s) if any did the pedestrian make toward the driver?

(Check all that apply)

(1) None
(1) Raises hand palm outward in a wave
(1) Thumbs up
(1) Okay sign
(1) Waves through
(1) Two finger wave
(99) Other (describe in "Notes")

(88) Unable to determine (describe in "Notes") – Use when a gesture appears, but it is unclear.
41. PedAssertiveness. **Rate your perception of the pedestrian’s assertiveness on a scale from 1 (extremely passive) to 7 (extremely assertive)**

   (1) Extremely passive (1)
   (2) Passive (2)
   (3) Somewhat passive (3)
   (4) Neutral (4)
   (5) Somewhat assertive (5)
   (6) Assertive (6)
   (7) Extremely assertive (7)

42. DriverFacial. **What facial gesture(s) if any did the driver make toward the pedestrian? (Check all that apply)**

   (1) None
   (1) Eye contact
   (1) Smile
   (1) Frown
   (1) Raised eyebrows
   (1) Head nod
   (99) Other (describe in "Notes")
   (88) Unable to determine (describe in "Notes") – Use when a gesture appears, but it is unclear.

43. DriverHand. **What gesture(s) if any did the driver make toward the pedestrian?**

   (Check all that apply)

   (1) None
   (1) Raises hand palm outward in a wave
(1) Thumbs up

(1) Okay sign

(1) Waves through

(1) Two finger wave

(99) Other (describe in "Notes")

(88) Unable to determine (describe in "Notes") – Use when a gesture appears, but it is unclear.

44. OpposingVehicle. Was a vehicle traveling in the opposing lane at any point during the event which could have interacted with the target pedestrian?

(1) Yes

(0) No

45. DriverHandPos. Where were the driver’s hands during the pedestrian encounter?

Throughout the encounter hand position may change. Select the highest position if it ever occurs (i.e., if the hands are ever on the top of the wheel select top of wheel. If the hands are never on the top, but are on the side of the wheel at least once, select side of wheel. If the hands are only on the bottom of the wheel select bottom of wheel).

(1) Top of wheel

(2) Side of wheel

(3) Bottom of wheel

46. FactorPedPath. What are the factors affecting the drivers path and behavior? (Check all that apply)

(1) No path obstructions
(1) Other pedestrians – include other pedestrians who are in the path and create some restrictions on this pedestrian’s behavior

(1) Other vehicles - include other vehicles (cars, bicycles, motorcycles, etc.) who are in the path and create some restrictions on this pedestrian’s behavior

(1) Construction

(1) Sidewalk closed or in disrepair

(1) Apparent urgency - fast walking speed or running, not including recreational jogging

(1) Walking with companion(s) – when not leading or catching up with someone

(99) Other pathway obstruction (describe in "Notes")

(88) Unable to determine (describe in "Notes") – Cannot tell from the video due to poor video quality, missing video, misaligned video, etc.

47. FactorDrivePath. What are the factors affecting the driver path and behavior?

   (Check all that apply)

(1) No path obstructions

(1) Other pedestrians – include other pedestrians who are in the path and create some restrictions on this pedestrian’s behavior

(1) Other vehicles - include other vehicles (cars, bicycles, motorcycles, etc.) who are in the path and create some restrictions on this pedestrian’s behavior

(1) Construction

(99) Other pathway obstruction (describe in "Notes")

(88) Unable to determine (describe in "Notes") – Cannot tell from the video due to poor video quality, missing video, misaligned video, etc.

48. PedCross. In relation to the experimental vehicle when does the pedestrian cross?
(1) Crosses in front of the experimental vehicle

(2) Crosses after experimental vehicle passes

(3) Did not cross due to experimental vehicle

(4) Did not cross due to non-experimental vehicle

(99) Other (describe in “Notes”)

49. Another Ped. Is there another ped to code?

(1) Yes

(0) No
Appendix J
Distance Coding Guide

Vehicle and Pedestrian relative distances for coding reference

Vehicle 30 feet from crosswalk pedestrian 10 feet from crosswalk
Vehicle 30 feet from crosswalk pedestrian 5 feet from crosswalk
Vehicle 30 feet from crosswalk pedestrian 0 feet from crosswalk
Vehicle 15 feet from crosswalk pedestrian 10 feet from crosswalk
Vehicle 15 feet from crosswalk pedestrian 5 feet from crosswalk
Vehicle 15 feet from crosswalk pedestrian 0 feet from crosswalk
Appendix K

Model One Variable Inclusion

Event history categorical

All categories have more than 5% of data. This variable is completely appropriate for the model.

