8-11-2017

Pedestrians' Receptivity Toward Fully Autonomous Vehicles

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Pedestrians’ receptivity toward fully autonomous vehicles

By

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A Dissertation
Submitted to the Faculty of
Mississippi State University
in Partial Fulfillment of the Requirements
for the Degree of Doctor of Philosophy
in Industrial and Systems Engineering
in the Department of Industrial and Systems Engineering

Mississippi State, Mississippi

August 2017

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Pages in Study: 122

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Fully Autonomous Vehicles (FAVs) have the potential to provide safer vehicle operation and to enhance the overall transportation system. However, drivers and vehicles are not the only components that need to be considered. Research has shown that pedestrians are among the most unpredictable and vulnerable road users. To achieve full and successful implementation of FAVs, it is essential to understand pedestrian acceptance and intended behavior regarding FAVs. Three studies were developed to address this need: (1) development of a standardized framework to investigate pedestrians' behaviors for the U.S. population; (2) development of a framework to evaluate their receptivity of FAVs; and (3) investigation of the influence of the external interacting interfaces of FAVs on pedestrian receptivity toward them. The pedestrian behavior questionnaire (PBQ) categorized pedestrian general behaviors into five factors: violations, errors, lapses, aggressive behaviors, and positive behaviors. The first four factors were found to be both valid and reliable; the positive behavior scale was not found to be reliable nor valid. A long (36-item) and a short (20-items) versions of the PBQ were validated by regressing scenario-based survey responses to the five-factor PBQ subscale scores. The pedestrian receptivity questionnaire for FAVs (PRQF)

consisted of three subscales: safety, interaction, and compatibility. This factor structure was verified by a confirmatory factor analysis and the reliability of each subscale was confirmed. Regression analyses showed that pedestrians' intention to cross the road in front of a FAV was significantly predicted by both safety and interaction scores, but not by the compatibility score. On the other hand, acceptance of FAVs in the existing traffic system was predicted by all three subscale scores. Finally, an experimental study was performed to expose pedestrians to a simulated environment where they could experience a FAV. The FAV in the simulated environment was either equipped with external features (audible and/or visual) or had no external (warning) feature. The least preferred options were the FAVs with no features and those with a smiley face but no audible cue. The most preferred interface option, which instilled confidence for crossing in front of the FAV, was the walking silhouette.

DEDICATION

To my Family

ACKNOWLEDGEMENTS

I would love to thank Dr. Lesley Strawderman for her constant support and inspiration throughout this dissertation. I am also grateful to Dr. Daniel Carruth, Dr. Janice DuBien, Dr. Brian Smith, and Dr. Teena Garrison for agreeing to be part of my committee, and for their suggestions. My gratitude also goes to Richard Sween and John McGinley for their support to accomplish this project successfully. I would like to thank my editor Ms. Iris Driscoll for all her hard work and time. My family has been a constant source of motivation, and made it entirely possible for me to be here. Finally, I am thankful to my two daughters who have sacrificed a lot.

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CHAPTER I

AN OVERVIEW OF THE RESEARCH

The objectives of this dissertation were to develop research frameworks to study pedestrian behavior on the road, in general and in the presence of Fully Autonomous Vehicles (FAVs). Since FAVs are operated by software and hardware, with no human driver required, interactions between other road-users and FAVs must be understood, and potential risks must be addressed. This is especially true for pedestrians, who often exhibit unpredictable behavior and are one of the most vulnerable road-user groups. A comprehensive review of (a) the current literature on pedestrian behavior, (b) the different aspects of the forthcoming FAVs, and (c) the existing research approaches for installing external interacting features on FAVs was conducted. The review identified three major gaps in pedestrian research: (a) lack of a pedestrian behavior questionnaire for the U.S. population, (b) lack of a pedestrian receptivity questionnaire for FAVs, and (c) lack of research investigating pedestrian design suggestions for FAVs. Achieving pedestrian acceptance of FAVs will require investigation of pedestrian risks and needs by transportation researchers and communication of the results to vehicle manufacturers and regulatory agencies. This study will be useful for further transportation research as well as to guide automated vehicle manufacturers in planning their future design and production of FAVs to ensure their successful implementation.

Three studies were designed for the dissertation. Chapter II describes the first study about validating a pedestrian behavior questionnaire for the U.S. population. Development and validation of a pedestrian receptivity questionnaire for FAVs is discussed in Chapter III. An experimental study investigating pedestrian preference for external interfaces on the FAVs is explained in Chapter IV. A summary of the aims for these studies is given below:

Study 1: Evaluating Pedestrian Behavior at Crosswalks: Validation of a Pedestrian Behavior Questionnaire for the U.S. Population

1. Developing a standard Pedestrian Behavior Questionnaire (PBQ) for the U.S. population by adapting the French version of the Pedestrian Behavior Scale (Granié, Pannetier, & Guého, 2013) and modifying it in accordance with U.S. traffic rules;
2. Validating the questionnaire using a survey approach;
3. Recommending changes to the survey (as necessary) based on the results of the validation study;
4. Investigating the influence of demographic variables on pedestrian behavior;
5. Identifying the types of pedestrian behavior that lead to traffic accidents and injuries in the United States.

Study 2: Developing and Validating a Questionnaire to Assess Pedestrian Receptivity toward Fully Autonomous Vehicles: A Survey Study

1. Identifying factors that affect pedestrian receptivity toward FAVs based on technology acceptance theories and published empirical studies;
2. Validating the questionnaire using a survey approach;

3. Recommending changes to the survey (as necessary) based on the results of the validation study;
4. Identifying the associations between pedestrians' general behavior and their receptivity of FAVs;
5. Investigating the influence of demographic variables on pedestrian receptivity of FAVs.

Study 3: Investigating Pedestrian Design Suggestions for FAVs: A Simulator Study

1. Identifying various external design features for FAVs based on current research;
2. Investigating the effect of the identified features on pedestrians' receptivity of FAVs using a simulator study;
3. Identifying the associations between pedestrians' general behaviors and their receptivity of FAVs;
4. Investigating the influence of demographic variables on pedestrian receptivity of FAVs.

The findings of the three studies are summarized and compared in Chapter V. Recommendations for future research and for research implementations are also discussed in that final chapter.

CHAPTER II

EVALUATING PEDESTRIAN BEHAVIOR AT CROSSWALKS: VALIDATION OF A PEDESTRIAN BEHAVIOR QUESTIONNAIRE FOR THE U.S. POPULATION

Introduction

Pedestrian safety is a rising problem across the world. According to the National Highway Traffic Safety Administration (NHTSA), in the United States there were 4,884 pedestrian deaths and around 65,000 injuries from traffic crashes during 2014 (NHTSA, 2016). Governors Highway Safety Association (GHSA, 2016) reported that there was an estimated 10% increase in pedestrian fatalities due to traffic crashes in the United States in 2015, which is the largest year-to-year increase in the last four decades. The report also states that this is an increasing trend, with pedestrian fatalities now accounting for around 15% of all motor vehicle crash-related deaths.

Previous research on pedestrians have shown that among all types of road-users, pedestrians are the most flexible and can respond most quickly; however, they are also the most unpredictable and cannot be effectively controlled by regulations (Jian, Lizhong, & Daoliang, 2005; Lavalette, Tijus, Poitrenaud, Leproux, Bergeron, & Thouez, 2009). In a report published by the NHTSA (2008), it was stated that most pedestrian accidents occur due to their unpredictable behavior. Researchers have also found that most of the problems and accidents occur when the pedestrians do not obey traffic rules (Ward et al., 1996; Zhuang & Wu, 2011), which is a common occurrence. For example, instead of patiently waiting at the curb, most pedestrians would prefer to cross a road in unauthorized places, even if it raises anxiety (Zhuang & Wu, 2011). The authors also reported that two-thirds of pedestrians did not look around for vehicles before crossing the street, and 16.1% did not look for an oncoming vehicle even while crossing the street. Among those who observed an approaching vehicle, 40.6% of them stopped, 11.4% stepped back to let the vehicle go by, but 31.9% hurried across anyway. There were many instances when pedestrians used cell phones or listened to music while walking or even crossing roads. Observation also revealed that pedestrians were often found to be so engrossed in conversation with their companions that they unintentionally violated the rules or forgot to look for vehicles while crossing a road. Therefore, it is important to understand the underlying pedestrian behavior causing these incidents so that transportation boards can implement the proper combination of engineering, education and enforcement to counteract this troubling trend.

Unlike the research tools available for risky driving behavior, agreed upon frameworks for investigating pedestrian behavior are rare. Recently, however, Granié, Pannetier, and Guého (2013) developed one of the most complete questionnaires, the self-report Pedestrian Behavior Scale (PBS). PBS was developed and validated in France and was utilized in Greece as well (Papadimitriou, Lassarre, & Yannis, 2016). The original PBS included survey items for five different types of pedestrian behavior: violations, errors, lapses, aggressive behaviors, and positive behaviors. In France, these five types of behaviors were combined into four components: *transgressions* (violations and errors), *lapses, aggressive behaviors,* and *positive behaviors*. In Greece, the researchers grouped pedestrian crossing behaviors into three components: *risk-taking and optimization* (violations, errors, aggressive behaviors, and lapses), *conservative* (positive behaviors), and *pedestrian for pleasure* (filter items included in the results). Until now, this tool has not been validated for the U.S. population, even though it is the most complete questionnaire available for gaining a more detailed understanding of risky behaviors among pedestrians of all ages. This study proposed a framework for pedestrian research by validating the French PBS for the U.S. population as an aid to understanding the kinds of behaviors that lead pedestrians to collisions and injuries in this country. This study used the terms "Pedestrian Behavior Questionnaire (PBQ)" for that framework.

Related Work

Pedestrian behavior

Under everyday traffic conditions, pedestrians display a rich variety of self-organized behaviors. Since pedestrians are the most vulnerable road-users in pedestrian-vehicle collisions, their safety is of great concern for transportation researchers. Studies in the past have examined pedestrian behaviors, including walking speed (Fitzpatrick et al., 2007; Manual, 2010); zone of comfort, defined as the accepted gap from other road users or objects (Meng & Kang, 2015; Wang, Wu, Zheng, & McDonald, 2010); and trip purpose and route choice (Lavaletteet al., 2009; Robin, Antonini, Bierlaire, & Cruz, 2009; Hoogendoorn & Bovy, 2004). These studies considered pedestrian behavior in many situations, not only crossing streets. Factors which were found to be significant in pedestrian behavior research include structural factors (road design, traffic-sign and signal design, traffic density); environmental factors (speed limit, vehicle type, population density, time of day, weather conditions); and human factors, for both drivers and pedestrians (decision-making errors, alcohol level, age, lack of proper education, and personality) (NHTSA, 2013).

According to the NHTSA (2008) report, almost three-fourths (73%) of the pedestrian fatalities in the U.S. occur in urban settings versus rural settings. Over two-thirds (70%) of the pedestrian fatalities occur at non-intersections versus at intersections. Eighty-nine percent of the pedestrian fatalities occur during normal weather conditions (clear/cloudy), not during rain, snow or fog conditions, although 70% of the fatalities occur during the nighttime (6:00pm – 5:59am) (U.S. Department of Transportation, 2014). Hamed (2001) stated that those pedestrians who had been involved in a traffic crash were less likely to take risks by violating rules thereafter. On the other hand, as reported by Xu, Li, & Zhang (2013), if a pedestrian crosses the road at an unauthorized place and has a successful experience in violating the traffic law, s/he is likely to repeat this offense at the same location. Koh & Wong (2014) found that a person would be more likely to violate the traffic rules on a 4-lane road with a wide median rather than on a 6- or 7-lane road, and as an individual rather than with companions. Mitman, Ragland, and Zegeer (2008) discovered that pedestrians at unmarked crosswalks prefer to look both ways before crossing, to wait for larger gaps, and then to run. Zhuang and Wu (2011) stated that middle-aged jaywalkers in urban cities are less likely to be involved in a crash when they cross in a group. Because of their flexibility and ability to respond quickly, pedestrians generally make faster decisions and experience smaller waiting times compared to other road users; however, this also increases road accident risk exposure (Grayson, 1987).

All of the research discussed above was performed using observational studies or historical data. However, this research approach is not comprehensive; it is not possible to collect every type of pedestrian behavior under all possible risky situations through observation. In addition, research boards would not approve putting pedestrians in unsafe road scenarios for experimental studies. In order to investigate risky behaviors, many researchers have proposed behavior questionnaires for different road users (drivers, bicyclists, motorcyclists, and pedestrians), as a low-cost, safer, and more comprehensive mode of collecting data (Papadimitriou et al., 2016; Özkan & Lajunen, 2005; Sexton, Baughan, Elliott, & Maycock, 2004; Aberg & Rimmo, 1998; Lawton et al., 1997; Reason et al. 1990). These studies have classified road behaviors using several categories. The first differentiation in road-user risky behaviors is made between intentional offenses and unintentional offenses. Intentional offenses can be classified into violations and aggressive behaviors, while unintentional offenses can be classified as lapses and errors. The most frequent behaviors are conservative or positive behaviors. However, sometimes positive behaviors involve the tendency not to minimize crossing time and distance. For example, “I let a car go by, even if I have the right-of-way, if there is no other vehicle behind it” (item P5). These kinds of behaviors can nevertheless confuse and/or annoy vehicle drivers because of pedestrians’ delayed actions and can therefore expose them to risk due to impatient responses from drivers. Definitions of these different road-user behaviors are given in Table 2.1.

Table 2.1 Definitions of different types of pedestrian behaviors

Pedestrian Behavior	Definition	Example	Reference
Violation	Deliberate deviation from social rules without intention to cause injury or damage.	Not using nearby pedestrian crosswalk to cross	Reason et al., 1990
Error	Deficiency in knowledge of traffic rules and/or in the inferential processes involved in making a decision.	Crossing diagonally to save time	Rasmussen, 1980; Reason et al., 1990
Lapse	Unintentional deviation from practices related to a lack of concentration on the task; forgetfulness.	Forgetting to look around for vehicles before crossing	Reason et al., 1990
Aggressive Behavior	A tendency to misinterpret other road users' behavior resulting in the intention to annoy or endanger.	Getting angry with another user and insulting him	Lawton et al., 1997; Baxter, Macrae, Manstead, Stradling, & Parker, 1990
Positive Behavior	Behavior that seeks to avoid violation or error and/or seeks to ensure traffic rule compliance.	Not crossing diagonally or letting other road users go first	Özkan, & Lajunen, 2005

Pedestrian behavior questionnaires

Using a driver behavior questionnaire (Parker, Manstead, Stradling, Reason, & Baxter,1992), Diaz (2002) developed a 16-item Pedestrian Behavior Questionnaire (PBQ) in Chile. The researcher used the PBQ to measure risky pedestrian behaviors and classified the data into three components: violations, errors and lapses. Similar to the responses with drivers, the pedestrian questionnaire found that young males were more inclined to commit a violation on the road. The PBQ was then validated in Brazil (Torquato & Bianchi, 2010) and in Turkey (Yildirim, 2007), and in both cases a similar effect of gender on committing violations was found.

In 2004, Elliott and Baughan developed a complete and reliable self-report instrument, the Adolescent Road User Behavior Questionnaire (ARBQ) in Britain. The questionnaire differentiated road-user behavior into three components: unsafe road crossing, dangerous playing in the road and planned protective behavior. The ARBQ, proposed in both a long (43-item) and a short (21-item) version, was largely supported by a complementary study in New Zealand (Sullman & Mann, 2009); the scale measured the same risk-causing variables for pedestrian behavior. The shortened version (21-item) of the ARBQ was also found to be valid in Spain (Sullman, Gras, Font-Mayolas, Masferrer, Cunill, Planes, 2011) and in Belgium (Sullman, Thomas, & Stephens, 2012).

The ARBQ was designed to assess both pedestrian and cyclist behavior with half of the items addressing pedestrian behavior. Therefore, to propose a framework regarding only pedestrian behaviors, Granié (2008) developed a 14-item Road User Behavior Perception Scale (RUBPS) in France and validated it with adult and adolescent pedestrians (Granié, 2009). The scale measured pedestrian behavior in terms of endangerment and transgression. In 2013, Granié et al. used the RUBPS to develop and validate a comprehensive self-report Pedestrian Behavior Scale (PBS) for all ages to differentiate pedestrian road-using behaviors into violations, errors, lapses, aggressions, and positive behaviors. The researchers administered and validated both a long (37-item) and short (23-item) version of this scale for the French population. Three years later, in 2016, Papadimitriou et al., applied the PBS in Greece to develop models for pedestrian crossing choices based on road, traffic and human factors. For the Greek population, the scale differentiated pedestrian behaviors into three components: risk-taking and optimization (e.g., tendency to cross at mid-block in order to save time), conservative (e.g., increased perception of risk at mid-block crossing), and pedestrian for pleasure (e.g., tendency to walk frequently for health purposes).

In the USA, where pedestrian-related motor vehicle collisions are a great concern and need to be addressed, a standard framework has, to the best of our knowledge, not yet been developed or validated. In 2012, the NHTSA conducted a telephone (cell phone and landline) interview survey which was used to evaluate the extent to which respondents engaged in walking outdoors; pedestrian demographic and typological descriptions; the extent and frequency of using electronic devices while walking; attitudes and perceptions about pedestrian activity; knowledge of various laws pertaining to pedestrians; and changes in pedestrian behavior and attitudes compared to the 2002 survey administration (Schroeder & Wilbur, 2013). This survey, like the ARBQ, studied both bicyclist and pedestrian behavior. The questions used in the NHTSA survey do not provide a framework, nor have they been validated, for pedestrian behavior research.

Having a framework of behavioral categories would be useful for understanding and addressing average road-user perspectives (Granié et al., 2013; Elliott & Baughan, 2004; Sexton et al., 2004; Reason et al., 1990). Therefore, this present study undertook a research effort to validate the PBS developed by Granié et al. (2013), the most recent and complete behavior questionnaire for pedestrians only, for the U.S. population. The study attempted to confirm that the behavioral differentiation in both the long and short versions of the scale is the same. In addition, the study explored demographic influences on different pedestrian behaviors. Finally, the present study investigated whether any of the behavioral factors were associated with a history of collision or injury.

Method

Survey instrument

The survey instrument used in this study included three sections: demographic information (11 questions), pedestrian behavior-based (PBQ-based) questions (43 items), and scenario-based questions (5). The self-report pedestrian behavior scale (PBS), developed by Granié et al. (2013), was modified for this study, using the English (U.S.) language and applied to the U.S. transportation systems. PBS was the first complete questionnaire to study a broad range of aspects of pedestrian behavior on the road for all age groups. This questionnaire was developed based on the conceptual framework of the driver behavior questionnaire (DBQ) (Reason et al., 1990), the aggressive driver behaviors scale (Lawton et al., 1997) and the positive driver behaviors scale (Özkan and Lajunen, 2005). The behavioral questions were divided into five subscales: violations (11 items), errors (12 items), lapses (8 items), aggressive behaviors (6 items), and positive behaviors (6 items). The positive behavior items were considered as reverse-scaled items compared to other items in the pedestrian behavior scale. The participants were required to answer the questions using a 6-point Likert scale (1-very infrequently or never, 2-quite infrequently, 3-infrequently, 4-frequently, 5-quite frequently, 6-very often or always.). The third section included five scenario-based questions, answered on a scale from 1 to 3 (1-conservative behavior, 2-moderately negative behavior and, 3-significantly negative behavior). The complete survey is attached in Appendix A.

Survey administration

The survey was created using Survey Monkey (https://www.surveymonkey.com) and administered online to the U.S. population through Amazon Mechanical Turk (https://www.mturk.com). Amazon Mechanical Turk provides access to a virtual community of workers who are willing to complete human intelligence tasks (HITs) at their convenience. HITs can include data cleaning, transcription, survey completion, or data categorization. MTurk has workers from different regions of the country with different backgrounds and ensures access to a diverse pool of participants, within limits (only among workers with MTurk accounts). The researcher of this study submitted a HIT and interested Mechanical Turk workers responded using the survey link. The requirements for the respondents were that they had to be located in the U.S. and have experience attempting at least 1000 Mechanical Turk HITs with an approval rate (successful completion of attempted HITs) of at least 95%.

The survey took an average of fifteen minutes to complete and the reward amount for successful completion of the survey was $1.75. Along with the demographics, behavioral survey items and scenario-based questions, there were seven filter items and two check questions. The filter items were used to determine if the respondents were qualified to answer the subsequent question/s, and the check questions ensured respondents' attention to the survey questions. Participants who answered "never" or "quite infrequently" to the filter question F1 (I walk Outdoors) and "very often" or "quite frequently" to the filter question F5 (I walk in covered areas to avoid traffic) were removed from further analysis.

