IMPACT OF BICYCLE ROLLING STOP LAWS ON SAFETY-RELEVANT BEHAVIORS IN THE PACIFIC NORTHWEST

FINAL PROJECT REPORT

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16. Abstract

Bicycle Rolling Stop (BRS) laws refer to legislation that allow bicyclists to treat stop signs as yield signs. Many states have passed statutes or attempted to pass similar statutes with varying permissive actions for bicyclists in response to stop signs. Previous research has focused on crash data analysis and the factors the motivate bicyclists who perfor a rolling stop when it is illegal under prevailing law, but no research has identified the safety effects of BRS laws. To that end, this research used stakeholder interviews, an online survey, and a networked driving and bicycling simulator experiment to evaluate the safety implications of the BRS law. Seventeen interviews were conducted with identified stakeholders, including emergency response and law enforcement personnel, legislators, avid cyclists, and non-cyclists. A total of 550 survey responses were collected from residents of Idaho, Washington, and Oregon. Sixty participants successfully completed a networked simulator experiment in which a "live interaction" occurred at a stop-controlled intersection between a participant in the driving simulator and a participant in the bicycling simulator. The results from these different methods consistently concluded that more outreach is needed with regard to BRS laws. This research also provides bicycle advocacy groups, transportation agencies, and decision makers with information to support future legislative decisions, program educational initiatives, and design enforcement practices regarding BRS laws.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

AOI:	Area of interest
BRS:	Bicycle rolling stop
EHS:	Environmental Health and Safety
GSR:	Galvanic skin response
IRB:	Institutional Review Board
LCD:	Liquid crystal display
LMM:	Linear Mixed Effects Model
LSD:	Least significant difference
m/s:	Meters per second
mph:	Mile per hour
OSU:	Oregon State University
PacTrans:	Pacific Northwest Transportation Consortium
PDO:	Property damage only
PET:	Post encroachment time
PPG:	Photoplethysmogram
SD:	Standard deviation
TFD:	Total fixation duration
TTC:	Time to collision
WSDOT:	Washington State Department of Transportation

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EXECUTIVE SUMMARY

Previous research has found that some bicyclists disregard circular red indications and stop signs. Possible justifications include a desire to increase safety, increase visibility, save energy, and save time. Many bicyclists feel as though stopping at stop signs, especially in the absence of conflicting vehicular traffic, is an undue hinderance to travel, resulting in slower speeds, instability, greater exposure to conflicting vehicles, and physical discomfort when motion resumes after stopping. Bicycle rolling stop (BRS) laws refer to legislation that allows bicyclists to treat stop signs as yield signs. Many states have passed or attempted to pass BRS legislation with varying permissive actions for bicyclists in response to stop signs. Previous research has focused on crash data analysis and the factors that motivate bicyclists who perform a rolling stop when it is illegal under prevailing law. No research has identified behaviors related to safety and the implementation of bicycle rolling stop laws. To fill this gap in existing knowledge, this research utilized stakeholder interviews, an online survey, and a networked driving and bicycling simulator experiment to evaluate the safety implications of BRS laws.

The researchers conducted seventeen interviews with identified stakeholders, including emergency response and law enforcement personnel, legislators, avid cyclists, and non-cyclists. The interviews offered anecdotal evidence and first-hand experience concerning usage of BRS laws across Oregon, Washington, and Idaho. Common themes discussed during interviews included safety, education, conflicts between motorists and bicyclists, fear of bicycling, legalizing prevailing behavior, and awareness of the law. Knowledge gained from the interviews helped inform the development of the public perception survey and the of the driver simulator experiments.

A total of 550 survey responses were collected from residents of Idaho, Washington, and Oregon with an online survey. The research team developed an online survey that sought to examine public perceptions of bicycle safety and behaviors at intersections. Specific questions focused on the Idaho Stop (and variations of this law adopted by individual states) were also developed and tailored to respondents, depending on their particular state of residence. Responses generally indicated that bicyclists viewed BRS laws more favorably than motorists, who generally felt that bicyclists should not be allowed to roll through a stop sign or a red light and should not be allowed to stop and then turn left or proceed through an intersection without waiting for a signal to change if there is no approaching traffic. Results suggested that universal

knowledge of the BRS law remains a work in progress, with over half of Oregon and Washington residents and nearly 44 percent of Idaho residents being unaware of the law.

Sixty participants successfully completed a networked simulator experiment in which a “live interaction” occurred at a stop-controlled intersection between a participant in the driving simulator and a participant in the bicycling simulator. Participants encountered 16 scenarios while riding or driving in the simulators. Time-space diagrams demonstrated that after education related to the BRS law, bicyclists preferred to yield at stop signs and had a higher average speed through intersections. Analysis of bicycling participant eye-movements found that bicyclists also allocated more attention to conflicting passenger cars after education about the BRS law. Driving participants’ trajectories showed that drivers approached intersections either slower or at a similar speed after education about the BRS law. Live interactions in the networked simulators validated the results when bicycling participants interacted with virtually controlled passenger cars.

The results from these different data collection methods suggested that more outreach is needed with regard to BRS laws. This research also provides bicycle advocacy groups, transportation agencies, and decision makers with information needed to support future legislative decisions, program educational initiatives, and design enforcement practices regarding BRS laws.

CHAPTER 1. INTRODUCTION

In 2019, the state of Oregon became one of a growing number to implement a bicycle rolling stop law, with the State of Washington following the next year. The new law allows any bicyclist approaching an intersection controlled by a stop sign to proceed through the intersection without stopping. However, under this new law bicyclists are required to yield to traffic and pedestrians in the intersection and must exercise care to avoid a crash.

The phrase bicycle rolling stop is another name for legislation sometimes referred to as the “Idaho Stop,” since a similar law was passed by Idaho’s Legislature in 1982. The original Idaho law allowed bicyclists to treat both stop signs and traffic signals as yield signs. The Idaho law was amended in 2006 to clarify the treatment of traffic signals by bicyclists as a stop-then-yield condition except for cases of right-turning or left-turning onto a one-way street, which remained yield conditions (Bicycle Law, 2009). The states of Delaware, Arkansas, and parts of Colorado have implemented various versions of the Idaho Stop. When Delaware implemented the “Idaho Stop,” it called it the “Delaware Yield.” Utah has brought forward similar legislation four times in the last decade, and although it failed to pass in the 2019 legislative session, Representative Carol Moss has stated that she would continue to bring forward the legislation until it passes (*Cycling West - Cycling Utah*, 2019). The term bicycle rolling stop (BRS) will be used throughout this research to describe the similar “Idaho Stop” and “Delaware Yield” laws for all states.

Because much of the country and the world has traffic laws that describe a a bicycle rollng stop as illegal, most of the existing research on the implications of these legislative actions has classified the action as non-compliance by bicyclists. Furthermore, most previous research has focused on a bicyclist’s compliance behavior at traffic signals as opposed to stop signs. In an Australian survey of 2,000 cyclists, 37 percent of the respondents indicated that they had illegally entered an intersection during the display of a circular red indication (Johnson et al., 2013). This study found higher noncompliance rates among younger and male cyclists. A similar rate was found in a smaller study in Brazil (Bacchieri et al., 2010). A 2014 study of New York City cyclists found a 34 percent non-compliance rate at signals, indicating similar behavior in the United States. A study using video footage of over 2,600 cyclists in Oregon found a 31 percent non-compliance rate, but this decreased to just over 10 percent when right-turning cyclists were removed from the study (Thompson et al., 2013).

These results lead to a natural question: Why do cyclists disregard red lights and stop signs in the absence of BRS laws? Research by Marshall et al. (2017) analyzed survey results from over 17,000 respondents from 73 countries, including over 14,000 from the United States. Respondents included bicyclists and non-bicyclists, so differences in behavior by modes could be explored. The research explored the reported reasons why road users broke the law and noted the differences by mode. Nearly all the respondents, regardless of mode, indicated some form of non-compliant behavior, with reporting rates of 95.9 percent for cyclists, 97.9 percent for pedestrians, and 99.97 percent for drivers. Non-compliant behaviors exhibited by drivers included running red lights and speeding. The study found that 77 percent of drivers and 85 percent of pedestrians broke traffic laws in order to save time. Bicyclists reported non-compliant behavior to increase personal safety (71 percent), save energy (56 percent), save time (50 percent), and increase their visibility (47 percent). A review of the open-ended survey responses suggested that bicyclists disregarded traffic control in situations where there was low risk, and they did so to overcome a car-dominated transportation system.

This research used stakeholder interviews, an online survey, and a networked driving and bicycling simulator experiment to evaluate the safety implications of BRS laws. First, an extensive literature review was conducted, including documenting the national legislative trends around BRS laws. To develop a knowledge base on the subject of BRS legislation and its impacts, interviews were conducted with stakeholders, including emergency response and law enforcement personnel, legislators, avid cyclists, and non-cyclists. The results from this work helped inform the development of a public perception survey of residents of Idaho, Washington, and Oregon. Lastly, a networked simulator experiment was conducted in which a "live interaction" occurred at a stop-controlled intersection between a participant in the driving simulator and a participant in the bicycling simulator. The simulator experimental design was partially guided by the results of the interview and survey tasks.

CHAPTER 2. LITERATURE REVIEW

2.1. Introduction

The purpose of this literature review was to compile existing information related to BRS laws. This chapter identifies states that have passed a version of the law and classifies the unique and varying elements of the laws that have been passed. Additionally, this section reviews and compiles information from previous research on the safety implications of the BRS. The literature review revealed that minimal crash data analysis has been conducted to evaluate safety. Most of the research that exists has detailed the factors that motivate bicyclists who perform a rolling stop where the movement is illegal. No research has identified behaviors related to safety and the implementation of BRS laws.

2.2. Bicycle Rolling Stop Current Laws

BRS laws, at times referred to as an Idaho Stop after Idaho became the first state to enact such a law in 1982, allows bicyclists to treat stop signs as yield signs. Legalizing this prevailing behavior enables bicyclists to use their own judgment of safety to maintain momentum through a stop-controlled intersection. The additional eight states that have passed legislation similar to Idaho's have done so in the last six years, in some cases after multiple attempts. Table 2.1 outlines the states and years they passed or failed to pass BRS laws.

A law related to BRS legislation is commonly referred to as a "dead red" law. The dead red law generally allows motorists and bicyclists to proceed through signalized intersections if detection fails. Some detectors at signalized intersections do not detect bicycles at sufficiently high rates, thus creating a dangerous situation in which the ability to proceed is not known. When detection fails, bicyclists have the option to disregard the light, wait for a vehicle to approach from behind, pushing the bicyclist farther into the intersection or off to the side, or turn right, which may add time and distance to the intended bicycle route. At least 16 states have passed a version of the dead red law, and they are recorded in the right columns of table 2.1.

Table 2.1 Bicycle Rolling Stop Law Summary

State/District	BRS Statute	BRS	BRS Year Passed or Failed	Dead Red Statute	"Dead Red"
Alabama					Failed
Arizona		Failed	2011	28-645	Passed
Arkansas	27-51-1802	Passed	2019	§27-52-206	Passed
California	(2022-A.B.1713)	Failed	2017 & 2018 & 2021	§21800	Passed
Colorado	HB22-1028	Passed	2022		
Delaware	§4196A	Passed	2017		
Idaho	49-720	Passed	1982	§49-720	Passed
Illinois				11-306(3.5)	Passed
Indiana				§9-21-3-7	Passed
Kansas				8-1508	Passed
Minnesota		Failed	2008	169.06	Passed
Missouri				304.285	Passed
Montana		Failed	2014		
Nevada				484B.307	Passed
New York	(2022-SB S920A)	Failed	2015		
North Carolina				20-158	Passed
North Dakota	HB 1252	Passed	2021		
Oklahoma	§47-11-202.1	Passed	2021	47-11-202	Passed
Oregon	814.414 & 814.416	Passed	2019	811.36	Passed
Pennsylvania				3112	Passed
South Carolina				56-5-970	Passed
Tennessee				55-8-110	Passed
Utah	HB 142	Passed	2021	41-6a-305	Passed
Virginia		Failed	2021	46.2-833	Passed
Washington	RCW 46.61.190(2)(b)	Passed	2020	46.61.184	Passed
Washington D.C.	(2022-B24-0673)	Failed	2016		
Wisconsin				346.37	Passed

2.3. Bicycle Rolling Stop Laws Classified by State

Select cities in the Pacific Northwest, specifically in the states of Oregon and Washington, have some of the largest percentages of bicycle commuters in the United States. According to the League of American Bicyclists' American Community Survey Data Report (2017), Portland, Oregon, has the second largest number of bicycle commuters in the United States, ranking behind only New York City. Seattle, Washington, has the eighth largest number of bicycle commuters. The states of Oregon, Washington, Montana, Wyoming, and Idaho make up five of the top ten states ranked by mode share percentage of commuters who bicycle. Figure 2.1 depicts the states that have passed BRS laws, and figure 2.2 depicts the states that have passed dead red laws. The potential growth of BRS laws can be seen in considering the states that have proposed similar legislation. At the time of this report, at least seven states had considered, but failed to pass, BRS legislation. Figure 2.3 shows the potential growth of BRS laws given these data.

Overall, 18 percent of states have passed a version of a BRS law, and 14 percent of states have attempted, but failed to pass, a BRS law. Comparatively, 32 percent of states have passed a version of the dead red law.