Speed limit categorical

The category ‘Drillfield (15 mph)’ contributed 23.2% of data while ‘Other town roads (25 mph)’ contributed 75.9% indicating that two categories contributed more than 5% each. The third and final category ‘Patrick Henry Drive (35 mph)’ only accounted for 0.8% of the overall data and a change will be investigated if the model requires.

Traffic flow, Number of contiguous travel lanes, and Number of through lanes

These variables are highly correlated with the variable speed limit and will be excluded from the model. The variables were correlated primarily due to video coding where the Drillfield is the only area that is 15 miles per hour and has fixed traffic conditions. The variables ‘Number of contiguous travel lanes’ and ‘Number of through travel lanes’ both included data primarily in a single category. With one lane comprising 93.6% and 94.6%, respectively.

Visual obstructions

Visual obstructions were coded as a yes or no response to the obstructions, ‘Stopped vehicle right’, ‘Stopped vehicle left’, ‘Moving vehicle right’, ‘Moving vehicle left’, ‘Building, billboard, or other roadway infrastructure design’, ‘Trees, crops, or vegetation’, and ‘Other’. For the purpose of analyses the responses were re-coded into a single new variable with the categories ‘No obstruction’ and ‘Visual obstruction’. If any visual obstructions were reported they were coded as having a visual obstruction. The category ‘No obstruction’ accounted for 55.2% of all data and ‘Visual obstruction’ was the other 44.8%.

Weather during the event

The weather was originally coded into five unique categories. Three of the categories included inclement weather, but two of the categories had low frequencies below 2% of the overall data. The two remaining categories, ‘Clear/partly cloudy’ and ‘Overcast’, included non-inclement weather and comprised 93.3% and 2.8% of the data, respectively. To ensure appropriate model estimation, the weather variable was condensed into two categories ‘Clear weather’ and ‘Inclement weather’. The inclement weather accounted for only 3.9% of all data and did not meet the 5% needed for inclusion in the model. The weather variable will be excluded from the regression model.

Lighting during the event

The lighting was originally coded with five independent levels. However, only one level included more than 5% of the data. In this case, ‘Daylight’ accounted for 95.1% of all the data and even combining all other categories into an ‘Other’ category will only produce 4.9% of the overall data. The variable for lighting during the event will be excluded from the regression model.

Traffic control

The variable traffic control was originally coded with seven levels. Three of the levels, ‘None’, ‘Yield to pedestrian sign’, and ‘Stop sign’, all had more than 5% of the overall data. In addition, these three levels comprised 99.2% of all data. To build an appropriate model, the traffic control variable was re-coded to have only three levels where all other traffic control types were combined with the category ‘None’. This changes the model interpretation of the odds ratio
estimates for the dummy coded variables ‘Yield to pedestrian sign’ or ‘Stop sign’ comparing to having no traffic control, to being ‘Not a yield sign or stop sign’.

Pedestrian signal
The variable pedestrian signal was coded into four categories. For this variable, 99.6% of all data fell into the ‘No signal’ category. Thus, the variable will be excluded from analysis.

Right of way
The variable right of way was coded into two categories indicating the party who had the right of way during the encounter. Each category accounted for more than 5% of all data. Therefore, right of way will be included in the model.

Vehicle position
The variable vehicle position was coded into eight categories. The category ‘Vehicle straight’ comprised 92.3% of all data. To include this variable in the regression model, all other categories would need to be used as a comparison to ‘Vehicle straight’. This comparison is not theoretically meaningful, as there is fundamental differences between ‘Vehicle turning with traffic’ and ‘Vehicle turning across traffic’. A substantial comparison would require each category to be separate. For this reason, vehicle position will be excluded from the model.

Vehicle distance to the crosswalk
The variable vehicle distance to the crosswalk was coded into four categories. Two categories had above 5% of all data and the remaining two each had above 2%. The variable vehicle distance will be included in the regression model.