Participants

A total of 500 participants were recruited from the Mechanical Turk workforce. Out of 500 participants, 425 participant responses were used for analyses; 28 participants were filtered based on their responses on filter questions (F1 and F5) and 47 more were removed for incorrect answers to at least one of the check questions. The sample of 425 included responses from participants in 47 different states within the United States. The age of the subjects ranged from 18 to 71 (M= 35.60, SD= 10.73): 39.53% were in the 18-30 age group, 43.30% were in the 31-45 age group and 17.17% were above 45 years of age. Males accounted for 53.65% of the sample, females 46.35%. Most of the participants (65.65%) walk often or very frequently, but the majority of the participants (52%) reported to walk less than 30 minutes a day.

Among the 425 participants, 42 reported having suffered collisions as pedestrians. Those who have suffered collisions, 45.24% were involved in an injury; 36.84% reported minor injuries, 42.11% reported moderate injuries, and 21.10% reported significant injuries.

Results

Statistical analyses were conducted using SPSS, Version 24.0 and AMOS, Version 24.0. Table 2.2 displays the descriptive statistics, means (M) and standard deviations (SD), for 43 behavioral items, ranked in descending order by mean value. The most frequently reported behaviors (mean response ≥ 4) involved positive interactions with vehicle drivers: (i) thanking a driver who stops to let a pedestrian cross, (ii) walking on the right-hand side of the sidewalk so as not to bother oncoming pedestrians. The behaviors that were least frequently reported (mean response ≤ 2) primarily included either lapses or aggressive behaviors toward other road users. Violations and errors were found in between these two extremes.

Table 2.2 Means and standard deviations of the PBQ behavior items (n=425)

Pedestrian behavior item (how often do you. . .)	**Mean**	**SD**
I thank a driver who stops to let me cross.	4.85	1.28
I walk on the right-hand side of the sidewalk so as not to bother the pedestrians I meet.	4.27	1.35
When I am accompanied by other pedestrians, I walk in single file on narrow sidewalks so as not to bother the pedestrians I meet.	3.96	1.30
I let a car go by, even if I have the right-of-way, if there is no other vehicle behind it.	3.89	1.26
On a two-way street with a median, I cross the first part and wait in the middle of the roadway to cross the second part.	3.43	1.53
If a car is blocking the crosswalk, I will walk behind the car to cross the street.	3.35	1.52
I watch the traffic light and start crossing as soon as it turns red.	3.30	1.59
I stop walking to let other pedestrians pass by.	3.16	1.26
If a car is blocking the crosswalk, I will walk in front of the car when crossing the street.	2.96	1.48
I walk on the curb.	2.90	1.50
I cross the street between parked cars.	2.88	1.37
I cross diagonally to save time.	2.74	1.34
I start to cross on a pedestrian crossing and I end up crossing it diagonally to save time.	2.64	1.37
I cross while talking on my cell phone or listening to music on my headphones.	2.57	1.49
I cross outside the pedestrian crossing even if there is one (crosswalk) less than 50 meters away.	2.56	1.27

Table 2.2 (continued)

Pedestrian behavior item (how often do you. . .)	Mean	SD
I walk on the roadway to be next to my friends on the sidewalk or to overtake someone who is walking slower than I am.	2.52	1.30
On a two-way street with no median, I cross the first part and wait in the middle of the roadway to cross the second part.	2.51	1.48
I start walking across the street, but I have to run the rest of the way to avoid oncoming vehicles.	2.49	1.21
I cross even though obstacles (parked vehicles, buildings, trees, trash bins, etc.) obstruct visibility.	2.48	1.22
I cross between vehicles stopped on the roadway in traffic jams.	2.35	1.32
I cross the street even though the pedestrian light is red.	2.32	1.30
I avoid using pedestrian bridges or underpasses for convenience, even if one is located nearby.	2.15	1.19
I cross even though the light is still green for vehicles.	2.07	1.19
I cross without looking when following other people who are crossing.	1.96	1.19
I walk in a way that forces other pedestrians to let me through.	1.86	1.11
I cross even if vehicles are coming because I think they will stop for me.	1.72	1.07
I lose my way because I get lost in my thoughts.	1.67	0.98
I get angry with another road user (pedestrian, driver, cyclist, etc.), and I make a hand gesture.	1.65	1.03
I take passageways forbidden to pedestrians to save time.	1.64	0.99
I realize that I do not remember the route I have just taken.	1.63	0.97
I walk on cycling paths when I could walk on the sidewalk.	1.62	0.96
I have run into a pedestrian or an obstacle while walking because I am not paying attention.	1.61	0.88
I walk on bicycle lanes when I could walk on the sidewalk.	1.54	0.88
I realize that I have crossed several streets and intersections without paying attention to traffic.	1.53	0.88
I get angry with another road user (pedestrian, driver, cyclist, etc.), and I yell at him.	1.52	0.92
I deliberately walk on the roadway when I could walk on the sidewalk or on the shoulder.	1.44	0.78
I cross without looking because I am talking with someone.	1.43	0.81
I forget to look before crossing because I am thinking about something else.	1.41	0.79
I get angry with another road user (pedestrian, driver, cyclist, etc.), and insult him/her.	1.40	0.81
I forget to look before crossing because I want to join someone on the sidewalk on the other side.	1.36	0.79
I run across the street without looking because I am in a hurry.	1.34	0.75
I cross very slowly to annoy a driver.	1.30	0.76
I have gotten angry with a driver and hit their vehicle.	1.22	0.66

PBQ validation

Confirmatory factor analysis (CFA)

A confirmatory factor analysis (CFA) was conducted for the five different behavior scales in the PBQ, excluding the seven filter items and two check questions, in order to test the factor structure of reported pedestrian behaviors by the U.S. population. Varimax rotation with the maximum likelihood estimation procedure were applied for CFA. As the results of this study were compared to the previous studies in this area (Granié et al., 2013; Papadimitriou et al., 2016), the researcher used similar approaches for rotation and estimation. From the output, estimate matrices and modification indices were used to guide model revision. CFA suggested the elimination of seven items (items V_{11}, E_1, E_5, E11, E_{12}, P_2, and P_6) due to low factor loadings (i.e., < .30) in all the tested models. In addition, the modification indices suggested adding error covariance between items V_1 and V_6, E_2 and E_3, E_8 and E_{10}, L_2 and L_3, L_4 and L_5, as well as between items A_1 and A_5. This can be attributed to the similarity in wording and content of the items. After introducing these minor changes, models using the revised 36-item questionnaire tended to fit the indices better. Table 2.3 exhibits the model fit outcomes for six models in terms of (a) absolute fit, using the root mean square error of approximation (RMSEA) and the chi-square test statistic; (b) comparative fit, using the comparative fit index (CFI); and (c) parsimonious fit, using parsimony normed CFI (PCFI).

Table 2.3 Alternatives for the best first-order confirmatory factor model

Models	χ^2	*df*	χ^2/df	Absolute Fit RMSEA	Comparative Fit CFI	Parsimonious Fit PCFI
First order models						
Model 1: One factor, pedestrian behavior	2747.44	623	4.410	0.09	0.737	0.69
Model 2: Transgressions (violations & errors), lapses, aggressive behaviors, and positive behaviors	1622.85	617	2.630	0.07	0.85	0.78
Model 3: Risk-taking and optimization (violations, errors, lapses, and aggressive behaviors), conservative (positive behaviors), and pedestrian for pleasures	3387.74	893	3.794	0.08	0.715	0.68
Model 4: Five factors (violations, errors, lapses, aggressive behaviors, and positive behaviors)	**1528.79**	**613**	**2.494**	**0.06**	**0.89**	**0.82**
Second order models						
Model 5: Second-order, two first-order factors: risky behaviors (violations, errors, lapses, and aggressive behaviors), and positive behaviors	1582.17	616	2.568	0.07	0.86	0.80
Model 6: Second-order (pedestrian behavior), five first-order factors: violations, errors, lapses, aggressive behaviors, and positive behaviors	**1349.84**	**581**	**2.323**	**0.06**	**0.90**	**0.83**

Note: Bold results show good model fit

As can be seen in Table 2.3 (models 1 to 4), the five-factor model (Model 4) has the best CFI and PCFI with the lowest RMSEA compared to the other models, particularly to Models 2 and 3 which had been validated respectively in France (Granié et al., 2013) and Greece (Papadimitriou et al., 2016). In addition, Model 4 also revealed good factor loadings (standard regression weights) for all 36 items, all of which were statistically significant ($p < .0001$). Figure 2.1 displays that four factors, not including positive behavior, are strongly interrelated, which leads to the assumption that a second-order underlying factor exists for those four factors. This second-order factor was termed "risky behaviors" and was tested as Model 5 (Table 2.3). An additional CFA was performed on Model 6 to test the five pedestrian behavioral factors under one second-order scale in order to determine a composite score for "pedestrian behaviors". Comparing these two second-order models (Models 5 and 6), the five-factor solution (Model 6) again showed better fit with good and statistically significant ($p < .0001$) factor loadings (Figure 2.2).

Given the good fit of Models 4 and 6, mean scores were computed for each of the individual behavioral components and used as composite scores for each of these five subscales for pedestrian behavior. The Cronbach's alpha (α) for the resulting subscales were calculated to test the internal reliability. The alpha values were found as: violations (10 items) = 0.89, errors (8 items) = 0.83, lapses (8 items) = 0.90, aggressive behaviors (6 items) = 0.88, and positive behaviors (4 items) = 0.58. These values indicated that all the scales had acceptable internal reliability ($0.7 \leq \alpha \leq 0.9$), except the positive behavior scale. An alpha value below 0.7 for the positive behavior scale could be due to too few questions, poor interrelatedness between items or multidimensional constructs.

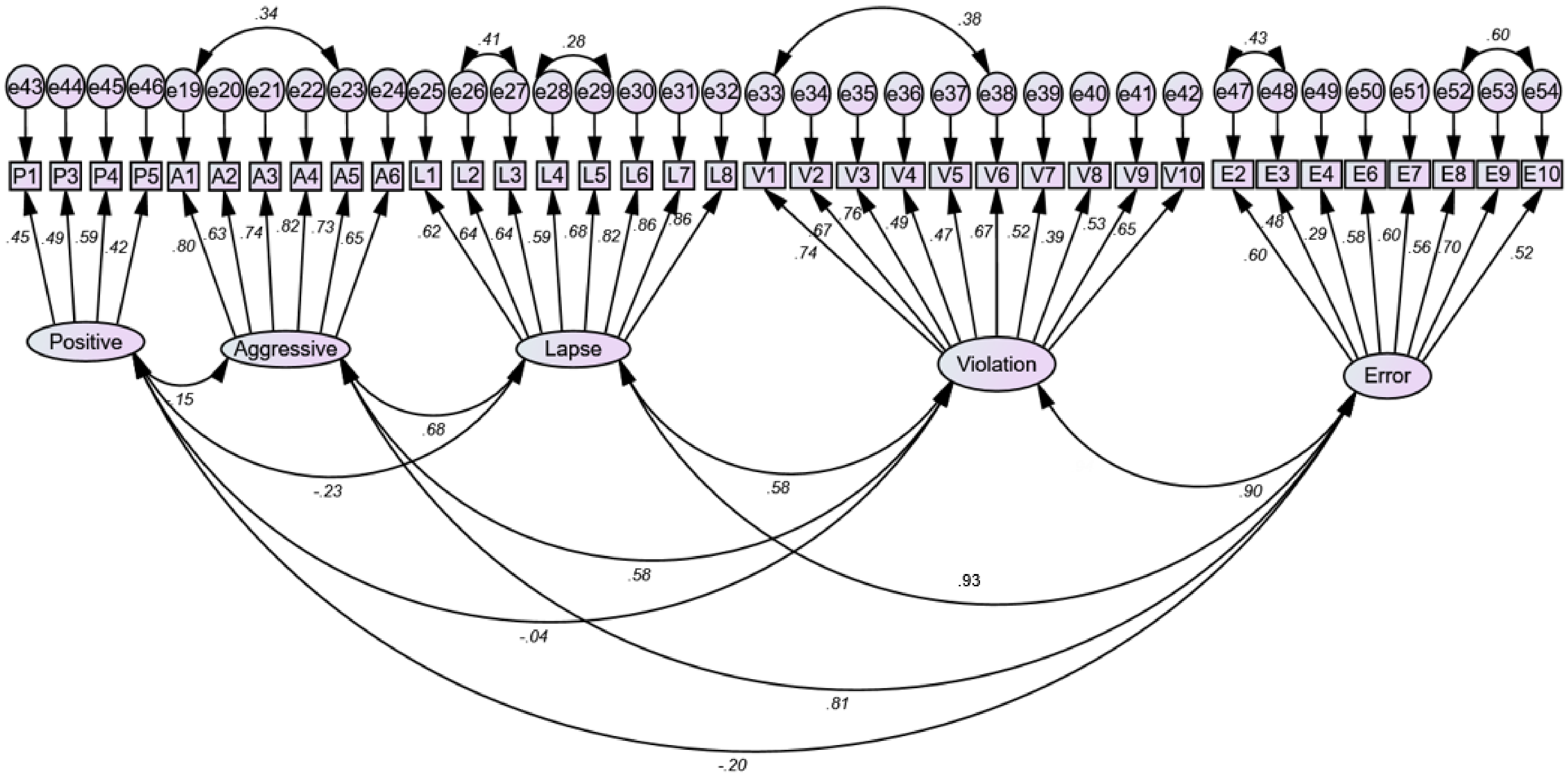


Figure 2.1 Standardized solution for the first-order five-factor confirmatory factor model

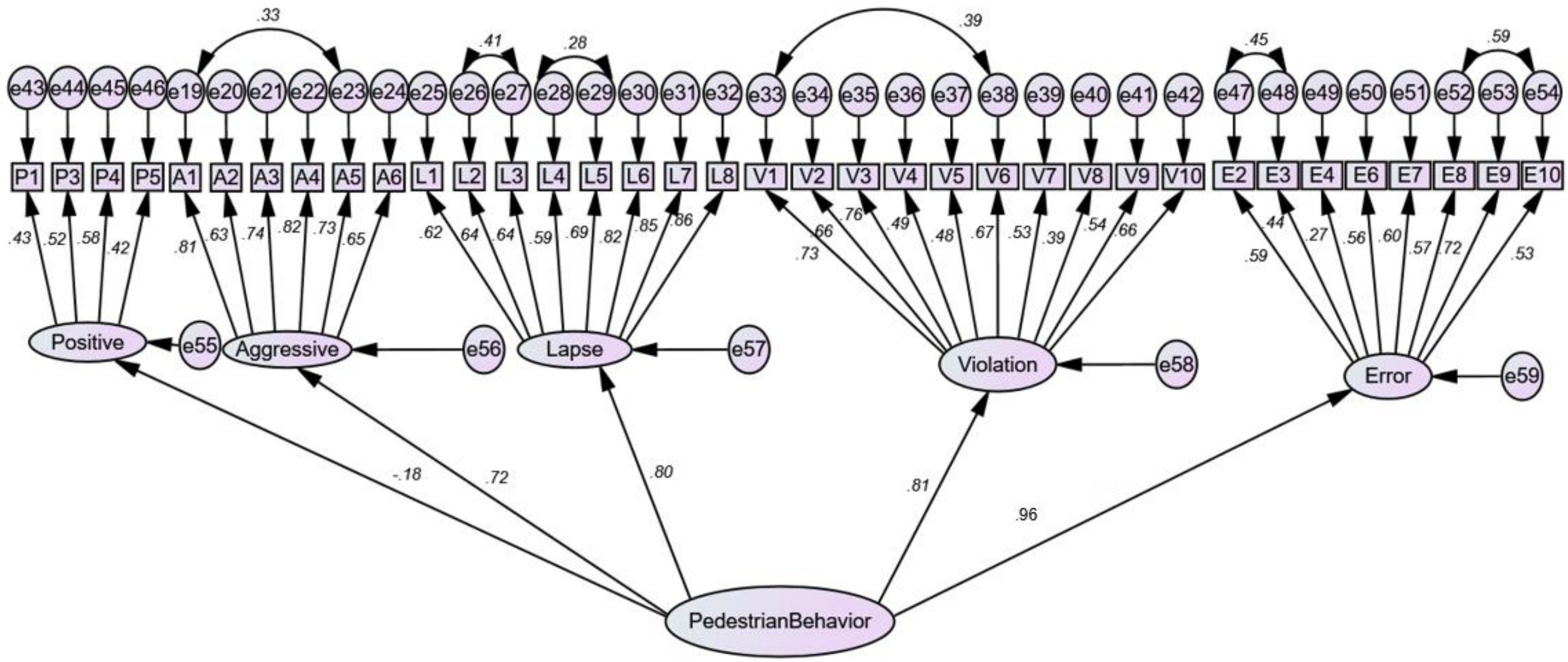


Figure 2.2 Standardized solution for the second-order five-factor confirmatory factor model

For all the subscales in the PBQ, except the positive behavior one, a lower score means safer pedestrian behavior. The composite score for pedestrian behavior was calculated by adding together the five subscale scores, considering positive behavior items as reverse-scaled. The reliability coefficient for this composite scale was found to be 0.86.

Regression analysis

The questionnaire included five scenario-based questions, developed around each of the five behavioral components: violation, error, lapse, aggressive behavior, and positive behavior. Multiple logistic regression was carried out to find the associations between the responses to each of the scenario-based questions and the five PBQ-based subscale scores. An ordinal logistic regression was then carried out to find the association between the responses to each of the scenario-based questions and the composite pedestrian behavior score. Table 2.4 displays the significant associations found from these logistic regressions. The hypothesis was that the response to each of the scenarios would be predicted by the subscale score for that specific behavior.

Table 2.4 Validation of the PBQ using logistic regression (N = 425)

	Scenario1: Violation		Scenario 2: Error		Scenario 3: Lapse		Scenario 4: Aggressive Behavior		Scenario 5: Positive Behavior	
Scale	b	χ^2	b	χ^2	b	χ^2	b	χ^2	b	χ^2
Analysis 1										
Violation	1.23	50.45**	-0.18	0.31	-0.40	2.27	0.06	0.10	0.30	2.65
Error	-0.39	1.84	0.93	25.10**	1.15	7.43**	-0.52	2.98	-0.35	0.33
Lapse	-0.07	0.09	0.18	0.52	0.47	2.73	-0.16	0.49	0.09	0.12
Aggressive Behavior	0.04	0.04	-0.35	2.24	-2.73	0.02	1.76	52.51**	0.11	0.23
Positive Behavior	-0.29	4.87*	-0.06	0.20	-0.04	3.69	-0.34	7.08**	0.04	0.09
Analysis 2										
Pedestrian Behavior	-0.21	28.42**	-0.19	16.86**	-0.24	20.42**	-0.16	16.74**	-0.05	1.24

*$p < 0.05$,
** $p < 0.0001$
b indicates the parameter estimate

The findings from Table 2.4 show that responses for scenario 1, designed around a violation, could be significantly predicted by the subscale scores for both violation (p<.0001) and positive behavior (p<.0273). As expected from the hypothesis, the positive parameter estimate on the violation score confirms that the larger the score on the PBQ-based violation subscale, the higher the possibility of committing a violation in the scenario. Similarly, the negative parameter estimate for the PBQ-based positive behavior score explains that the lower score on that subscale predicts a scenario-based violation. Error and aggressive behavior scores also significantly predicted the respective responses in scenario 2 (p<.0001) and 4 (p<.0001) with positive estimated effect. In contrast, scenario 3 (developed around a lapse) was found to be predicted by the PBQ-based error score, instead of the lapse score. A hierarchical regression analysis of the PBQ-based lapse score found a significant relationship with the response to scenario 3 (B=1.01, χ^2= 31.69, p<.0001) when it was mediated by the addition of error (error: B=0.73, χ^2= 6.17, p=.013; lapse: B=0.522, χ^2= 3.95, p=.053) to the model. The PBQ-based positive behavior scale did not show any relationship with the response to the scenario 5 question; neither individually nor mediated by other scores. The composite score for pedestrian behavior was able to significantly predict each of the scenario-based responses except positive behavior. The validated version is attached in Appendix B.