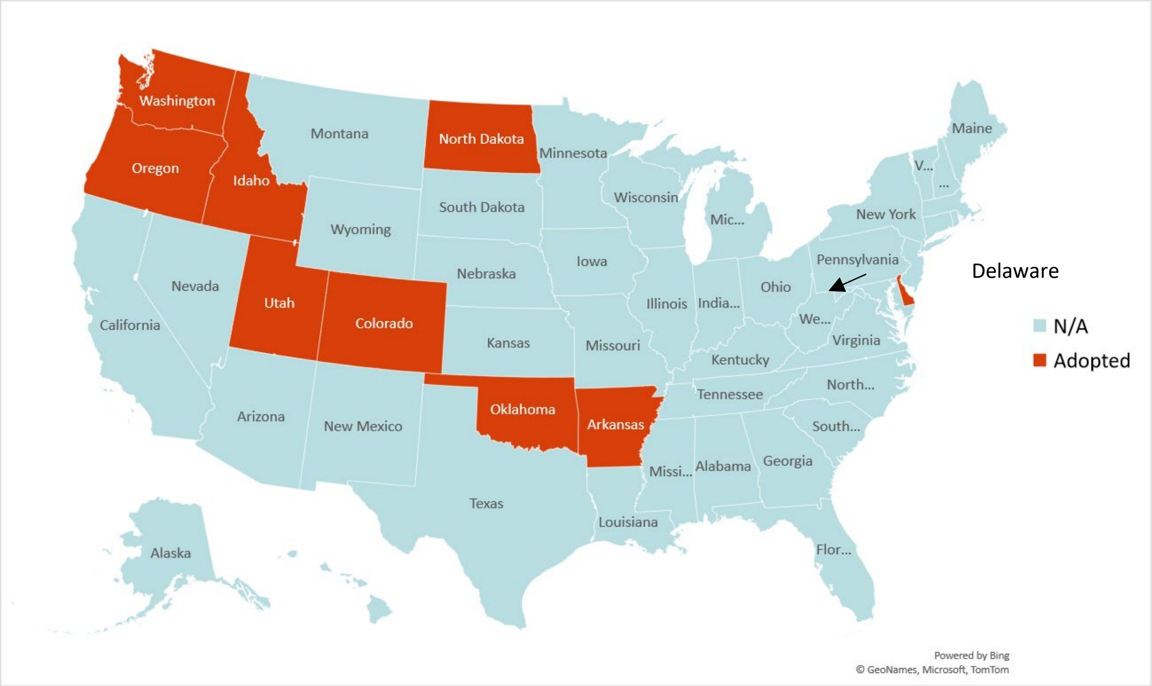


Figure 2.1 Bicycle Rolling Stop Laws Adopted by State

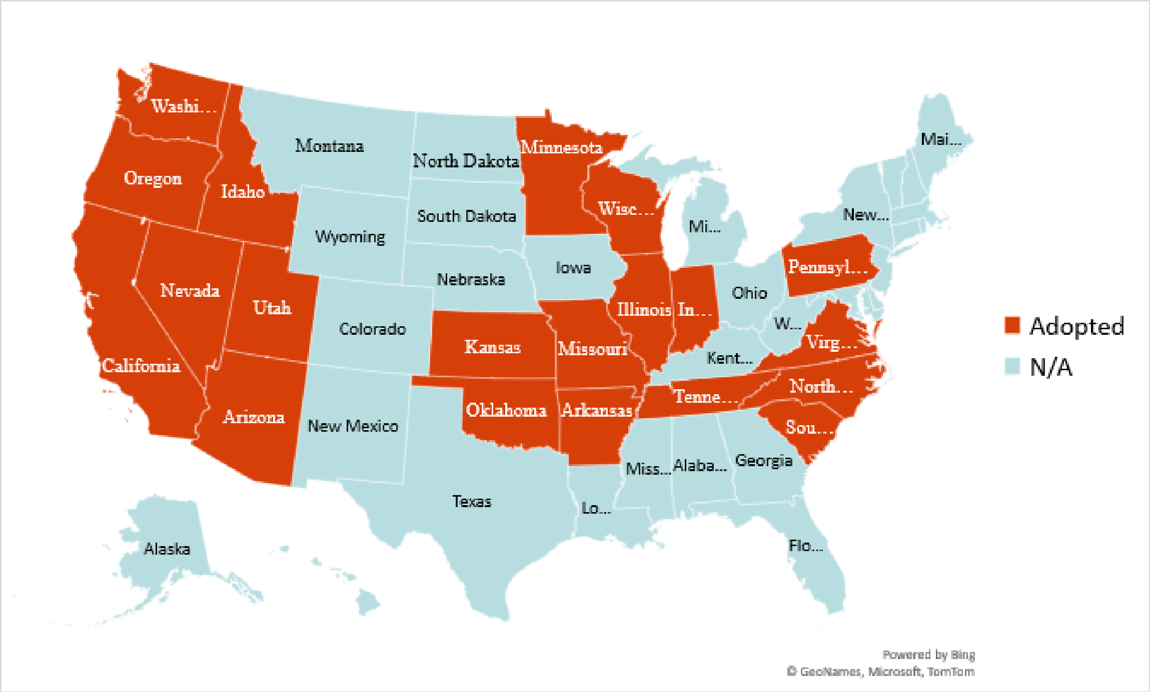
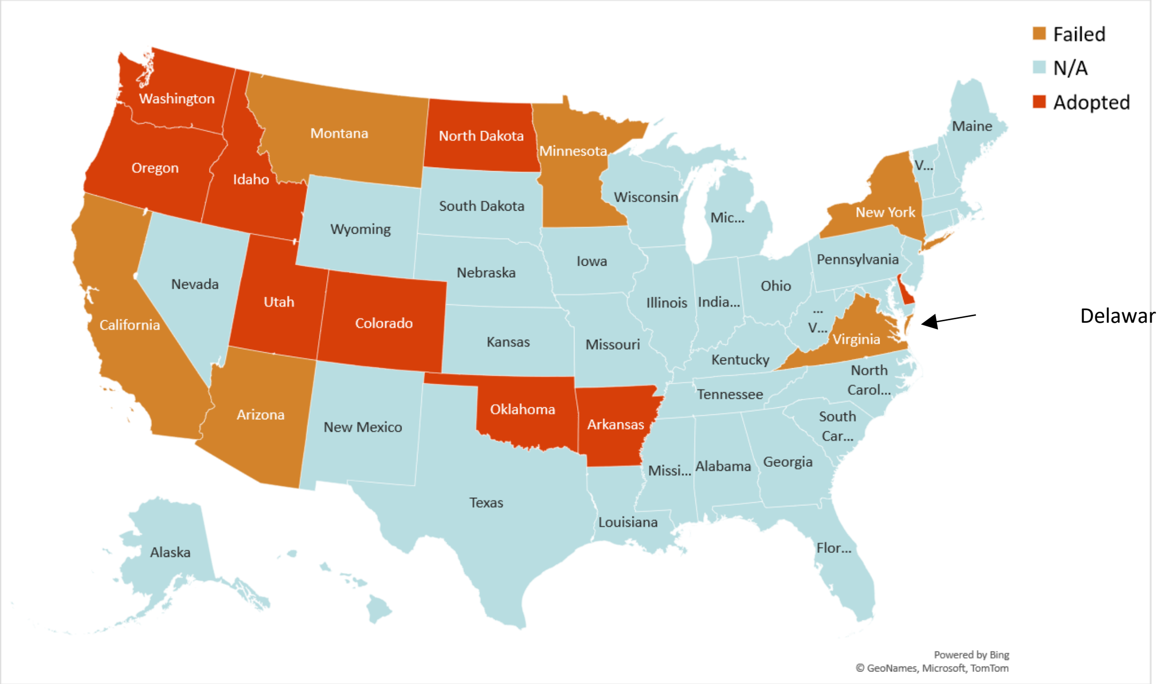


Figure 2.2 Dead Red Laws Adopted by State



Delaware

Figure 2.3 Potential Growth in Bicycle Rolling Stop Laws

The BRS laws that states have implemented vary in permissive actions. These variations, shown in table 2.2, specify which traffic control devices are included, define how bicyclists can enter intersections, and determine whether electric bikes are specifically included.

The research team identified three main classifications of BRS laws. Classification I is defined as allowing bicyclists to enter a stop-controlled intersection after yielding. Classification II is defined as allowing bicyclists to enter a signal-controlled intersection on red to complete a right turn movement after yielding. Classification III is defined as allowing bicyclists to enter a signal-controlled intersection on red to complete a left turn or through-movement after coming to a complete stop. These classifications are tabulated by state in table 2.2.

Table 2.2 Bicycle Rolling Stop Classifications by State

State/ District	Stop Sign as Yield	Bicycle Can Enter Stop Sign-Controlled Intersection…	Red Light as Yield	Bicycle Can Enter Signal-Controlled Intersection…	Red Light as Stop Sign	Bicycle Can Enter Signal-Controlled Intersection…	Includes Electric Bicycles
Arkansas	Yes	After yielding right-of-way	Yes	After yielding right-of-way, Right turn only	Yes	After Stopping and yielding right-of-way, Straight or Left	
Colorado[1]	Yes	After slowing to "reasonable speed" and yielding right-of-way			Yes	After stopping and yielding right-of-way, Left onto one-way	Yes
Delaware[2]	Yes	If there is no vehicle stopped at same stop sign; after yielding right-of-way					
Idaho	Yes	After yielding right-of-way	Yes	After yielding right-of-way, Right turn only	Yes	After Stopping and yielding right-of-way, Straight or Left	Yes
North Dakota[2]	Yes	After yielding right-of-way					
Oklahoma	Yes	After yielding right-of-way	Yes	After yielding right-of-way, Right turn and Left onto one-way only	Yes	After Stopping and yielding right-of-way	
Oregon[3]	Yes	After yielding right-of-way					
Utah[4]	Yes	After yielding right-of-way					
Washington[5]	Yes	After yielding right-of-way					Yes

1. Applies only to ages 15 and older.
2. Applies only on roadways with two or fewer lanes.
3. May also treat flashing red light as yield.
4. Does not apply to stop signs at railroad crossing.
5. Does not apply to stop signs at railroad crossing or stop signal by school bus.

2.4. Crash Data Analysis

Several studies have analyzed traffic injuries and fatalities in the state of Idaho to assess the safety of bicycle rolling stops. Research by Meggs (2010) compared statewide summaries of traffic injuries and fatalities for a period of time before and after the BRS law was adopted in Idaho. These summaries were evaluated from 1966 to 1992, and no evidence of a long-term increase in injury or fatality rates was found. Bicycle injury rates were found to decrease 14.5 percent the year after adoption of the law, with no change in bicycle fatality rates. Interviews conducted in Idaho with police, legislators, transportation professionals, and bicycle leaders in recreational and advocacy groups showed that there was full support for the BRS law, with no negative safety outcomes identified from implementing the law (Meggs, 2010).

Another way to analyze crash data is to compare cities that have similar characteristics. Meggs (2010) compared injury data from Sacramento, California, and Bakersfield, California, to those from Boise, Idaho. Meggs noted that the BRS law was one of the major differences between these cities, whereas similarities were found in weather, topography, street layout, and development of bicycle infrastructure. An injury-to-bicycle-commuter ratio was developed using U.S. Census data from 2000, and Boise was determined to be 30 percent to 61 percent safer than Sacramento and 150 percent to 252 percent safer than Bakersfield.

One university thesis project that looked to determine whether there was a statistical difference in crash severity compared intersection data in Boise, Idaho, where the BRS law had been implemented, and Champaign/Urbana, Illinois, where BRS had not been implemented (Whyte, 2013). The study found that there was no significant statistical difference in crash severity between stop-controlled intersections and all intersections, but there was a significant statistical difference between study areas at traffic signals. Champaign/Urbana held a higher percentage of crashes with incapacitating injuries, and Boise had a higher percentage of crashes with non-incapacitating injuries. There was no significant statistical difference between study areas regarding injury severity, but there was a significant statistical difference between cities regarding property damage only (PDO) crashes at midblock crossings.

2.5. Time-Space Diagrams

The research team developed time-space diagrams to help conceptualize legal and illegal movements as bicycles move through an intersection. The diagrams represent general examples of the differences in legal and illegal movements, and therefore, acceleration and deceleration profiles of movements were idealized for simplicity of visualization. Figures 2.4 and 2.5 show bicycle movements based on Classifications I, II, and III. Classifications were defined as shown in table 2.3. Classifications I and II allow for more legal movements of bicyclists than Classification III.

Table 2.3 Classifications of Bicycle Rolling Stop Laws Defined

Classification	Definition
I	Bicyclist is able to enter a stop-controlled intersection after yielding.
II	Bicyclist is able to enter a signal-controlled intersection on red to complete a right turn movement after yielding.
III	Bicyclist is able to enter a signal-controlled intersection on red to complete a left turn or straight movement after coming to a complete stop.

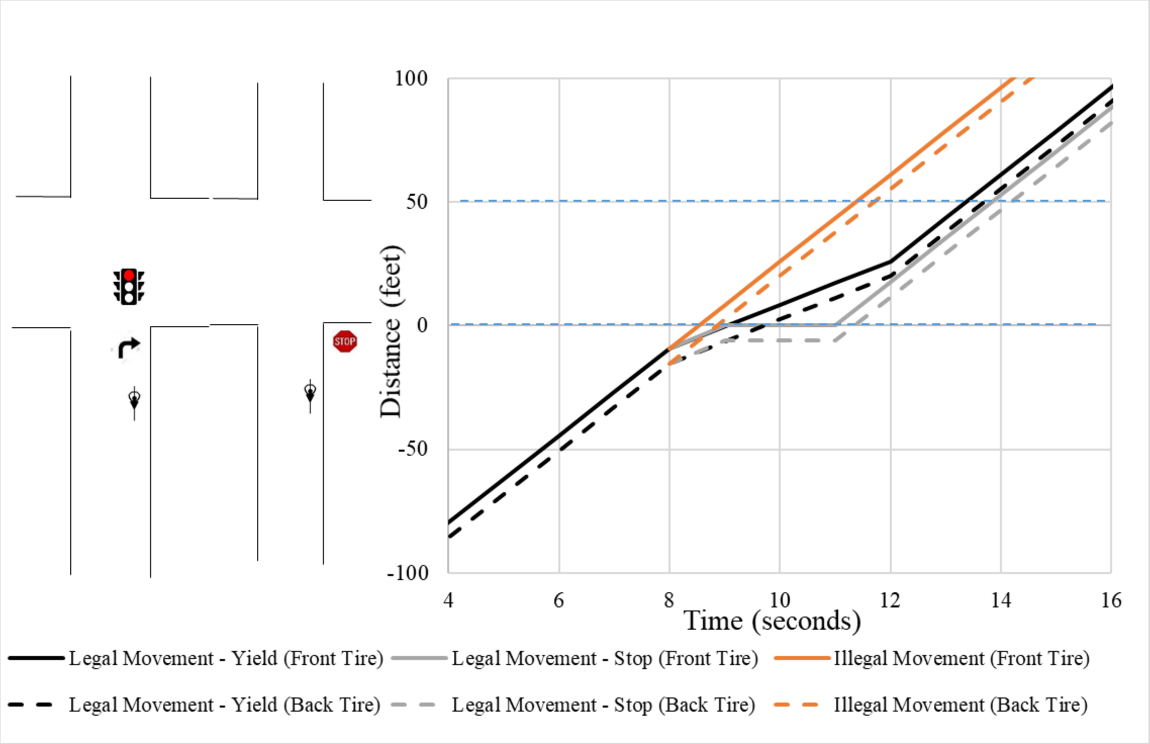


Figure 2.4 Time-Space Diagram for Classifications I and II

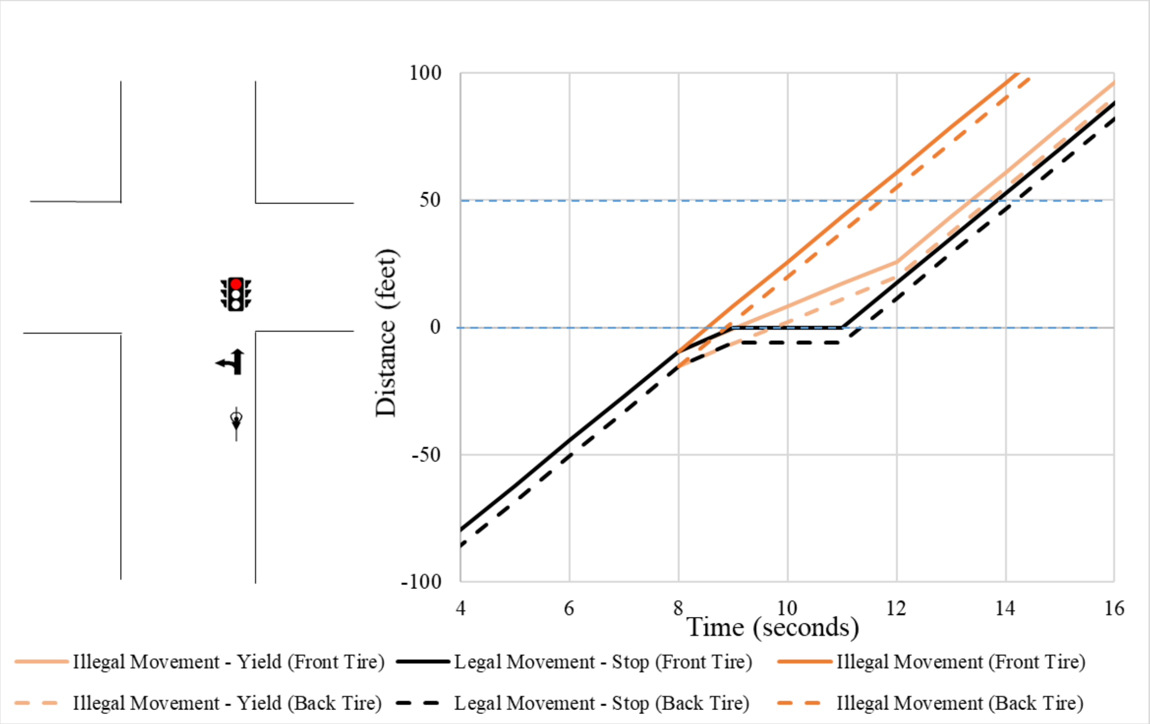


Figure 2.5 Time-Space Diagram for Classification III

2.6. Dead Red Law Classifications

The dead red laws that have been implemented by states also vary in permissive actions. These variations, shown in table 2.4, specify which traffic control devices are included, define how the vehicle can enter the intersection, and determine whether electric bikes are specifically included. Some states allow only movement through a signal-controlled intersection on a red indication to occur if the light is inoperative or malfunctioning. However, at least five states allow movement through a signal-controlled intersection on a red indication after the cyclists has come to a complete stop for a specified length of time. This variation is similar to the BRS laws considered in this study. Table 2.4 outlines variations in dead red laws by state. Dead red laws allow bicyclists to take action similar to those of Classification III of the BRS law, as defined in table 2.3.