Pedestrian distance to the crosswalk
The variable pedestrian distance to the crosswalk was coded with five categories. Four of the categories included more than 5% of the overall data. The category ‘10+ feet’ only included 0.6% of all data and was re-coded as a combination with the category ‘5-10 feet’ to produce a new category ‘5+ feet’. This variable will be included in the model.

Pedestrian position
The variable pedestrian position was coded into four categories and each had more than 5% of the overall data. This variable will be included in the model.

Pedestrian path
The variable included two levels each with more than 5% of all data and will be included in the model.

Pedestrian reaction
The pedestrian reaction in response to the experimental vehicle was coded into seven distinct categories. Four of the categories had more than 5% of the data. Two categories had more than 2% of the data and only one category ‘Other’ had 1.1% of the data. Since combining the category ‘Other’ with any other category fails to provide a meaningful comparison the variable will be used in the model as is.

Driver reaction
The driver reaction in response to the pedestrian was coded into six categories. Four of the categories had more than 5% of the overall data and only one category ‘Other’ included less than 2%. The other category had only one case and the notes describing the event indicated the coding should have been placed into the ‘Continue, but accelerate’ category. This case was re-coded and all categories had more than 2% of the overall data. This variable was included in the model.

Pedestrian clothing
The pedestrians' clothing were recorded as a variable with eight levels, five of the levels included more than 5% of the data while the other three categories all included more than 2% of the data.

Pedestrian gender
Pedestrian gender was coded as ‘Male’, ‘Female’, or ‘Unable to determine’. Both categories, ‘Male’ and ‘Female’, had greater than 5% of data while ‘Unable to determine’ had more than 2%. This variable met all inclusion criteria and was selected for the model.

Pedestrian age
The variable pedestrian age was coded into three possible categories, ‘Young’, ‘Middle’, and ‘Older’. The category ‘Middle’ comprised 97.0% of the data. Since no other category or combination could reach 5%, this variable was excluded from the model.

Pedestrian phone use
The variable phone use was coded into five categories. The ‘Other category’ included one case, but no notes were recorded so the case was moved to the ‘Unable to determine’ category. In addition, ‘Listening or talking’ represented 2.6% of the data and was combined with ‘Looking and/or manipulating controls’. The combinations created a new variable with three categories all above 5% of the data. The new categories are ‘None’, ‘Phone use’, and ‘Unable to determine’. The new variable was included in the model.

Pedestrian headphone use
The variable for headphone use was excluded from the model because less than 5% of pedestrian were recorded under any type of headphone use. An additional issue was 30.8% of cases were categorized as ‘Unable to determine’. This primarily occurred due to video quality and difficulty determining if someone was wearing earbuds.

Pedestrian carrying
The variable for items a pedestrian was carrying had low frequency for all categories other than ‘Backpack/bag’. The only way to remedy this was to collapse the other categories into an all encompassing ‘Other’ category providing all three remaining categories with more than 5% of the overall data. This variable was included in the model because it lacked a substantive meaningful interpretation.

Pedestrian eating/drinking and pedestrian jogging
The variables for if a pedestrian was eating/drinking and pedestrian jogging were excluded from the model because more than 99% of cases were coded as ‘No’ for both variables.

Pedestrian other activities
Other activities were primarily coded into two categories ‘None’ and ‘Talking to someone’. These two categories each comprised more than 5% of the data. In addition, all other categories were low frequencies below 2%. The only available fix to avoid this issue required all categories with less than 2% being combined into a category ‘Other’. This variable was not included in the model because it lacks a meaningful comparison.

Pedestrian facial communication
Pedestrian facial communication were coded as a yes or no response to the expressions, ‘None’, ‘Eye contact’, ‘Smile’, ‘Head nod’, ‘Other’, or ‘Unable to determine’. For the purpose of analyses the responses were re-coded into a single new variable with the categories ‘None’, ‘Eye contact’, and ‘Unable to determine’. The categories accounted for 34.3%, 56.8%, and 8.8% of data, respectively. These categories were selected based on low frequencies in any other category.