Short version of the PBQ

With the aim being to develop a reliable and time-efficient self-reporting pedestrian behavior questionnaire, it was clear to the researcher that a 36-item survey would not be very useful or popular. Therefore, a shorter version was suggested which includes the four survey items from each of the subscales with the highest factor loadings. In cases where there was high error covariance, one of the items was dropped and the item having the next highest factor loading was included. The resulting questionnaire was then tested with another CFA considering the second-order five factor model. The model fit indices showed acceptable fit for this 20-item short version (attached in Appendix C) of the PBQ (*RMSEA* =0.07 *CFI*= 0.92, *PCFI* =0.80). Mean scores were computed to find each of the five subscale scores, and the composite pedestrian behavior score was calculated by adding the five subscale scores, considering positive behavior items as reverse-scaled. Cronbach's alpha for each of these subscales (violations = 0.84, error = 0.73, lapses = 0.87, aggressive behavior = 0.83, and positive behavior = 0.58) showed acceptable internal consistency for all except the positive behavior scale, as with the long version. For the rest of the analyses used in this study, however, the long version (36-item) of the PBQ was used in order to ensure a comprehensive understanding of pedestrian behavior.

Effects of demographic variables

Analysis of Variance (ANOVA) was conducted to determine the influence of gender (2 levels: Male and Female) and age (3 levels: 18-30, 31-46, and 45+) on each of the five subscale scores as well as on the composite pedestrian behavior score. The pedestrian behavior score was also influenced significantly by age and gender. Table 2.5 presents the ANOVA results and Table 2.6 exhibits means and standard deviations of each scale score for each gender and age group. Comparisons among the three age groups revealed significantly different scores between all age groups for violations, errors, lapses, and composite pedestrian behavior scales, each of the groups shows significantly different scores. However, for aggressive behaviors, the only significant difference in scores was found between the youngest (18-30) and the oldest (45+) age groups. In the case of positive behaviors, the oldest age group showed significantly higher scores than the other two age groups.

Table 2.5 ANOVA results

Demographics	F statistics from ANOVA (*p*-value)					
	Violations	Errors	Lapses	Aggressive Behaviors	Positive Behaviors	Pedestrian Behavior
Gender (*df*: 1, 423)	19.85 (<0.0001)	12.71 (<0.0001)	4.29 (0.039)	15.41 (<0.0001)	10.09 (0.002)	9.11 (0.003)
Age (*df*: 2, 422)	17.33 (<0.0001)	10.78 (<0.0001)	10.03 (<0.0001)	7.92 (<0.0001)	3.09 (0.046)	11.28 (<0.0001)

Table 2.6 Means (standard deviations) of scores on the PBQ for each gender, the three age groups and the total sample

Gender	Age (N)	Mean (Standard deviation)					
		Violations	Errors	Lapses	Aggressive Behaviors	Positive Behaviors	Pedestrian Behavior
Male	18-30 (103)	2.72 (0.91)	2.40 (0.86)	1.78 (0.87)	1.68 (0.90)	4.10 (0.88)	4.48 (2.82)
	31-45 (97)	2.53 (0.77)	2.23 (0.74)	1.56 (0.61)	1.63 (0.70)	4.09 (0.87)	3.86 (2.47)
	45+ (28)	2.05 (0.49)	1.96 (0.47)	1.40 (0.41)	1.32 (0.34)	4.28 (0.69)	2.45 (1.24)
	Overall Male (228)	2.56 (0.83)	2.27 (0.78)	1.64 (0.73)	1.61 (0.78)	4.12 (0.85)	3.96 (2.77)
Female	18-30 (65)	2.44 (0.90)	2.20 (0.75)	1.65 (0.79)	1.52 (0.74)	4.29 (0.86)	3.52 (2.70)
	31-45 (87)	2.19 (0.63)	2.00 (0.62)	1.51 (0.60)	1.31 (0.45)	4.35 (0.78)	2.66 (1.89)
	45+ (45)	1.90 (0.74)	1.79 (0.62)	1.25 (0.37)	1.19 (0.36)	4.58 (0.86)	1.55 (1.90)
	Overall Female (197)	2.21 (0.77)	2.02 (0.68)	1.50 (0.65)	1.35 (0.56)	4.38 (0.83)	2.70 (2.24)
Overall	18-30 (168)	2.61 (0.91) A	2.32 (0.83) A	1.73 (0.84) A	1.58 (0.78) A	4.18 (0.88) A	4.06 (3.03) A
	31-45 (184)	2.37 (0.73) B	2.12 (0.70) B	1.54 (0.61) B	1.46 (0.59) A B	4.21 (0.83) A	3.28 (2.23) B
	45+ (73)	1.96 (0.65) C	1.85 (0.57) C	1.31 (0.39) C	1.24 (0.35) B	4.46 (0.81) B	1.90 (1.67) C
	All Participants (425)	2.40 (0.75)	2.15 (0.74)	1.57 (0.69)	1.49 (0.69)	4.24 (0.85)	3.37 (2.56)

Letters (A, B, C) show the multiple comparisons
Means with the same letters are not significantly different

Table 2.7 Pedestrian behaviors and self-reported traffic collision and injury

Pedestrian-related motor vehicle collision history (Dependent Variable)		Subscale (Independent Variable) *b*, *p* value *M (SD)*				
		Violations	Errors	Lapses	Aggressive Behaviors	Positive Behaviors
Involvement in pedestrian-related motor vehicle collision as pedestrian (N=425, *df*=1)		-0.72*	0.71	0.34	-0.25	0.17
	Yes (42)	2.68 (0.82)	2.12 (0.79)	1.86 (0.94)	1.76 (0.81)	4.24 (0.89)
	No (383)	2.46 (0.92)	1.84 (0.66)	1.54 (0.66)	1.46 (0.67)	4.27 (0.85)
Involvement in collision resulting in injury (N=42, *df*=1)		-2.10*	-2.81*	-0.18	0.17	0.49
	Yes (19)	2.51 (0.87)	2.14 (0.87)	1.97 (1.03)	1.82 (0.91)	4.14 (0.87)
	No (23)	2.40 (0.79)	1.95 (0.68)	1.77 (0.86)	1.71 (0.73)	4.42 (0.91)
Severity of injury (N=19, *df*=2)		-0.83	1.07	3.68*	-5.01*	-0.806
	Minor (7)	2.61 (0.49)	2.51 (0.81)	1.89 (0.90)	2.04 (0.99)	4.68 (0.66)
	Moderate (8)	2.17 (1.17)	2.11 (0.97)	1.97 (1.42)	1.81 (1.05)	4.56 (0.96)
	Significant (4)	2.50 (0.78)	2.5 (0.89)	2.13 (0.23)	1.46 (0.39)	4.10 (1.09)

b indicates the parameter estimate
*$p < 0.05$,
** $p < 0.01$
Involvement in pedestrian-related motor vehicle collision as pedestrian [2 levels: yes (1), no (2)]
Involvement in collision resulting in injury [2 levels: yes (1), no (2)]
Severity of injury [3 levels: minor (1), moderate (2), significant (3)]

PBQ and history of pedestrian-related motor vehicle collisions and injuries

Table 2.7 presents results from ordinal logistic regression analyses to show the association between previous history of pedestrian-related motor vehicle collisions and each of the subscale scores for five different types of pedestrian behavior. The objective was to identify what type of behavior results in pedestrian-related motor vehicle collision and injury, with the assumption that previous history has not influenced current behavior.

Overall, only pedestrian behaviors related to traffic rule violation tended to be associated with motor vehicle collisions. When resulting injury was considered, errors were found to play an influencing role along with violations. In the case of injury severity, forgetfulness (lapses) and aggressiveness lead the pedestrians to severe injuries.

Discussion

Developing a framework for pedestrian behavior research

The main objective of this study was to validate a PBQ in the U.S. that was validated for a French population. This PBQ was designed to differentiate between diverse aspects of pedestrian behaviors on the road. Several validation approaches were used, and most of the results confirmed the usefulness of this PBQ for the U.S. population, with only a few modifications necessary.

Four behavioral items from the five most frequently reported behaviors and four behavioral items from the five least frequently reported behaviors matched exactly with the French sample (Granié et al., 2013). Similar to the French study, the most often declared behaviors were positive behaviors and the least often reported behaviors included mostly aggressions and lapses. Around 12% of the participants from the U.S.

study declared that they get angry with drivers and hit their vehicle, 15% intentionally cross slowly to annoy drivers, and more than 20% run across the street in a hurry. The Granié et al. (2013) study reported higher proportions of negative behaviors as compared to the findings with the U.S. population for these items. Although the U.S. percentages might seem low, they are nevertheless alarming. Particularly, 'not making proper judgements in traffic due to distraction' or 'responding to other road-users out of anger' when crossing a road are behaviors that show lack of control in the situation and reflect the emotional response of the pedestrians. These behaviors can arouse confusion in drivers and pedestrians, which may potentially result in injuries or fatalities. Interestingly, after the positive behaviors, the most frequently reported behaviors were errors and violations. Thus, it can be said that the most common behaviors are not always the most desirable behaviors from a pedestrian safety point of view. Therefore, promoting pedestrian safety awareness and training programs remains a challenge for transportation researchers.

With respect to the internal structure of the pedestrian behavior questionnaire (PBQ), the confirmatory factor analysis (CFA) empirically grouped survey items into five different aspects of pedestrian behavior (violations, errors, lapses, aggressive behavior, and positive behavior). This differentiation is acceptable in that each factor seems to relate differently to pedestrian safety. Nonetheless, it was also found that four risky behavior factors (violations, errors, lapses, aggressive behavior) had strong correlations between them, with errors and lapses having the strongest correlation (0.93). In contrast, positive pedestrian behaviors were negatively associated with each of these risky behaviors. These findings disprove the suggestion made by Granié et al. (2013) that error should be combined with violation (into a single factor called "transgression") and advocate instead for the plausibility of a model with two factors (risky behaviors and positive behaviors). As far as is known, Papadimitriou et al. (2016) are the only ones who have decided to group the four risky behavioral factors together based on the factorization of their version of PBQ. However, only three of the six correlations were strong enough (>0.70) to support combining risky behaviors into one factor. In fact, the results of CFA revealed that the first-order five factor model (Model 4) and the second-order five factor model (Model 6) were the best models. This indicates that the five factors should be studied separately and that the four risky behaviors should not be grouped together. Past driver behavior questionnaires (DBQ) also support differentiating between the behavioral approaches of road users (Özkan, & Lajunen, 2005; Lawton et al., 1997; Reason et al., 1990). Analyzing the five factors separately can result in either five different subscales or one composite scale. The subscale scores can be useful in studying different behavioral characteristics of pedestrians with respect to a particular scenario or task, whereas a composite score can give an understanding of an individual pedestrian's risky attitudes on the road.

CFA was used to validate the 36-item long version of the PBQ for the U.S. population and to create a 20-item short version. Both the short and long versions were built on a five-factor structure and were easy to interpret. Both showed high internal reliability (>0.7) for the four risky behavior subscales, but not for the positive behavior scale (0.58). The inconsistency with the positive behavior scale was seen by Granié et al. (2013) in the French population as well. This inconsistency suggests that a modification of the positive behavior scale is necessary. The researcher anticipates that additional positive behavior items will need to be included and validated.

In line with previous research (Zhou & Horrey, 2010; Holland and Hill, 2007; Evans and Norman, 2003) which used scenario-based responses to investigate pedestrian behavioral intention while crossing a road, participants in this study were asked to respond to five scenario-based questions related to the five different pedestrian behaviors. The regression analyses between the five different PBQ-based subscale scores and the associated scenario-based ordinal responses confirmed the validity of the subscales for predicting pedestrian behaviors related to violations, errors, and aggressive behaviors. The subscale score for lapse had an individual relationship with its associated scenario-based response; however, the addition of error to the model mediated the effect of lapse. This finding can be supported by the Yildirim (2007) study which did not differentiate errors and lapses because both are unintentional deviances from traffic rules. Not surprisingly, the validation of the positive behavior subscale was not confirmed through this analysis either and confirms the need for modification in future studies. Consistent with the subscale validation, the composite scale was also validated based on the scenario-based responses, except in the case of the positive behavior scenario.

Demographic influences

In line with previous findings, the subscale results showed that males reported a significantly higher frequency of unsafe behaviors (violations, errors, and aggressions) on the road than females (Tom & Granié, 2011; Yildirim, 2007; Rosenbloom, Nemrodov, & Barkan, 2004; Díaz, 2002). In general, this gender difference for not complying with traffic rules is consistent with driver behavior research as well (Harré et al., 1996; Simon

& Corbett, 1996). This can be explained through the tendency for females to be more conservative and considerate, whereas males tend to be more competitive and controlling.

Age was found to influence the composite score and all the subscale scores. Younger people reported more unsafe behaviors for all the intentional and unintentional risky behaviors. In particular, consistent with previous studies, younger people reported committing more violations and errors (Papadimitriou et al., 2016; Granié et al., 2013; Zhou, Horrey, & Yu, 2009). Low income, unawareness of traffic rules, high energy, and lack of alternatives to walking may lead younger pedestrians to more aggressive and less compliant behavior. Surprisingly, lapses were found to be lower with higher age. Older people may have an increased awareness of sharing spaces, greater control in behavior, patience and a considerate attitude. In addition, with age, walking can become a health or pleasure choice rather than a constraint as it is for the younger generation.

A tool for investigating pedestrian-related motor vehicle collisions

The objective of developing a pedestrian behavior questionnaire for the U.S. population was to investigate pedestrians' overall behaviors in the U.S. With the self-reporting pedestrian-related motor vehicle collision reports, the researcher determined which kinds of behavior resulted in collision and/or injury, as well as the severity of injury. The results obtained with the developed PBQ tool were reasonable, even using a smaller sample size. Violations were found to be associated with a higher incidence of collision with injury. This result is supported by previous findings that have stated that pedestrian crashes are the results of violating traffic rules (Zhuang & Wu, 2011; NHTSA, 2008; Ward et al., 1994). When considering only the cases of pedestrian-related motor vehicle crashes which resulted in injury, both violations and errors were found to be significant. Interestingly, people who were aggressive or distracted were at highest risk of suffering severe injury. This is also confirmed through a study which showed that pedestrian distraction and aggressive behaviors can cause anger in other road users (e.g., drivers), resulting in dangerous confrontation (Schwebel, Stavrinos, & Kongable, 2009) and potentially injury or fatality.

Limitations

This study had a number of methodological limitations due to the participant recruitment. All the participants were from the Mechanical Turk workforce, filtered with a few specifications for quality responses. This process of recruitment may possibly have resulted in a population of respondents which differed in some way from the general population of the U.S. In addition, in the case of collision involvement and injury, the small and unequal size of the sample groups (42 and 19) may not be insightful enough. These findings concerning collision history obviously need to be confirmed through more studies using the PBQ.

As also stated in the DBQ, ARBQ, and PBS (respectively by Reason et al., 1990; Elliott & Baughan, 2004; Granié et al., 3013), the behavioral classification provided by the PBQ in this study is based on participants' responses, not on observed behaviors. Pedestrians' responses could be different from their actual behaviors on the road. In addition, it should be made clear that the researcher is not inclined to believe that this type of instrument should be used for a police investigation of a collision incident, as the responses can be biased by the crash experience.

Conclusion

This study clarifies a basis for differentiating pedestrian behaviors into five categories: violations, errors, lapses, aggressive behaviors and positive behaviors. The study also provides new evidence supporting the potential use of the five separate categories for pedestrian safety research. Each of these five individual subscales were tested and found to be reliable, except in the case of positive behaviors which requires further expansion.

In addition to its efficacy in research, the PBQ could be used to promote awareness in pedestrians so that they would modify their risky behaviors. This tool can serve as an instrument of pedestrian self-assessment in educational and training contexts; in other words, it is a tool to help pedestrians become aware of their personal tendencies when crossing a road and interacting with other road users. Hopefully, this instrument will help pedestrians become aware of traffic rules and change their risky behaviors.

In summary, this study was designed to assemble and validate a pedestrian behavior questionnaire for the U.S. population. The objective was to propose a valid framework for pedestrian research in the United States which until now has not existed in a comprehensive, standardized and generally accepted format. This research found that the pedestrian behavior questionnaire developed for the U.S. population met this objective overall. It is therefore useful to all researchers investigating pedestrian safety for all age groups.

CHAPTER III

DEVELOPMENT AND VALIDATION OF A QUESTIONNAIRE TO ASSESS PEDESTRIAN RECEPTIVITY TOWARD FULLY AUTONOMOUS VEHICLES

Introduction

The highest percentage increase in traffic deaths within one year in the United States occurred in 2015 (National Safety Council, 2016), the most recent year for which statistics are available. Among the fatalities in that year, the number of pedestrian fatalities was 5,376, a 9.5% increase from 4,910 pedestrian fatalities in 2014 (National Center for Statistics and Analysis, 2017). *The National Motor Vehicle Crash Causation Survey* (NMVCCS), conducted from 2005 to 2007, reported that around 94% of traffic crashes are at least partially a result of human error (Singh, 2015). In the case of pedestrian-related traffic crashes, the driver, the pedestrian, or both may be the guilty party. Previous reports have revealed that a large percentage of pedestrians see themselves as vulnerable and do not trust that vehicles (drivers) will respond appropriately toward them (Matcalfe, 2016; Snyder, 2013; U.S. Department of Transportation, 2012). However, pedestrians can be the most spontaneous road-users and can make risky decisions in assessing the danger that vehicles pose. Pedestrians can also allow themselves to be distracted with cell phones, music, a companion, or any number of other daily distractions while interacting with traffic. To address these issues with human error made both by drivers and pedestrians, recent research has been focusing on transferring vehicle control from human drivers to automated systems with the ultimate goal of developing fully autonomous vehicles (FAVs).

The current research on semi and/or fully autonomous vehicles and the subsequent innovation of emerging automotive technologies indicate a potential for improved traffic safety along with expanded mobility. Automated vehicle technologies can sense and make judgments about the external environment (e.g. road signs, other road-users, traffic density) and actions the vehicle should take. However, these judgments are dependent on the proper functioning of all cameras, lasers, sensors, and radar scanners that comprise the technology. FAV, the most advanced invention within automated vehicle technologies, is still in the research-and-development phase with numerous ongoing experiments; studies seek to improve this technology by addressing all the risks associated with it, especially in the detection of other road-users (drivers, bicyclists, motorcyclists, and pedestrians). An additional aspect of research on automated vehicle technologies must be the response of other road-users to an unfamiliar technology and unknown dynamic.

The process of introducing a new technology is not always smooth. Many significant innovations fail to satisfy user requirements and get abandoned before their launch into the market (Story, O'Malley, & Hart, 2011). The main obstacles in achieving a place in the market include not only technological issues, but also the lack of acceptance toward new ideas (Vahidi & Eskandarian, 2003). Many researchers have studied acceptance of advanced vehicle technologies from the user or buyer perspectives (Kyriakidis, Happee, & de Winter, 2015; Underwood, 2014; Missel, 2014; Wallace &

Silberg, 2012). The current research is focused on pedestrian receptivity to advanced vehicle technology and has found it important to understand this receptivity so that pedestrian perspectives can also be considered with technology improvements.

Human factors research on autonomous vehicles

In an autonomous vehicle, various functions are controlled by software and hardware allowing those functions to operate independent of a driver. This technology can reduce physical and mental stress for drivers, as well as increase safety for all road-users and reduce fuel consumption (Keen, 2013). Based on the levels of automation proposed by Parasuraman, Sheridan, and Wickens (2000), NHTSA has categorized vehicle automation into five levels (level 0: *No Automation*, level 1: *Function-Specific Automation*, level 2: *Combined Function Automation*, level 3: *Limited Self-Driving Automation*, and level 4: *Full Self-Driving Automation*) (NHTSA, 2013). A Fully Autonomous Vehicle (FAV) is categorized as a level 4, a vehicle automation technology that takes full control of the vehicle to execute all safety-critical driving tasks for an entire trip. At this level of automation, the vehicle can be occupied or unoccupied, and the driver is not expected to take control of the vehicle at any time during the trip, other than to provide navigation input.