Table 2.4 Dead Red Law Classifications by State

State/ District	Bicyclist Can Proceed Through a Red Light	Bicyclist Can Proceed Through and Inoperative and/or Malfunctioning Light	Bicyclist Can Enter Intersection…	Includes Electric Bicycles	Notes
Arizona	Applies to motor vehicles only				
Arkansas	Applies to motorcycles only				
California	Applies to motor vehicles only				
Idaho	Applies to motorcycles only				
Illinois		Yes	After waiting at least 120 seconds and yielding right-of-way	Yes	Does not apply to municipalities of over 2M people
Indiana	Yes		After waiting at least 120 seconds and yielding right-of-way	Yes	
Kansas		Yes	After yielding right-of-way	Yes	
Minnesota		Yes	After yielding right-of-way	Yes	
Missouri		Yes	After yielding right-of-way	Yes	
Nevada		Yes	After waiting for two traffic light cycles and yielding right-of-way	Yes	
North Carolina	Applies to motorcycles only				
Oklahoma	Yes		After coming to complete stop and yielding right-of-way	Yes	
Oregon		Yes	After waiting for one traffic light cycle and yielding right-of-way		Signal must have vehicle detection
Pennsylvania	Applies to any vehicle				
South Carolina	Yes		After waiting at least 120 seconds and yielding right-of-way	Yes	
Tennessee		Yes	After coming to complete stop and yielding right-of-way	Yes	Signal must have vehicle detection
Utah	Yes		After waiting at least 90 seconds and yielding right-of-way	Yes	Only applies to 16 years of age and older

State/ District	Bicyclist Can Proceed Through a Red Light	Bicyclist Can Proceed Through and Inoperative and/or Malfunctioning Light	Bicyclist Can Enter Intersection…	Includes Electric Bicycles	Notes
Virginia	Yes		After waiting for two traffic light cycles or two minutes, whichever is shorter, and yielding right-of-way	Yes	
Washington		Yes	After waiting for one traffic light cycle and yielding right-of-way	Yes	Signal must have vehicle detection
Wisconsin	Yes	Yes	After waiting at least 45 seconds and yielding right-of-way		Must reasonably believe signal has vehicle detection

2.7. Validation of Bicycling Simulators as a Tool for Evaluating Behavior

Bicycling simulation is progressively being used as a tool for evaluating the behavior of cyclists. Simulation is an attractive experimental tool because it allows studies to consider safety critical scenarios without putting participants in situations that could ultimately be unsafe.

Numerous studies have validated the use of bicycling simulation for studying behavior. Kaths et al. (2019) found that tactical choice in the simulator is similar to tactical choice in the real world as long as the virtual environment is "realistic enough." Speed in the bicycling simulator has been found to depend on the accuracy of the sensors in the simulator and the ability for the single-track movement to recreate bicycle movement (Kaths, 2019). Kaths et al. (2019) also concluded that acceleration cannot be validated in the simulator because of the fact that the bicycle in the simulator does not accurately represent real world conditions. For example, the bike in the simulator cannot fall over. Kaths found that creating realism in appearance and movement of road users in the virtual world is equally important as studying interactions such as time to collision (TTC) and post encroachment time (PET). These interactions are sensitive to accurate velocity measurements (Kaths, 2019).

O'Hern et al. (2017) found that lane position in a bicycle lane and passing distance to parked cars have absolute validity in comparison to real world results. They also found that average speed in the simulator was not exact but had a linear relationship to average speed in the real world, suggesting relative validity for studying speed (O'Hern, 2017). Speed reduction when a cyclist approached an intersection was also found to have relative validity when compared on a percentage basis to real world speed reduction upon approaching an intersection. O'Hern's study could not validate head movements because of the constant change in traffic conditions in the real world in comparison to the static environment in the simulator. Some validity was suggested, however, in the number of head movements and average duration of head movements as cyclists approached intersections in the real world in comparison to the those in the simulator environment (O'Hern, 2017).

Kwigizile et al. (2017) concluded that a simulator could be used to study gap acceptance, while Nazemi et al. (2018) found that the simulator adequately captured the behavioral differences in cyclists on different cycling infrastructure. This study found that behavior in the simulator was similar to that in reality and that speed choices directly related to perceptions of safety of the participants on different bicycling infrastructure (Nazemi, 2019).

CHAPTER 3. CHARACTERIZATION OF CURRENT ATTITUDES TOWARD STATE BICYCLE ROLLING STOP LEGISLATION BASED UPON TESTIMONIES OF INTERVIEWED STAKEHOLDERS

3.1. Introduction and Background

Bicycle rolling stop laws allow bicyclists to treat stop signs as yield signs, thereby permitting riders to use their own senses of safety, momentum, and ease when deciding whether to come to a complete stop at intersections. These laws allow bicyclists to proceed through stop sign-controlled intersections without stopping, provided that they do not impede the travel of any other vehicles possessing right-of-way. Under these laws, bicyclists approaching a controlled intersection are still required to yield to traffic and pedestrians in the intersection, and they must always exercise care to avoid potential collisions.

From its history of legislative expansion and public interest, it is clear that bicycle safety stop legislation is an important and current topic in both the transportation and legislative communities. As with any proposed legislation that affects public health, safety, well being, and day-to-day activities, bicycle rolling stop legislation has also provoked passionate public dialogue and spirited debate, particularly among the citizens of states where new legislation was considered or enacted. This chapter attempts to capture this kind of public dialogue to understand broadscale views of BRS laws and to inform future legislative decisions, educational initiatives, and enforcement practices. This chapter describes the interviewing methodologies used by Gonzaga University researchers to develop a knowledge base concerning BRS legislation.

A limited number of stakeholders, each directly affected and deeply engaged with safety stop legislation, were interviewed, and their testimonies were used to build the current knowledge base concerning broadscale public opinion about these laws. The results gained from these interviews were used to inform the public perception survey (Chapter 4) and driver and bicycle simulator study (Chapter 5).

3.2. Methodology: Interview Development and Participant Recruitment

The interview phase of this research consisted of four major stages. First, interviewees were selected from a diverse group of stakeholder types, geographic locations, and demographic descriptions to accurately encompass a variety of viewpoints concerning BRS laws. Second, a standardized interview script was developed with specific questions to pinpoint opinions and obtain a diversity of valuable viewpoints. Third, interviews were conducted by researchers, and fourth, the data gained from the interviews were analyzed and appropriate descriptive themes were developed. Each of these steps is discussed in further detail in this section, with quantitative and qualitative results discussed subsequently.

3.2.1. Selecting Interviewees: Stakeholder and Demographic Distributions

In developing appropriate interview methodologies to analyze public opinion comprehensively, Gonzaga University researchers identified five distinctive stakeholder groups, each with a meaningful connection to BRS legislation. It was not assumed that all of the individuals interviewed already possessed significant knowledge bout this legislation; however, members of all five groups were considered likely to deal with the effects of safety stop statutes in meaningful and recurring ways. The characteristics of the stakeholders were defined as follows:

Avid Cyclists: Avid cyclists are individuals who utilize bicycles as their primary mode of transportation, who regularly commute to work via bicycle, or who otherwise ride a bicycle an average of more than three times per week. Because they are most likely to encounter stop sign-controlled intersections while bicycling, initial hypotheses asserted that avid cyclists would be the most knowledgeable group concerning new laws, and it was thought that these cyclists would most strongly support and understand Idaho BRS legislation.

Emergency Response Personnel: Responding to the scenes of collisions in which motorists, cyclists, and pedestrians may have been injured or killed, emergency response personnel were included in interviews to assess the real safety implications of new legislation. It was hypothesized that members of this stakeholder group would support BRS laws only if they deemed them to increase actual road user safety.

Law Enforcement Personnel: Law enforcement personnel are responsible for enforcing laws, including laws concerning bicycle safety and stopping. In states where bicycles are required to stop at stop signs, law enforcement officers can give citations to bicyclists who fail to come to a complete stop and put a foot down at a stop sign or signal-controlled intersection. While no longer citing bicyclists who roll through stop signs could reduce the workload of law enforcement officers, anecdotal evidence from later interviews suggested that these laws were initially seldom enforced, so citations might not drastically change with the implementation of revised BRS statutes. On the other hand, law enforcement personnel are also tasked with promoting roadway safety, so researchers hypothesized that viewpoints on safety stop laws might more closely align with those of emergency response personnel concerning roadway danger mitigation.

Legislative Representatives: Responsible for promoting, passing, or failing to pass BRS legislation, legislators were hypothesized to support the enactment of BRS laws only if it was within their constituents' best interests to do so. The researchers also hoped that because public officials write the particular language of statutes, legislators would be more knowledgeable concerning specific BRS legislation that had been adopted in their respective states.

Non-Cyclists: To balance the influence of avid cyclists in interviews, it was important to also include a non-cyclist group of interviewees whose only interactions with safety stop laws were from motorist and pedestrian viewpoints. Initial literature reviews found that several non-cyclists, including the writers of numerous strongly worded opinion columns, also shared intense sentiments regarding bicycle safety stop legislation. Therefore, non-cyclists who did not belong to the other categories were also incorporated into the interview research.

After potential interviewees had been divided into the categories outlined above, a list of contacts used for interview planning was generated with input from the general PacTrans research team, as well as local resources, such as bicycle riding committees and police departments to help locate candidate research subjects. The 33 interviewees initially identified by the researchers came from diverse backgrounds and locations, including urban, suburban, and rural regions of both Washington and Oregon. Before the interview process began, the researchers estimated that ten to twelve interviews would be conducted, given the project timeline and budget. Given that recruiting interview participants can sometimes be challenging, the reserchers wanted to have a candidate pool larger than the desired number of interviewees.

An interviewee saturation model was developed to ensure that interview data collected could be maximized while extraneous or unnecessary data were minimized (Fusch and Ness, 2015). Therefore, the researchers agreed to continue conducting interviews until three consecutive conversations yielded no new results or useful materials. The researchers arrived at this material saturation level after 17 interviews, at which point the interviewing process ceased, and any remaining subjects were not contacted.

The demographic distributions for the 17 subjects interviewed, demonstrating certain aspects of subject diversity, are shown in figure 3.1, which outlines statistics concerning the interviewees' self-identified gender, ridership, and stakeholder profiles. It was difficult to identify potential interview participants from certain demographics, especially women and non-cyclists who were interested in talking about cycling issues. The potential biases in the interview data were considered when the data were used to inform the development of the survey instrument in the next task.

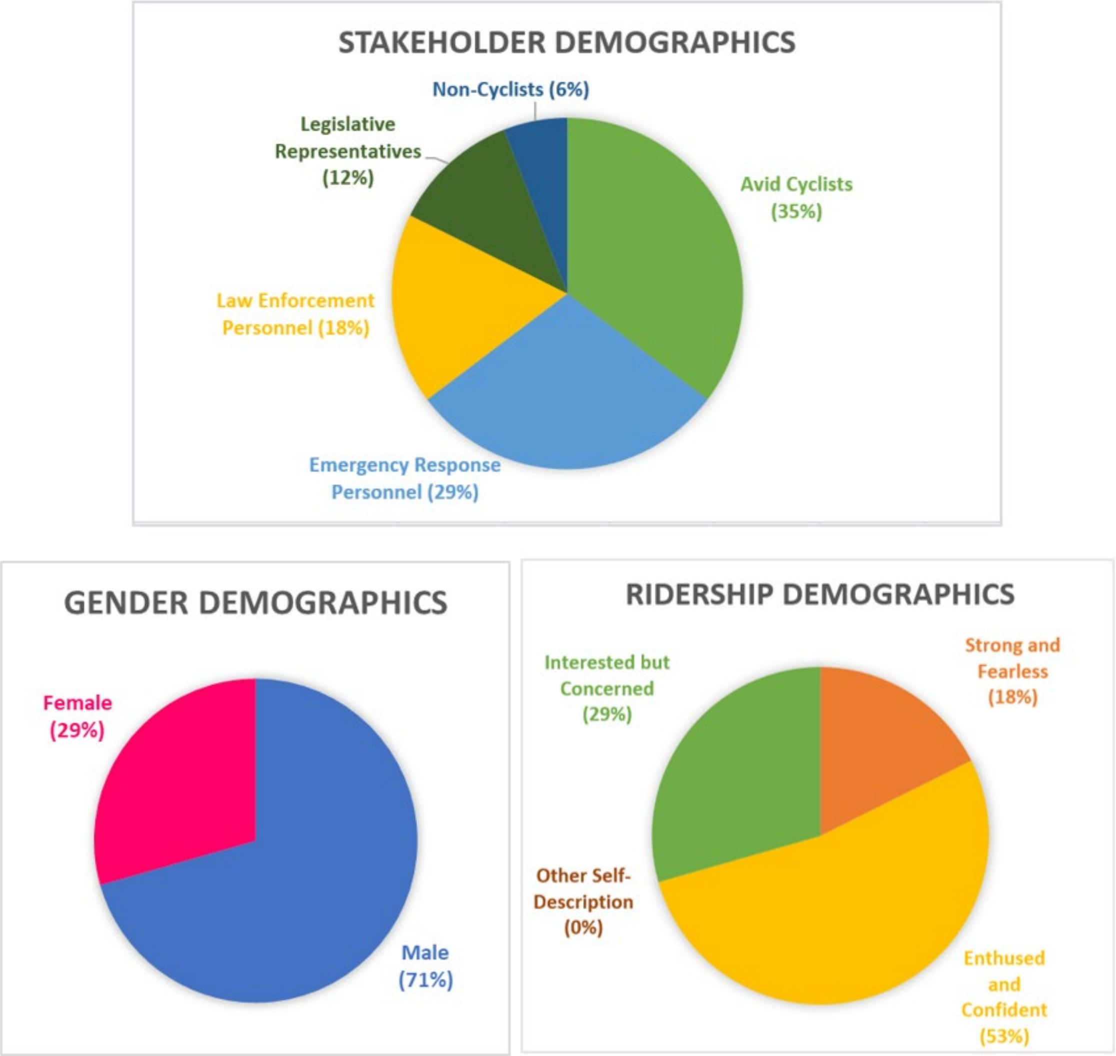


Figure 3.1 Interview Subject Demographic Descriptions of Gender, Ridership Level, and Stakeholder Type

When a contact list for these interviewees was finalized, emails were sent to all individuals asking if they were interested in participating in an approximately 30-minute interview concerning bicycle usage, recently enacted legislation, and law enforcement. The research group determined that this length of appointment was likely, given the number of questions that would be asked, and also was a length that interviewees would likely not view as overly burdensome. The exact length of the interview could be shorter or longer, depending on the length of the participant's responses. No mention was yet made of BRS legislation, which had been passed in both Oregon and Washington in 2020, so that researchers could gauge participants' understanding and knowledge concerning recent laws. After responding to this initial email, individuals who agreed to participate were prompted to use "Calendly" software to schedule an interview with members of the Gonzaga University research team. After scheduling a time, participants were also asked to complete an interview consent form indicating their willingness to engage in earnest conversation concerning current legislation, under the protection of anonymity in any subsequently published findings. This consent form was approved by Gonzaga University's Institutional Review Board (IRB) before dissemination, and its promises of anonymity, transparency, and documentation were kept.

3.2.2. Interview Script Questions and Formulation

Gonzaga University researchers worked to develop a set of standardized interview questions concerning recently enacted bicycle safety stop legislation. The following questions were each asked of interviewees in the same phraseology and order, regardless of stakeholder type:

1. Did you complete the informed consent form, or would you verbally agree to give your informed consent concerning recording and transcription of this interview? Are you aware that, by signing the consent form, you indicate that you are voluntarily choosing to take part in this research?
2. During the seasons of warm weather, from April to October, how often do you bicycle in a typical week?
3. How would you describe yourself as a cyclist? Possible categories include: Strong and fearless, meaning that you can mix comfortably with cars regardless of volume or speed. Enthused and confident, meaning that you are comfortable in bike lanes. Or, interested but concerned, meaning that you require separated, high-quality bicycle facilities. Also, if none of the above apply, how would you describe yourself as a cyclist?
4. What is your most common reason for cycling?

5. When cycling, how do you choose the route you take? i.e., Do you prefer the shortest route, the most scenic route, or the easiest route?
6. What are your primary factors related to safety when riding a bicycle?
7. What are the actions you believe you must perform to increase your personal safety when cycling?
8. Do you feel any of the actions necessary to increase your personal safety require you to not fully follow existing traffic and bicycle laws?
9. Roadway compliance means conforming to the laws of the road for all members who use it, whether they be bicyclists, pedestrians, or drivers. Compliant behaviors include following posted speed limits, fully obeying posted regulatory signs, and crossing at signals during the walk signal only. As a roadway user, whether as a driver, cyclist, or pedestrian, are you always fully compliant with all road laws?
10. What do you think about the noncompliant behaviors of drivers as compared to the noncompliant behaviors of bicyclists?
11. The State of Idaho's "safety stop law" is a statute that has been in place in Idaho since the 1980s that allows bicyclists to treat stop signs as yield signs. Therefore, cyclists are able to pass through a stop-controlled intersection with a stop sign without having to come to a complete stop as long as they do not impede the actions of road users who have right-of-way. Recently, in the Pacific Northwest, including Oregon and Washington, similar laws have been enacted. In Oregon, a similar law went into place at the beginning of January 2020. Then, in Washington, one went into place at the beginning of October 2020. As, a cyclist, what are your thoughts about these laws?
12. And, as a driver, what are your thoughts about these laws?
13. Will the implementation of these laws change the way you behave at a stop sign controlled intersection in any mode?
14. Some states have adopted similar bicycle laws that allow bicyclists to treat red traffic lights as stop signs. This means that bicyclists are allowed to proceed on red after stopping, provided that there is no conflicting traffic. What are your thoughts concerning these so-called “Dead Red” Laws?

