Pedestrians’ Perceptions of and Behavioral Responses to Driverless Cars

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June 2023

A publication of the USDOT Tier 1 Center:
Cooperative Mobility for Competitive Megaregions
At The University of Texas at Austin

Technical Report Documentation Page

<table>
<tr><td>1. Report No. CM2-#71</td><td>2. Government Accession No.</td><td colspan="2">3. Recipient's Catalog No.
ORCID:
Erick Guerra: 0000-0002-7769-2581
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<tr><td colspan="2" rowspan="2">4. Title and Subtitle
Pedestrians' Perceptions of and Behavioral Responses to Driverless Cars</td><td colspan="2">5. Report Date: June 2023</td></tr>
<tr><td colspan="2">6. Performing Organization Code</td></tr>
<tr><td colspan="2">7. Author(s)
PI: Erick Guerra
Co-PI's: Xiaoxia Dong, Ricardo A. Daziano</td><td colspan="2">8. Performing Organization Report No.
CM2-#71</td></tr>
<tr><td colspan="2" rowspan="2">9. Performing Organization Name and Address
The University of Pennsylvania
Weitzman School of Design
210 S. 34th St.
Philadelphia, PA 19104</td><td colspan="2">10. Work Unit No. (TRAIS)</td></tr>
<tr><td colspan="2">11. Contract or Grant No.
USDOT 69A3551747135</td></tr>
<tr><td colspan="2" rowspan="2">12. Sponsoring Agency Name and Address
U.S. Department of Transportation
Federal Transit Administration
Office of the Assistant Secretary for Research and Technology, UTC Program
1200 New Jersey Avenue, SE
Washington, DC 20590</td><td colspan="2">13. Type of Report and Period Covered
Technical Report conducted August 2022 - June 2023</td></tr>
<tr><td colspan="2">14. Sponsoring Agency Code</td></tr>
<tr><td colspan="4">15. Supplementary Notes
Project performed under a grant from the U.S. Department of Transportation's University Transportation Center's Program.</td></tr>
<tr><td colspan="4">16. Abstract
When interacting with driverless cars, pedestrians might be emboldened to jaywalk knowing the vehicles will slow down for them automatically. Expecting cars to slow down for them automatically, some pedestrians might become more emboldened to jaywalk. Excess jaywalking disrupts traffic flow and poses challenges for traffic law enforcement. Few studies have examined pedestrians' attitudes toward driverless cars' safety implication, management strategies for the interactions between pedestrians and driverless cars, and how pedestrians would expect their street crossing behavior to change in the presence of driverless cars. Our findings remind cities that proven street design strategies could help to ensure safer interactions between pedestrians and driverless cars and greater acceptance of driverless cars operating on urban streets.</td></tr>
<tr><td colspan="2">17. Key Words
Crossing behavior, driverless car, jaywalking, pedestrian safety, stated preference survey, street design</td><td colspan="2">18. Distribution Statement
No restrictions.</td></tr>
<tr><td>19. Security Classif. (of report)
Unclassified</td><td>20. Security Classif. (of this page)
Unclassified</td><td>21. No. of pages
30 pages</td><td>22. Free</td></tr>
</table>

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

Acknowledgements

Ms. Nata Kovalova created the section drawings in the choice experiments.

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Chapter 1. Introduction

Planners and city officials have promoted walking as a healthy and sustainable mode of transportation. Over the past two decades, many cities have proposed and implemented multi-pronged approaches to encourage walking. Some of the notable efforts include land use strategies such as transit-oriented development, transportation infrastructure upgrades such as widening sidewalks and improving first/last mile transit connections for pedestrians, and educational campaigns such as safe routes to school. Meanwhile, the COVID-19 pandemic has foregrounded pedestrian safety. In large cities, traffic crashes that involved pedestrians spiked in 2020, despite fewer cars and pedestrians on the road. The City of Philadelphia, for example, recorded its highest pedestrian fatality rate in more than a decade. Traffic crashes that involve pedestrians have remained high even post-pandemic.

The crash avoidance function in driverless cars enables vehicles to detect and slow down for pedestrians to avoid collisions. By mitigating human errors caused by unalerted drivers, driverless cars have the potential to reduce pedestrian crashes and make streets safer for the most vulnerable road users. The crash avoidance capability of driverless cars could be beneficial not only in dense urban cores such as downtowns where pedestrian-involved crashes are common due to the numerous interactions between vehicles and pedestrians, but also on urban and suburban commercial arterials where pedestrian fatality rates are high due to high vehicle speeds. For pedestrians, the peace of mind provided by crash avoidance could make them less risk averse when interacting with vehicles. Expecting driverless cars to stop for them automatically, some pedestrians might become less concerned about jaywalking, much like people having no qualms about sticking their arms in closing elevator doors. Excess jaywalking could disrupt traffic flow, create friction between pedestrians and vehicle operators, and pose challenges for the enforcement of traffic laws.

In this study, we answer three related research questions. First, what are the general perceptions toward the safety implications of driverless cars on pedestrians? Second, what are pedestrians' attitudes toward strategies that manage the interactions between pedestrians and driverless cars?

Third, how do pedestrians expect their crossing behavior to change in the presence of driverless cars under different traffic volumes and road configurations?