The human factors research for automated vehicles is mainly focused on its development, implementation and user (driver) acceptance. The literature reveals extensive research efforts in the development of autonomous vehicles (TRB, 2011), in their promotion (Bamonte, 2013; Motavalli, 2012), in discovering their potential in traffic facility planning and design (Guerra, 2015; Litman, 2015; Lutin, Kornhauser, & Lerner-

Lam, 2013), in uncovering their limitations (high price, possibility for malfunction, liability for accidents, security from hacking, insurance regulation; etc.; Fagnant & Kockelman, 2015; Gomes, 2014; Gurney, 2013), and in identifying implementation factors (environmental: rural-urban, day-night; user individuality: demographics, driver personality; Preston & Waterson, 2015; Kyriakidis et al., 2015). Studies have also investigated public opinion of FAVs; researchers have assessed both willingness to buy as well as the conditions under which drivers would use these vehicles (Kyriakidis et al., 2015; Underwood, 2014; Missel, 2014; Wallace & Silberg, 2012). Although public opinion regarding buying/using FAVs and acceptance and/or trust for the technology is important to research for the implementation of this new technology in the market, recent studies have mostly considered the opinions of drivers, not of other road-users. Research which includes other road-users is focused primarily on the automated technology itself (road-user detection and electronic safety-critical control systems) (Edwards et al., 2015, Llorca et al., 2011), and not on the receptivity of other road-users toward FAVs. For instance, in order to reduce pedestrian risk exposure, transportation researchers and automobile manufacturers are collaborating to develop and install different types of pedestrian protection systems (PPS) in autonomous vehicles. These PPS technologies (radars, cameras, laser, etc.) can detect the existence and position of any still or moving pedestrian in their surroundings and respond appropriately (Gandhi & Trivedi, 2007). Autonomous vehicles equipped with PPS have the potential to reduce pedestrian-motor vehicle crashes as well as to mitigate the possibility of severe injuries by performing driving controls effectively without the constraint of driver inputs. However, the research on PPS has not factored in pedestrian acceptance and behavior toward FAVs. In fact, none of the aforementioned research has considered anticipated pedestrian behavior in the presence of FAVs on the road.

Pedestrian receptivity toward FAVs

Receptivity is the willingness to accept a new idea. Pedestrian receptivity toward FAV technology is shown in the willingness to cross the road in front of a FAV. Many previous studies have attempted to model receptivity or acceptance of technology in terms of behavioral intention. Researchers have either adapted current technology acceptance models or proposed new constructs relevant to the technology under study. Existing technology acceptance models consider behavioral intention to *use* a technology (BI) as a measure of acceptance and identify influencing factors as the predictors of BI. However, in the context of pedestrian receptivity toward FAVs, behavioral intention to *interact with a FAV* or *cross the road in front of a FAV* (not to *use* a FAV) will be used as the BI measure.

With the rise of technology in society, behavioral scientists have developed several technology acceptance models to measure behavioral intention. In 1985, Davis adapted the Theory of Reasoned Action (TRA) model (Fishbein & Ajzen, 1975), which was originally developed to predict general human behavior or behavioral intention in terms of two factors: the attitude toward the behavior and the subjective norm. His model was called the Technology Acceptance Model (TAM). TAM, focused on behavior vis-à-vis technology, replaced attitude toward behavior by two new factors: perceived usefulness and perceived ease of use of a technology, and removed subjective norm as a factor. In 2000, Venkatesh and Davis modified TAM by reconsidering subjective norm as an influencing factor in their model, TAM2.

While TAM and TAM2 were focused more on evaluating the acceptance of those who use a technology, Ajzen (1991) proposed the Theory of Planned Behavior (TPB) which evaluated the acceptance of all those who are affected by a technology. According to TPB, behavioral intentions are predictive of actual behaviors and are influenced by attitudes toward the behavior, subjective norms, and a new predictor, perceived behavioral control. Among these models, TPB is probably the most prevalent in the literature related to pedestrian crossing behavior (Xu, Li, & Zhang, 2013; Sun, Acheampong, Lin, & Pun, 2015; Dıaz, 2002; Evans & Norman, 1998; Holland & Hill, 2007; Yang, & Sun, 2013). The results of these TPB studies showed significant influence for the three factors of TPB on road-crossing intentions, with perceived behavioral control emerging as the most important predictor variable.

Another model, the Unified Theory of Acceptance and Use of Technology (UTAUT), developed by Venkatesh, Morris, Davis, and Davis (2003) considered four main constructs: performance expectancy, effort expectancy, social influence, and facilitating conditions. The first two factors are similar to the factors of TAM, perceived usefulness and ease of use, respectively, and the last two cover factors from TPB, specifically subjective norm and perceived behavioral control. UTAUT also proposes four moderating variables: age, gender, experience, and voluntariness in the model. Although the constructs of UTAUT are not applicable to pedestrian road-crossing research, the four moderating variables might be useful.

Two recent studies have developed technology acceptance models specific to automobiles. Osswald, Wurhofer, Trösterer, Beck, and Tscheligi (2012) developed the Car Technology Acceptance Model (CTAM) to identify variables that explain adoption and use of new car technology. The researchers included psychological and personality variables that distinguish users who accept the technologies from those who reject them. These variables are attitudes toward using technology in general, perceived safety while driving, anxiety in the car context, and social influence. In the same year, Ghazizadeh, Lee, & Boyle (2012) proposed the Automation Acceptance Model (AAM) which is based on TAM with the inclusion of trust and compatibility as additional influencing factors. Of all the variables which have been suggested by these technology acceptance models, trust and compatibility are especially applicable in the context of pedestrian receptivity toward FAVs. Many researchers consider trust as a key variable for receptivity (Lee & See, 2004; Kazi, Stanton, Young, & Harrison, 2005). Experience and practice have been shown to improve trust in automated systems, but trust also varies as a function of the effectiveness of the technology (Muir, 1994; Muir & Moray, 1996). Extensive empirical evidence has shown that there is a decline in trust when there is a defect in the automation (Lee & See, 2004); negative experience with defective automation results in negative expectations. System effectiveness, therefore, is an important factor to be considered as an influence in technology acceptance. For a system to be effective, it requires not only that the technology itself work as it is designed, but also that the environment where it is applied be compatible. For instance, before launching highly delicate autonomous vehicles in the market, it would be important to ensure that the traffic environment is well-prepared with the required infrastructure and regulatory policies. Thus, compatibility should be added to trust and effectiveness as factors in pedestrian receptivity research. Table 3.1 summarizes and defines the factors that can be considered influential for pedestrian receptivity toward FAVs.

Table 3.1 Factors affecting pedestrian receptivity toward FAVs

Factors Influencing Behavioral Intention	Definition	Studies that Considered the Factor
Attitude toward FAVs	Positive or negative feelings toward FAVs in general as well as each specific advanced vehicle technology	Larue, Rakotonirainy, Haworth, & Darvell (2015); Rödel, Stadler, Meschtscherjakov, & Tscheligi (2014); Osswald, et al. (2012); Carsten et al. (2008); Davis (1993); Ajzen & Fishbein (1980)
Subjective Norm	Individual perception of what important and influencing people think about FAVs	Regan et al. (2006); Young (2007)
Trust	Individual belief that a FAV will perform its intended task with high effectiveness	Van Houten (2014); Donmez, Boyle, Lee, & McGehee (2006)
Effectiveness	Extent to which a FAV successfully detects pedestrians and other obstacles on the road, stops for them and/or allows safe pathway for them	Regan et al. (2006); Llaneras (2006); Buckley, Larue, Haworth, & Rakotonirainy (2013)
Compatibility	Degree to which a FAV is perceived as being consistent with the existing transportation system	Ghazizadeh, Lee, & Boyle (2012)

Behavioral Intention indicates intention to cross the road in front of a FAV

In addition to the above factors, it is also important to consider demographic variables and personality factors in technology acceptance research. Researchers have identified age and gender as well as the concept of personal innovativeness as upstream antecedents of most of the factors that influence technology acceptance (Diatmika, Irianto, & Baridwan, 2016; Mun, Jackson, Park, & Probst, 2006; Venkatesh et al., 2003). Personal innovativeness can be defined as the willingness of a pedestrian to try something new in the face of unknowns; in this case to cross the road in front of a FAV (Agarwal et al., 1998). Individuals' personal innovativeness reflects their receptivity to change (Nov & Ye, 2008) and was found to have influence on their attitude, their behavior, and their perception of social norms (Lee, Qu, & Kim, 2007; Chen & Chen, 2011).

To summarize, the research conducted to this point on car technology acceptance as well as on pedestrian behavior yielded the following factors which were used in the current study: attitude toward FAVs, subjective norms, trust, effectiveness, compatibility, personal innovativeness, gender, and age.

Method

Based on these identified factors, a conceptual model (Figure 3.1) for pedestrian behavioral intention to cross the road in front of a FAV was proposed. A pedestrian receptivity questionnaire was then created and validated to assess the effect of these factors. The development and validation of the pedestrian receptivity questionnaire for FAVs (PRQF) was performed online.

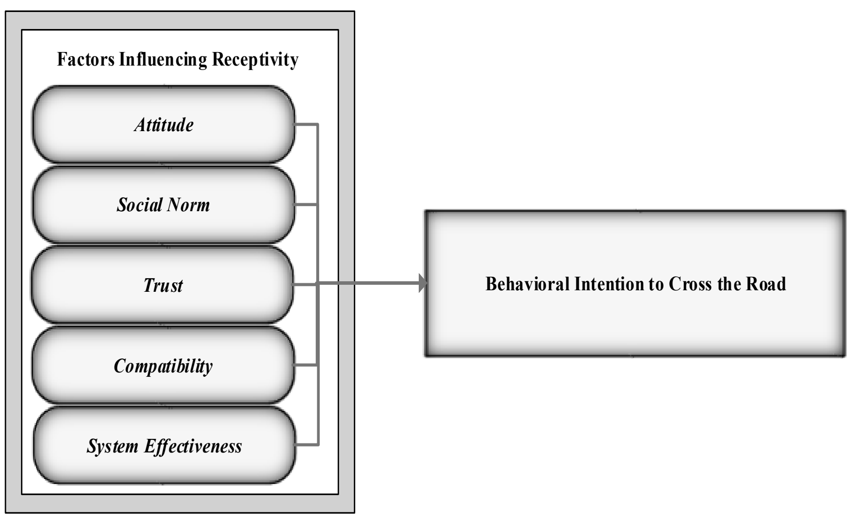


Figure 3.1 Conceptual model for pedestrian receptivity toward FAVs

Survey instrument

Approval from the Mississippi State University Institutional Review Board (IRB) was collected prior to the beginning of survey data collection. The survey instrument for this study included five sections: a 7-item demographic questionnaire, a 4-item personal innovativeness scale adapted from (Agarwal & Prasad, 1998), a 20-item general pedestrian behavior questionnaire (PBQ, short version from Deb et al., 2017), a 16-item questionnaire of pedestrian receptivity toward FAVs (PRQF, includes items based on the conceptual model in Figure 3.1), and two scenario-based questions for behavioral intention to cross the road in front of a FAV. The PRQF scale includes five items based on attitude, three based on social norm, three for trust, two items related to compatibility, two for system effectiveness, and one shared item between compatibility and system effectiveness. The demographic questionnaire, PRQF, and scenario-based questions are attached in Appendix D. PBQ questions were answered on a 6-point scale, where a higher score represents higher risk in pedestrian behaviors. In the case of PRQF questions, participants needed to respond on a 7-point Likert scale (1= strongly disagree, 2= moderately disagree, 3= somewhat disagree, 4= neutral, 5= somewhat agree, 6= moderately agree, 7= strongly agree). There is one reverse-scaled item for subjective norms on the PRQF. A higher score represents higher receptivity toward FAVs. Finally, the two scenario-based questions, one based on pedestrian experience of a FAV at a crosswalk and the other based on pedestrian perspective of FAVs being compatible in their area, were answered on a 5-point ordinal response scale with higher scores indicating greater receptivity toward FAVs. In order to ensure respondents' attention during the survey, two check questions were added to the survey instrument.

Survey administration

The survey was created using Survey Monkey (https://www.surveymonkey.com) and administered online in the U.S. population through Amazon Mechanical Turk (MTurk) (https://www.mturk.com). Amazon Mechanical Turk provides access to a virtual community of workers who are willing to complete human intelligence tasks (HITs) at their convenience. HITs can include data cleaning, transcription, survey completion, or data categorization. Workers from different regions of the country with varying backgrounds participate in MTurk which ensures access to a diverse pool of participants, within limits (only among workers with MTurk accounts). The researcher of this study submitted a HIT and interested MTurk workers responded using the survey link. The requirements for the respondents were that they had to be living in the U.S. and have attempted at least 1000 Mechanical Turk HITs with an approval rate (successful completion of attempted HITs) of at least 95%.

Participants

A total of 500 participants were recruited from the Mechanical Turk workforce. Out of 500 participants, the responses of 482 participants were used for analyses; 18 participants were removed for incorrect answers to at least one of the check questions. The sample of 482 included responses from participants in 43 different states within the United States. The age of the subjects ranged from 19 to 70 (Mean= 35.67, Standard Deviation= 10.72); 39.42% were in the 18-30 age group, 41.91% were in the 31-45 age group and 18.67% were above 45 years of age. Males accounted for 56.64% of the sample and females 43.36%.

Of all the respondents, 0.83% had not graduated from high school, 14.73% of them had a high school degree, 34.23% had some college education, 40.46% had a bachelor degree and 9.75% had done graduate study. Around 66.39% of the participants were from an urban area. A slight majority (59.54%) of the participants reported walking less than 30 minutes a day and 63.69% reported using crosswalks often or very frequently.

Results and discussions

Statistical analyses were conducted using SPSS, Version 24.0 and AMOS, Version 24.0. Table 3.2 displays the descriptive statistics as responses in percentages for the PRQF survey items. For the convenience of analysis, responses of moderately disagree and somewhat disagree were merged into a new category, disagree. Similarly, responses of moderately agree and somewhat agree were merged into a new category, agree. This narrowed the responses from seven possibilities to five. Reponses to the first two attitude questions showed that more than 65% of the participants believed that the inclusion of FAVs on the road would enhance the overall transportation system and make the road safer. Nevertheless, the participants were divided in their opinions about whether to cross the road in front of a FAV. Similarly, a slight majority of the respondents (>55%) believed that FAVs would work effectively. However, the responses to the social norm items portrayed a general view that participants believed friends and family would not recommend crossing the road in front of a FAV. In addition, respondents did not trust these technologies enough to recommend them to their family and loved ones and/or to allow themselves to get distracted while interacting with FAVs. Participants also expressed uncertainty whether FAVs would be compatible with existing traffic infrastructure. Overall, participants reported that they trust FAVs' ability to detect on-road obstacles correctly, yet they find it difficult and overwhelming to interact with a FAV and trust it with their beloved.

Table 3.2 Descriptive statistics for PRQF items

Survey Item		Reponses by percentages to PRQF				
		Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
AT1	FAVs will enhance the overall transportation system	4.15	10.17	18.05	47.51	20.12
AT2	FAVs will make the roads safer	5.39	13.49	20.54	44.40	16.18
AT3	I would feel safe to cross roads in front of FAVs	12.24	26.56	13.28	39.00	8.92
AT4	It would take less effort from me to observe the surroundings and cross roads if there are FAVs involved	21.58	33.82	16.39	24.69	3.53
AT5	I would find it pleasant to cross the road in front of FAVS	18.26	23.44	30.29	24.48	3.53
EF1	Interacting with the system would not require a lot of mental effort	4.56	24.07	15.77	46.68	8.92
EF2	FAV can correctly detect pedestrians on streets	2.70	10.79	20.33	52.49	13.69
S1	People who influence my behavior would think that I should cross roads in front of FAVs	18.88	30.08	30.29	18.67	2.07
S2	People who are important to me would not think that I should cross roads in front of FAVs	13.49	33.82	27.80	17.84	7.05
S3	People who are important to me and/or influence my behavior trust FAVs (or have a positive attitude toward FAVs)	3.94	22.41	35.27	34.02	4.36
T1	I would feel comfortable if my child, spouse, parents – or other loved ones – cross roads in the presence of FAVs	14.94	25.52	17.22	33.20	9.13
T2	I would recommend my family and friends to be comfortable while crossing roads in front of FAVs	15.15	22.20	21.99	32.16	8.51
T3	I would feel more comfortable doing other things (e.g., checking emails on my smartphone, talking to my companions) while crossing the road in front of FAVs than non-automated cars	29.25	35.48	11.41	18.88	4.98
C1	The traffic infrastructure supports the launch of FAVs	7.68	26.97	26.97	32.57	5.81
C2	FAV is compatible with all aspects of transportation system in my area	9.75	26.56	26.56	32.78	4.36
EF3C3	FAVs will be able to effectively interact with other vehicles and pedestrians	4.98	10.79	26.76	47.72	9.75

The first column notes the scales from the conceptual model, where AT indicates Attitude, S indicates Social Norm, T indicates Trust, C indicates Compatibility, and EF indicates Effectiveness

Scale development

In order to explore the factor structure for PRQF, a principal component analysis (PCA) with maximum likelihood estimation and orthogonal varimax rotation was carried out on all 16 items in the scale. A cut-off point of 0.40 was used for factor loading. Three components with eigenvalues greater than 1 were identified which cumulatively accounted for 60.46% of the total variance. The Kaiser-Meyer-Olkin measure of sampling adequacy was satisfactory (0.89), Bartlett's test of sphericity was significant ($p<0.0001$), and the determinant of the matrix was close to zero (5.886E−06).

The first component, "safety," explained 24.33% of the variance. It was defined by 4 items: attitude (2 items), social norm (1 item), and effectiveness (1 item), concerning the successful control and operation of FAVs on the road. The second component, "interaction," explained 22.03% of the variance and was determined by 8 items related to pedestrians' confidence to cross the road in front of a FAV. This component includes survey items for trust (3 items), crossing-related attitude (3 items) and social norm (2 items). The final factor, "compatibility," accounted for 14.1% of the total variance and includes 3 items that consider the ability to successfully implement FAVs within the existing traffic system. The results from the PCA are presented in Table 3.3.

Table 3.3 Principal component analysis

Principal Component Analysis with Varimax Rotation	Components		
	Safety	Interaction	Compatibility
AT1: FAVs will enhance the overall transportation system	.849		
AT2: FAVs will make the roads safer	.865		
S3: People who are important to me and/or influence my behavior trust FAVs (or have a positive attitude towards FAVs)	.506		
EF2: FAV can correctly detect pedestrians on streets	.619		
T1: I would feel comfortable if my child, spouse, parents – or other loved ones – cross roads in the presence of FAVs		.711	
T2: I would recommend my family and friends to be comfortable while crossing roads in front of FAVs		.714	
T3: I would feel more comfortable doing other things (e.g., checking emails on my smartphone, talking to my companions) while crossing the road in front of FAVs than non-automated cars		.608	
AT3: I would feel safe to cross roads in front of FAVs		.700	
AT4: It would take less effort from me to observe the surroundings and cross roads if there are FAVs involved		.409	
AT5: I would find it pleasant to cross the road in front of FAVS		.653	
S1: People who influence my behavior would think that I should cross roads in front of FAVs		.759	
S2: People who are important to me would not think that I should cross roads in front of FAVs		.658	
C1: The traffic infrastructure supports the launch of FAVs			.864
C2: FAV is compatible with all aspects of transportation system in my area			.874
EF3C3: FAVs will be able to effectively interact with other vehicles and pedestrians			.459

Reliability of the scale

The mean scores for the safety, interaction, and compatibility items were calculated and used as composite scores for each of these three subscales of pedestrian receptivity toward FAVs. The Cronbach's alpha (α) for the resulting subscales were calculated to test the internal reliability.

There are different recommendations for the acceptable range of alpha from 0.70 to 0.95 (Bland & Altman, 1997; Streiner, 2003; DeVellis, 2016); however, a maximum alpha value of 0.90 has been recommended for survey research (Streiner, 2003). A low alpha value could be the result of a low number of items, poor interrelatedness between survey items, or heterogeneous constructs. If alpha is too high (>0.9), it may suggest that some items are redundant, testing the same question but in a different guise (Tavakol & Dennick, 2011). Cronbach's alphas for the three subscales, range from 0.865 to 0.890 (Figure 3.2), indicate that the scales have acceptable internal reliability.