15. Are there any additional comments you have regarding your role as a cyclist or as a driver? What about the characteristics of compliance or the Idaho safety stop specifically?
16. We will be conducting a survey with the University of Idaho on the Idaho safety stop in the Pacific Northwest, and we are wondering if you think there are any questions that you would like to be asked in the survey.

As scripted, the questions above were developed and approved in consultation with the Institutional Review Board at Gonzaga University before any interviews occurred. These questions were developed specifically to target each demographic of interviewees and generate a more holistic understanding of expert opinions and experiences concerning the implementation of these new statutes.

As may be observed, each interview began with logistical questions regarding interview recording, confidentiality, letter of consent, and team member introductions. Next, interviewees were asked general opening questions concerning their cycling frequency, behavior, preference, skill level, and decision-making while cycling. The goal of this initial group of questions was to determine the cyclist type of the interviewee. Overall, these questions helped to establish the interviewee's comfort, as well as his or her frequency and level of ridership, if any.

The next series of questions focused upon the interviewee's compliance with existing roadway legislation. Initially, compliance was explained to the interviewee so that a clear research definition could be maintained. Then, the interviewee was asked about his or her personal compliance as a roadway user–driver, bicyclist, or pedestrian. Questions regarding compliance helped to establish a means of comparison between non-compliant behaviors as cyclists versus non-compliant behaviors as drivers and as pedestrians. The interviewee was also asked to elaborate on his or her personal opinions about the comparison. This allowed the interviewee to put himself or herself into each role and directly compare his or her personal modal experiences to see whether there were major differences or contradictions between them.

The third series of questions transitioned to focus upon bicycle safety stop laws specifically. This section began with a definition of the Idaho safety stop statute and similar laws in Oregon and Washington. If the interviewee indicated that he or she bicycled in the opening round of questions, then he or she was next asked about his or her current behavior with regard to stop signs. The interviewee's opinions about safety stop laws in general were also addressed.

The goal of this group of questions was to determine whether the change in legislation had a meaningful impact on the behavior of the cyclist. To this end, the interviewee was also asked to think about the laws as a driver and explain any differing opinions from the perspective of other road users. Additionally, the concept of treating red light signals as stops or yield signs was introduced with the explanation that cyclists would be able to treat a traffic signal like a stop sign. The interviewee was then asked to explain his or her opinions on these aspects of the law. Overall, the Idaho safety stop questions were directed toward not only official legislation but also the interviewee's personal opinions and sentiments concerning recent law changes and discrepancies between driver and cyclist behaviors.

In concluding each expert interview, the interviewee was finally asked to provide any additional comments about road user roles, compliance behaviors, or laws related to the bicycle rolling stop. The University of Idaho survey phase of the project was briefly introduced to the interviewee as the final question of the interview. This requested that the interviewee provide any questions that he or she thought should be included in the survey based upon the interview just experienced. This question helped to provide content and questions that the PacTrans team might not have initially considered. Of course, open-ended questions like these also provided more information regarding the most important topics, concerns, and considerations of each different interviewed demographic.

3.2.3. Conducting the Interviews

All interviews completed for this research project were conducted with "Zoom" online meeting software, and automatic transcriptions of each interview were composed. Because these automatic transcriptions were often incomplete or incorrect, the recorded video files of each interview were also always retained, and they were used as the basis for later correction and assessment of transcriptions. Thus, all quotations utilized in this report can be considered exactly representative of interviewee sentiments. For privacy considerations, all video and audio files were deleted at the end of this research project, in accordance with IRB recommendations.

For this project, an interviewee saturation model was developed to be sure that interview data collected could be maximized while extraneous or unnecessary data were minimized. Therefore, the researchers agreed to continue conducting interviews until three consecutive conversations yielded no new results or useful materials. The researchers arrived at this material saturation level after 17 interviews, at which point the interviewing process ceased, and any remaining subjects were let go.

Some simplified demographic information concerning the participants from each of the 17 final interviews has been tabulated in table 3.1.

Table 3.1 Interview Stakeholder Sorting and Classification

Interviewee #	Stakeholder Group	Region
1	Emergency Response Personnel	Washington
2	Emergency Response Personnel	Washington
3	Legislator	Washington
4	Avid Cyclist	Washington
5	Avid Cyclist	Oregon
6	Avid Cyclist	Washington
7	Non-Cyclist	Oregon
8	Avid Cyclist	Washington
9	Avid Cyclist	Oregon
10	Law Enforcement Personnel	Oregon
11	Avid Cyclist	Washington
12	Law Enforcement Personnel	Oregon
13	Law Enforcement Personnel	Oregon
14	Emergency Response Personnel	Oregon
15	Avid Cyclist	Oregon
16	Avid Cyclist	Oregon
17	Avid Cyclist	Oregon

These 17 interviews were conducted by student researchers at Gonzaga University between February 10, 2021, and March 17, 2021. At that time, the Gonzaga team determined that the information gathered was comprehensive enough to proceed, and no further interviews were required.

3.2.4. Interview Analysis

Analysis of each interview began with the creation of an accurate transcription, which was produced in the combined automatic and manual method previously described. Once each transcription had been corrected to represent, precisely, what was said by both interviewers and interviewees, these records were then uploaded to a software called Dedoose for further analysis.

Dedoose is an application-based coding platform intended to aid in the codification and systematic analysis of qualitative data. To use the Dedoose program, a researcher uploads documents (in this case, interview transcriptions) and then creates codes to recognize similar word patterns, phrases, and content labels across all documents. Codes can also be created by reading the transcriptions, manually highlighting important passages, and assigning thematic codes to isolate and save those passages.

After first writing codes to recognize and isolate each interview question and response in Dedoose, the researchers next read through all interviews in detail, focusing upon intensive rhetorical analysis and extensive thematic analysis of written elements, such as diction, syntax, and detail choice. From these analyses, eleven themes were developed and coded, each representing a particular topic or consideration addressed by at least one quarter of interviewees. By defining, coding, and isolating each of these themes in Dedoose, researchers could more easily compare the specific responses of different stakeholder groups, identifying which groups were more oriented toward which thematic concepts. Thus, Dedoose helped to turn subjective interview results into objective and quantitatively supportive conclusions. The eleven coding themes are briefly explained and formally defined below:

Theme 1. Safety: This included all aspects of safety, including traffic safety, roadway and infrastructure safety, and feelings of security or insecurity.

Theme 2. Helmets: This included any mention of helmets, whether for or against their use.

Theme 3. Visibility (Reflections, Clothing, Signals): This included any mention of reflectors, reflective clothing, hand signaling, special lighting, special mirrors, or other equipment intended to increase bicycle rider visibility.

Theme 4. Education: This included any mention of education, including the need for more formal education or the need for more social education concerning the Idaho safety stop law.

Theme 5. Conflict between Motorist/Bicyclist: This included any mention of conflict between motorist and bicyclist interests, including intersection and right-of-way conflicts.

Theme 6. Fear of Bicycling (Feeling of Danger): This included any concerns for general cyclist safety, including fear of cars, fear of breaking the law, or impairment of cycling activity due to personal safety risk and concern. Note that “fear” is an emotional trigger term (*pathos*) which differs from general safety remarks (*logos*). This was a unique code for statements expressing great "terror," "concern," or "anxiety" about the current bicycling situation.

Theme 7. Legalizing Already-Occurring Behaviors: This included any remarks about cyclists already practicing stop sign yields before the passage of the Idaho Safety Stop law in Washington and Oregon. This also included instances of admission of rule-breaking activities for the purposes of safety or convenience before official legalization and/or decriminalization of such behaviors.

Theme 8. Confidence: This included the mention of feelings of "confidence," "comfort," or "fearlessness" as being requisite attitudes of the bicycling community.

Theme 9. Awareness of the Law: This included any comments suggesting ignorance of the law or the fear of the general public not being familiar with the Idaho safety stop law or other bicycling rules and regulations.

Theme 10. Particularly Strong Opinions: This was a more subjective category for the purposes of quotation population. Some shareholders expressed incredibly strong opinions for or against the passage of the Idaho Safety Stop law, and these exclamatory remarks were specially coded to be isolated and analyzed to judge level of community involvement, interest, and satisfaction/dissatisfaction with current measures.

Theme 11. Land-Use Considerations: This theme included any direct mentions of differences experienced between rural versus urban land uses. Note that far more rural interviewees drew this distinction than did urban interviewees, who tended to discuss only city biking.

3.3. Interview Results by Stakeholder, Gender, and Ridership Type

The immediate results gained from the data collection process described above were both interesting and revealing, providing a few novel surprises as well as general confirmation of the initial hypotheses. The Dedoose programming software transforms qualitative interview data into quantitative data by plotting what percentage of text in each interview transcription "belongs" to each identified theme through rhetorical analysis and manual highlighting. Thus, the percentage values described in figures 3.2 through 3.4 and tables 3.2 through 3.4 represent the quantitative percentages of total transcribed text that were qualitatively assigned to each thematic concept. With this in mind, some striking results may be seen in figure 3.2, in which the overall percentage of total transcriptions belonging to each identified theme are plotted.

Additionally, each bar on that graph is chronologically subdivided by stakeholder type to accentuate interesting differences and disparities that demonstrate which stakeholders were most interested in which thematic concepts. For example, a total of 15 percent of transcribed text related to "Theme 11: Land-Use Considerations," consisting of 12 percent of *total transcribed* text coming from law enforcement interviewees and 3 percent of *total transcribed* text coming from avid cyclist interviewees. Because some passages of text related simultaneously to multiple coding themes, some passages were over-highlighted and counted for all applicable topics. Meanwhile, other passages were never coded because they did not relate to any particular theme, but they instead contained extraneous conversation or otherwise non-thematic dialogue. For this reason, the sum of all themes' percentages is not equal to 100 percent.

In figure 3.2, the overall height of each bar demonstrates what percentage of all combined interviews focused on each particular theme. From this, it is interesting to note that the age-old adage "safety first" certainly held true in this data set, since "Theme 1: Safety" was by far the most discussed topic, mentioned in over 68 percent of the content of combined interviews. "Theme 7. Legalizing Already-Occurring Behaviors" was the second most discussed topic, at approximately 45 percent of overall responses, and "Theme 5. Conflict between Motorist/Bicyclist" was the third most discussed theme, at 43 percent of responses overall.

Certainly, the quantity of mentions for these three top themes was corroborated by the qualitative intensity of discussion concerning each of these three important concepts. While a large majority of all stakeholders discussed safety in various forms, it is also true that some particular interviewees described intense feelings of "terror" and "insecurity" regarding new safety stop legislation and transportation systems in general. While most avid cyclists were likely to attribute their utmost safety concerns to "cars," "traffic," and "inattentive drivers," few motorists were likely to ascribe any personal safety concerns to bicyclists, although one interviewee confessed that "as a driver, I don't feel safe on the road with cyclists, just like as a cyclist, I don't feel any safer with cars around." Indeed, the safety concern of conflict between motorists and bicyclists, comprising elements of themes 1, 5, and 6, was avery one-sided yet recurring theme in the research. This suggests that many riders were extremely conscious of automobile hazards in a way that motorists did not reciprocate. Meanwhile, the high number of mentions concerning "Theme 7. Legalizing Already-Occurring Behaviors" corresponded to previously conducted literature reviews, which indicated that many people see new safety stop legislation as, in the words of some interviewees, “simple decriminalization” or “counter-legislation” that “helps to recognize the present reality.”

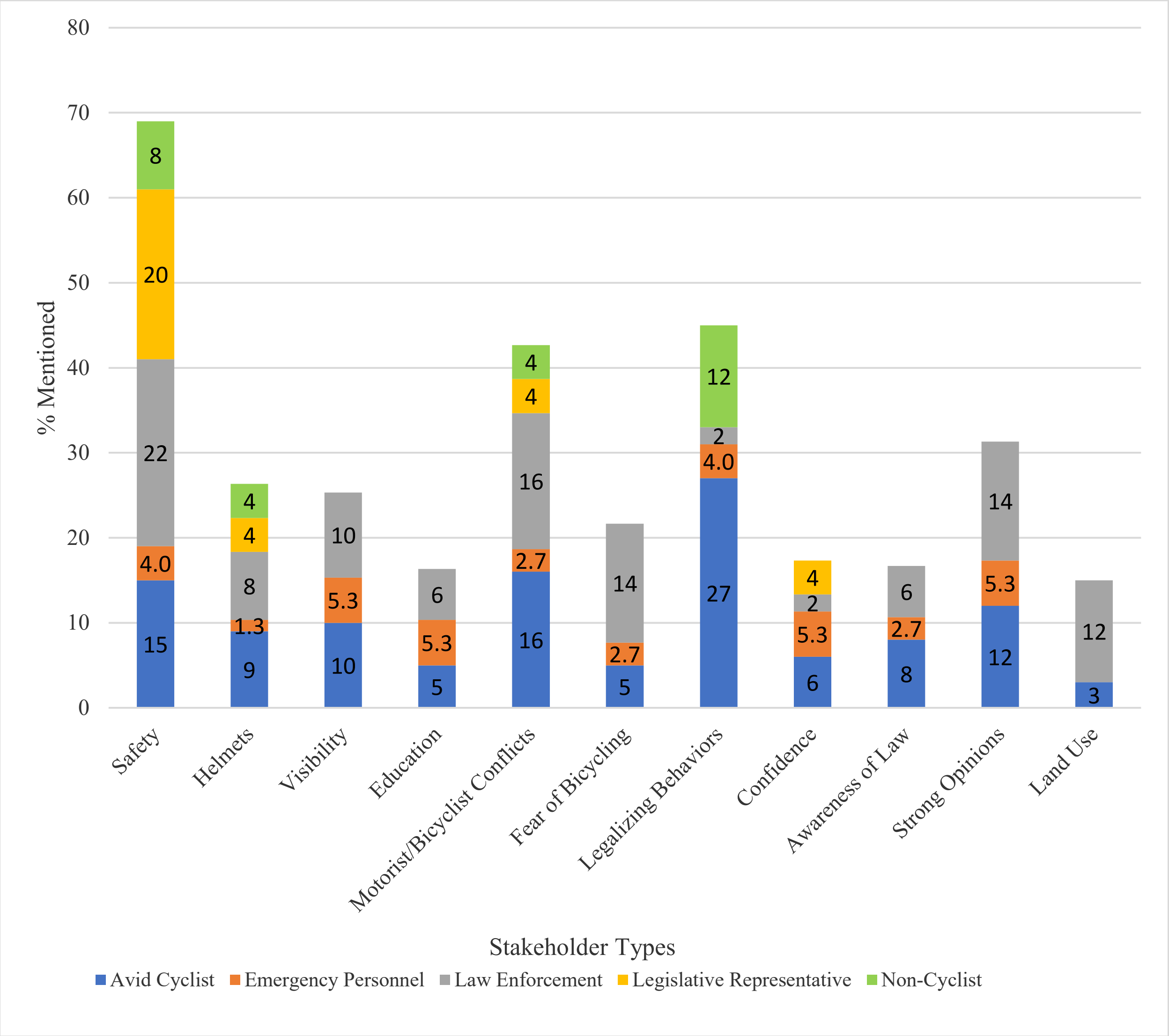


Figure 3.2 Percentages of Interview Text by Theme and Stakeholder Type

Conversely, it is also interesting to consider which themes did not appear as frequently in the interviews. While it is true that many individual interviewees offered unique and novel contributions not seen in any other transcripts, it was also observed that some weaker themes pervaded this stage of research. For example, it was hypothesized that a large majority of expert interviewees would be aware of Idaho safety stop and similar laws, but this was not seen in the research. In fact, only about 16 percent of expert respondents claimed that they were up-to-date about the current laws concerning bicyclists at stop signs. On the other hand, ironically, only 17 percent of respondents agreed that education was a priority to increase the effectiveness of the law and public awareness of it.