To answer the research questions, we conducted an online survey study of 1,000 residents in the Philadelphia and Seattle metropolitan areas. We chose regions with reputations for high (Philadelphia) and low (Seattle) rates of jaywalking. Through descriptive data analysis and multilevel binomial logit analysis, we find that overall pedestrians feel less safe with driverless cars on the road. Pedestrians are more receptive of limiting the speeds of driverless cars or disabling driverless functions altogether in dense urban cores with heavy pedestrian traffic and less receptive of increasing enforcement for jaywalking laws. We also find that pedestrians might be less concerned about jaywalking in light traffic and good visibility when driverless cars become prevalent. Additionally, bigger, faster roads are significant deterrents to jaywalking in the presence of driverless cars.

Our findings remind cities that even though pedestrians might become less concerned about jaywalking in the presence of driverless cars, their crossing behavior will likely be affected by roadway configurations, traffic volumes, and their confidence in driverless technology. To prevent excess jaywalking, cities should consider installing more mid-block crossings to provide more, safer crossing opportunities for pedestrians. Furthermore, driverless cars' ability to follow other vehicles more closely, obey the speed limits, and react to emergencies quickly provides opportunities for cities to design and construct smaller, slower streets that are more pedestrian-friendly.

Chapter 2. Survey Design

2.1. Study Areas

The study area for the survey is the Philadelphia Metropolitan Statistical Area (MSA) and Seattle Metropolitan Statistical Area. The Philadelphia and the Seattle MSAs are homes to approximately 6 million and 4 million residents, respectively. Philadelphia and Seattle, the principal cities of their respective MSAs, have different street layouts. Downtown Philadelphia, for example, is characterized by its regular grid, short blocks, and narrow one-way streets. Downtown Seattle has a less coherent grid system with wider, often two-way streets intersecting at odd angles. According to the U.S. Census, both MSAs have similar walk commute mode share at just below 3% (U. S. Census Bureau, n.d.).

In addition to the different layouts of their street grids, Philadelphia and Seattle have vastly different jaywalking culture. Reports in the popular media claim that Seattleites generally avoid jaywalking more than residents in other cities do (D. Wang & Gyimah-Brempong, 2019; Wing, 2011). Meanwhile, pedestrians in Philadelphia are known to be less compliant with traffic rules (Cheng, 2015; Nussbaum, 2014).

Philadelphia and Seattle also have different pedestrian safety records. Seattle is often considered one of the safest big cities (Seattle Department of Transportation, 2018b). In 2020, Seattle had a pedestrian fatality rate of 1.56 per 100,000 residents (National Highway Traffic Safety Administration, 2022; Seattle Department of Transportation, 2018a). By contrast, Philadelphia had 3.04 pedestrian fatalities per 100,000 residents (National Highway Traffic Safety Administration, 2022). Pedestrian fatalities, however, make up a larger share of all traffic fatalities in Seattle (46.2%) than in Philadelphia (28.9%) (National Highway Traffic Safety Administration, 2022).

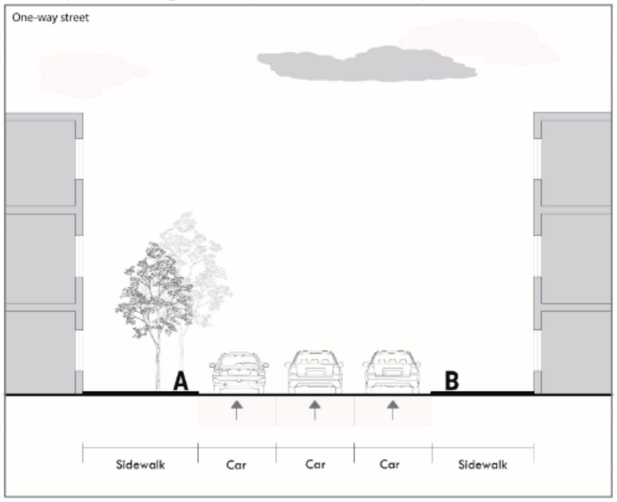
Having both the Philadelphia MSA and the Seattle MSA in the survey sample ensures that the study captures a wide range of built environment, pedestrian behavior, and more generally walking culture.

2.2. Survey Design and Distribution

To investigate pedestrians' attitudes toward driverless cars and the trade-off between jaywalking at mid-block and walking to the nearest intersection, we conducted three separate online surveys among a total of 1,003 respondents in the Philadelphia MSA and the Seattle MSA between March 29 and April 21, 2023. All three surveys include stated preference questions in the form of choice experiments, as well as questions on respondents' demographics, socioeconomics, walking behavior, and attitudes toward driverless cars. The main difference across the three surveys is that in the choice experiments presented to respondents, each survey depicts a unique driverless car saturation scenario. The three saturation scenarios presented to the respondents are no driverless cars, half of the cars are driverless, and all the cars are driverless. Respondents were randomly assigned to only one of the three scenarios.