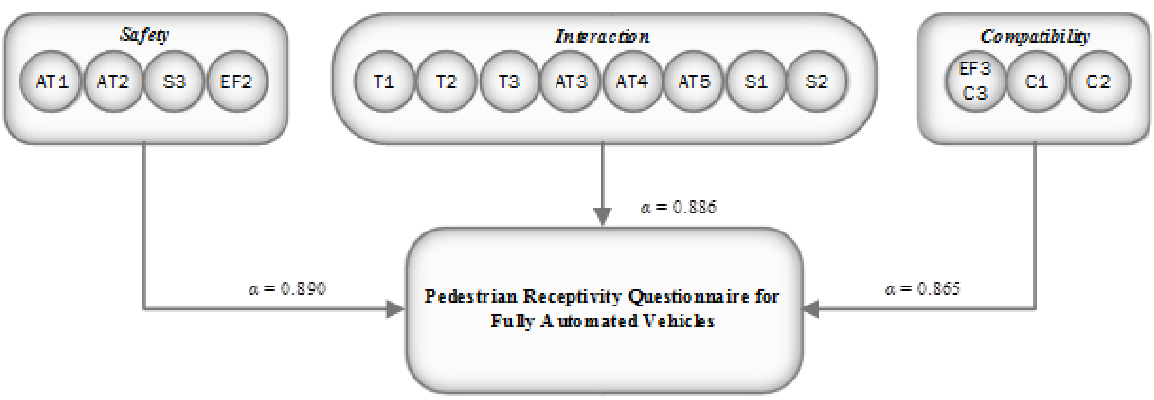


Figure 3.2 Internal consistency of the scale

Scale validation

In order to verify the factor structure developed from the PCA results, a confirmatory factor analysis (CFA) was conducted using AMOS 24. Based on the modification indices, CFA suggested adding error covariance between items AT1 and AT2, T1 and T2, T3 and AT4, AT3 and AT5, AT5 and S1, as well as between items C1 and C5. This was necessary due to the similarity in wording and content of the items. After introducing these minor changes, the 15-item questionnaire confirmed the PCA-developed factor structure with a large value for the comparative fit index (CFI) (>0.9) and a low root mean square error of approximation (RMSEA). Table 3.4 exhibits the model fit outcomes from the CFA for the PRQF model in terms of (a) absolute fit, using RMSEA and the chi-square test statistics and (b) comparative fit, using CFI. Many past studies suggested guidelines for acceptable model fit as RMSEA value to be from .06 to 0.08 and CFI to be .95 or greater (Hooper, Coughlan, & Mullen, 2008; Schreiber, Nora, Stage, Barlow, & King, 2006). For the three-factor solution in this study, the guidelines were consistent with acceptable overall fit; RMSEA = 0.061 and CFI = .973. Figure 3.3 presents the standardized solution for the model of the PRQF scale. The value for χ^2/df (=2.812) indicates that the three-factor model cannot be improved any further (Brown, 2014).

Table 3.4 Model fit indices for second-order confirmatory factor analysis

Model fit indices	Statistics
χ^2	227.78
df	81
χ^2/df	2.812
Absolute Fit (RMSEA)	0.061
Comparative Fit (CFI)	0.973

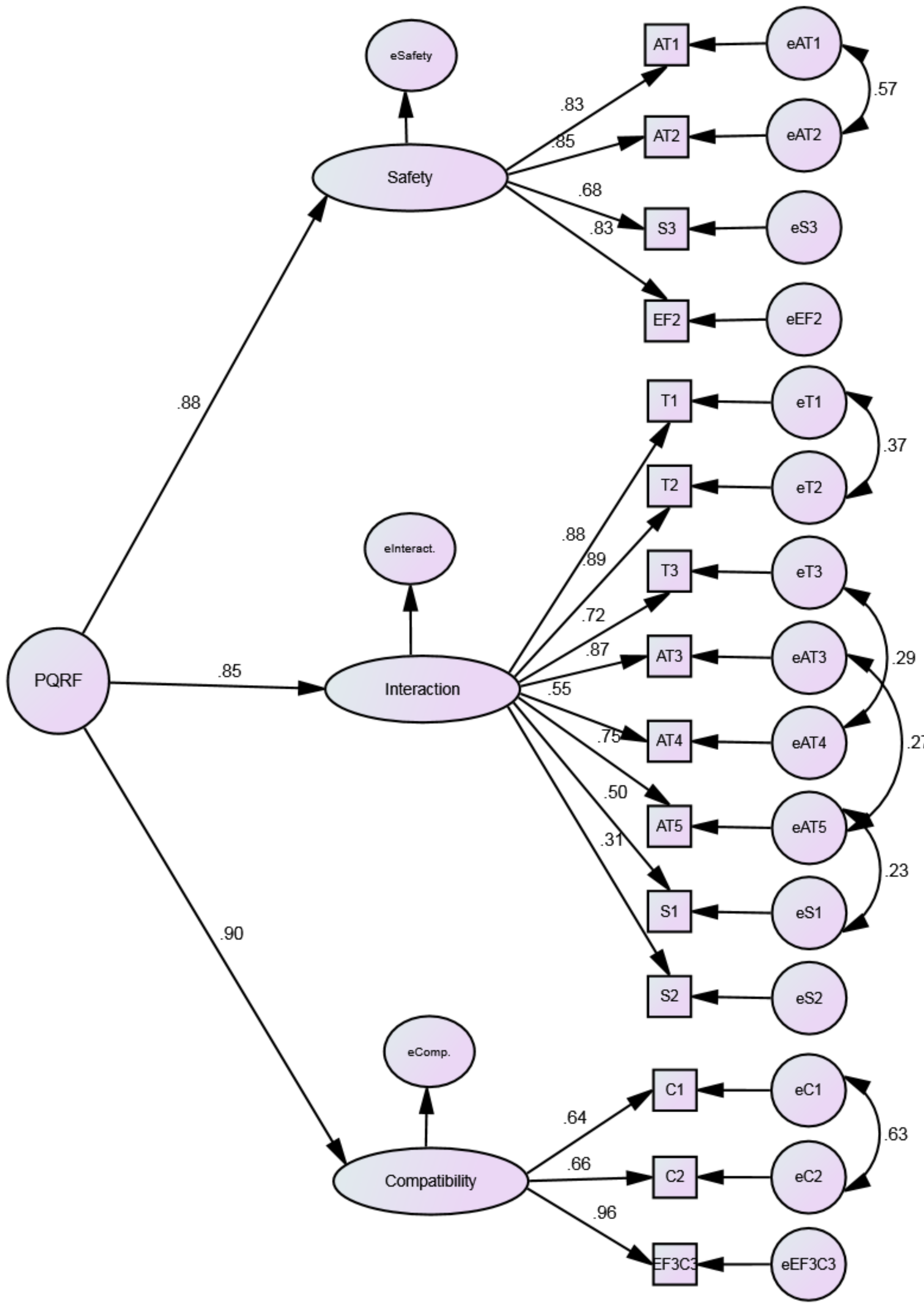


Figure 3.3 Standardized solution for the PRQF model. Correlation among factors and standard regression weights were all statistically significant, $p < .001$

To validate the PRQF scale, ordinal logistic regression was carried out to find the associations between the ordinal responses to each of the two scenario-based questions from the survey and the three PRQF-based subscale scores. Table 3.5 displays the results from these logistic regression results. The hypothesis was that the behavioral-intention response to each of the scenarios would be predicted by each of the subscale scores.

The findings from Table 3.5 show that responses for scenario 1 (designed around pedestrians' intention to cross the road in front of a FAV) could be significantly predicted by both safety and interaction scores, but not by the compatibility score. As expected, the positive parameter estimates on the first two scores confirm that the higher the perception of safety and willingness to interact with FAVs, the higher the likelihood of crossing the road in front of FAVs. In contrast, scenario 2 (developed around accepting autonomous vehicles in their area) was found to be predicted by all three PRQF-based subscale scores. The positive parameter estimates on the scores confirm that the higher the pedestrians' perception of safety, willingness to interact, and perception of compatibility, the higher the possibility of accepting FAVs in their area. In addition, based on the regression coefficients, safety has the largest impact when looking at acceptance into area and interaction has largest impact when looking at behavioral intention to cross the road in front of a FAV.

Table 3.5 Validation of the proposed PRQF

Scenario	Scenario-based question	Subscales	*b*	*χ2 Stat.*	*p value*
#1	What will your response at the crosswalk be, with the FAV approaching (Pseudo R^2 = 0.341)	Safety	0.4383	12.9382	0.0003*
		Interaction	0.5815	30.6356	<.0001*
		Compatibility	0.0250	0.0685	0.7935
#2	As a pedestrian, how will you accept the presence of driverless vehicles in your area (Pseudo R^2 = 0.596)	Safety	1.2772	88.3735	<.0001*
		Interaction	0.3930	14.4037	0.0001*
		Compatibility	0.2521	6.3486	0.0117*

* indicates significant results

Effects of demographic variables

Analysis of Variance (ANOVA) was conducted to determine the influence of gender, age, and location on the PRQF-based subscale scores. In order to identify the influence of personal innovativeness score on each of the three subscale scores, a simple linear regression analysis was performed. The scale scores were considered as the dependent variables and demographics were considered as the independent variables in these one-way ANOVAs and regression. Table 3.6 presents the results for demographic influence and Table 3.7 exhibits means and standard deviations of the scale scores for each of the demographic groups. Comparisons among the three age groups are also presented in Table 3.7 with alphabetic symbols.

Table 3.6 Demographic influence on PRQF subscales

Demographics	*F statistics (p-value)*		
	Safety	Interaction	Compatibility
Gender *(df: 1, 480)*	15.58 (0.0001)*	22.13 (<0.0001)*	7.85 (0.005)*
Age *(df: 2, 479)*	3.68 (0.0699)	8.40 (0.0003)*	7.73 (0.0005)*
Location *(df: 1, 480)*	7.73 (0.006)*	3.17 (0.076)	12.63 (0.0004)*
Personal innovativeness	*b*= 0.343 15.78 (<0.0001)*	*b*=0.265 11.60 (<0.0001)*	*b*=0.282 11.84 (<0.0001)*

df denotes degrees of freedom for one-way ANOVA
b indicates parameter estimate from regression analysis
* indicates significant results

Table 3.7 Summary statistics for different levels of demographics

		Subscale Scores [Mean (Standard Deviation)]				
	Levels	Safety	Interaction		Compatibility	
Gender	Male	4.93 (1.25)	3.81 (1.31)		4.35 (1.41)	
	Female	4.47 (1.34)	3.25 (1.30)		3.99 (1.35)	
Age	18-30	4.87 (1.22)	3.80 (1.29)	A	4.46 (1.27)	A
	31-45	4.60 (1.34)	3.35 (1.35)	B B	3.97 (1.44)	B B
	45+	4.58 (1.36)	3.37 (1.28)	B	4.05 (1.43)	B
Location	Rural	4.50 (1.38)	3.42 (1.40)		3.88 (1.38)	
	Urban	4.85 (1.25)	3.65 (1.29)		4.35 (1.37)	

Gender and personal innovativeness showed significant influence on each of the subscale scores. Male pedestrians were more inclined to accept FAVs than females. The parameter estimate for each of the subscales confirms that with the increase in personal innovativeness, the receptivity toward FAVs increases, showing a positive relationship.

Age was found to have significant influence on interaction and compatibility scores, while location showed significant influence on safety and compatibility scores. The youngest age group (18-30) showed significantly higher receptivity toward FAVs than the other two age groups. In the case of location, the people from urban regions were more receptive toward FAVs than the people from rural regions.

Influence of pedestrian behaviors on the receptivity of FAVs

Table 3.8 Influence of pedestrian behavior on their receptivity toward FAVs

Pedestrian Behaviors	PRQF subscales		
	Safety	Interaction	Compatibility
Violation	b= -0.0113 F=0.540 (p=0.877)	b= 0.098 F=3.47 (p=0.084)	b= 0.0069 F=1.55 (p=0.935)
Error	b= -0.0115 F=0.898 (p=0.926)	b= 0.251 F=7.08 (p=0.001)*	b= 0.0537 F=2.41 (p=0.685)
Lapse	b= -0.0111 F=0.776 (p=0.932)	b= 0.0811 F=6.64 (p=0.001)*	b= 0.0655 F=2.43 (p=0.641)
Aggressive behavior	b= -0.0334 F=1.058 (p=0.775)	b= 0.0861 F=5.31 (p=0.008)*	b= -0.0015 F=1.76 (p=0.991)
Positive behavior	b= 0.1215 F=3.93 (p=0.044)*	b= -0.0956 F=2.99 (p=0.135)	b= 0.0583 F=1.33 (p=0.391)

* indicates significant associations

Linear regressions were conducted considering each of the subscale scores as the dependent variable and five types of pedestrian behaviors as independent variables. Results showed significant associations between pedestrian receptivity of FAVs (PRQF subscales) and pedestrian behavior (based on PBQ subscales; Deb, et al., 2017). According to the findings (see Table 3.8), people who comply with traffic rules and show positive behavior toward other road users believe that the addition of FAVs will improve traffic safety by detecting pedestrians on the road and making correct accommodations. Interestingly, people who do not have enough knowledge about traffic rules, do not pay attention to traffic, and/or get aggressive when drivers behave unexpectedly, were found to feel more confident than people with less risky behaviors about crossing the road in front of a FAV.

Discussion

The main objective of this study was to develop and validate a questionnaire for pedestrian receptivity of fully autonomous vehicles (FAVs). The PRQF was designed to identify the factors that influence pedestrian acceptance of FAVs, specifically while crossing the road in front of them. Several statistical analyses confirmed a three-component factor structure for the PRQF: safety, interaction, and compatibility. The subscale safety included survey items that expressed participants' sense whether the inclusion of FAVs created a safer traffic environment. In the case of the subscale interaction, survey items were centered on the decision to cross the road in the presence of FAVs. Finally, the survey items included in the subscale compatibility considered participants' understanding of what would be required for effective accommodation of FAVs in the existing traffic environment.

Developing a survey tool for pedestrian receptivity of FAVs

In the case of vehicle technology acceptance research in general, the inclusion of the factors "perceived safety" (Cavoli, Phillips, Cohen, & Jones, 2017; Osswald et al., 2012), "vehicle-pedestrian interaction" (Cavoli et al., 2017; Parkin, Clark, Clayton, Ricci, & Parkhurst, 2016; Le Vine & Polak, 2014), and "compatibility with existing traffic infrastructure" (Cavoli et al., 2017; Clark, Parkhurst, & Ricci, 2016) was found to be very common. Therefore, it was not unexpected to find that similar factors were significant for pedestrian receptivity toward FAVs. Concerning the first subscale safety, pedestrians show increased receptivity toward FAVs when they believe FAVs' operation to be effective and when they feel safe around FAVs as compared to conventional vehicles. These results can be supported by past survey studies where respondents considered FAVs to be safer than the conventional vehicles and would cause fewer accidents (Begg, 2014; Underwood, 2014). Concerning the second subscale interaction (pedestrian-vehicle interaction while crossing), FAV is a novel technology, self-driven, and to which most pedestrians have not been exposed. The anxiety which is aroused when interacting with driverless vehicles plays the defining role in pedestrians' decision not to cross in front of them. Previous research showed that participants' concerns about FAVs' equipment failure, liability issues and/or hacking of their information systems led them not to trust these vehicles (Howard & Dai, 2014; Kyriakidis et al., 2015). Concerning the final subscale compatibility (with the existing traffic infrastructure), respondents showed positive attitude toward accommodating FAVs in their area. However, around 5% of the participants provided statements about having difficulties accepting these vehicles in their area without any interaction experience with FAVs. Adams (2015) reported that with the introduction of FAVs on the road, conventional vehicles and other road users, especially pedestrians, may claim priority, expecting that FAVs will automatically stop or slow down in the interest of safety, which could disturb normal traffic flow. Hence, these vehicles need to be supported with proper traffic infrastructure (e.g., separate lanes for FAVs, obstacle-free roads, controlled intersections with traffic signs), policy making (liability, insurance), and promotion (educating the public about FAVs).

Results for the effects of demographic variables

Gender effect

Research on the effect of gender suggests that gender can play an important role in determining technology acceptance (Howard & Dai, 2014; Payre, Cestac, & Delhomme, 2014; Venkatesh & Morris 2000; Gefen & Straub 1997). In this study as well, gender played a role in how all the subscales were likely to influence a pedestrian's receptivity toward FAVs. Males expressed a greater perception of safety around FAVs, found it easier to interact with them at crosswalks and believed they would be easier to accommodate in the existing traffic infrastructure, as compared to females. In general, females are more likely than males to value interpersonal relationships (Holmes, 2013; Rosener, 1990), and since FAVs are driverless vehicles, the lack of human-to-human interaction arouses confusion in most females. Males, on the other hand, are more likely to value science and technology and show a more positive attitude and greater trust toward FAVs (Payre et al., 2014; Canada & Brusca, 1993).

Age effect

The effect of age was found to be significant for interaction and compatibility, but not for safety. For each age group, respondents were mostly positive about the safety of including FAVs into the traffic system. However, younger people showed more interest in interacting with FAVs and accommodating them into the traffic environment. In general, young people are enthusiastic about experiencing new technologies while older people are concerned about their family, especially about their children, and these tendencies affect receptivity toward this change in the transportation system and the consequences.

Location effect

Location (urban/rural) showed a significant effect on the acceptance of FAVs; participants from urban areas are more receptive toward them than participants from rural areas. Traffic volume and flow are much higher in urban areas as compared to rural areas; therefore, inclusion of FAVs can enhance traffic safety to a higher degree in these areas through reduced traffic flow, fewer parking spaces, minimized visual obstruction due to traffic congestion, and eventually, reduced pedestrian risks. With these benefits, people would show positive receptivity toward FAVs in urban areas.

Personal innovativeness effect

In line with past research outcomes considering the role of personal innovativeness on technology acceptance (Diatmika et al., 2016; Mun et al., 2006; Venkatesh et al., 2003), this study showed that an increased level of personal innovativeness increases pedestrians' acceptance of FAVs for all three subscales. It has long been recognized that individuals with higher innovativeness seek information about new ideas, can cope with high levels of uncertainty and show more positive intentions toward acceptance (Rogers, 1995). Agarwal and Prasad (1998) also argue that highly innovative individuals are expected to take risks more frequently and develop more positive beliefs about technology.

Influence of pedestrian behaviors

This study investigated five categories of pedestrian behaviors (violation, error, lapse, aggressive behaviors, and positive behaviors) on pedestrian receptivity of FAVs on the road. Some of these pedestrian behaviors were found to be significant for the safety and interaction subscales of the PRQF. Individuals who show conservative behaviors as pedestrians and try to be cooperative and appreciative while sharing the road with other road-users, perceived FAVs as being safe. Pedestrians with positive behaviors are concerned with traffic rules and unexpected behaviors from other road-users. Therefore, it can be expected that these individuals would respond similarly in the presence of FAVs by complying with necessary traffic rules. However, pedestrians who show mostly risky behaviors, whether due to inexperience, stress or aggressiveness, would take advantage of FAVs' accurate detection and braking systems to cross the road without paying attention. Adams (2015) reported that with the inclusion of FAVs into the traffic infrastructure, pedestrians would no longer wait at the roadside trying to judge whether an approaching car would stop for them or whether a gap in the traffic would be safe enough for crossing. They would stride confidently into the road, knowing that FAVs would always stop for them. The third subscale, compatibility, was not influenced by any of the pedestrian behaviors, perhaps due to the complexity and novelty of adding a new technology into an existing traffic infrastructure.

Conclusion

This study proposed and validated a framework for evaluating pedestrian receptivity toward FAVs with three subscales: safety, interaction, and compatibility. Responses to the questionnaire can be used to understand pedestrian intended behavior in front of a FAV and to identify necessary modifications to the traffic system as well as the technology. Each of the individual subscales were tested and found to be reliable and valid for pedestrian receptivity toward FAVs. The researchers also provided new evidence supporting the potential use of PBQ (developed by Deb et al., 2017) for the research regarding pedestrian receptivity of FAVs.

In the U.S. alone, FAVs could save thousands of lives annually as well as billions of dollars of expense for victims of traffic accidents. FAVs could reduce urban congestion with fewer freeway lanes and parking lots. On the other hand, traffic in urban environments could be unacceptably slowed down if road-users, especially pedestrians, jump into traffic, assuming that FAVs must be programmed to anticipate these issues, and thus compromise safety. Therefore, some potentially complex behavioral changes may be generated by the introduction of FAVs which will have to be addressed to anticipate potential safety and/or traffic flow issues. In order to establish an organized transportation system, future research is necessary to design FAVs with a focus on road-user-to-FAV interaction as well as to educate road-users.

Overall, the present study provided a tool to assess FAV acceptability from a pedestrian perspective in future research. The tool can also be modified for the receptivity of other road-users to FAVs. Moreover, receptivity of and actual behavior toward FAVs appeared to be complementary concepts when evaluating intention to interact with a FAV. If participants showed higher receptivity, they were more likely to cross the road in front of a FAV. From an industrial viewpoint, the findings can be used as potential guidelines for designing and improving FAVs for pedestrians. The manufacturers should focus on not only improving the quality and satisfaction of FAVs, but also developing an accurate and reliable systems to enhance road-users' perceptions and acceptance of the technology. Finally, manufacturers and researchers should also keep in mind while developing and designing FAVs that there is a potential risk that pedestrians (and other road-users) will take advantage of FAVs' automated control system.