Finally, figure 3.2 shows which stakeholders were most attuned to which themes. Only three themes, "Safety," "Helmets," and "Conflict between Motorist/Bicyclist," were discussed by all stakeholders, which represents only very limited consensus among the general public concerning safety stop legislation, particularly given that fewer than half (only 47 percent) of interviewees who mentioned "helmets" even advocated for their use. Also worth noting, once again, is "Theme 7. Legalizing Already-Occurring Behaviors," under which both avid cyclists and non-cyclists concurred that bicycles yielding at stop signs should be decriminalized, with little support from other stakeholders.

Also noteworthy were some unusually intense quotations categorized as "Theme 10. Particularly Strong Opinions," including a number of passionate pleas both for and against the implementation of BRS statutes. Every law enforcement officer interviewed held strong opinions against the implementation of such statutes, and no other group could claim such homogeneity in its responses for or against the new laws. Specifically, certain law enforcement officers responded to questions concerning BRS legislation with statements ranging from such mild sentiments as, "when I heard about this in Oregon, I initially didn't think it was the brightest idea," to downright outrage in phrases like, "Am I concerned? F*** yeah!" and "it doesn't matter how right you are if you are dead." Numerous law enforcement officers further backed up their claims by describing incidents in which they had seen cyclists struck by cars as a result of BRS laws, or they discussed other road perils experienced on the job. In contrast, cyclists and motorists who supported the new laws attested that they "love the new freedom" that the laws provide, and they asserted that they would "be very careful" using the new yields but that they were "necessary" and "super helpful."

Table 3.2, offers a more numerical presentation of the graph in figure 3.2, using percentages of transcribed text to demonstrate the relative amount that different stakeholder types discussed each coded theme. While many stakeholders did not discuss certain themes at all, the law enforcement stakeholders made a more united plea concerning safety, discussing that theme throughout 22 percent of their interviews. Avid cyclists also made a united claim that the new legislation would simply decriminalize already-occurring behavior, a topic that they brought up 27 percent of the time. Legislators also discussed safety 20 percent of the time as the third largest trend.

Table 3.2 Percentages of Interview Text by Theme and Stakeholder Type

Themes	Avid Cyclists	Emergency Personnel	Law Enforcement	Legislative Representatives	Non-Cyclists
Theme 1. Safety	15	4	22	20	8
Theme 2. Helmets	9	1	8	4	4
Theme 3. Visibility (Reflections, Clothing, Signals)	10	5	10	0	0
Theme 4. Education	5	5	6	0	0
Theme 5. Conflict between Motorist/Bicyclist	16	3	16	4	4
Theme 6. Fear of Bicycling (Feeling of Danger)	5	3	14	0	0
Theme 7. Legalizing Already-Occurring Behaviors	27	4	2	0	12
Theme 8. Confidence	6	5	2	4	0
Theme 9. Awareness of the Law	8	3	6	0	0
Theme 10. Particularly Strong Opinions	12	5	14	0	0
Theme 11. Land Use Considerations	3	0	12	0	0

Thus far, the results of the interview stage of this research project have been discussed in terms of stakeholder groups versus coded themes. While this was likely the most valuable overlay of the data attained, it was also interesting to observe overlays of gender and rider type, since unique trends were seen in these data comparisons as well.

For the overlay of self-identified genders and themes shown in figure 3.3 certain unique differences can be seen between male and female stakeholders. Although these results were somewhat skewed by the fact that fewer women than men volunteered to be interviewed, it is nevertheless interesting to note that women discussed “Theme 4: Education” and “Theme 9: Awareness of the Law” a great deal more than men, whereas men appeared to be more concerned with “Theme 1: Safety,” “Theme 7. Legalizing Already-Occurring Behaviors,” and “Theme 11: Land-Use Considerations” than did women. These results are further supported with textual examples of women claiming that “communication and education are necessary” for good ridership, and "it can be difficult to remember that we each have equal responsibility on the roadways, so education is important to stay [up-to-date] on the laws."

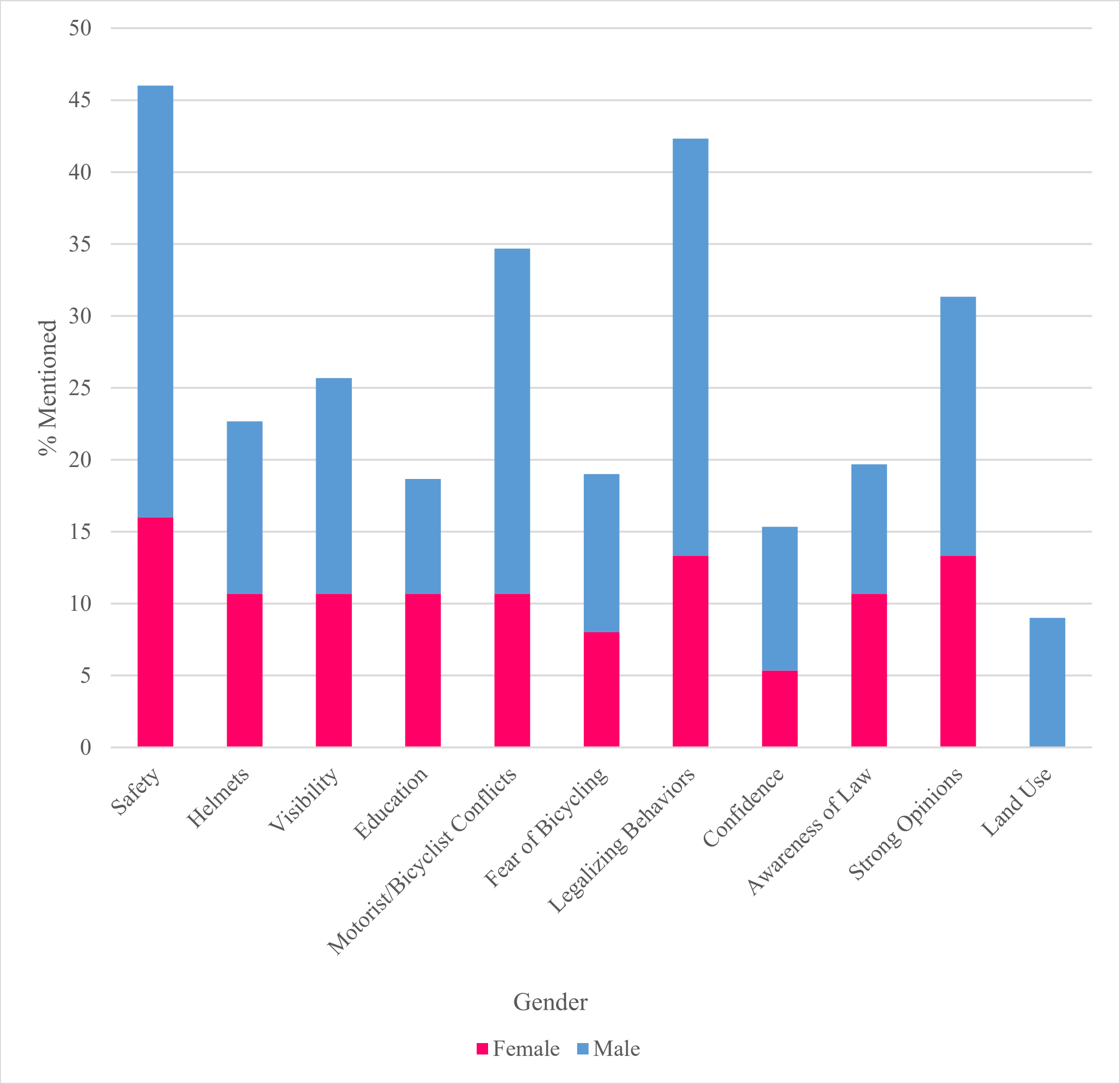


Figure 3.3 Percentages of Interview Text by Theme and Gender

In Figure 3.3, note that, as before, the percentage axis represents the actual percentage of transcribed text and not the percentage of respondents. This means that although participants' gender distribution was somewhat skewed, the textual percentages still represent meaningful and comparative data.

Table 3.3 offers a more numerical presentation of the graph in figure 3.3, using percentages of transcribed text to demonstrate the relative amount that each gender discussed each coded theme.

Table 3.3 Percentages of Interview Text by Theme and Gender

Themes	**Women**	**Men**
Theme 1. Safety	16	30
Theme 2. Helmets	11	12
Theme 3. Visibility (Reflections, Clothing, Signals)	11	15
Theme 4. Education	11	8
Theme 5. Conflict between Motorist/Bicyclist	11	24
Theme 6. Fear of Bicycling (Feeling of Danger)	8	11
Theme 7. Legalizing Already-Occurring Behaviors	13	29
Theme 8. Confidence	5	10
Theme 9. Awareness of the Law	11	9
Theme 10. Particularly Strong Opinions	13	18
Theme 11. Land Use Considerations	0	9

Finally, an overlay of bicycle rider type and coded themes revealed interesting trends concerning level of bicycle comfort and usage versus unique individual concerns and interests. While it is true that some interviewees did not bicycle at all, and a few even identified themselves as “non-cyclists,” all respondents nevertheless identified with one of three ridership levels, with zero interviewees choosing the “Other” or “I Never Bicycle” categories offered. The three categories chosen, therefore, were “Strong and Fearless,” meaning that the cyclist could mix comfortably with cars regardless of volume or speed; “Enthused and Confident,” meaning that the cyclist was comfortable in bike lanes; and, “Interested but Concerned,” meaning that the cyclist required separated, high-quality bicycle facilities.

The results of this plotted data, displayed in figure 3.4 and tabulated in table 3.4, are striking. By and large only the top 1 percent (Strong and Fearless) of bicyclists discussed “Theme 7. Legalizing Already-Occurring Behaviors,” and had “Theme 10. Particularly Strong Opinions.” However, other sizable thematic topics, such as “Theme 1: Safety,” were far more equally distributed among ridership types, thus suggesting that all cyclists at least mentioned safety. Understandably, some topics, such as “Theme 8: Confidence,” were more applicable to more daring riders and not to those who described themselves as concerned.

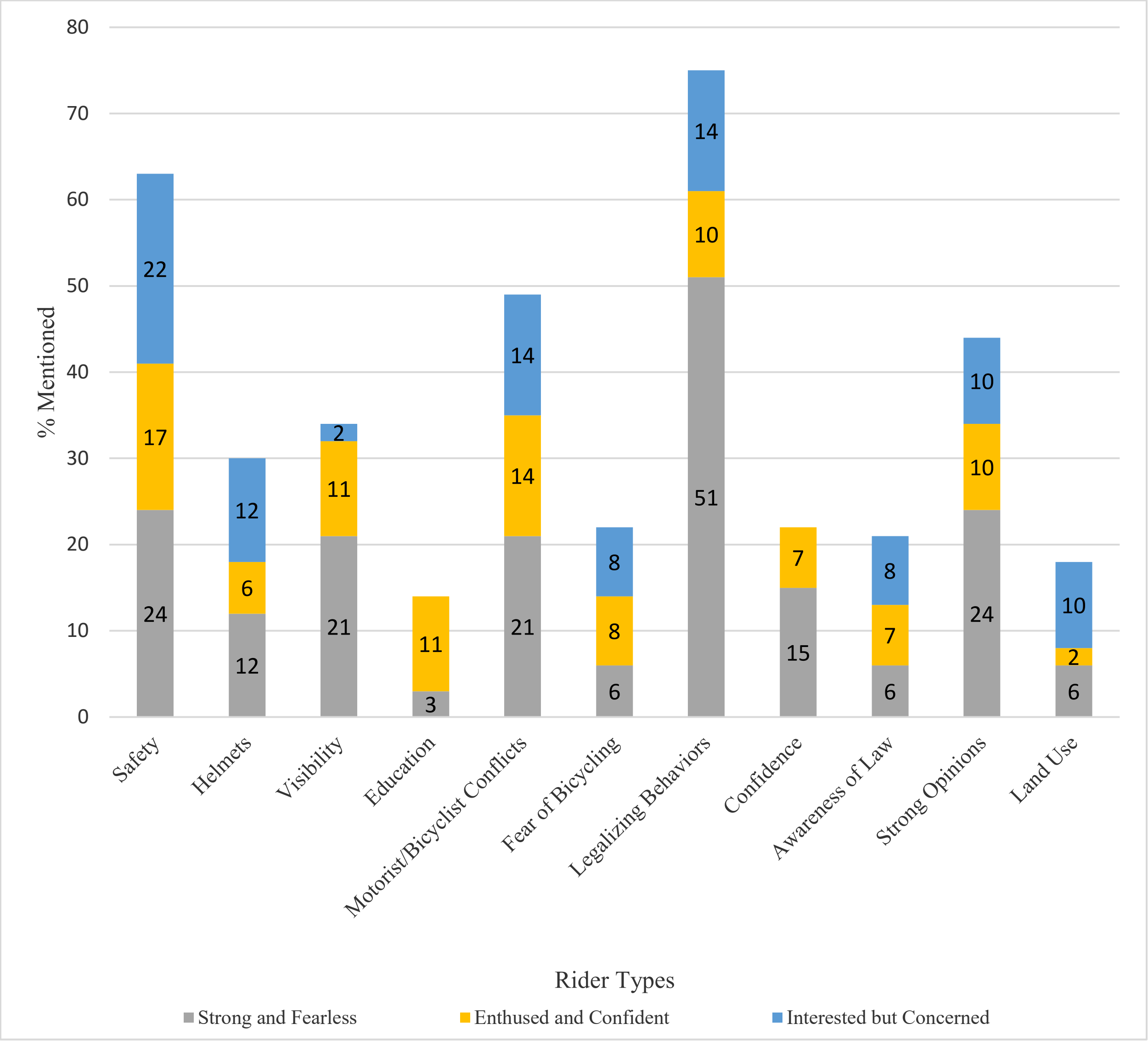


Figure 3.4 Percentages of Interview Text by Theme and Rider Type

Table 3.4 Percentages of Interview Text by Theme and Rider Type

Themes	Strong and Fearless	Enthused and Confident	Interested but Concerned
Theme 1. Safety	24	17	22
Theme 2. Helmets	12	6	12
Theme 3. Visibility (Reflections, Clothing, Signals)	21	11	2
Theme 4. Education	3	11	0
Theme 5. Conflict between Motorist/Bicyclist	21	14	14
Theme 6. Fear of Bicycling (Feeling of Danger)	6	8	8
Theme 7. Legalizing Already-Occurring Behaviors	51	10	14
Theme 8. Confidence	15	7	0
Theme 9. Awareness of the Law	6	7	8
Theme 10. Particularly Strong Opinions	24	10	10
Theme 11. Land Use Considerations	6	2	10

3.4. Conclusions

Combining quantitative and qualitative data to create a multifaceted view of current public opinions concerning relatively new and novel pieces of BRS legislation, the interview component of this research project arrived at interesting conclusions characterizing current public sentiments across ridership levels, genders, and stakeholder types. The interview methodologies and results described above, although informative in their own right, also became integral components of further steps in the research process.

Perhaps most importantly, the interviews conducted also offered a wealth of anecdotal evidence and first-hand experience concerning the usage of BRS laws across the Pacific and Inland Northwest. Numerous stakeholders contributed personal narratives and considerations of current legislation to help inform not only quantitative research proceedings but also the decisions and actions of future legislators and law enforcement officers. This sort of public dialogue and conversation is an important step toward the implementation, amendment, and improvement of new and existing laws, both in the three states studied and across the nation.

CHAPTER 4. PUBLIC PERCEPTION SURVEY

4.1. Introduction

On the basis of the results from the expert interviews and the literature review, the research team developed an online survey that sought to examine public perceptions of bicycle safety and behavior at intersections. After they had identified the main purpose of the survey, they developed an extensive list of potential survey questions after several brainstorming sessions. These questions were then edited for clarity or, in some cases, removed from the survey instrument if their relevancy was limited in nature. At the end of this iterative process, the research team enlisted the help of close colleagues to evaluate the questions for respondent comprehension and understanding. Specific questions focused on the Idaho Stop (and the variations of this law as adopted by individual states) were tailored to respondents' particular state of residence.

After the survey questions had been finalized, the research team enlisted the help of Qualtrics, an experience management company, to provide a platform to conduct the web-based survey. Qualtrics was contracted to gather and collect survey samples from residents of three Pacific Northwest states: Idaho, Washington, and Oregon. The survey was administered in June and July of 2021.

4.2. Results

A total of 550 survey responses were collected for this study. Because of the nature of the survey questions, residents from the states of Idaho (n=157), Washington (n=195), and Oregon (n=198) were specifically targeted. Table 4.1 summarizes of the demographic information of this sample population.