In the choice experiments, the surveys ask each respondent to play a series of 12 choice games under the scenario to which the respondent was assigned. Figure 1 provides an example of a choice game presented to the respondents. Each choice game presents attributes that describe the roadway configuration, traffic volume, visibility, walking time to the nearest signalized intersection, and speed limit. Based on these attributes, respondents chose between crossing at the current location at mid-block with no pedestrian crossing, traffic signal, or stop sign (i.e., jaywalking) and walking to the nearest signalized intersection with traffic signals and pedestrian crosswalks to cross. In all three surveys, the 12 choice games presented to each respondent were randomly selected from a pool of 60 choice games. Attributes and attribute levels in the choice games were decided by the authors based on factors that are commonly associated with pedestrian crossing behavior (Kwon et al., 2022; Luu et al., 2022). We provide in-depth discussion of the attributes included in the choice games in the Variables and Model Framework section. For each choice game, the combination of attribute levels was generated a D-efficient design through the Ngene choice experiment design software.

Choose whether you would cross from A to B at your current location at mid-block (no pedestrian crosswalk, traffic signal, or stop sign) or walk to the nearest intersection (with traffic signals and pedestrian crosswalks) to cross. **Half of the cars on the road are driverless**.



Road configuration and conditions	Levels
Street direction	One-way
Car travel speed	40 mph
Number of car lanes in each direction	3
Walk time to nearest signalized intersection	2.5 minutes
Time of day and road visibility	Night, poor visibility
Traffic intensity	Heavy traffic

○ Cross at current mid-block location

○ Walk to nearest intersection

Figure 2.1 A choice game presented to the respondents in the half-driverless-car scenario

In the half-driverless-car and all-driverless-car surveys, we present the following description of driverless cars before the choice experiments to familiarize respondents with the concept of driverless cars and their crash avoidance feature.

> *Driverless cars are vehicles that operate without a human driver and are driven entirely by sensors and computer systems. Driverless cars' crash avoidance technology allows the vehicles to stop for pedestrians automatically to avoid collisions. In the future, experts predict that an increasing number of cars on the road will be driverless. By appearances alone, one may not tell driverless cars and conventional cars apart.*

The other questions are identical across all three surveys. These questions solicit the respondents' demographics such as age and gender; socioeconomics, such as income and driver status; walking behavior, such as frequencies of walking and jaywalking; familiarity with driverless cars;

perceptions of driverless cars' potential impact on pedestrian safety; and preferences of management strategies for the interactions between pedestrians and driverless cars. In all three surveys, before the questions on respondents' familiarity of and attitudes toward driverless cars, we provide a description of driverless cars, same as the text given in the all- and half-driverless-car scenarios. All survey questions were presented to the respondents as multiple choices.

The survey company Qualtrics recruited the respondents and distributed the online surveys. Qualtrics builds survey samples from multiple sources, with each sample from the panel base being proportioned to the general population (Qualtrics, 2014). The survey study did not collect personal identifiers and was approved by the University of Pennsylvania's institutional review board under the category exempt. Respondents must be over 18 years old and live in either the Philadelphia MSA or the Seattle MSA to participate in the survey study.

2.3. Survey Respondent Characteristics

Table 2.1 shows the demographic breakdown of the sample by MSA for each of the three surveys. In general, the gender, age, and income of the sample, as well as the overall sample size, are proportional to those of the population of the MSAs. The surveys under-sample residents with high school degrees or less in both MSAs, oversample residents with some college education in the Philadelphia MSA, and oversample residents with bachelor's degrees or higher in the Seattle MSA. The surveys also oversample residents with one vehicle and under-sample residents with 2 or more vehicles.

Table 2.1 Comparison of socioeconomic characteristics between survey respondents and the populations in the study areas (in percent)

	Philadelphia MSA (n = 576)				**Seattle MSA (n = 427)**			
	No (n = 193)	*Half (n = 193)*	*All (n = 190)*	*Census*	*No (n = 142)*	*Half (n = 142)*	*All (n = 143)*	*Census*
Age								
18 to 44	48.2	48.7	46.8	46	58.5	57	51	51
45 to 59	24.4	23.8	26.3	24	18.3	23.2	26.6	24
60 to 74	22.8	21.8	24.2	22	19	17.6	17.5	19
75 and over	4.7	5.7	2.6	9	4.2	2.1	4.9	7
Gender								
Male	48.2	48.2	48.4	48	48.6	51.4	46.9	50
Female	49.7	49.2	50	52	50.7	47.9	52.4	50

Other	2.1	2.6	1.6	NA	0.7	0.7	0.7	NA
Race								
White	66.3	69.9	69.5	60.5	76.1	79.6	82.5	60.1
Black or African American	20.2	21.8	16.3	19.8	7.7	4.9	3.5	6.2
Asian or Pacific Islander	6.2	3.1	6.8	6.4	10.6	7	11.2	16.3
Other	7.3	5.2	7.4	13.3	5.6	8.5	2.8	17.5
Income								
Less than $30,000	20.2	20.2	21.1	20	11.3	11.3	11.2	13
$30,000-60,000	19.2	19.2	19.5	19	14.1	14.1	14	16
$60,000-100,000	21.2	21.2	21.6	21	26.1	26.1	25.9	20
$100,000 or more	34.7	34.2	36.3	40	45.8	43.7	47.6	51
Prefer not to answer	4.7	5.2	1.6	NA	2.8	4.9	1.4	NA
Education								
High school or less (including prefer not to answer)	25.9	30.6	25.3	35.5	15.5	19	16.8	26.8
Some college (including associate degree)	31.6	32.6	35.8	25.2	31.7	31	30.8	29.2
Bachelor's degree or higher	42.5	36.8	38.9	39.3	52.8	50	52.4	44
Vehicle ownership								
0	12.4	5.7	10.5	5.9	7	7	4.9	4.2
1	39.4	44.6	38.9	23.5	43.7	36.6	41.3	23.1
2 or more	48.2	49.7	50.5	70.7	49.3	56.3	53.8	72.7