Although this study presented significant insights into the subscales and factors that affect pedestrians' perspectives on interacting with FAVs, there were several methodological limitations due to the participant recruitment. All the participants were from the Mechanical Turk workforce, filtered with a few specifications for quality responses. This process of recruitment may possibly have resulted in a population of respondents which differed in some way from the general population of the U.S. Also, the classification of pedestrian perception of FAVs provided by the PRQF in this study is based on participants' responses, not on observed behaviors. Pedestrians' responses could be different from their actual behaviors on the road interacting with FAVs. Therefore, future research should consider pedestrian-FAV interaction on the road to understand their acceptance of this vehicle technology.

CHAPTER IV

INVESTIGATING PEDESTRIAN DESIGN SUGGESTIONS FOR FAVS: A SIMULATOR STUDY

Introduction

Once road-users enter the road network, they start a constant exchange of information with other road-users around them. Signals, vehicle lights (for example, brake lights, signal lights), road position, and weather conditions provide important clues to the road-users, sometimes requiring immediate action. Being one of the most vulnerable road-users, it is very important for pedestrians to make human-to-human contact while crossing a road; for example, through a wave of a hand or direct eye contact with a driver. Human-to-human interaction can offer a sense of road safety that technology is not able to provide. Therefore, the traffic system of the future, filled with driverless cars operated by computers, not humans, may make pedestrians uncomfortable with crossing the road. It is a matter of concern as to how manufacturers can build public trust in driverless vehicles since there is no human inside with whom to interact.

Through constant technological innovation, research and improvement, as well as through the use of excellent advertising strategies, manufacturers are building public receptivity for FAVs. FAVs have the potential to sense and make judgments about the vehicle's external environment, but cannot be modified in real time even though they may need to adjust to changes in on-road traffic conditions such as other road-users' static objects, road quality and elements (e.g., lane markings and signs), and weather and lighting conditions (Anderson, Kalra, Stanley, Sorensen, Samaras, & Oluwatola, 2014). Therefore, the performance requirements of sensors and sensor-fusion systems still require development and improvement and must be tested under a wide range of on-road traffic conditions (Anderson et al., 2014).

Even though there are regulation and liability issues that need to be addressed before FAVs can be commercially available (Schijndel-de Nooij et al. 2011), a lot of research is currently going on. Vehicle manufacturers are conducting or planning field trials with FAVs. Volvo Cars is, for example, planning a trial including 100 FAVs that will be used by regular customers on designated highway roads in 2017 (Volvo Car Group, 2013). Google's fleet of FAVs has, as of June 2015, driven over 1.6 million km on public roads (Google, 2015). The research related to FAVs has thus far mainly focused on the user's willingness to own one, their preference of interface design, and their experience with the system (Beller, J., Heesen, M. & Vollrath, M. 2013; Szymaszek, 2014; Ju, W & Mok, B. 2014; Johns, M., Ju, W. & Sibi, S. 2014). Users are, however, not the only road-users with whom research should be concerned. Since pedestrian actions are unpredictable and cannot always be controlled by traffic rules, this dissertation found it necessary to identify modes with which pedestrians are comfortable interacting with autonomous vehicles. Thus, along with the PRQF to measure pedestrian receptivity toward FAVs, this study performed an experimental procedure to identify design features preferred by the pedestrian which would increase their receptivity toward autonomous vehicles.

Literature review

Research has shown that road-users feel comfortable interacting with vehicle drivers (Lukits, 2015; Lin, Kourtellis, Wang, & Guo, 2015). However, in the case of FAVs, a human driver is not in control of the vehicle, making interaction impossible. In response to this lack of pedestrian-to-FAV communication, Lagström and Lundgren (2015) performed observations and interviews with a "Wizard of Oz approach" which gave pedestrians the experience of interacting with a FAV. Results indicated that the pedestrians wanted to know that a vehicle was in automated driving mode. In response, a prototype was introduced which communicates the vehicle's current driving mode and intentions to the pedestrians. LED strip lights were designed in different sequences to communicate that the vehicle is "in automated driving mode", "is about to yield", "is resting" or "is about to start". The pedestrians reported that the LED lights provided clear and excellent interaction which replaced the role of the driver in the encounters with the FAVs. However, the prototype did not provide a message, the interfaces required training to learn, and the study did not consider distracted pedestrians and visually disabled pedestrians. Using a similar approach, Semcon (2016) developed a prototype with a single external interface, the smiling car. When the smiling car detects a pedestrian, a smile lights up on the front car display that confirms that the car will stop for the pedestrian., This single, visual-only interacting interface could signal the vehicle's intention to stop at a crosswalk; however, there was no means to signal other intentions, nor were audible signals included for the visually impaired.

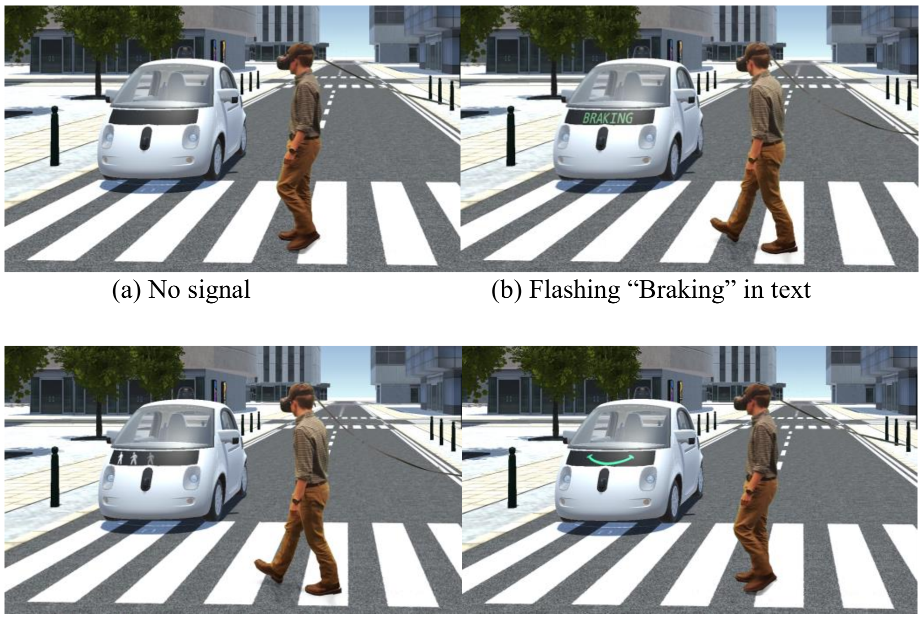
Recently, a survey study identified pedestrians' expectations for external design features on FAVs (Deb, Poudel, Bhandari, & Warner, 2016), considering both visual and audible features. Most of the respondents preferred a visual sign, such as a flashing 'walk' sign or a timer clock, mounted on top of the FAV indicating the vehicle's intention to stop at a crosswalk. Deb et al., (2016) also recommended including audible interacting features to the FAVs for distracted pedestrians as well as for pedestrians with vision disability.

In 2017, the Imperial College of London and the Royal College of Art developed a new technology, Blink (Peters, 2017). Using vehicle sensors and machine learning, Blink can show a silhouette of the pedestrian using visual displays fitted to the four corners of the autonomous vehicle, indicating that it acknowledges the existence of the pedestrian. If pedestrians want to cross and they're not at a crosswalk, they can hold up their hand, and the car will stop (provided it can brake in time) and light up with a green walk signal on the front display to let the pedestrians know that it is safe to cross. If they don't want to cross, they can wave the vehicle ahead, and it will signal that it understands and continue on its way.

Based upon these studies, a list of feasible external design features which can be installed on a FAV to increase pedestrian trust in these vehicles is shown in Table 4.1. The visual features are displayed in Figure 4.1. These features will continue providing visual and/or audible warning until the vehicle starts moving. In order to overcome the lack of FAVs on the road and to ensure pedestrian safety, the proposed design features were investigated using a pedestrian simulator to determine their effect on improving pedestrian receptivity toward autonomous vehicles. The findings from this experiment can provide automated vehicle manufacturers with information that would be helpful for future commercialization of FAVs.

Table 4.1 External design features for FAVs

Audible features	Visual features
Beep sound	Pedestrian silhouette
Music	Braking in text
Verbal statement “safe to cross”	Smile



(a) No signal

(b) Flashing “Braking” in text

(c) Five pedestrian crossing signs animated to appear and disappear from one side to another

(d) Flashing “Smiling” sign

Figure 4.1 Visual design features for FAVs

Method

This study was designed to test and recommend certain external design features for autonomous vehicles to increase pedestrian acceptance of FAVs. The study proposed these features based on a previous survey and on on-going research in this arena. An experimental procedure immersed the participants into a virtual world equipped with FAVs in the traffic environment. The experiment included the proposed features as factors affecting pedestrians’ road crossing decisions in front of a FAV. Based on their interaction with various FAVs, which were equipped with different features and feature combinations, the participants were asked to rate feature options on a 7-point Likert scale. A higher rating indicated greater receptivity toward FAVs.

Participants

The study was run based on the approval of the Mississippi State University Institutional Review Board. A total of 31 participants were recruited from Mississippi State University and the surrounding community. All participants were fluent English speakers, had normal or corrected full-color vision, and were able to walk at a normal pace and gait. The study took about 40 minutes to complete and participants were compensated with $20 for their time.

Of the 31 participants, the data from one participant was not included for analyses due to a technical issue. As a result, the data from 30 participants (17 males: mean age=30.65, range=22-47 and 13 females: mean age=31.62, range=18-47) were included in the analyses. Participants aged 18-30 were categorized as "age group 1" (n= 17; mean age= 24.82), 31-45 were categorized as "age group 2" (n= 8; mean age= 35.00), and those aged 45 and above were categorized as "age group 3" (n=5; mean age= 46.00). Of the 30 participants, nine were undergrad students, fifteen working on graduate degree, and the rest had a graduate degree.

Pedestrian Simulator

The simulator used in this study consisted of two parts: an HTC Vive consumer VR headset and a Unity 5 virtual environment. The HTC Vive setup includes a headset that the participant wears with two Lighthouse sensors to track the position and orientation of the Vive headset. The Lighthouse sensors flash a pattern of infrared laser beams over the headset and calculate its position and orientation in virtual space in relation to the Base Stations. For this experiment, the Lighthouse sensors were positioned facing each other at opposite ends, approximately 8 meters apart, as shown in Figure 4.2. The area under the Vive tracking was approximately 4 by 7 meters with a 5.5-meter-long crosswalk and sidewalks on both sides.

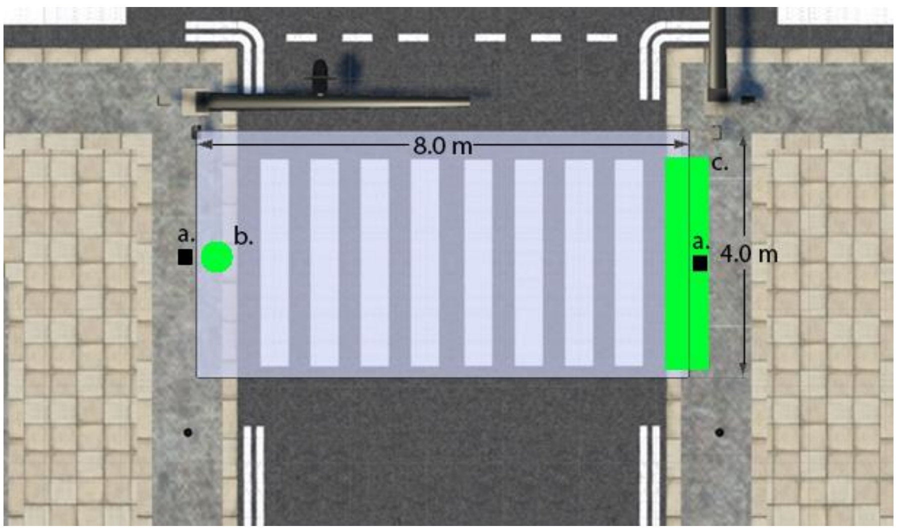


Figure 4.2 Overview of the crosswalk virtual environment

The available area for the participant to move is indicated by the grey box overlaid in the environment. Specific features are: a. Lighthouse sensor positions; b. participant start position; c. participant end sensor.
Source: Deb, Carruth, Sween, Strawderman, and Garrison, (2017).

Three virtual environments were designed for the study: a familiarization virtual environment, a lobby area, and a test environment. All virtual environments (VEs) were implemented in Unity 5. The general familiarization VE (shown in Figure 4.3) was designed to allow participants to become familiar with navigation in virtual reality (VR) in general, as well as with the specific interface elements used to prompt participants during this study. The VE seen through the headset consisted of a small room with a chalkboard, a table, a bulldog statue, a stack of books, two windows, a cabinet under the table, and a doorway leading out of the room. Participants were directed with in-environment instructions (text written on a chalkboard) to look at the 4 objects in the environment (statue, books, either window, the cabinet) and then walk out of the room. This introduced concepts of in-environment instructions, looking at objects, and moving through the environment, while helping to move the participant past the novelty effect of being in a virtual environment.

Figure 4.3 Familiarization virtual environment

The second VE, the lobby area (shown in Figure 4.4), provided a clear break between the trials as well as an opportunity to give instructions to the participants. A virtual marker was placed on the ground in the lobby environment to indicate where participants should stand. When participants were standing on the marker, they were instructed to look at a virtual button to indicate that they were ready to continue.

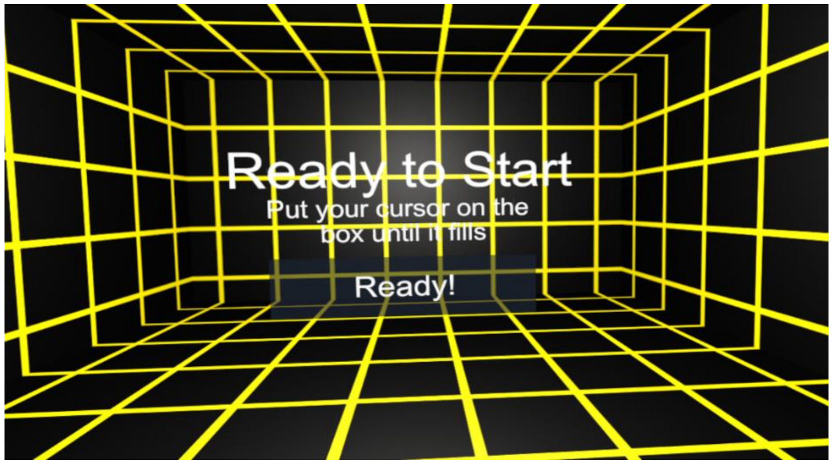
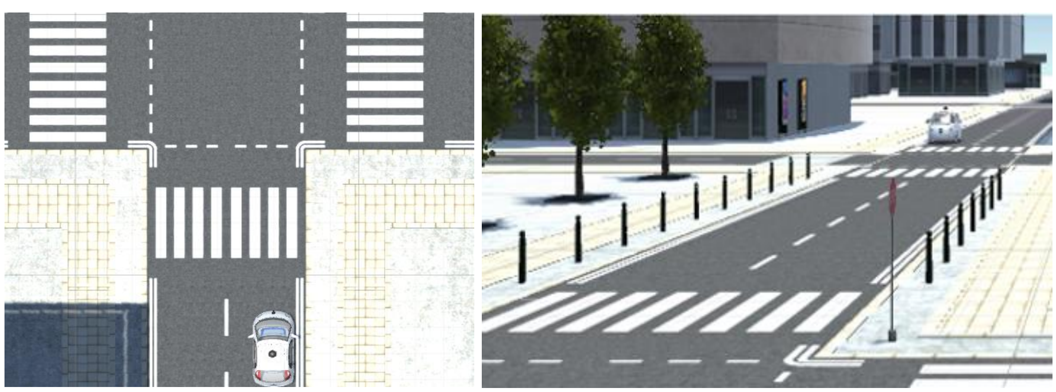


Figure 4.4 Lobby of virtual environment

The third VE, the test environment (shown in Figure 4.5), was an urban downtown scene focused on a four-way intersection of two-lane streets with two-way stop signs on one of the streets and pedestrian crosswalks. The streets were perpendicular to each other. Participants started on a sidewalk facing one of the crosswalks with the intersection to their left. The FAV approached from the farthest lane, perpendicular to the lane with stop signs.



(a) (b)

Figure 4.5 Test environment (a) four-way intersection with the crosswalk (b) crosswalk (bottom of image, nearest stop sign) used in the study

Experimental setup

A randomized complete block design was used to investigate the effect of the design features. The two treatments were visual features (4 levels: a walking sign, braking in text, a flashing smile, control or no signal) and audible features (4 levels: a horn sound, music, a verbal warning, control or no signal) with the participant as the block. There was only one trial condition: a car stops at the intersection. Two replications were collected, each having sixteen trials for sixteen feature combinations (4×4). The dependent variables included ratings for the different features (the questionnaire is attached in Appendix E), crossing time, waiting time before crossing, and walking speed. A single trial condition was programmed for the vehicle to approach from the right side in a lane with no signal or stop sign.

The study also collected participants' demographic variables for gender and age, personal innovativeness and general pedestrian behavior which were evaluated using the short version of the PBQ questionnaire (Deb et al., 2017a), and baseline and after-experience pedestrian receptivity toward FAVs which were assessed using two scenario-based questionnaires (Deb et al., 2017b).

Procedure

Upon arrival, the participants were asked to read and sign the consent form as a confirmation of their agreement to participate. Following this, they filled out a simulation sickness questionnaire (SSQ, attached in Appendix F) as a record of their baseline health status. A score above 5 on the SSQ disqualified them from participation. At this point, the qualified participants also responded to the 2-item scenario-based survey on pedestrian behavioral intention to express their baseline receptivity toward FAVs. The participants then were asked to put on the headset and explore a general familiarization virtual environment. This familiarization step allowed participants to become comfortable with the virtual reality by navigating around the virtual world and interacting with the elements and the instructions used in the actual study. After the familiarization step, they again responded to the SSQ, and based on their score, were selected to perform a practice walk in the test environment. The practice walk included three crossings, without any traffic in the VE.

In the experimental study, each of the participants had sixteen randomly assigned trails (4×4) for each replication. The FAV always came from the right and stopped at the intersection for each of the trials. Participants entered the lobby environment after each trial and pressed the "Ready" button to continue with the next trial. After the first sixteen trials, participants were asked to take a break and again fill out the SSQ to assess their fitness to continue with the study. After completion of the last sixteen trials (second replication), the participants completed the demographic information survey, the PBQ, and the feature-rating survey, and retook the 2-item scenario-based survey for pedestrian receptivity toward FAVs. With the completion of these surveys, the participants were compensated and the experiment was terminated. The flowchart of the procedure is drawn in Figure 4.6.