Pedestrian hand signals

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Pedestrian hand signals were coded as a yes or no response to the signals ‘None’, ‘Raises hand palm outward in wave’, ‘Thumbs up’, ‘Okay sign’, ‘Waves through’, ‘Two finger wave’, ‘Other’, or ‘Unable to determine’. For the purpose of analyses the responses were re-coded into a single new variable with the categories ‘None’, ‘Wave’, and ‘Unable to determine’. These categories were selected due to extremely low frequencies in the other categories. The category ‘None’ accounted for 81.6% of the data, while ‘Wave’ and ‘Unable to determine’ accounted for 8.8% and 9.6%, respectively. This variable was not included in the predictive model due to the variable generally representing a response to the decision to yield rather than an antecedent of the yielding behavior.

Driver facial communication

Driver facial communication were coded as a yes or no response to the expressions, ‘None’, ‘Eye contact’, ‘Smile’, ‘Frown’, ‘Raised eyebrows’, ‘Head nod’, ‘Other’, or ‘Unable to determine’. For the purpose of analyses the responses were re-coded into a single new variable with the categories ‘None’, ‘Eye contact’, and ‘Other’. The categories accounted for 9.0%, 88.7%, and 2.3% of data, respectively. These categories were selected based on low frequencies in any other category.

Driver hand signals

Pedestrian hand signals were coded as a yes or no response to ‘None’, ‘Raises hand palm outward in wave’, ‘Thumbs up’, ‘Okay sign’, ‘Waves through’, ‘Two finger wave’, ‘Other’, or ‘Unable to determine’. For the purpose of analyses the responses were re-coded into a single new variable with the categories ‘None’ (87.3%), ‘Waves through’ (7.9%), and ‘Wave palm out’ (4.8%). These categories were selected due to extremely low frequencies in the other categories. This variable was not included in the model due to the variable generally representing a response to the decision to yield rather than an antecedent of the yielding behavior.

Vehicle traveling in opposing lane

The variable vehicle traveling in opposing lane was code as a yes or no response. Each category had more than 5% of the data and the variable was selected for inclusion in the model.

Factors affecting pedestrian path

The factors affecting the pedestrians path were coded as yes or no responses to the categories ‘None’, ‘Other pedestrian’, ‘Other vehicle’, ‘Construction’, ‘Sidewalk closed or in disrepair’, ‘Apparent urgency’, ‘Walking with companion(s)’, ‘Other’, and ‘Unable to determine’. The questions ‘Other pedestrian’ and ‘Walking with companion(s)’ were excluded from further investigation due to training issues. The first category was excluded because one coder marked a pedestrian as obstructing the path if a pedestrian was present and represented nearly 100% of the instances marked as a pedestrian obstructing another pedestrians path. The second category was excluded because it was coded in an identical manner with the response ‘Talking with someone’ from the variable pedestrian other activities. The remaining path obstructions were combined into a single variable with the categories ‘Path not obstructed’ and ‘Path obstructed’. Each of the two categories had more than 5% of the overall data and the variable was included for analysis.

Factors affecting driver path

The factors affecting the drivers path were coded as yes or no responses to the categories ‘None’, ‘Other pedestrian’, ‘Other vehicle’, ‘Construction’, ‘Other’, and ‘Unable to determine’. For the purpose of analysis a single variable was created with the categories ‘Path not obstructed’ and ‘Path obstructed’. Each of the two categories had more than 5% of the overall data and the variable was included for analysis.

Another pedestrian to code
The variable another pedestrian to code met the inclusion criteria for model two. However, the variable was encompassed by the continuous variable measuring the number of pedestrians within ten feet of the crosswalk. For this reason, the variable another pedestrian to code was excluded from model one.
## Appendix L