2.4. Survey Limitations

Stated preference surveys collect data about respondents' intentions in hypothetical settings when real-life controlled experiments are infeasible, such as when soliciting responses about a new transport mode (Ortúzar & Willumsen, 2011). Since stated preference surveys are based on respondents' statements of how they would respond to different hypothetical alternatives, a general limitation is "how much faith we can put on individuals actually doing what they stated they would do when the case arises" (Ortúzar & Willumsen, 2011). In addition to this general shortcoming, the current survey study has two specific limitations. First, the choice experiments ask respondents to assume a routine trip at a generic location. In reality, pedestrians' choice between jaywalking and crossing the street legally might be affected by trip purpose and familiarity with the location. Specifying trip purpose might limit the generalizability of the study while choosing only locations that are known to respondents is not feasible as the survey study is currently constructed. Second, while the age, gender, and income of the survey sample are generally proportional to those of the population in the study areas, the sample might not be representative of the population due to the online nature of the survey. Omissions of certain segments of the population from the sample might lead to biased results.

Chapter 3. Variables and Model Framework

To model pedestrians' crossing behavior, we estimate a multilevel binomial logit model for each survey scenario. The dependent variable in the models is whether a respondent chose to jaywalk at current mid-block location or walk to the nearest signalized intersection to cross the street. The independent variables capture respondents' demographics and walking behavior, as well as roadway configuration and traffic conditions.

3.1. Variables

Table 3.1 shows the attribute levels of the variables presented to the respondents in the choice games. Roadway configuration includes whether a street is one way or two way and the number of vehicular lanes in each direction. Traffic conditions capture the speed limit and traffic volumes. To mimic the typical urban environment, we set the maximum number of vehicular lanes in each direction to three and the maximum speed limit to 40 miles per hour in all choice games. Visibility likely affects pedestrians' decision between jaywalking and crossing at a signalized intersection and is therefore included in the models as well (Kwon et al., 2022).

Table 4.1 Attribute levels in the choice experiments

Attributes	Attribute levels
Street direction	One-way/Two-way
Car travel speed	20/25/30/35/40 mph
Number of car lanes (in each direction)	1/2/3
Walking time to nearest signalized intersection	0.5/1/1.5/2/2.5 minutes
Road visibility/lighting condition	Night, poor visibility/dusk, medium visibility/mid-day, high visibility
Traffic volume	Light/moderate/heavy

The models include respondents' age and gender, which have been found to correlate with pedestrians' street crossing behavior (Anik et al., 2021; Chai et al., 2016; Holland & Hill, 2007; T. Wang et al., 2010; Xie et al., 2017). Scholars have also found that the acceptance of driverless cars and crossing behavior in the presence of driverless cars are related to age and gender (Clamann et al., 2017; Dong et al., 2017; Hulse et al., 2018; S. Wang et al., 2022). Including age and gender captures their potential effects on the trade-off between jaywalking and crossing at signalized intersection.

In terms of walking behavior, we include frequency of jaywalking to capture the potential difference in risk-tolerance between frequent and less frequent jaywalkers. Walking time is often considered a burden or disutility in transportation research. For some pedestrians, the inconvenience of walking to the nearest intersection might outweigh its safety benefits. We calculate walking time to the nearest signalized intersection based on the lengths of typical city blocks in Philadelphia and Seattle and the average walking speed for pedestrians (Tumlin, 2011). To capture the potential non-linear relationship between walking time and respondents' crossing preferences, we reclassify walking time into three categories, under one minute (0.5 or 1 minute), one to two minutes (1.5 or 2 minutes), and 2.5 minutes.

3.2. Model framework

Given the binary nature of the choice games, we use the multilevel binomial logit model with random intercepts to estimate the associations between respondents' crossing choices and their demographic characteristics, roadway configurations, and traffic conditions. The multilevel model framework is suitable for the current analysis for two reasons. First, each respondent was asked to play 12 choice games in the choice experiment. The multilevel model accounts for the unobserved variations for each individual across the repeated choices. Second, each respondent belongs to either the Philadelphia MSA or the Seattle MSA, giving the data a hierarchical structure. Respondents living in the same MSA might share certain unobserved characteristics that could be related to their choices. The multilevel model estimates the correlations that vary by MSA and thus allows us to capture the unobserved variations across respondents in the same MSA. We direct the interested reader to Gelman & Hill (2006) for an in-depth discussion of multilevel binomial logit model with random intercepts (Gelman & Hill, 2006).