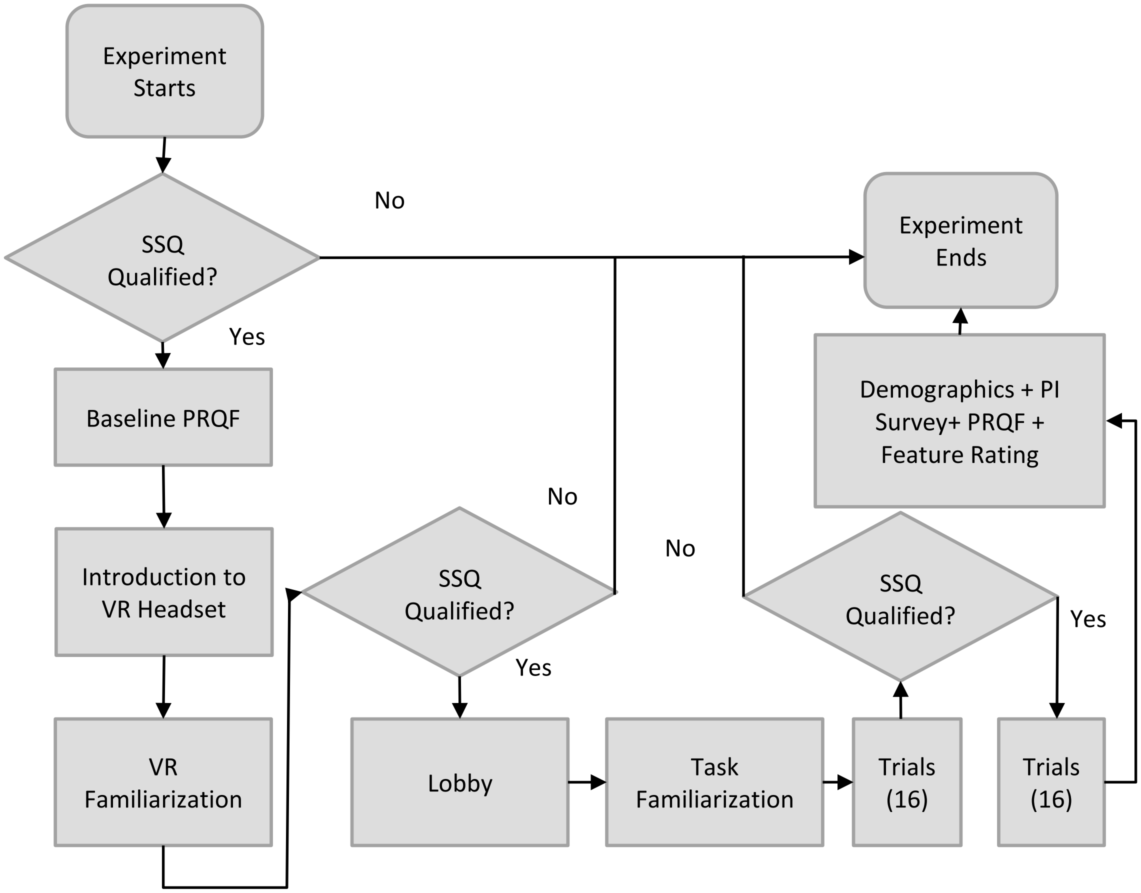


Figure 4.6 An overview of the study procedure

PRQF indicates pedestrian receptivity questionnaire for FAVs

PI indicates personal innovativeness
SSQ indicates simulation sickness questionnaire

Results and discussion

Data was analyzed using SAS version 9.4 for both simulator-collected objective measures (crossing time, wait time before entering crosswalk, and walking speed) and survey responses on feature rating. ANOVA was performed to determine the effect of the features on ratings and objective measures. ANOVA was also performed to explore demographic influence on both objective measures and subjective ratings. Regression analysis was conducted to investigate the influence of the five different types of pedestrian behavior scores on their feature preference. A t-test was used to compare participants' responses on the pedestrian receptivity questionnaire, before and after their exposure to a FAV with external interfaces in the simulated world.

Survey data analyses

To identify a design recommendation for an external interface on FAVs for pedestrian-to-FAV (P2F) interaction, survey responses were collected on pedestrian rating (7-point scale) for each of the sixteen feature combinations.

Effect of external features on FAV receptivity

The ANOVA results (see Table 4.2) showed that two factors, audible and visual features, interact significantly [F (9, 435) = 10.88, p<0.001] to affect the average rating for the features. Multiple comparisons revealed that there was a significant difference between the feature rating the participants gave to the walking silhouette and braking text features than to the other two visual features when they were combined with the beep or no audio features. For the smile as a visual feature, only the inclusion of a verbal message made it significantly preferred compared to its combinations with any other audible feature. Overall, however, a no-signal FAV was the significantly least favored option of all; 1.97 out of 7. The descriptive statistics are presented in Figure 4.7.

Table 4.2 ANOVA for features

Effect	*F* statistics (*df*)	*p* value
Participants	15.48 (29, 435)	<.0001
Audible	36.95 (3, 435)	<.0001
Visual	64.55 (3, 435)	<.0001
Visual*Audible	**10.88 (9, 435)**	**<.0001**

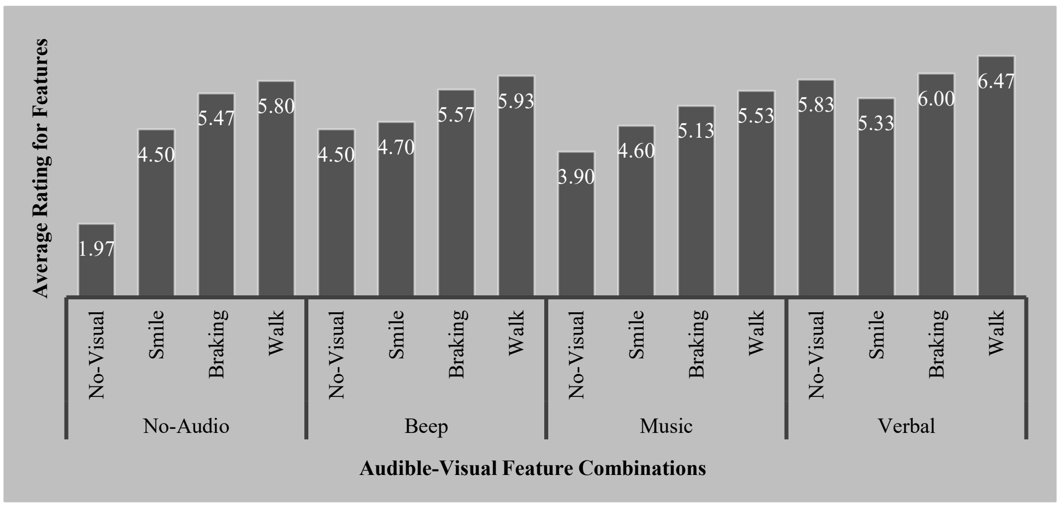


Figure 4.7 Descriptive statistics of the ratings for different feature combinations

This finding enlightens the necessity of external feature on a FAV to ensure convenient P2F interaction and to improve pedestrian receptivity toward FAVs. The ratings also revealed that among the audible signals, the verbal message, “safe to cross” had the higher ratings (>5), even with no visual feature. Because of learning styles, different people register a message better either visually or audibly. However, because of the multitude of things that can distract a pedestrian at an intersection (including texting/phone conversation), an audible message has a better chance of breaking into that distraction. In addition, a verbal message would be useful for pedestrians with visual disabilities or poor visibility. On the other hand, some participants worried about getting confused by the beep and the music with the other sounds that are part of the traffic environment. These participants rated both the "animated pedestrian silhouette (walk)" and the "flashing braking in text" over 5 point. The walking silhouette is a very common feature at pedestrian crossings, and thus provided the pedestrians with something familiar, something they were comfortable with, as a signal of the vehicle's intention to let them cross. The participants also found the flashing text message clear enough to understand the FAV's intention to stop for them. However, the smile proved to be a less effective feature; the participants did not trust it because it did not provide a clear message about the vehicle's intended action.

Improvement in pedestrian receptivity

T-test analyses on the pedestrian receptivity survey responses, run before and after exposure to the FAV with features, found that inclusion of features improved participants' receptivity level toward FAVs. Participants were significantly more comfortable (t = 2.21, df = 29, p<0.0349) interacting with the FAVs and crossing roads in front of them when the FAVs had an external interface installed. Also, the participants felt significantly more positive (t = 4.27, df = 29, p<0.0002) about accepting these vehicles in their area if features were included.

Influence of demographic variables on FAV receptivity

In order to explore the influence of age and gender on which external features were preferred with respect to improved pedestrian receptivity toward FAVs, ANOVA was conducted (see Table 4.3). The results showed an overall significant gender effect [F (1, 448) = 19.26, p<0.0001] on pedestrian receptivity; no significant difference was found for any combination of features. It is interesting to note that the females rated the features with significantly higher ratings than the males. In general, females show lower receptivity toward technology, and this was also found to be true for FAVs and relevant automated technologies (Payre et al., 2014; Canada & Brusca, 1993). However, in this case, the inclusion of the external interfaces may have given the females a perception of safety for themselves and for their friends and families. Summary statistics for different levels of age and gender are presented in Table 4.4.

Table 4.3 Effect of demographics on external feature preference

Effect	*F* Stat. (*df*)	*p* value	Effect	*F* Stat. (*df*)	*p* value
Gender	**19.26 (1, 448)**	**<.0001**	Age	**16.21 (2, 432)**	**<.0001**
Audible*Gender	0.24 (3, 448)	0.8675	Audible*Age	0.78 (6, 432)	0.5849
Visual*Gender	2.05 (3, 448)	0.1064	Visual*Age	**2.78 (6, 432)**	**0.0117**
Audible*Visual*Gender	0.09 (9, 448)	0.9997	Audible*Visual*Age	0.13 (18, 432)	0.9999

Bold results are significant at α=0.05

Table 4.4 Summary statistics for different levels of demographics

Demographics	Levels	Feature Rating [Mean (SD)]
Gender	Male	4.81 (1.86)
	Female	5.43 (1.82)
Age	18-30	4.71 (1.91) A
	31-45	5.42 (1.85) B
	45+	5.64 (1.46) B

Age was found to have a significant influence [F (2, 432) = 16.21, p<0.0001) on pedestrian overall receptivity toward FAVs, as well as a significant interaction effect with visual features [F (6, 432) = 2.78, p<0.0117] between visual features and receptivity toward FAVs. Further analysis with multiple comparisons revealed that the older people found it more necessary to have an external interface as compared to the younger age groups. Nevertheless, young people found the walking silhouette and the braking signs significantly more trustworthy than the smile or no-visual features. Young people are more positive about the long-term impact of technological change on life (Veruggio, Operto, & Bekey, 2016; Smith, 2014). Participants aged 31-45, who often had young children, found the no-visual feature to be the worst condition and the walking silhouette to be the best interface for trusting a FAV. These age group found no difference between the smile or the braking in text features. After the experiment, many of those in this age-group expressed concern about young children getting confused by the latter visual two features; they found the animated silhouette to be a clear and excellent signal indicating a safe walking condition. The third age group population (age 45+ years) indicated that as long as there was a visual feature to notify them about the vehicle’s intention, they would trust them; they would feel more *certain* or *secure* that they would see the message from the FAV if it were flashing or animated. No interaction effect of age was found with audible features.

Influence of pedestrian behaviors on FAV receptivity

Simple linear regression analysis was conducted to find the influence of pedestrians’ general behaviors (based on PBQ subscales; Deb, et al., 2017) on their ratings for features. Five different types of pedestrian behavior were considered as independent variables and feature rating was considered as the dependent variable. The results shown in Table 4.5 reveal that feature rating is significantly associated with three types of pedestrian behaviors: errors, aggression, and positive behaviors. Pedestrians who commit errors often and frequently get angry at drivers rated the features with lower scores. Errors are usually the result of a lack of knowledge about traffic rules, and aggressiveness is an individual characteristic. The inclusion of FAVs, even with the features, would not benefit pedestrians who do not have enough knowledge about the traffic system and always expect to have the right of the way.

Table 4.5 Effect of pedestrian behaviors on external feature preference

Pedestrian Behaviors	Standardized Estimate	t Value	*p* Value
Violation	-0.08547	-1.46	0.1443
Error	-0.15294	-2.54	**0.0112**
Lapse	-0.04661	-0.86	0.3899
Aggression	-0.23754	-5.26	**<.0001**
Positive	0.12390	2.75	**0.0062**

Bold results are significant at α=0.05
df = 29

Simulator data analysis

Simulator data was collected for each of the sixteen feature combinations (4×4), with the sixteen trials considered a single scenario. Two replications were conducted with a short break between the replications, for a total of 32 sets of responses for each participant. Three types of objective measures were analyzed from the simulator study: crossing time, waiting time before entering the crosswalk, and walking speed. The summary of the ANOVAs for each of these variables are displayed in Table 4.6.

Table 4.6 Summary of ANOVA for objective measures

Parameters	Effect	Statistics
Crossing time	Audible	F (3, 885) = 2.70 (p=.0444)
	Visual	F (3, 885) = 1.14 (p=.3329)
	Audible *Visual	**F (9, 885) = 3.36 (p=.0005)**
	Audible	F (3, 885) = 0.27 (p=.8487)
Waiting Time	Visual	F (3, 885) = 2.00 (p=.1125)
	Audible *Visual	F (9, 885) = 1.586 (p=.1162)
Walking Speed	Audible	F (3, 885) = 1.28 (p=.2808)
	Visual	F (3, 885) = 1.41 (p=.2393)
	Audible *Visual	F (9, 885) = 1.33 (p=.2191)

Bold results are significant at α=0.05

Influence of features on objective measures

ANOVA revealed that audible and visual features interacted significantly to affect the crossing time. FAVS with no-features or with no-audio cue but with a smile on the external display provided the least favorite interface options for the participants to cross confidently in front of the vehicle. There was no significant influence on waiting time or walking speed. The descriptive statistics for crossing time are shown in Figure 4.8. Consistent with the survey results for the audible features, verbal messages provided more confidence for crossing the road without hesitation in a shorter time. Contrary to the survey ratings, music produced results similar to verbal messages in the simulator data. On the other hand, without any audible message, a smile confused participants to such an extent that they hesitated to cross the road even longer than when no feature was present. Overall, the walking silhouette and the braking signs elicited the most trust in the FAVs, except when combined with a beep as an audible sound. The beep, which sounds like an alarm, was probably perceived as a warning instead of the notification for safe crossing.

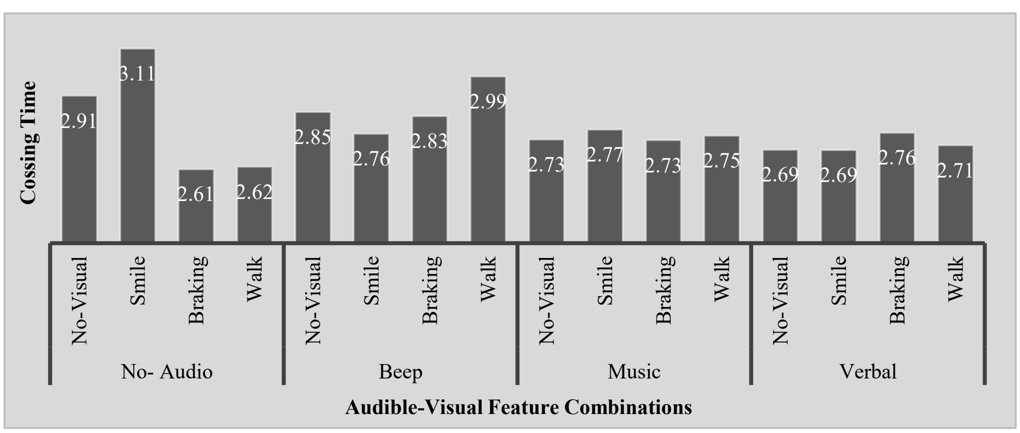


Figure 4.8 Descriptive statistics of the crossing time for the feature combinations

Influence of pedestrian behaviors on the objective measures

Table 4.7 Influence of pedestrian behaviors on simulator collected objective measures

Crossing Time			
Variable	Standardized Estimate	t Value	Pr > |t|
Violation	-0.11088	-2.56	**0.0108**
Error	0.20408	4.57	**<.0001**
Lapse	-0.16860	-4.19	**<.0001**
Aggression	0.15336	4.57	**<.0001**
Positive	0.01656	0.50	0.6205
PI	-0.00988	-0.27	0.7858
Waiting Time			
Violation	0.27671	6.63	**<.0001**
Error	-0.31012	-7.23	**<.0001**
Lapse	-0.02975	-0.77	0.4419
Aggression	-0.16070	-4.98	**<.0001**
Positive	0.20851	-6.49	**<.0001**
PI	0.17125	4.90	**<.0001**

PI indicates personal innovativeness
Bold results indicate significant effect

Regression Analysis, which is presented in Table 4.7, found significant influence of general pedestrian behaviors on intended behavior in front of a FAV. Pedestrians who make errors and get angry frequently took a longer time to cross the road in front of the stopped car and waited less before entering the crosswalk. On the other hand, pedestrians who violate traffic rules intentionally and get distracted on the road, as well as those who behave positively toward other road-users were more cautious in the presence of FAVs. They delayed before starting to cross and then crossed in hurry to avoid being in front of a FAV longer than necessary. Speed was not found to be influenced by any of the behaviors except for -being distracted. Usually, distracted pedestrians take longer to cross roads. However, the presence of FAVs makes them uncomfortable and they do not feel it is safe to walk at a normal pace and gait.

Conclusion

This study was designed to give pedestrians a first-time interaction with a fully autonomous vehicle. The external features were included to investigate which interface designs can increase pedestrians' trust in FAVs at crosswalks and thereby improve receptivity.

The survey responses confirmed that the inclusion of an external interface should be recommended. Overall, the visual features of a walking silhouette or braking in text were the most favored; however, the inclusion of a verbal message also increased the level of comfort for most of the participants. The simulator study also revealed that participants significantly preferred the visual signals at their first experience with FAVs. Interestingly, females were more excited about the inclusion of the features and showed greater receptivity toward the FAVs with interacting interfaces. Older people were comfortable having any type of visual feature on the FAVs, while younger people found the silhouette and text to be best for indicating a safe road crossing.

The inclusion of FAVs in the traffic system will cause a change in pedestrian behaviors. People with violent natures and those who become distracted may get more cautious in front of FAVs. However, people with a lack of knowledge about traffic rules, who show either aggression or positive behaviors in general, may take advantage of the presence of FAVs and slow down the overall traffic system. Manufacturers and transportation researchers should consider these impacts and design the FAVs accordingly.

The experimental study designed a trial that involved a single controlled scenario in which a FAV came from one side of the road and stopped at the intersection. The scenario also did not consider the termination of the interacting feature indicating safe crossing so that participants would know when the vehicle would restart. The addition of more complex traffic situations could cause changes in a pedestrian’s choice of features as well as in their intended behaviors. Future studies should consider a complex traffic system with multiple FAVs and near miss conditions to observe pedestrian perception of some of the highly rated features from this study. Starting and terminating signals at an intersection would be also interesting to investigate in future studies.

CHAPTER V

CONCLUSION OF THE DISSERTATION

In recent years, transportation researchers and vehicle manufacturers have become increasingly enthusiastic about commercializing fully autonomous vehicles (FAVs) and entering them into the market. To ensure the successful implementation of FAVs, acceptance research has been conducted from the drivers' perspective. A need exists to research receptivity from other road-users as well, therefore three studies were designed to explore pedestrian behavior and their receptivity of FAVs in the U.S. transportation system.

The first study identified a gap in pedestrian safety research: the lack of a pedestrian behavior questionnaire. The French version of a pedestrian behavior scale was modified and investigated to ascertain its reliability and validity for the U.S. population. This PBQ can serve as an instrument for pedestrian self-assessment in educational and training contexts and can be useful to all researchers investigating pedestrian safety for all age groups. Future studies may want to consider using the PBQ in future pedestrian safety research considering specific circumstances; for example, to identify a change in pedestrian behavior due to a change in traffic infrastructure or to the inclusion of advanced vehicles on the road.

In the second study, a research gap was identified regarding the upcoming change in the transportation system with the inclusion of FAVs. A pedestrian receptivity questionnaire toward FAVs (PRQF) was developed and validated for the U.S. population. The questionnaire was found to be a useful tool for studying pedestrians' intended behavior in front of a FAV. This PRQF can be a research tool for designing and improving FAVs, giving consideration to road-users outside the vehicles.

The final study was designed to provide manufacturers with research findings which would encourage them to consider installing external interfaces on FAVs so that pedestrian trust and perception of safety regarding FAVs could be improved. A simulator study explored the advantages of placing an external interacting interface on FAVs and recommended features based on participants' age and gender as well as their general pedestrian behavior on the road. Future studies can investigate the feasibility and preference for the recommended features from other road-users' perspectives.

FAVs can enhance traffic safety by reducing human errors. Inauguration of FAVs will cause a huge change in our way of life. Public approval of FAVs will not be possible overnight. Researchers should confirm FAV's successful implementation in the existing traffic system by conducting receptivity studies and identifying road-users' suggestions for improvements.

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APPENDIX A

SELF-REPORTING PEDESTRIAN BEHAVIOR QUESTIONNAIRE

Demographics

We'd like to ask you a few questions about yourself.

1. What is your gender?

   - ☐ Male
   - ☐ Female
   - ☐ Other

2. What is your current age?

3. What is your highest level of education?
   - ☐ Some high school
   - ☐ High school
   - ☐ Some college
   - ☐ College degree
   - ☐ Graduate degree

4. What is your present occupation?

   - ☐ Unemployed
   - ☐ Self-employed
   - ☐ A homemaker
   - ☐ Student
   - ☐ Salaried employee
   - ☐ Managerial-level employee
   - ☐ Retired
   - ☐ Unable to work

8. How often do you walk in a day?

   - ☐ Never
   - ☐ Rarely (0-2 times a day)
   - ☐ Often (2-4 times a day)
   - ☐ Frequently (4+ times a day)

9. What range best describes your daily walking time?

- ☐ 0-15 minutes
- ☐ 15-30 minutes
- ☐ 30-45 minutes
- ☐ 45-60 minutes
- ☐ 60 minutes and above

10. In which US state do you live?

[ ]

11. How would you describe the area where you live?

- ☐ Urban: Places with an overall population density of at least 500 people per square mile.
- ☐ Rural: Places with less than 500 people per square mile.