### Model One Results

<table>
<thead>
<tr>
<th>Variable</th>
<th>Odds ratio</th>
<th>Estimate</th>
<th>Standard error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>0.02</td>
<td>-4.17</td>
<td>3.13</td>
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<tr>
<td>Vehicle speed</td>
<td>1.01</td>
<td>0.01</td>
<td>0.03</td>
</tr>
<tr>
<td>Event history - stopped for infrastructure</td>
<td>0.88</td>
<td>-0.13</td>
<td>0.92</td>
</tr>
<tr>
<td>Event history - stopped for vehicle</td>
<td>1.71</td>
<td>0.54</td>
<td>0.87</td>
</tr>
<tr>
<td>Event history - stopped for pedestrian</td>
<td>0.85</td>
<td>-0.17</td>
<td>0.97</td>
</tr>
<tr>
<td>Speed limit - 25 mph</td>
<td>2.62</td>
<td>0.96</td>
<td>0.72</td>
</tr>
<tr>
<td>Speed limit - 35 mph</td>
<td>39.00</td>
<td>3.66</td>
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<tr>
<td>Visual obstruction - Obstructed</td>
<td>0.94</td>
<td>-0.06</td>
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<tr>
<td>Traffic control - yield to pedestrian</td>
<td>1.20</td>
<td>0.18</td>
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<tr>
<td>Traffic control - stop sign</td>
<td>0.00</td>
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<tr>
<td>Right of way - pedestrian</td>
<td>31.13</td>
<td>3.44</td>
<td>1.91</td>
</tr>
<tr>
<td>Vehicle distance - 0-15 feet away</td>
<td>5.21</td>
<td>1.65</td>
<td>1.72</td>
</tr>
<tr>
<td>Vehicle distance - 15-30 feet away</td>
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<tr>
<td>Vehicle distance - 30+ feet away</td>
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<tr>
<td>Number of pedestrians in path</td>
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<td>Number of pedestrians near path</td>
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<td>Pedestrian distance - 0 feet away</td>
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<td>Pedestrian distance - 0-5 feet away</td>
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<td>Pedestrian distance - 5-10 feet away</td>
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<tr>
<td>Pedestrian position - Waiting on curb to cross</td>
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<tr>
<td>Pedestrian position - In roadway, crossing before vehicle trajectory</td>
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<tr>
<td>Category</td>
<td>Value 1</td>
<td>Value 2</td>
<td>Value 3</td>
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<td>---------</td>
<td>---------</td>
<td>---------</td>
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<tr>
<td>Pedestrian position - In roadway, crossing in vehicle trajectory</td>
<td>0.09</td>
<td>-2.40</td>
<td>1.44</td>
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<tr>
<td>Pedestrian path - Roadway (no crosswalk)</td>
<td>14.99</td>
<td>2.71</td>
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<tr>
<td>Pedestrian reaction - continue, but accelerate</td>
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<td>-1.89</td>
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<td>Pedestrian reaction - continue, but decelerate</td>
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<td>Pedestrian reaction - begin walking from stationary</td>
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<tr>
<td>Pedestrian reaction - interrupted walking, then continues</td>
<td>0.70</td>
<td>-0.35</td>
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<td>Pedestrian reaction - interrupted walking, then abort</td>
<td>65.24</td>
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<tr>
<td>Pedestrian reaction - other</td>
<td>0.00</td>
<td>-18.17</td>
<td>25809.20</td>
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<tr>
<td>Driver reaction - continue, but accelerate</td>
<td>1.18</td>
<td>0.17</td>
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<tr>
<td>Driver reaction - continue, but decelerate</td>
<td>0.04</td>
<td>-3.16</td>
<td>0.64</td>
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<tr>
<td>Driver reaction - comes to a complete stop</td>
<td>0.00</td>
<td>-22.62</td>
<td>5262.53</td>
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<tr>
<td>Driver reaction - interrupted driving, then continues</td>
<td>0.00</td>
<td>-7.34</td>
<td>1.61</td>
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<tr>
<td>Pedestrian clothing - white</td>
<td>0.16</td>
<td>-1.82</td>
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</tr>
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<td>Pedestrian clothing - VT bright</td>
<td>0.63</td>
<td>-0.46</td>
<td>1.13</td>
</tr>
<tr>
<td>Pedestrian clothing - VT dull</td>
<td>0.17</td>
<td>-1.77</td>
<td>1.07</td>
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<tr>
<td>Pedestrian clothing - color bright</td>
<td>0.92</td>
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</tr>
<tr>
<td>Pedestrian clothing - color dull</td>
<td>1.41</td>
<td>0.35</td>
<td>0.75</td>
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<tr>
<td>Pedestrian clothing - unable to determine</td>
<td>0.25</td>
<td>-1.38</td>
<td>1.85</td>
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<tr>
<td>Pedestrian clothing - other</td>
<td>0.17</td>
<td>-1.76</td>
<td>1.46</td>
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<tr>
<td>Pedestrian gender - male</td>
<td>0.40</td>
<td>-0.93</td>
<td>0.56</td>
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<table>
<thead>
<tr>
<th>Factor</th>
<th>Mean</th>
<th>Variance</th>
<th>SD</th>
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</thead>
<tbody>
<tr>
<td>Pedestrian gender - unable to determine</td>
<td>3.62</td>
<td>1.29</td>
<td>2.09</td>
</tr>
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<td>Phone use - using</td>
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<td>0.73</td>
<td>0.91</td>
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<td>Phone use - unable to determine</td>
<td>1.71</td>
<td>0.54</td>
<td>1.08</td>
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<td>Pedestrian facial expression - eye contact</td>
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<td>Pedestrian assertiveness</td>
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<td>Vehicle in opposing lane - yes</td>
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<tr>
<td>Factor affecting pedestrian path - path obstruction</td>
<td>3.58</td>
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<td>Factor affecting driver path - path obstruction</td>
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<td>0.76</td>
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<tr>
<td>Another pedestrian - yes</td>
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<td><strong>Random effect</strong></td>
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<td><strong>Variance</strong></td>
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<tr>
<td><strong>SD</strong></td>
<td>1.62</td>
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</tr>
</tbody>
</table>
Appendix M
Model Two Variable Inclusion