Equation 1 below shows the basic structure of the multilevel binomial logit model with random intercepts.

$$\Pr(y_i = 1) = \text{logit}^{-1}(\alpha_{j[i]} + \gamma_{k[i]} + \mathbf{X}\boldsymbol{\beta} + \epsilon_i) \quad (1)$$

In the equation, the subindex i represents one of the 12 choice games presented to each respondent j. The subindex k represents each respondent's home MSA. The multilevel model allows the intercepts αj and γ_k to vary by respondent and MSA, respectively. The term X represents a matrix of independent variables, including respondents' demographics, jaywalking behavior, as well as roadway configurations and traffic conditions. $\boldsymbol{\beta}$ is a parameter vector. Finally, ϵ_i represents the error term of the model.

Chapter 4. Findings

This chapter discusses respondents' attitude toward driverless cars' potential impact on pedestrian safety, preferences of management strategies for driverless cars, and street crossing choice under different driverless car saturation levels.

4.1. Attitudes Toward Driverless Cars' Safety Impact

Overall, respondents felt less safe as pedestrians with driverless cars on the road. When asked to select the statement that best describes one's attitude toward driverless cars, roughly half of the respondents in both the Philadelphia MSA and the Seattle MSA indicated that as pedestrians, they felt less safe with driverless cars on the road than they do with conventional cars. Meanwhile, only around 14% of respondents in each MSA felt safer as pedestrians with driverless cars on the road.

The attitudes toward driverless cars' safety impact vary by familiarity with driverless technology. As illustrated in Figure 4.1, a greater share of respondents who were unfamiliar (had never heard of driverless cars before the survey study) or only somewhat familiar with driverless cars (had heard of driverless cars before the survey but have limited knowledge about them in general) felt less safe with driverless cars on the road compared to respondents who were very familiar with driverless cars (familiar with driverless cars and follow their development closely). Roughly one third of respondents who were very familiar with driverless cars felt safer with driverless cars on the road, compared to 8 to 25% among respondents who were less familiar with the technology.

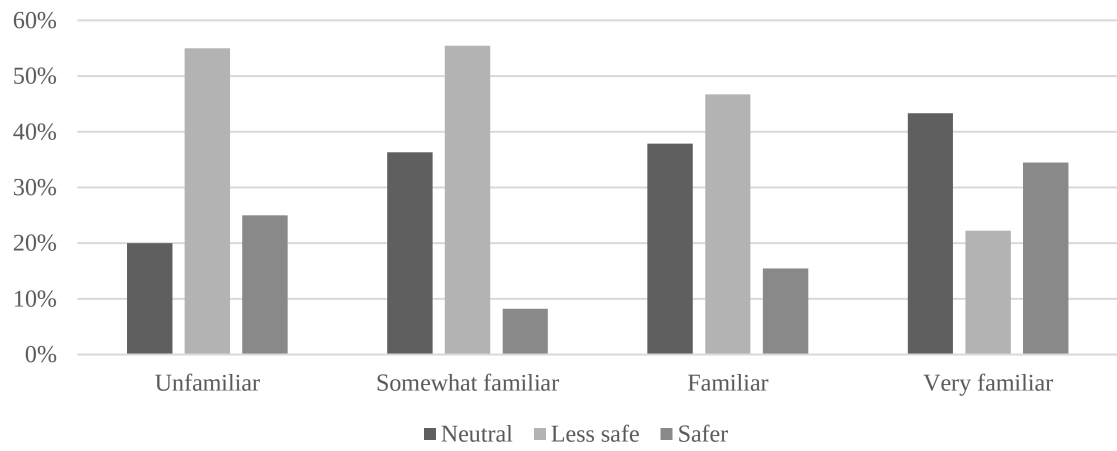


Figure 4.1 Attitudes toward the safety impact of driverless cars by familiarity with driverless cars

4.2. Preference of Management Strategies for Driverless Cars

More respondents were in favor of limiting speed and disabling driverless features than doing nothing differently or increasing enforcement of jaywalking to ensure pedestrian safety, as shown in Figure 4.2. Slightly over one third of respondents in both the Philadelphia MSA and the Seattle MSA indicated that self-driving functions should be disabled in areas with heavy pedestrian traffic. Around 25% indicated that driverless cars should not be allowed to exceed 30 miles per hour on urban streets. By contrast, less than 15% of respondents in each MSA favored more enforcement of jaywalking laws to ensure pedestrians do not interfere with driverless cars. Even fewer respondents chose “cities do not need to do anything differently from what they do today with regard to the interaction between cars and pedestrians”. Around 16% of the respondents in each MSA favored fences or other obstacles to create more separation between driverless cars and pedestrians to make streets less “jaywalkable”.