11. Have you ever been struck by a vehicle while walking as a pedestrian?

- ☐ Yes
- ☐ No

a. If the answer is yes, did you suffer an injury?

- ☐ Yes
- ☐ No

b. If the answer is yes, how severe was your injury?

- ☐ Minor: managed with fast aid help.
- ☐ Moderate: needed to go to Emergency Department (ED) and got released on the same day.
- ☐ Significant: had to get admitted at ED for at least one day.

c. When did the accident happen? Year:

d. Where did the accident happen?

- ☐ In a signalized crosswalk, as you were crossing the street with a "walk sign".
- ☐ In a signalized crosswalk, as you were crossing the street without a "walk sign".
- ☐ In an un-signalized crosswalk.
- ☐ In the street, as you were crossing where there was no crosswalk
- ☐ On the sidewalk; the car drove onto the sidewalk where you were walking.
- ☐ Other. Please describe.

Self-reporting pedestrian behavior questionnaire

"As a pedestrian, how often do you have the following behaviors?" Answers should be given on a 6-point scale:

1=very infrequently or never,
2=infrequently,
3=quite infrequently,
4=quite frequently,
5=frequently,
6=very often or always.

1. I thank a driver who stops to let me cross.
2. I walk outdoors.
3. I take public transportation (buses, metro, tramway, etc.).
4. I walk without being accompanied.
5. I walk for the pleasure of it.
6. I start to cross on a pedestrian crossing and I end up crossing it diagonally to save time.
7. I cross between vehicles stopped on the roadway in traffic jams.
8. I cross the street between parked cars.
9. I watch the traffic light and start crossing as soon as it turns red.
10. I stop walking to let other pedestrians pass by.
11. I cross the street even though the pedestrian light is red.
12. I cross diagonally to save time.
13. I cross outside the pedestrian crossing even if there is one (crosswalk) less than 50 meters away.

14. When I am accompanied by other pedestrians, I walk in single file on narrow sidewalks so as not to bother the pedestrians I meet.
15. I walk in covered areas to avoid traffic (such as shopping centers).
16. I walk on the right-hand side of the sidewalk so as not to bother the pedestrians I meet.
17. I let a car go by, even if I have the right-of-way, if there is no other vehicle behind it.
18. On a two-way street with no median, I cross the first part and wait in the middle of the roadway to cross the second part.
19. On a two-way street with a median, I cross the first part and wait in the middle of the roadway to cross the second part.
20. I walk accompanied by other people.
21. I walk on the roadway to be next to my friends on the sidewalk or to overtake someone who is walking slower than I am.
22. I cross while talking on my cell phone or listening to music on my headphones.
23. I cross even though the light is still green for vehicles.
24. I walk because I have no other choice.
25. I start walking across the street, but I have to run the rest of the way to avoid oncoming vehicles.
26. I walk on the curb.
27. I avoid using pedestrian bridges or underpasses for convenience, even if one is located nearby.
28. I cross even though obstacles (parked vehicles, buildings, trees, trash bins, etc.) obstruct visibility
29. I cross even if vehicles are coming because I think they will stop for me
30. I cross without looking when following other people who are crossing
31. I lose my way because I get lost in my thoughts
32. I realize that I do not remember the route I have just taken
33. I get angry with another road users (pedestrian, driver, cyclist, etc.), and I yell at him
34. I walk in a way that forces other pedestrians to let me through
35. I have run into a pedestrian or an obstacle while walking because I am not paying attention
36. I take passageways forbidden to pedestrians to save time
37. I walk on cycling paths when I could walk on the sidewalk
38. I cross very slowly to annoy a driver
39. I realize that I have crossed several streets and intersections without paying attention to traffic.
40. I get angry with another road users (pedestrian, driver, cyclist, etc.), and I make a hand gesture.

41. I forget to look before crossing because I am thinking about something else.
42. I cross without looking because I am talking with someone.
43. I deliberately walk on the roadway when I could walk on the sidewalk or on the shoulder.
44. I get angry with another road users (pedestrian, driver, cyclist, etc.), and insult him.
45. I forget to look before crossing because I want to join someone on the sidewalk on the other side.
46. I run across the street without looking because I am in a hurry.
47. I have gotten angry with a driver and hit their vehicle.
48. I walk on bicycle lanes when I could walk on the sidewalk.
49. If a car is blocking the crosswalk, I will walk behind the car to cross the street.
50. If a car is blocking the crosswalk, I will walk in front of the car when crossing the street.

Note: Higher score (>4) on violation, error, lapse, and aggressive behavior components express risky pedestrian behavior and higher score (>4) on positive behavior components present safe pedestrian behaviors.

Scenario-based questions

In the following section, five narrative scenarios are presented, each illustrating a different context in which a pedestrian needs to make a decision for crossing the road. Context will vary in terms of factors likely to affect the behavior of the pedestrian: violation, error, lapse, aggressiveness, and positive behavior. Scenarios are written in such a way as to place you, the participant, within the context (i.e., "You're walking to a restaurant from the parking lot. . . "). Following each scenario, you will be asked to answer a question in the specific scenario described.

Scenario 1: You have gone downtown to take care of some important affairs. You have parked your car in a metered on-street parking space for two hours. With only 5 minutes left on the meter, you find yourself en route to the parking spot, approaching a signalized intersection. You reach the intersection and find the current traffic light indicates 'Red Man' (don't walk). All other pedestrians are waiting for the 'Green Man' (walk) signal to cross. You are tired, eager to get home and don't want to pay more for the parking. What choice would you make to cross the road?

1. Wait for the walk signal.
2. Cross during 'Red Man' (don't walk) signal when you see other pedestrians crossing.
3. Hurry across the roadway during a gap in the traffic.
4. Other. Please describe.

Scenario 2: You have just moved to a new city to start a job. The morning of your first day, you leave your house later than you planned. You are hurrying to catch the bus to go to your office. Suddenly you see your bus stopped on the other side of the street from you. It is a busy residential street with cars parked along each side. The quickest route to the bus would be crossing the street between the parked cars. There is a crosswalk 10 meters away at the intersection, behind the bus stop. You are worried that you will miss your bus if you go all way to the crosswalk. What choice would you make to cross the road?

1. Go to the crosswalk and cross the road.
2. Cross the road between the parked cars, watching for traffic both ways.
3. Hurry across the road in front of the stopped bus to keep it from taking off.
4. Other. Please describe.

Scenario 3: You are hurrying to a bus stop from your office to pick up your five-year old child who is returning from school. You are late and the bus has already dropped your child off. You find yourself at a crosswalk across a two-way street from your child. The traffic is not very busy on that street, but you are afraid that your child may try to cross the road to come to you. How would you most likely respond to this situation?

1. Call to your child to stay there and start crossing the road, watching for traffic both ways.
2. Step into the street, realize your mistake, and look both ways before crossing.
3. With your focus on your child, hurry across the street, not checking for traffic in both directions.
4. Other. Please describe.

Scenario 4: You're walking to a restaurant from a city parking lot for a business meeting. You're very anxious because there's an important business issue you need to solve. You did not find parking close to the restaurant and on your way to your destination you have to cross a signalized intersection. You step into the crosswalk when the traffic light indicates "walk". Suddenly a car crosses in front of you, wanting to turn right. This scares you and makes you angry. What would be your response toward the driver?

1. Do nothing.
2. Yell or make a hand gesture toward the driver.
3. Hit the car as it drives by or throw something at it.
4. Other. Please describe.

Scenario 5: You need to catch a bus and find yourself across the street from where the bus has now briefly stopped. The crosswalk in front of you is crowded with pedestrians walking both ways. If you miss this bus, you will have to wait another 15 minutes to catch the next one, which you do not want to do. Suddenly you find a young child walking with his mother in front of you on the crosswalk, slowing down your progress. What choice would you make to cross the road?

1. Slow down and let the child and mother proceed safely.
2. I would try to go around them politely, or ask them to let me by.
3. Push your way around them.
4. Other. Please describe.

Note: The responses indicate
1-Conservayive behavior
2-Moderately negative behavior
3-Significantly negative behavior

APPENDIX B

LONG VERSION OF THE PBQ

50-item PBQ

P1	I thank a driver who stops to let me cross. (**reverse-scaled**)
E2	I cross between vehicles stopped on the roadway in traffic jams.
E3	I cross the street between parked cars.
E4	I watch the traffic light and start crossing as soon as it turns red.
V1	I cross the street even though the pedestrian light is red.
V2	I cross diagonally to save time.
V3	I cross outside the pedestrian crossing even if there is one (crosswalk) less than 50 meters away.
P3	When I am accompanied by other pedestrians, I walk in single file on narrow sidewalks so as not to bother the pedestrians I meet. (**reverse-scaled**)
P4	I walk on the right-hand side of the sidewalk so as not to bother the pedestrians I meet. (**reverse-scaled**)
P5	I let a car go by, even if I have the right-of-way, if there is no other vehicle behind it. (**reverse-scaled**)
V4	On a two-way street with no median, I cross the first part and wait in the middle of the roadway to cross the second part.
V5	I cross while talking on my cell phone or listening to music on my headphones.
V6	I cross even though the light is still green for vehicles.
V7	I start walking across the street, but I have to run the rest of the way to avoid oncoming vehicles.
V8	I walk on the curb.
V9	I avoid using pedestrian bridges or underpasses for convenience, even if one is located nearby.
E6	I cross even though obstacles (parked vehicles, buildings, trees, trash bins, etc.) obstruct visibility.
E7	I cross even if vehicles are coming because I think they will stop for me.
L1	I cross without looking when following other people who are crossing.
L2	I lose my way because I get lost in my thoughts.
L3	I realize that I do not remember the route I have just taken.
A1	I get angry with another road user (pedestrian, driver, cyclist, etc.), and I yell at him.
A2	I walk in a way that forces other pedestrians to let me through.
L4	I have run into a pedestrian or an obstacle while walking because I am not paying attention.
V10	I take passageways forbidden to pedestrians to save time.
E8	I walk on cycling paths when I could walk on the sidewalk.
A3	I cross very slowly to annoy a driver.
L5	I realize that I have crossed several streets and intersections without paying attention to traffic.

A4	I get angry with another road user (pedestrian, driver, cyclist, etc.), and I make a hand gesture.
L6	I forget to look before crossing because I am thinking about something else.
L7	I cross without looking because I am talking with someone.
A5	I get angry with another road user (pedestrian, driver, cyclist, etc.), and insult him.
L8	I forget to look before crossing because I want to join someone on the sidewalk on the other side.
E9	I run across the street without looking because I am in a hurry.
A6	I have gotten angry with a driver and hit their vehicle.
E10	I walk on bicycle lanes when I could walk on the sidewalk.

Note: V indicates Violations, E indicates Errors, L indicates Lapses, A indicates Aggressive Behaviors, and P indicates Positive Behaviors

APPENDIX C

SHORT VERSION OF THE PBQ

20-item PBQ

Violations

V1 I cross the street even though the pedestrian light is red.
V2 I cross diagonally to save time.
V3 I cross outside the pedestrian crossing even if there is one (crosswalk) less than 50 meters away.
V10 I take passageways forbidden to pedestrians to save time.

Errors

E2 I cross between vehicles stopped on the roadway in traffic jams.
E7 I cross even if vehicles are coming because I think they will stop for me.
E8 I walk on cycling paths when I could walk on the sidewalk.
E9 I run across the street without looking because I am in a hurry.

Lapses

L5 I realize that I have crossed several streets and intersections without paying attention to traffic.
L6 I forget to look before crossing because I am thinking about something else.
L7 I cross without looking because I am talking with someone.
L8 I forget to look before crossing because I want to join someone on the sidewalk on the other side.

Aggressive behaviors

A1 I get angry with another road user (pedestrian, driver, cyclist, etc.), and I yell at him.
A3 I cross very slowly to annoy a driver.
A4 I get angry with another road user (pedestrian, driver, cyclist, etc.), and I make a hand gesture.
A6 I have gotten angry with a driver and hit their vehicle.

Positive behaviors (Reverse-scaled items)

P1 I thank a driver who stops to let me cross.
P3 When I am accompanied by other pedestrians, I walk in single file on narrow sidewalks so as not to
bother the pedestrians I meet.
P4 I walk on the right-hand side of the sidewalk so as not to bother the pedestrians I meet.
P5 I let a car go by, even if I have the right-of-way, if there is no other vehicle behind it.

APPENDIX D

PEDESTRIAN RECEPTIVITY QUESTIONNAIRE FOR FAVS

Demographic questionnaire

1. What is your age? ____________

2. What is your gender?

[ ] Male [ ] Female

3. What is your level of education?

[ ] Some high school
[ ] Associates/Bachelor's Degree
[ ] High school graduate
[ ] Graduate Degree
[ ] Some college
[ ] Other: __________

4. How often do you walk in a day?

[ ] Never
[ ] Rarely (0-2 times a day)
[ ] Often (2-4 times a day)
[ ] Frequently (4+ times a day)

5. What range best describes your daily walking time?

[ ] 0-15 minutes
[ ] 15-30 minutes
[ ] 30-45 minutes
[ ] 45-60 minutes
[ ] 60 minutes and above

6. In which US state do you live?

____

7. How would you describe the area where you live?

[ ] Urban: Places with an overall population density of at least 500 people per square mile

[ ] Rural: Places with less than 500 people per square mile.

Pedestrian receptivity questionnaire

A fully autonomous vehicle (FAV) is driven by technology instead of by a human. A FAV is equipped with radars, cameras, and sensors which can detect the presence, position, and speed of other vehicles or road-users. With this information, the FAV can then respond as needed by stopping, decelerating and/or changing direction. A driverless vehicle has the potential to reduce pedestrian-motor vehicle crashes and to decrease the possibility of severe injuries by controlling the driving task effectively.

You have recently learned that there will be fully autonomous vehicles on the road in your area. As you consider this, how much would you agree or disagree with the following statements. All items will be measured on the following 7-point Likert scale:

1 = strongly disagree
2 = moderately disagree
3 = somewhat disagree
4 = neutral (neither disagree nor agree)
5 = somewhat agree
6 = moderately agree
7 = strongly agree

---

1. (A) FAVs will enhance the overall transportation system.
2. (A) FAVs will make the roads safer.
3. (A) I would feel safe to cross roads in front of FAVs.
4. (A) It would take less effort from me to observe the surroundings and cross roads if there are FAVs involved.
5. (A) I would find it pleasant to cross the road in front of FAVS.
6. (S) People who influence my behavior would think that I should cross roads in front of FAVs.
7. (S) People who are important to me would not think that I should cross roads in front of FAVs. **[reverse-scaled]**
8. (S) People who are important to me and/or influence my behavior trusts FAVs (or has a positive attitude towards FAVs).
9. (E) Interacting with the system would not require a lot of mental effort.
10. (E) FAV can correctly detect pedestrians on streets
11. (T) I would feel comfortable if my child, spouse, parents – or other loved ones – cross roads in the presence of FAVs.
12. (T) I would recommend my family and friends to be comfortable while crossing roads in front of FAVs.
13. (T) I would feel more comfortable doing other things (e.g., checking emails on my smartphone, talking to my companions) while crossing the road in front of FAVs

---

14. (C) The traffic infrastructure supports the launch of FAVs.
15. (C) FAV is compatible with all aspects of transportation system in my area.
16. (E, C) FAVs will be able to effectively interact with other vehicles and pedestrians.

Note: A-Attitude, S-Subjective norm, E-Effectiveness, T-Trust, C-Compatibility
Higher scores indicate higher receptivity toward FAVs

Personal Innovativeness – adapted from Agarwal and Prasad (1998) and Chen and Chen (2011)

17. If I heard about a new technology, I would look for ways to experiment with it.
18. Among my peers, I am usually the first to try out new technologies.
19. In general, I am hesitant to try out new technologies. [**reverse-scaled**]
20. I like to experiment with new technologies.

Note: Higher scores indicate higher innovativeness toward new technologies

Scenario-based question

You are walking home from shopping. On your way, you need to cross multiple crosswalks, both signalized and un-signalized. As you prepare to cross at an un-signalized crosswalk, you find that a driverless vehicle is approaching the crosswalk (with no one sitting in the driver seat). Based on the scenario, please select the choice that best reflects your behavior for each question.

A.	What will your response at the crosswalk be, with the FAV approaching?
1.	I will not cross the road at the crosswalk to avoid crossing in front of the FAV.
2.	I will run across the road even though the driverless vehicle has stopped for me.
3.	I will make sure that the driverless vehicle stops before I start crossing.
4.	I will wait to see if the vehicle decelerates before I start crossing.
5.	I will cross the road with full confidence that the driverless vehicle will stop for me.
B.	As a pedestrian, how will you accept the presence of driverless vehicles in your area?
1.	I will be angry to see driverless vehicles in my area; I think they will cause more problems.
2.	I will feel anxious about the presence of driverless vehicles in my area; I don’t trust them.
3.	I will be indifferent to the presence of driverless vehicles in my area; it doesn’t matter to me.
4.	I will have no problem with driverless vehicles in my area; I trust the technology.
5.	I will feel excited to see driverless vehicles in my area; I believe they will make my area safer.

APPENDIX E

RATING SCALE FOR EXTERNAL FEATURES OF A FAV

Feature rating scale

Based on your experience, how safe would you feel entering the crosswalk with the addition of following features to a fully autonomous vehicle?

---

1. Walking sign

1	2	3	4	5	6	7
Not Safe at all						Very Safe

2. 'Braking' written in text

1	2	3	4	5	6	7
Not Safe at all						Very Safe

3. Smiley face

1	2	3	4	5	6	7
Not Safe at all						Very Safe

4. Horn sound

1	2	3	4	5	6	7
Not Safe at all						Very Safe

5. Music

1	2	3	4	5	6	7
Not Safe at all						Very Safe

6. Verbal message

1	2	3	4	5	6	7
Not Safe at all						Very Safe

7. Walking sign and horn sound

1	2	3	4	5	6	7
Not Safe at all						Very Safe

8. Walking sign and music

1	2	3	4	5	6	7
Not Safe at all						Very Safe

9. Walking sign and verbal message

1	2	3	4	5	6	7
Not Safe at all						Very Safe

10. Braking in text and horn sound

1	2	3	4	5	6	7
Not Safe at all						Very Safe

11. Braking in text and music

1	2	3	4	5	6	7
Not Safe at all						Very Safe

12. Braking in text and verbal message

1	2	3	4	5	6	7
Not Safe at all						Very Safe

13. Smiley face and horn sound

1	2	3	4	5	6	7
Not Safe at all						Very Safe

14. Smiley face and music

1	2	3	4	5	6	7
Not Safe at all						Very Safe

15. Smiley face and verbal message

1	2	3	4	5	6	7
Not Safe at all						Very Safe

16. No feature

1	2	3	4	5	6	7
Not Safe at all						Very Safe

Note: Higher score for a feature or feature combination indicates greater preference for that feature option

APPENDIX F

SIMULATION SICKNESS QUESTIONNAIRE

Simulation sickness questionnaire

Please circle the appropriate items below according to your CURRENT feelings with respect to the symptoms listed.

1.	General Discomfort	Severe	None	Slight	Moderate
2.	Fatigue	Sever	None	Slight	Moderate
3.	Headache	Severe	None	Slight	Moderate
4.	Eyestrain	Severe	None	Slight	Moderate
5.	Difficulty Focusing	Severe	None	Slight	Moderate
6.	Salivation Increase	Severe	None	Slight	Moderate
7.	Sweating	Severe	None	Slight	Moderate
8.	Nausea	Severe	None	Slight	Moderate
9.	Difficulty Concentrating	Severe	None	Slight	Moderate
10.	"Fullness of the Head"	Severe	None	Slight	Moderate
11.	Blurred Vision	Severe	None	Slight	Moderate
12.	Dizziness with eyes open	Severe	None	Slight	Moderate
13.	Dizziness with eyes closed	Severe	None	Slight	Moderate
14.	Vertigo	Severe	None	Slight	Moderate
15.	Stomach Awareness	Severe	None	Slight	Moderate
16.	Burping	Severe	None	Slight	Moderate

Note: None= 0, Slight=1, Moderate=2, Severe=3
Participants indicating simulator sickness based on SSQ score (a difference > 5 in score from the baseline condition) will be withdrawn from the participation.
Source: (Kennedy, Lane, Berbaum, & Lilienthal (1993)