Event history
The variable event history has more than 5% of data in each category and had no correlations beyond the cutoff point. Thus, this variable was included in model two.

Speed limit
As mentioned in the description for prediction model one, the low frequency for the category ‘Patrick Henry drive (35 mph)’ could be causing an issue. Due to the extremely low frequency in the category this variable was not included in the second model.

Visual obstructions
The variable visual obstructions was not highly correlated with other predictors and included more than 5% of all data in each category and was included in model two.

Traffic control
The variable traffic control was not highly correlated with other predictors and included more than 5% of all data in each category and was included in model two.

Right of way
The variable right of way was highly correlated with pedestrian path. Pedestrian path was removed to remedy this. Right of way included more than 5% of all data in each category and was included in model two.

Vehicle distance
The variable from prediction model one was not highly correlated with other predictors, but failed to have 5% of max data in each category. This variable was re-coded to create two categories ‘0-15 feet’ and ‘15+ feet’ each category had more than 5% of the overall data. The re-coded variable was included in model two.

Pedestrian distance
The variable pedestrian distance was highly correlated with pedestrian position. To remedy the correlation, pedestrian position was removed from the model. Pedestrian distance included more than 5% of all data in each category and was included in model two.

Pedestrian position
One level of the variable pedestrian position, ‘Pedestrian in roadway’, was correlated 0.73 with pedestrian distance ‘0-5 feet’. This variable was removed to reduce multicollinearity.

Pedestrian path
Pedestrian path was correlated 0.81 with right of way. The variable pedestrian path was removed from the model.

Pedestrian reaction
Pedestrian reaction did not account for 5% of overall data in each category and was removed from the model.

Driver reaction
Driver reaction did not account for 5% of overall data in each category and was removed from the model.

Pedestrian clothing
Pedestrian clothing did not account for 5% of overall data in each category and was removed from the model.

Pedestrian gender
Pedestrian gender did not account for 5% of overall data in each category and was removed from the model.

Phone use
The variable phone use was not highly correlated with other predictors and included more than 5% of all data in each category and was included in model two.

Pedestrian facial expression
The variable pedestrian facial expression was not highly correlated with other predictors and included more than 5% of all data in each category and was included in model two.

Driver facial expression
The variable driver facial expression was not highly correlated with other predictors and included more than 5% of all data in each category and was included in model two.

Opposing vehicle
The variable opposing vehicle was not highly correlated with other predictors and included more than 5% of all data in each category and was included in model two.

Factors affecting pedestrian path
The variable factors affecting pedestrian path was not highly correlated with other predictors and included more than 5% of all data in each category and was included in model two.

Factors affecting driver path
The variable factors affecting driver path was not highly correlated with other predictors and included more than 5% of all data in each category and was included in model two.