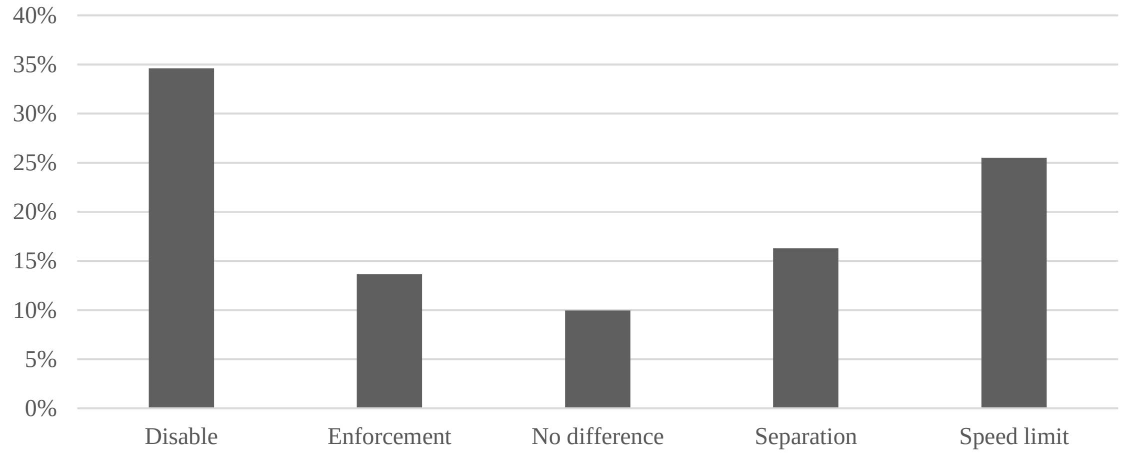


Figure 4.2 Preference of strategies toward the interactions between driverless cars and pedestrians

The preference of disabling driverless function in areas with heavy pedestrian traffic is observed across walking frequencies, as shown in Figure 4.3. Limiting the speed of driverless cars to below 30 mph on urban streets is the second most popular choice for all but respondents with very high walking frequency. Meanwhile, enforcement of jaywalking laws and not doing anything differently than today are the least popular choices among respondents with medium, high, and very high walking frequencies, and two of the three least popular options among respondents with lowest walking frequency.

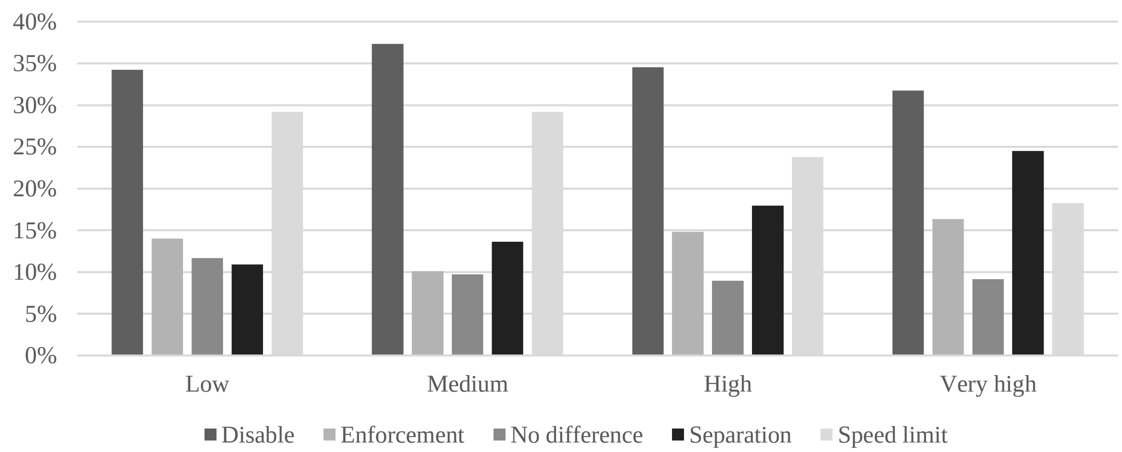


Figure 4.3 preferences of management strategies by frequency of walking

4.3. Multilevel Analysis of Crossing Choices

Table 4.1 reports the point estimates from the multilevel binomial logit models under each driverless car saturation scenario. Exponentiated independent variables have interpretations as odds ratios. For example, compared to female respondents, male respondents have roughly 21% higher odds ($e^{0.191} - 1 = 0.21$) of jaywalking at current mid-block location than walking to the nearest intersection to cross.

Table 4.1 Point estimates from multilevel binomial logit models for the three scenarios

Variable (reference category)	All	Half	No
	Point estimate (S.E.)		
Intercept	1.670*** (0.450)	1.169** (0.437)	1.567*** (0.410)
Direction (one-way)			
Two-way	-0.838*** (0.098)	-0.603*** (0.095)	-0.803*** (0.095)
Speed	-0.018** (0.007)	-0.018** (0.006)	-0.018** (0.006)
No. Lanes	-0.646*** (0.054)	-0.583*** (0.053)	-0.510*** (0.053)
Walk time (=2.5 mins)			
1-2 mins	-0.055 (0.145)	0.142 (0.140)	-0.034 (0.136)
<1 min	-0.387** (0.144)	-0.092 (0.141)	-0.308* (0.139)
Visibility (high)			
Medium	-0.321** (0.106)	-0.306** (0.105)	-0.319** (0.104)
Poor	-0.726*** (0.121)	-0.602*** (0.118)	-0.466*** (0.117)
Traffic volume (heavy)			
Light	0.789*** (0.131)	0.684*** (0.127)	0.698*** (0.122)
Moderate	0.483*** (0.143)	0.350* (0.138)	0.204 (0.132)
Age	-0.020** (0.007)	-0.018** (0.006)	-0.022*** (0.006)
Sex (Female)	0.268 (0.217)	0.355 (0.190)	0.191 (0.198)
Jaywalk frequency (<3 times)			
3-5 times	1.223*** (0.260)	1.145*** (0.219)	1.160*** (0.241)
6-8 times	1.836*** (0.444)	1.201** (0.388)	1.475*** (0.372)
>8 times	2.292*** (0.467)	1.690*** (0.486)	1.623*** (0.411)
Log likelihood	-1874.4	-1887.1	-1917.5
AIC	3782.9	3808.3	3869
BIC	3889.2	3914	3975.1