Table 4.1 Demographic Information for Interview Samples (n=550)

Demographic Information	No.	%
Age		
18 - 35	154	28.0%
36 - 49	157	28.6%
50 - 64	133	24.2%
65 and over	106	19.3%
Gender		
Female	347	63.1%
Male	193	35.1%
Non-Binary	8	1.5%
Other	1	0.2%
Prefer not to answer	1	0.2%
Race		
White / Caucasian	450	81.8%
Hispanic / Latino	28	5.1%
Asian / Pacific Islander	26	4.7%
Black / African American	15	2.7%
American Indian / Alaskan Native	8	1.5%
Multiple / Other	23	4.2%
Household Income		
Less than $50,000	261	47.5%
$50,000 to $99,999	169	30.7%
Over $100,000	94	17.1%
Prefer not to answer	26	4.7%

The respondents were also asked to self-select the cyclist type that best fit their personal activity (table 4.2). These cyclist types were developed by Roger Geller, who served as the Bicycle Coordinator for Portland, Oregon. He defined four types of cyclists, namely Strong and Fearless, Enthused and Confident, Interested but Concerned, and No Way No How (Dill and McNeil, 2013).

Table 4.2 Self-selected Cyclist Type (n=550)

Description	Count	Percentage
Strong and Fearless: Willing to bicycle with limited or no bicycle-specific infrastructure	91	**16.6%**
Enthused and Confident: Willing to bicycle if some bicycle-specific infrastructure is in place	176	32.0%
Interested but Concerned: Willing to bicycle if high-quality bicycle infrastructure is in place	188	34.2%
No Way, No How: Unwilling to bicycle even if high-quality bicycle infrastructure is in place	95	**17.3%**

4.2.1. Examining the Perspectives of Bicycle Riders

From the overall sample size of 550 respondents, 59.1 percent (n=325) indicated that they had ridden a bicycle in the last two years. This time period was meant to take into consideration the fact that bicycle riding behaviors may have deviated from past practices as a result of the COVID-19 pandemic.

This subset of respondents indicated that their main purpose for riding a bicycle was for recreation and leisure (42.0 percent, n=256) and/or physical exercise (37.0 percent, n=225). Approximately 13.3 percent (n=81) of the respondents indicated that they used a bicycle for general transportation purposes as an alternative to driving or walking. Only 5.8 percent (n=35) indicated that they used their bicycle for commuting to work, and 2.0 percent (n=12) of the respondents indicated that they used their bicycle as part of their work responsibilities. Note that respondents were given an option to choose more than one response to this question, so the number tally exceeded the actual number of surveyed bicycle riders.

When asked to categorize the facility type that represented the largest portion of their trip, bicycle respondents ranked a designated bicycle lane (25.2 percent, n=82) the highest. This was followed by riding in the street or roadway (20.0 percent, n=65), roadway shoulder (16.6 percent, n=54) or multi-use pathway (16.6 percent, n=54), and sidewalk (16.0 percent, n=52). The remaining 5.5 percent of bicyclists (n=18) indicated that they used some other type of facility, which presumably could have represented some form of off-road facility.

Riding preferences varied by season (figure 4.1). In the Pacific Northwest, snow and ice are common in the winter and can impair travel opportunities. The results from this survey indicated that 58.2 percent (n=189) of bicyclists either occasionally (ride three to four times per month), frequently (two to three times per week), or very frequently (every day) rode their bicycle during the spring. This percentage increased to 64.0 percent (n=208) in the summer before dipping to 49.2 percent (n=160) in the fall. Only 22.5 percent (n=73) of the bicyclists indicated that they still rode a bicycle with the same frequency in the winter months, and most respondents (77.5 percent, n=252) indicated either never or infrequently riding (one to two times in a season) between December and February.

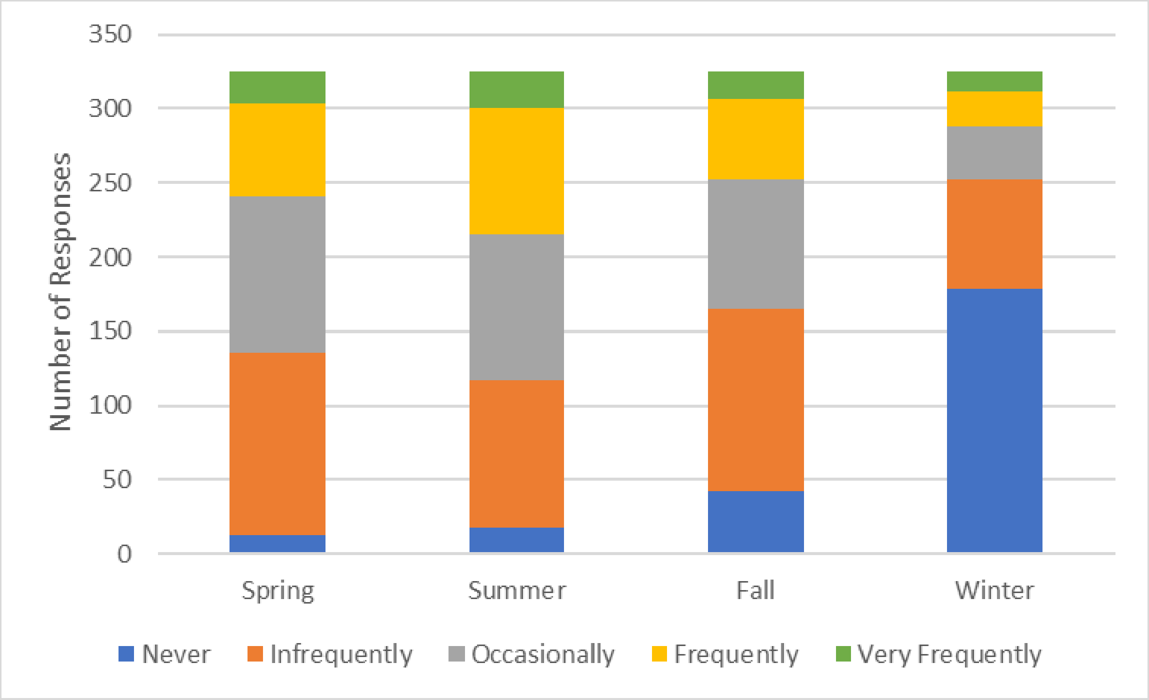


Figure 4.1 Seasonal Riding Preferences by Bicyclists

A closer look at the behaviors of those who rode a bicycle in the last two years (n=325) indicated that the during the season that they rode their bicycle the most, a majority of the respondents (44.6 percent, n=145) traveled between 1 and 5 miles by bicycle during a typical week. Other weekly mileage tallies included 6 to 10 miles (26.5 percent, n=86), less than 1 mile (15.1 percent, n=49), 11 to 20 miles (8.0 percent, n=26), and more than 20 miles (5.9 percent, n=19).

The research team explored the perceived travel environment of bicyclists (see table 4.3). In this study, most bicyclists (53.5 percent, n=174) agreed or strongly agreed with the sentiment that drivers were aware of them when they were bicycling. Only 29.9 percent (n=97), however, agreed or strongly agreed that they felt safe when riding in the roadway with or alongside vehicular traffic.

Table 4.3 Perceptions of Bicyclists when Riding (n=325)

Statement	**Strongly Disagree**	**Disagree**	**Neither Agree nor Disagree**	**Agree**	**Strongly Agree**
Drivers are aware of me when I am cycling.	6.2% (20)	16% (52)	24.3% (79)	**43.1%** **(140)**	10.5% (34)
When I ride in the roadway (with or alongside vehicular traffic), I feel safe.	12% (39)	**32.9%** **(107)**	25.2% (82)	24.3% (79)	5.5% (18)

4.2.2. Bicycle Behaviors at Intersections

Two of the key objectives of this study were to diagnose how people felt about general bicycle behavior at intersections and to better understand public familiarity with BRS laws such as the Idaho Stop. As part of this survey, respondents were asked to rate on a five-point Likert scale their level of agreement with three specific statements regarding bicycle travel through an intersection if no approaching traffic was present:

- Bicyclists should be allowed to roll through a stop sign at an intersection (i.e., not have to stop) if there is no approaching traffic.
- Bicyclists should be allowed to roll through a red light when making a right turn at an intersection if there is no approaching traffic.
- Bicyclists should be allowed to stop and then turn left or proceed through an intersection without waiting for a signal to change if there is no approaching traffic.

Participant responses are provided in tables 4.4 and 4.5. In this case, a distinction was made to separate the responses of bicyclists (those who had ridden in the last two years) with the responses of non-bicyclists.

Table 4.4 Bicyclist Behavior at Intersections, by Bicyclists (n=325)

Statement	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
Bicyclists should be allowed to roll through a stop sign at an intersection (i.e., not have to stop) if there is no approaching traffic.	15.7% (51)	**29.8% (97)**	16.3% (53)	29.5% (96)	8.6% (28)
Bicyclists should be allowed to roll through a red light when making a right turn at an intersection if there is no approaching traffic.	15.1% (49)	26.8% (87)	14.2% (46)	**32.0% (104)**	12.0% (39)
Bicyclists should be allowed to stop and then turn left or proceed through an intersection without waiting for a signal to change if there is no approaching traffic.	19.4% (63)	**31.4% (102)**	16.9% (55)	25.8% (84)	6.5% (21)

Table 4.5 Bicyclist Behavior at Intersections, by Non-Bicyclists (n=225)

Statement	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
Bicyclists should be allowed to roll through a stop sign at an intersection (i.e., not have to stop) if there is no approaching traffic.	**32.4% (73)**	28.0% (63)	15.6% (35)	20.0% (45)	4.0% (9)
Bicyclists should be allowed to roll through a red light when making a right turn at an intersection if there is no approaching traffic.	24.0% (54)	**28.4% (64)**	16.4% (37)	26.7% (60)	4.4% (10)
Bicyclists should be allowed to stop and then turn left or proceed through an intersection without waiting for a signal to change if there is no approaching traffic.	32.0% (72)	**35.6% (80)**	16.4% (37)	13.3% (30)	2.7% (6)

The results shown in these tables suggest that non-bicyclists generally preferred bicyclists to follow the behaviors of the motoring public. As a comparison, public support to allow a bicyclist to roll through either a stop sign or red light was higher from bicyclists (39 percent and 44 percent, respectively) than from respondents who had not ridden a bicycle in the last two years (24 percent and 31 percent, respectively).

A similar outcome was identified when survey respondents were asked about their familiarity with bicycle rolling stop laws (see table 4.6). In this case, 55 percent of bicyclists (n=176) were either aware or had heard of these laws but were not entirely sure of their meaning. Idaho residents were more familiar with bicycle rolling stop laws than their Oregon and Washington counterparts. By comparison, nearly two-thirds of all non-bicyclists (65.8 percent, n=148) had not heard of bicycle rolling stop laws (see table 4.7).

Table 4.6 Familiarity with Bicycle Rolling Stop Laws, by Bicyclists (n=325)

Statement	Yes	No	Have heard but unsure of meaning
Idaho Residents: Are you aware of Bicycle Rolling Stop laws such as the Idaho Stop law?	**43.0%** **(37)**	33.7% (29)	23.3% (20)
Oregon Residents: Are you aware of Bicycle Rolling Stop laws such as the Idaho Stop law?	25.8% (31)	**50.8%** **(61)**	23.3% (28)
Washington Residents: Are you aware of Bicycle Rolling Stop laws such as the Idaho Stop law?	23.5% (28)	**49.6%** **(59)**	26.9% (32)

Table 4.7 Familiarity with Bicycle Rolling Stop Laws, by Non-Bicyclists (n=225)

Statement	Yes	No	Have heard but unsure of meaning
Idaho Residents: Are you aware of Bicycle Rolling Stop laws such as the Idaho Stop law?	22.5% (16)	**56.3%** **(40)**	21.1% (15)
Oregon Residents: Are you aware of Bicycle Rolling Stop laws such as the Idaho Stop law?	21.8% (17)	**67.9%** **(53)**	10.3% (8)
Washington Residents: Are you aware of Bicycle Rolling Stop laws such as the Idaho Stop law?	5.3% (4)	**72.4%** **(55)**	22.4% (17)

4.2.3. State-Specific Outcomes

The timeline for the enactment and adoption of bicycle rolling stops has varied from state to state. In Idaho, rolling stop laws were initially passed in 1982; these allowed bicyclists to treat both stop signs and traffic signals as yield signs. In 2006, the state law was amended to clarify the treatment of traffic signals by bicyclists as a stop-then-yield condition except for certain cases of turning onto a one-way street. By comparison, rolling stop laws in Oregon and Washington were only recently passed, in 2019 and 2020, respectively. These new laws allow any bicyclist approaching an intersection controlled by a stop sign to proceed through the intersection without stopping. Bicyclists are still required to yield to traffic and pedestrians in the intersection.

Since the timeline for bicycle rolling stop laws has varied from state to state, the research team took a closer look at the state-specific responses provided by Idaho, Oregon, and Washington residents. In each case, residents were asked to share their perspectives about these laws. A series of statements were provided, and survey respondents were asked to provide a response based on a five-point Likert scale in which the scale ranged from strongly disagree to strongly agree, or from very negative to very positive.

The statements, which focused on safety, included the following:

- Bicycle Rolling Stop laws (would) decrease conflict between bicyclists and motorists in my community.
- Bicycle Rolling Stop laws (would) reduce the number of crashes between bicycles and automobiles in my community.
- Bicycle Rolling Stop laws (would) make bicyclists in my community feel more comfortable.
- Bicycle Rolling Stop laws (would) make motorists in my community feel more comfortable.

Two additional statements were asked exclusively to those who had indicated riding a bicycle in the last two years:

- What kind of effect do you think Bicycle Rolling Stop laws (would) have on your safety while cycling?
- What kind of effect do you think Bicycle Rolling Stop laws (would) have on the efficiency of your cycling trips?

As noted previously, residents from Idaho have been following BRS laws for 40 years. The survey results suggest that the opinions of residents remained mixed (see table 4.8). When asked if rolling stop laws decreased conflicts between bicyclists and motorists, nearly the same percentage agreed or strongly agreed (31.2 percent, n=49) as those who disagreed or strongly disagreed (29.9 percent, n=47). When asked if rolling stop laws reduced the number of crashes between bicycles and automobiles, a slightly higher percentage (34.4 percent, n=54) disagreed or strongly disagreed with this statement than those who agreed or strongly agreed (31.3 percent, n=49). Idaho residents did respond favorably when asked if rolling stop laws made bicyclists feel more comfortable. In this case, a large number agreed or strongly agreed (42.7 percent, n=67). By comparison, only 33.2 percent (n=52) agreed or strongly agreed that rolling stop laws made motorists feel more comfortable, a percentage that was equal to those who disagreed or strongly disagreed (33.2 percent, n=52).

Idaho residents who identified as bicycle riders in the last two years viewed the rolling stop laws more favorably than their non-bicycle riding counterparts (see table 4.9). When asked if rolling stop laws had a positive or very positive effect on their safety, 43.0 percent (n=37) agreed in comparison to only 19.7 percent (n=17) who disagreed. When asked if rolling stop laws positively or very positively contributed to their trip efficiency, over half agreed (51.2 percent, n=44).

Table 4.8 Bicycle Rolling Stop Perspectives, by Idaho Residents

Statement	**Strongly Disagree**	**Disagree**	**Neither Agree nor Disagree**	**Agree**	**Strongly Agree**
Bicycle Rolling Stop laws (would) decrease conflict between bicyclists and motorists in my community.	7.6% (12)	22.3% (35)	**38.9%** **(61)**	24.8% (39)	6.4% (10)
Bicycle Rolling Stop laws (would) reduce the number of crashes between bicycles and automobiles in my community.	12.1% (19)	22.3% (35)	**34.4%** **(54)**	26.8% (42)	4.5% (7)
Bicycle Rolling Stop laws (would) make bicyclists in my community feel more comfortable.	4.5% (7)	10.8% (17)	**42.0%** **(66)**	37.6% (59)	5.1% (8)
Bicycle Rolling Stop laws (would) make motorists in my community feel more comfortable.	9.6% (15)	23.6% (37)	**33.8%** **(53)**	28.7% (45)	4.5% (7)

Table 4.9 Bicycle Rolling Stop Effects, by Idaho Bicyclists

Statement	Very Negative	Negative	Neutral / No Effect	Positive	Very Positive
What kind of effect do you think Bicycle Rolling Stop laws (would) have on your safety while cycling?	2.3% (2)	17.4% (15)	**37.2%** **(32)**	**37.2%** **(32)**	5.8% (5)
What kind of effect do you think Bicycle Rolling Stop laws (would) have on the efficiency of your cycling trips?	2.3% (2)	9.3% (8)	37.2% (32)	**44.2%** **(38)**	7% (6)

The recent adoption of bicycle rolling stop laws in Oregon and Washington suggests that residents in these two states may have still been familiarizing themselves with the new law. For this reason, the results for these two states were examined together but separated from the Idaho results (see table 4.10 to table 4.13).