Significance levels: < 0.001 ***, < 0.01 **, < 0.05*

Consistent with the existing literature, older adults are less likely to jaywalk at current mid-block location than younger adults. On average, each additional year in age corresponds to 1.8 to 2.2%

lower odds of jaywalking across the three survey scenarios, all else being equal. We also estimated models with a quadratic age term to capture the potential non-linear relationship between age and street crossing choices. This variable is not statistically significant and is therefore not included in the reported models.

Current jaywalking behavior is a significant predictor of jaywalking in the choice experiments. Within each survey scenario, respondents who jaywalk more often are more likely to choose jaywalking at current mid-block location over walking to nearest intersection than respondents who jaywalk less often. For example, in the half-driverless-car scenario, respondents who reported to jaywalk 3-5 times, 6-8 times, and more than 8 times per week have respective 2.1, 2.3, and 4.4 times higher odds of jaywalking than respondents who jaywalk less than 3 times a week.

The difference in the willingness to jaywalk at mid-block locations between the most and the least frequent jaywalker appears to increase as the streets become more saturated with driverless cars. Compared to respondents who jaywalk less than 3 times a week, those who jaywalk more than 8 times per week have 4, 4.4, and almost 9 times higher odds of jaywalking at mid-block location in the no-driverless-car, half-driverless-car, and all-driverless-car scenarios, respectively.

In terms of roadway width, respondents are less willing to jaywalk across bigger roads, especially in the presence of driverless cars. On average, each additional vehicular lane corresponds to 40% lower odds of jaywalking at mid-block in the no-driverless-car scenario, while holding other factors constant. In the half-driverless-car and all-driverless-car scenarios, each additional lane is associated with 44% and 48% lower odds of jaywalking, respectively.

Compared to one-way streets, two-way streets are a bigger deterrent to jaywalking. When facing two-way streets, respondents have 55 to 57% lower odds of jaywalking in the no-driverless-car and all-driverless-car scenarios, and 45% lower odds in the half-driverless-car scenario.

While respondents are more willing to jaywalk in light traffic, the degree of their willingness varies across the three scenarios. In the all-driverless-car scenario, respondents have 2.2 times the odds of jaywalking in light traffic as in heavy traffic. In the half-driverless-car and no-driverless-car scenarios, the odds of jaywalking in light traffic double the odds of jaywalking in heavy traffic, all else being equal. Furthermore, in the all-driverless-car scenario, respondents are significantly more likely to jaywalk in moderate traffic than in heavy traffic. By contrast, the difference in the willingness to jaywalk between moderate and heavy traffic is less pronounced in the half-driverless-car and no-driverless-car scenarios.

Regardless of the presence of driverless cars, lower visibility is associated with lower willingness to jaywalk. Compared to high visibility, the willingness to jaywalk in medium visibility is consistent across the three scenarios, with coefficients ranging from -0.306 to -0.321. When the visibility is poor, respondents' willingness to jaywalk decreases as the streets become more saturated with driverless cars. On average, respondents' odds of jaywalking decrease by 37%, 45%, and 52% in the no-driverless-car, half-driverless-car, and full-driverless-car scenarios, respectively.

Across all three scenarios, traffic speed is a significant deterrent to jaywalking. On average, each mile per hour increase in traffic speed corresponds to roughly 1.8% lower odds of crossing at current mid-block location, all else being equal.

Walking time to the nearest intersection has limited associations with respondents' crossing choice, and the associations vary across driverless car scenarios. When walking time is between 1 and 2 minutes, the analysis finds no significant difference in respondents' willingness to jaywalk than when the walking time is 2.5 minutes. When walking time is under 1 minute, respondents in the all-driverless-car and no-driverless-car scenarios are significantly more likely to walk to the nearest intersection than when the walking time is 2.5 minutes.

We find no significant associations between respondents' sex and their preferences of jaywalking in all three models. We also estimate models with respondents' income and walking frequency but find no significant associations between these factors and respondents' crossing choices. Thus, we exclude these variables from the reported models.

Chapter 5. Implications of Findings on Practice

In this chapter, we discuss respondents' attitude toward driverless cars' potential impact on pedestrian safety, preferences of management strategies for driverless cars, and street crossing choice under different driverless car saturation levels.

5.1. Implications

As driverless cars, or certain driverless features such as crash avoidance, become more common, city officials need to rethink the physical and regulatory interventions to manage the interactions between driverless cars and pedestrians effectively. In this section, we structure the study's implications on jaywalking laws, traffic interventions, and roadway design around three main findings from the survey analysis.

The first implication relates to respondents' preferences for regulating driverless cars over increasing enforcement of jaywalking laws in the presence of driverless cars. Among respondents in both the Philadelphia and the Seattle MSAs, increasing enforcement of jaywalking laws is the second least popular strategy, chosen by only 14% of the respondents as their preferred option. In recent years, many cities have deemphasized the enforcement of jaywalking laws. Philadelphia, for example, issued an average nine jaywalking tickets a year (Cheng, 2015), a number that almost certainly underrepresents the true extent of jaywalking in the city based on media reports and the authors' observations. Several cities have even decriminalized jaywalking, with a few others, including Seattle, considering similar actions. Results from the current survey study indicate that pedestrians will likely welcome deemphasizing enforcement of jaywalking laws in the presence of driverless cars.

Meanwhile, disabling driverless functions and capping the speed of driverless cars in dense urban cores are the most popular strategies, chosen by a respective one third and one quarter of the respondents in both MSAs. These responses suggest that there may be mistrust of driverless technologies' reliability to interact with pedestrians safely. The mistrust is also manifested in pedestrians' reluctance to jaywalk in poor visibility in the presence of driverless cars. While it might help to mitigate the public's skepticism of driverless technologies, disabling driverless functions altogether could diminish the safety benefits of crash avoidance in the long run. Our findings suggest that respondents' perceptions of the safety benefits of driverless cars improve with familiarity with driverless technologies. The gradual maturation and increasing presence of driverless functions might help ease pedestrians' mistrust of the technology. Meanwhile, research has found vehicle speed to be a major contributor to traffic fatality. Driverless cars can be preprogrammed to obey traffic laws, thus making it easier for cities to cap the speed of driverless cars in certain areas to improve pedestrian safety.

The second implication relates to the physical interventions that facilitate pedestrian crossing in anticipation of pedestrians' potential lack of concern for jaywalking in the presence of driverless cars. In light and moderate traffic when all cars are driverless, respondents are more likely to jaywalk at current mid-block location than in heavy traffic compared to when none of the cars are driverless or only half of the cars are driverless. When the traffic volume is low, jaywalking's disruption to traffic is likely limited. However, as traffic volume increases, jaywalking could slow down traffic as driverless cars are programmed to stop for pedestrians. Findings also indicate that not only does current jaywalking frequency serve as a good indicator of jaywalking behavior in the presence of driverless cars, but more frequent jaywalkers might be more likely to jaywalk as driverless cars become more common. These findings remind city planners and traffic engineers that major behavioral shifts from today's interactions between pedestrians and cars might be unlikely in the presence of driverless cars. Given that increasing enforcement of jaywalking laws and physically separating pedestrians from cars are among the least popular strategies among the respondents, cities might find merits in physical countermeasures that increase safe crossing opportunities for pedestrians. Shorter blocks, for example, reduce pedestrians' walking burden to accessing controlled intersections when crossing the streets. Additionally, more frequent, well-designed mid-block crossings could create safe and predictable situations for both pedestrians and vehicles (National Association of City Transportation Officials, 2013). These proven design interventions may continue to serve as strategies that ensure safe interactions between pedestrians and driverless cars as driverless cars become more common.

The last implication relates to ensuring pedestrian safety in the presence of driverless cars through sound roadway design and street configuration. Consistent with existing transportation studies, our findings indicate that two-way streets, wider roads, and higher vehicle speeds are significant deterrents to jaywalking across all three survey scenarios. The deterrence of bigger roads on jaywalking is especially pronounced in the all-driverless-car scenario. While wider, faster roads might deter jaywalking and facilitate vehicular traffic movement, the harm of auto-oriented roads that solely emphasize vehicle throughput on the urban fabric and pedestrian experience especially in the urban core has been well-documented. Roadway design strategies that promote smaller streets and more space for pedestrians could help encourage walking and improve pedestrian safety. As driverless functions such as lane keeping continue to mature, driverless cars will become more adept at navigating smaller streets, making smaller streets in the urban core more feasible. Smaller streets also have the added advantage of slowing down traffic, which is one of the preferred strategies to cope with driverless cars by the survey respondents.

5.2. Conclusion

In anticipation of driverless cars, cities face regulatory and planning challenges to manage the interactions between pedestrians and driverless cars. In this study, we conducted surveys to answer three research questions regarding pedestrians' attitudes toward driverless cars and their crossing behavior under various roadway configuration and traffic conditions under three scenarios. We found that respondents across almost all walking frequencies preferred disabling driverless functions and capping the speed of driverless cars in dense urban areas with heavy pedestrian traffic to increasing enforcement of jaywalking laws. Roadway configurations, traffic conditions, and current jaywalking frequency are closely related to respondents' preferences of jaywalking when crossing the street.

One near consensus among the respondents was that cities should not take a business-as-usual approach to manage the interactions between pedestrians and driverless cars. Proven strategies that enhance the urban environment and pedestrian experience, such as short blocks, well-designed mid-block crossing, and smaller streets, could help to ensure not only safer interactions between pedestrians and driverless cars but also greater general acceptance of driverless vehicles operating on urban streets.

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