When asked if rolling stop laws decreased conflict between bicyclists and motorists, nearly the same percentage agreed or strongly agreed (31.2 percent, n=49) as those who disagreed or strongly disagreed (29.9 percent, n=47). When asked if rolling stop laws reduced the number of crashes between bicycles and automobiles, the Oregon responses were very similar to those of the Idaho residents, with a slightly higher percentage (31.4 percent, n=62) who agreed or strongly agreed with this statement in comparison to those who disagreed or strongly disagreed (29.3 percent, n=58). In Washington, respondents were more inclined to agree or strongly agree with this statement (39.4 percent, n=77) than disagree or strongly disagree (29.2 percent, n=57).

When asked if rolling stop laws would reduce the number of crashes between bicycles and automobiles, the responses from the two states were nearly identical. In Oregon, 33.9 percent (n=67) either strongly agreed or disagreed, and 31.3 percent (n=62) either disagreed or strongly disagreed. In Washington, 35.4 percent (n=69) either strongly agreed or disagreed, and 32.8 percent (n=64) either disagreed or strongly disagreed.

Oregon and Washington residents mirrored the responses of their Idahoan neighbors when asked if rolling stop laws made bicyclists feel more comfortable. In Oregon, a large number of people agreed or strongly agreed (38.4 percent, n=76). Similar results were found in

Washington, with 47.7 percent (n=93) in agreement or in strong agreement. There was less agreement when residents were asked if rolling stop laws made motorists feel more comfortable. In Oregon, a larger percentage (35.9 percent, n=71) disagreed or strongly disagreed with this statement than agreed or strongly agreed (26.8 percent, n=53). In Washington, the results yielded a nearly even split, with 35.4 percent (n=67) disagreeing or strongly disagreeing and 34.9 percent (n=68) agreeing or strongly agreeing.

Table 4.10 Bicycle Rolling Stop Perspectives, by Oregon Residents

Statement	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
Bicycle Rolling Stop laws (would) decrease conflict between bicyclists and motorists in my community.	9.6% (19)	19.7% (39)	**39.4%** **(78)**	26.8% (53)	4.6% (9)
Bicycle Rolling Stop laws (would) reduce the number of crashes between bicycles and automobiles in my community.	9.1% (18)	22.2% (44)	**34.9%** **(69)**	26.8% (53)	7.1% (14)
Bicycle Rolling Stop laws (would) make bicyclists in my community feel more comfortable.	5.6% (11)	14.1% (28)	**41.9%** **(83)**	31.3% (62)	7.1% (14)
Bicycle Rolling Stop laws (would) make motorists in my community feel more comfortable.	10.6% (21)	25.3% (50)	**37.4%** **(74)**	21.7% (43)	5.1% (10)

Table 4.11 Bicycle Rolling Stop Perspectives, by Washington Residents

Statement	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
Bicycle Rolling Stop laws (would) decrease conflict between bicyclists and motorists in my community.	8.7% (17)	20.5% (40)	**31.3%** **(61)**	29.7% (58)	9.7% (19)
Bicycle Rolling Stop laws (would) reduce the number of crashes between bicycles and automobiles in my community.	9.7% (19)	23.1% (45)	**31.8%** **(62)**	27.2% (53)	8.2% (16)

Bicycle Rolling Stop laws (would) make bicyclists in my community feel more comfortable.	3.6% (7)	10.3% (20)	**38.5%** **(75)**	36.9% (72)	10.8% (21)
Bicycle Rolling Stop laws (would) make motorists in my community feel more comfortable.	6.7% (13)	28.7% (56)	**29.7%** **(58)**	26.2% (51)	8.7% (17)

Oregon and Washington residents who identified as bicycle riders in the last two years viewed the rolling stop laws more favorably than their non-bicycle riding counterparts. This outcome was similar to the responses of Idaho bicyclists. When asked if rolling stop laws had a positive or very positive effect on their safety, 39.1 percent (n=47) agreed in Oregon and 47.9 percent (n=57) agreed in Washington. When asked if rolling stop laws positively or very positively contributed to their trip efficiency, 45.0 percent (n=54) agreed in Oregon and 49.5 percent (n=59) agreed in Washington.

Table 4.12 Bicycle Rolling Stop Effects, by Oregon Bicyclists

Statement	**Very Negative**	**Negative**	**Neutral / No Effect**	**Positive**	**Very Positive**
What kind of effect do you think Bicycle Rolling Stop laws (would) have on your safety while cycling?	3.3% (4)	17.5% (21)	**40.0%** **(48)**	30.8% (37)	8.3% (10)
What kind of effect do you think Bicycle Rolling Stop laws (would) have on the efficiency of your cycling trips?	4.2% (5)	7.5% (9)	**43.3%** **(52)**	35% (42)	10% (12)

Table 4.13 Bicycle Rolling Stop Effects, by Washington Bicyclists

Statement	**Very Negative**	**Negative**	**Neutral / No Effect**	**Positive**	**Very Positive**
What kind of effect do you think Bicycle Rolling Stop laws (would) have on your safety while cycling?	2.5% (3)	21% (25)	28.6% (34)	**37.0%** **(44)**	10.9% (13)
What kind of effect do you think Bicycle Rolling Stop laws (would) have on the efficiency of your cycling trips?	1.7% (2)	10.9% (13)	37.8% (45)	**40.3%** **(48)**	9.2% (11)

4.3. Analysis

The survey responses were further analyzed to determine potential next steps from both an education and outreach standpoint. In particular, the research team sought to examine several key questions, given the fact that BRS laws have been adopted in Idaho since 1982, whereas these laws were adopted in Oregon and Washington only in 2020:

- Given the longevity of the law in Idaho, are Idahoans more or less inclined than Oregonians and Washingtonians to support bicyclists rolling through a stop sign at an intersection (i.e., not have to stop) if there is no approaching traffic?
- Are Idahoans more or less inclined than Oregonians and Washingtonians to support bicyclists rolling through a red light when making a right turn at an intersection if there is no approaching traffic?
- Are Idahoans more or less inclined than Oregonians and Washingtonians to support bicyclists stopping and then turning left or proceeding through an intersection without waiting for a signal to change if there is no approaching traffic?
- Bicycle rolling stop laws have been adopted by all three states for at least one year. Are there knowledge or awareness gaps based on gender, age, race, or income level?

Because the questions were answered with categorical responses (as noted earlier), chi-square tests of independence were conducted for each scenario. With regard to the personal opinions of bicyclists rolling through a stop sign, residents from all three states felt that bicyclists should not be allowed to do so, and the relationship comparing Idaho residents with Oregon and Washington (combined) residents was not significant, $\chi 2$ (2, N = 550) = 0.97, p = .62.

The residents from these three states were also in agreement that bicyclists should not be allowed to roll through red lights, and the relationship again between Idaho residents with Oregon and Washington (combined) residents was not significant, $\chi 2$ (2, N = 550) = 2.80, p = .25. Similar results were determined for the condition of allowing bicyclists to stop and then turn left or proceed through an intersection without waiting for a signal to change if there was no approaching traffic. The residents were opposed to this behavior, and the relationship between Idaho residents and Oregon and Washington (combined) residents was not significant, $\chi 2$ (2, N = 550) = 2.96, p = .23.

With regard to awareness of BRS laws, Idaho residents were more aware than their Oregon and Washington counterparts, and the relationship was significant, $\chi 2$ (2, N = 550) =

12.47, $p < .05$. This result was expected to some degree, as BRS laws have been enacted in the state for nearly 40 years. However, 43.9 percent (69 out of 157) of Idaho residents indicated that they still had not heard of these laws, suggesting that universal knowledge remains a work in progress. By comparison, over half of Oregon and Washington residents (58.0 percent, or 228 out of 393 responses) had not heard of BRS laws.

The outcomes based on gender, age, race, and household income yielded varying results. The relationships between women's and men's responses ($\chi 2$ (2, N = 550) = 4.76, $p = .09$), white/Caucasian and non-white/other ($\chi 2$ (2, N = 550) = 0.28, $p = .87$), and household income levels ($\chi 2$ (4, N = 550) = 5.80, $p = .22$) were not significant. However, the age of the individual, which was grouped into four categories, was determined to be significant, $\chi 2$ (6, N = 550) = 14.32, $p < .05$. In this case, younger individuals, between the ages of 18 and 35 years, were more likely to be aware of BRS laws than their counterparts over the age of 35.

CHAPTER 5. NETWORKED DRIVING AND BICYCLING SIMULATOR EXPERIMENT

5.1. Introduction

On the basis of the feedback from the stakeholder interviews and the survey, a BRS experiment was designed that could be tested using networked bicycling and driving simulators.

5.2. Methodology – OSU Simulator Environment

The Driving and Bicycling Research Laboratory that completed this research is in the School for Civil and Construction Engineering at Oregon State University (OSU). The facilities of this laboratory include a Desktop Development Simulator, Full Cab Driving Simulator, Quarter Cab Heavy Driving Vehicle Simulator, and a full-scale Bicycling Simulator. The facilities are used to conduct research in areas of transportation human factors, transportation safety, pedestrians and bicycles, commercial motor vehicles, and connected and automated vehicles. The data acquisition system allows for networked data collection while the bicycling and driving simulators operate simultaneously.

5.2.1. Bicycling Simulator

The full-scale Bicycling Simulator consists of an instrumented urban bicycle placed on top of a stationary platform. The visual field of the bicyclist is projected onto a 10.5-ft x 8.3-ft screen that provides a forward view and reflects inputs from the bicycle for braking, pedaling, and steering, as seen in figure 5.1. The screen has a visual angle of 109° (horizontally) x 89° (vertically) and image resolution of 1024 x 768 pixels. The simulator is equipped with a surround sound system that produces ambient sound. Three digital cameras are mounted around the bicycling simulator, synchronously recording performance data such as speed, position, and headway of any dynamic actor in the simulation environment at a sampling frequency of up to 60 Hz.

Figure 5.1 OSU Bicycling Simulator from the participant's perspective

5.2.2. Driving Simulator

The Full Cab Driving Simulator consists of a 2009 Ford Fusion cab placed on top of an electric pitch motion system capable of rotating ±4 degrees (figure 5.2). The electric pitch allows for accurate representation of acceleration and deceleration for the participant in the simulator. The fully functional cab instruments allow for accurate representation of steering torques based on vehicle speed and steering angle. The cab is placed at the center of three screens measuring 11 ft x 7.5 ft (each) with a projected resolution of 1,400 x 1,050 pixels and a 180° full frontal view. The two side mirrors display a rear view with LCD displays, with a fourth projector displaying the rear view in the driver's center mirror. The simulator is equipped with a surround sound system that produces ambient sound to represent familiar driving sounds (Jannat et al., 2020). Five digital cameras are mounted around the driving simulator synchronously recording performance data such as speed, position, and headway of any dynamic actor in the simulation environment at a sampling frequency of up to 60 Hz.

Figure 5.2 OSU Driving Simulator from Outside the Vehicle (image by Mafruhatul Jannat)

5.2.3. Eye Tracking

Eye movement data were collected by using the iMotions platform in conjunction with Tobii Pro Glasses 3 (figure 5.3). These eyeglasses allow for unconstrained head and eye movement while calculating the participant's gaze based on corneal reflection, dark pupil, and stereo geometry. Data are collected synchronously, with data from the driving and bicycling simulators generating a sampling rate of 50 Hz or 100 Hz and an accuracy of 0.6 degrees (https://www.tobiipro.com/product-listing/tobii-pro-glasses-3/ n.d.). Two laptop computers operate the iMotions software for processing the eye movement data, allowing for advanced analysis with tools such as gaze replays and areas of interest (AOI) output metrics, including fixation time (https://imotions.com/biosensor/eye-tracking-glasses/ n.d.).

Figure 5.3 OSU Eye Tracking. *Left*: Tobii Pro Glasses 3 with Recording Unit. *Right*: Tobii Pro Glasses 3 Worn by a Researcher.

5.2.4. Galvanic Skin Response (GSR)

Galvanic skin response (GSR) data are dependent on sweat gland activity that is collected by two electrodes attached to two separate fingers on one hand while still allowing for freedom of movement (figure 5.4). Photoplethysmogram (PPG) signals are detected to track heart rate, and GSR sensors are used to detect changes in moisture. Data analysis tools include automated peak detection and time synchronization with other experimental data, allowing for an accurate depiction of the participants' physical state, anxiety, and stress levels.

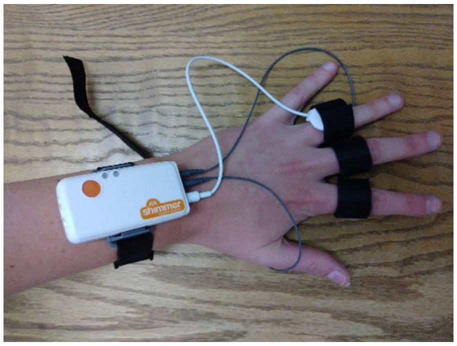


Figure 5.4 Shimmer3 GSR+ GSR and PPG Sensors (image by David S. Hurwitz)

5.3. Study Design

The simulator environment was developed by using Internet Scene Assembler (ISA) and SimCreator, which uses JavaScript-based coding to display dynamic objects such as changing traffic signals, ambient traffic, and left-turning vehicles and bicycles at intersections.

5.3.1. Networked Simulator Environment

The study was designed as a networked simulation to observe a "live interaction" at an intersection between a participant negotiating right-of-way in the driving simulator and a participant in the bicycling simulator. This was done to contribute to a novel methodology for networked experiments in which the observed interaction might require authentic responses from two human actors to reflect real world situations more accurately. To accomplish this, two virtual worlds were designed, one for the driving simulator and one for the bicycling simulator, with the final intersection being the live interaction.

In the simulation environment, dynamic objects were coded as triggers to ensure the timing of the live interaction. Figure 5.5 illustrates the design of test Tracks 1 and 2, including the separate routes for the driving and bicycling simulator, the test intersections, and dynamic triggers. As participants in the driving simulator reached the area of Wait Trigger 1, they were stopped by circular red indication; this indication remained red until the participant in the bicycling simulator arrived at Arrive Trigger 1 and caused the circular light to change to a green light, thus allowing the participant in the driving simulator to proceed. This was repeated at the Wait Trigger 2 location, where the driving simulator participant waited for a circular red indication, with a supplemental "No Turn on Red" sign, to change to a circular green indication once the participant in the bicycling simulator had reached Arrive Trigger 2. Timing was based on the researchers' understanding of a casual biking speed, and participants in the driving simulator following regulatory speed limits.

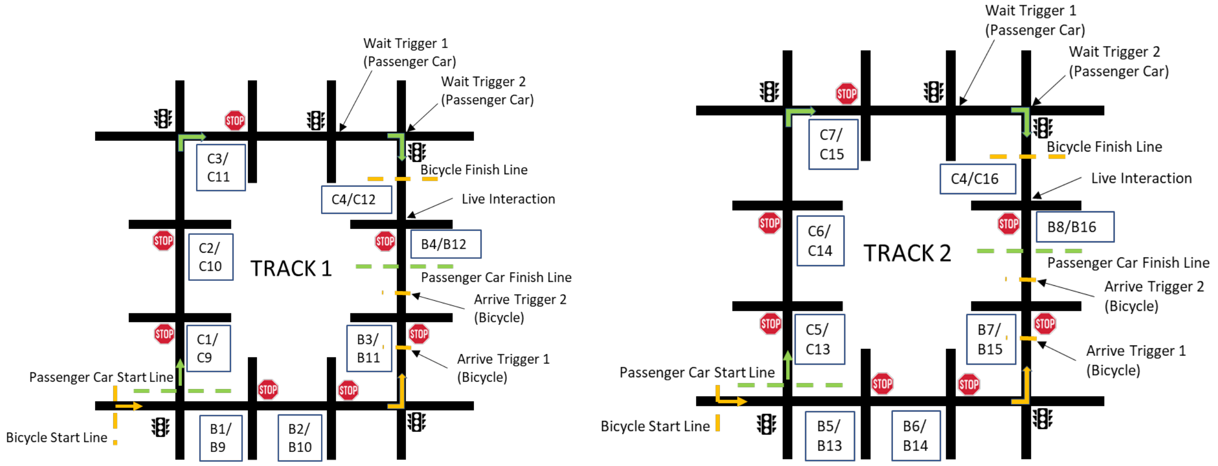


Figure 5.5 Simulator Tracks 1 and 2

All simulation environments were designed with asurroundings of medium density residential land use with light ambient traffic and were intended to imitate the town surrounding the university. Intersection approaches that were designed with test variables were stop controlled with one traffic lane in each direction. Other intersections were signal controlled, as shown in figure 5.5. Signal controlled intersections were used to provide variability to the test track and to facilitate the live interaction between the bicycling and driving participants. Roadway cross-sections consisted of one travel lane in each direction separated by a yellow center line, a 5-ft bike lane (where intended), and sidewalks on both sides of the road.

5.3.2. Independent Variables

Three primary independent variables with corresponding levels were chosen, including movement of conflicting vehicles, roadway treatment, and education about the BRS law. The movement of conflicting vehicles was presented at four different levels, including no conflicting vehicle, left turning vehicle arriving with a short gap acceptance, left turning vehicle arriving with a longer gap acceptance, and networked live interaction. The bicyclists were presented with conflicting movements by passenger cars, while drivers were presented with conflicting movements by bicycles. The different gap acceptances used to determine bicyclist through-movement behavior were based on proximity of virtual passenger cars performing left turning and through-movements at stop-controlled intersections. Alternatively, driving participants were presented with conflicting movements of virtual bicycles performing left turning movements at stop-controlled intersections. A gap was defined as a "Short Gap" when a second virtual vehicle arrived at the stop sign 5 seconds after the first virtual vehicle had completed a movement through the intersection; a "Long Gap" was when the second vehicle arrived 10 seconds after the first vehicle. Two roadway treatments were chosen—shared roadway and dedicated bike lane—to determine whether decision making was affected by exclusivity or perceived volume of traffic.

Education about the BRS law was another independent variable identified in the experimental design. Participants were asked to complete two tracks based on their current knowledge of traffic laws. At that time, the researchers educated participants about the rules and existence of the BRS law, and participants were asked to complete the same two tracks taking this knowledge into account. Table 5.1 shows the independent variables and corresponding levels.

Table 5.1 Major Independent Variables and Levels

VARIABLE	LEVEL	LEVEL DESCRIPTION
Movement of Conflicting Vehicle	0	No conflicting vehicle
	1	Left turning vehicle, long gap acceptance
	2	Left turning vehicle, short gap acceptance
	3	Live interaction
Roadway Treatment	0	Shared Roadway
	1	Bike Lane
Education on BRS Law	0	Before Education
	1	After Education

5.3.3. Dependent Variables

Dependent variables for the bicyclist included fixation time on conflicting vehicles, minimum speed of bicycle at the decision point to enter the intersection, and GSR data to determine level of stress based on peaks per minute. The dependent variable for the driver included minimum speed at the stop sign before entering the intersection.

Position and speed data were recorded using the RTI SimObserver platform throughout the entire experiment. Eye-tracking fixations and GSR data were collected and evaluated with the iMotions data acquisition and analysis software to determine visual attention and level of stress throughout the experiment.

5.3.4. Simulator Scenarios

Each participant encountered 16 simulator scenarios created in response to the independent variables identified in table 5.2. Eight scenarios were repeated for each participant, and performance measures were compared for changes before and after education about the BRS law.

Table 5.2 Simulator Scenarios

Bicycling Simulator Scenario	Roadway Treatment	Movement of Conflicting Vehicle	Driving Simulator Scenario	Roadway Treatment	Movement of Conflicting Vehicle
Track 1 – Before Education					
B1	Shared	Long Gap: Left-turning passenger cars	C1	Bike Lane	None: No bicycles
B2	Shared	None: No passenger cars	C2	Bike Lane	Short Gap: Left-turning bicycles
B3	Bike Lane	Long Gap: Through passenger cars	C3	Shared	None: No bicycles
B4	Bike Lane	Live: Live Interaction	C4	Shared	Live: Live Interaction
Track 2 – Before Education					
B5	Bike Lane	Short Gap: Left-turning passenger cars	C5	Shared	Short Gap: Left-turning bicycles
B6	Bike Lane	None: No passenger cars	C6	Shared	Long Gap: Left-turning bicycles
B7	Shared	Short Gap: Left-turning passenger cars	C7	Bike Lane	Long Gap: Left-turning bicycles
B8	Shared	Live: Live Interaction	C8	Bike Lane	Live: Live Interaction
Track 1 – After Education					
B9	Shared	Long Gap: Left-turning passenger cars	C9	Bike Lane	None: No bicycles
B10	Shared	None: No passenger cars	C10	Bike Lane	Short Gap: Left-turning bicycles
B11	Bike Lane	Long Gap: Through passenger cars	C11	Shared	None: No bicycles
B12	Bike Lane	Live: Live Interaction	C12	Shared	Live: Live Interaction
Track 2 – After Education					
B13	Bike Lane	Short Gap: Left-turning passenger cars	C13	Shared	Short Gap: Left-turning bicycles
B14	Bike Lane	None: No passenger cars	C14	Shared	Long Gap: Left-turning bicycles
B15	Shared	Short Gap: Left-turning passenger cars	C15	Bike Lane	Long Gap: Left-turning bicycles
B16	Shared	Live: Live Interaction	C16	Bike Lane	Live: Live Interaction

5.4. Experimental Protocol

This experiment was unique in that it studied two participants in the lab simultaneously and required two researchers to run the networked simulation. Participants were in separate rooms during the informed consent portion of the protocol to ensure privacy.

The study was accepted by the OSU Institutional Review Board (IRB), and all procedures were followed as outlined in Study Number IRB-2020-0745. COVID-19 protocols were also followed according to OSU's requirements for campus-wide activities during Spring Quarter 2022. Participants and researchers were welcom to wear masks, but they were not required. The lab operated two HEPA grade air filtration units and adhered to cleaning protocols according to Environmental Health and Safety (EHS).

5.4.1. Recruitment, Informed Consent, and Compensation

A total of 80 individuals, 40 for the bicycling simulator and 40 for the driving simulator, were recruited for this experiment. Recruitment came primarily from the surrounding Corvallis, Oregon, community. Advertisements were sent to two listservs, OSU Today and Oregon State University's Institute of Transportation Engineers student chapter weekly newsletter. Snowball sampling was used once a researcher had contacted a potential participant. Potential participants were asked whether they knew someone who might be willing to participate with them, making recruitment and scheduling easier and reducing the logistical complications such as cancellations. About 30 participant contacts were made through snowball sampling. Only licensed drivers were recruited for the driving simulator, and those capable of sustaining 30 minutes of physical activity were recruited for the bicycling simulator. Additionally, participants needed to be physically and mentally capable of legally operating a vehicle, have a vision prescription of no greater than +5.0, and be 18 years or older to provide written, informed consent.

The researchers did not screen participants based on gender, and an effort was made to incorporate participants of all ages from 18 to 75 years. Each participant was assigned a number to remove unique identifiers from the recorded data, and all information was kept in compliance with the approved IRB protocol.

Consent was obtained from all participants before the beginning of the experiment. The informed consent document provided an overview of the objectives of the study and the potential risks and research benefits associated with using the simulators. Simulator sickness was discussed so that participants knew symptoms and mitigation strategies should symptoms arise. Participants were given $20 compensation at the end of the experiment, and if for any reason participants were not able to complete the study, they were allowed to leave without penalty and in receipt of full compensation.

5.4.2. Pre-Simulator Questionnaire

A pre-simulator questionnaire was completed after consent and before the simulator portion of the experiment. Two different questionnaires were developed, one for the driving participant and one for the bicycling participant. The questionnaires asked the same demographic questions, including gender, age, race, household income, and highest level of education.

- Bicycling Simulator: Participants were asked about bicycling experience, how often they bicycled and for what primary purpose, and they were asked to self-categorize based on previous research on typology and bicycling behavior (Dill 2013).
- Driving Simulator: Participants were asked how many years they had been a licensed driver and how often they drove per week.

5.4.3. Simulator Calibration

To obtain familiarity with the equipment and to assess a participant's possibility of experiencing simulator sickness, a simulator calibration was completed. This was done for both the driving and bicycling participants.

- Bicycling simulator: Participants were shown the equipment and how it operated similarly to a stationary bicycle. They were asked to adjust the height of the seat to their comfort level, to not adjust the gears on the bicycle, and to ride as normally as they would in the built environment. The participants were instructed to "obey all traffic laws." The simulator calibration was conducted on a generic city environment track so participants could become familiar with the operational characteristics of the bicycle.
- Driving simulator: Participants were asked to sit in the driving simulator and adjust the seat, rearview mirror, and steering wheel to maximize comfort and driving experience during the experiment. The participants were instructed to "obey all traffic laws." The simulator calibration was conducted on a generic city environment track so participants could become familiar with the operational characteristics of the passenger car.

No data were collected during the simulator calibration, but being accustomed to the mechanics of the passenger car and bicycle helped participants behave more naturally in the virtual reality environment. If participants started to feel simulator sickness or discomfort, they were offered cold water and a chance to sit away from the simulator. If a participant could not continue, the experiment ended for that participant, and he or she was compensated the standard $20 sum.

5.4.4. Eye Tracking Calibration and GSR Sensor Equipment

After the simulator calibration, participants were fitted with eye-tracking and GSR equipment. The participant was asked to wear the Tobii Pro Glasses 3 and look directly at the target card for, typically, less than 10 seconds. Once the calibration had succeeded, as seen in figure 5.6, the eye-tracking recording could proceed.

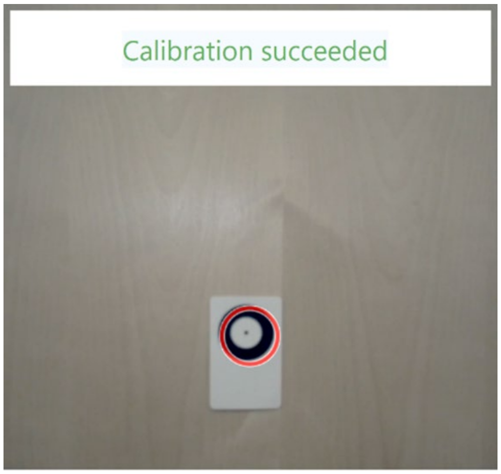


Figure 5.6 Eye-Tracking Calibration Image

The GSR, Shimmer3 GSR+ auxiliary input was strapped to each participant's non-dominant wrist. The sensors were placed on the participant's index, middle, and ring fingers without affecting normal driving and bicycling behavior. The auxiliary input unit and the eye-tracking recording unit were connected wirelessly to laptop computers collecting data using the iMotions platform.

5.4.5. Simulation Experiment

After being fitted with data collection equipment, participants were asked to perform the simulator experiment. Both drivers and bicyclists were asked to follow the route; verbal directional cues were given to the driver, and directional signs were used for the bicyclist. Participants were also asked to obey traffic laws and drive or bicycle as they typically would in the built environment. Each participant drove four tracks that were designed to be completed in 20 to 30 minutes each. After each track had been completed, the researchers checked on the participants to assess their comfort level. If a break was needed, all participants would leave the simulator rooms; if any participant experienced simulator sickness, the experiment stopped immediately.

After the first two tracks had been completed, the researchers educated the participants about BRS laws. Since the BRS had been enacted into law in Oregon in early 2020, there was no concern about having participants perform a traffic maneuver that was illegal. Participants were told that bicyclists were allowed to proceed through a stop-controlled intersection after yielding and ensuring there were no immediate hazards. Researchers then asked participants whether they would be able to perform as naturally as they would in the built environment with knowledge of the law. Once the participant had agreed and confirmed knowledge of the law, the two tracks were repeated. Data were collected during these portions of the experiments and were used to compare before education behavior with after education behavior.

5.4.6. Post-Simulator Questionnaire

After completing the simulation experiment, each participant was asked to respond to questions about comprehension and perceptions while driving and bicycling in the simulator. Participants in both simulators were asked about their knowledge of the BRS law before the experiment and whether knowledge of the law influenced their behaviors.

- Bicycling simulator: Participants were asked about their perceived level of comfort while approaching intersections using a ranking scale response method.
- Driving simulator: Participants were asked about their perception of safety of bicyclists while approaching intersections using a ranking scale response method.

The entire experiment lasted approximately 60 minutes.

5.5. Statistical Modeling

To better understand the relationship between the independent and dependent variables in the simulation experiments, a Linear Mixed Effects Model (LMM) was chosen for analysis for the following reasons:

- its ability to handle the errors generated from repeated subject variables as the participants were exposed to all scenarios
- its ability to handle fixed or random effects
- its accommodation of categorical and continuous variables
- its low probability of Type I error occurrence (e.g., Jashami et al. 2019).

A potential limitation of LMM is that more distributional assumptions need to be addressed (e.g., Jashami et al., 2020). The sample size for this study was 30 participants, which was greater than the minimum required for an LMM analysis (e.g., Barlow et al., 2019). Therefore, LMM was chosen to model the experimental data and was formulated as follows:

$$y_{ij} = \beta_0 + \beta_1 X_{ij} + b_{i0} + \varepsilon_{ij} ,$$

$$b_{i0} \sim \text{iid N } (0,\sigma_0^2),$$

$$\varepsilon_{ij} \sim \text{iid N } (0,\sigma_\varepsilon^2)$$

where β_0 is the intercept at the population level, and β_1 is the slope (both are for the fixed effect). b_{i0} is the random intercept of the i^{th} participant, which follows a mean normal distribution with variances σ_{b0}^2. ε_{ij} is the error term. Hence, b_{i0}, and ε_{ij} are assumed to be independent.

Three models were developed for each of the dependent variables (bicyclists' speed, drivers' speed, and bicyclists' visual attention). Each model was developed to consider the independent variables of roadway treatment, conflict vehicle, and education. These variables were included in the model as fixed effects. While the participant variable was also included in the model as a random effect, in the case of statistically significant effects, custom post hoc contrasts were performed for multiple comparisons using Fisher's least significant difference (LSD). All statistical analyses were performed at a 95 percent confidence level. Restricted maximum likelihood estimates were used in development of this model.

5.6. Bicycle Performance Results

5.6.1. Bicycling Participant Demographics

A total of 40 participants were recruited for the bicycling portion of the networked simulator experiment. All participants were recruited from Corvallis, Oregon, and the surrounding area, including 12 men, 24 women, three non-binary people, and one who preferred not to answer. The participants' ages ranged from 18 to 71 years, with an average age of 35.5

years (SD= 15.1). Three (7.5 percent) participants were not able to complete the experiment because of simulator sickness. In the networked experiment, if the bicycling participant exhibited simulator sickness, the experiment ended for both bicycling and driving participants. If the driving participant exhibited simulator sickness, researchers continued with the simulation experiment for the bicycling participant. However, there was one experiment that ended because the driving participant experienced simulator sickness, and data were not collected for the bicycling participant. These cases of simulator sickness brought the sample size for the bicycling portion to 36 participants, with an average age of 34.1 years (SD = 14.96), including 12 men (average age= 28.91, SD= 10.82 years), 20 women (average age= 35.7, SD= 14.55 years), three non-binary people (average age= 31.67, SD= 18.5 years), and one who preferred not to answer (age= 71 years), as seen in table 5.3.

Table 5.3 Bicycling Participants

	Total	**Male**	**Female**	**Non-Binary**	**Prefer Not to Answer**
Total Enrolled	40 (100%)	12 (30%)	24 (60%)	3 (7.5%)	1 (2.5%)
Simulation Sickness	3 (7.5%)		3 (100%)		
Data Not Collected	1 (2.5%)		1 (100%)		
Total Sample	36 (90%)	12 (33%)	20 (56%)	3 (8%)	1 (3%)
Age Range			18 - 71		

Some data were lost during the experiment, resulting in different final analyzed sample sets for data collected with the SimObserver, eye-tracker, and GSR. Unknown to the researchers at the time, but due to the networked experiment, if a driving participant stopped because of simulator sickness after the experiment had started, no data were collected on the SimObserver. However, if the experiment began with only a bicycling participant, then SimObserver data were recorded. Additionally, one data set was lost on the SimObserver, so the final analyzed sample was the same as the total sample.

The final analyzed sample for the SimObserver was 30, with an average age of 29.9 years (SD= 11.9), including 12 men, 15 women, and three non-binary persons. The final analyzed sample for the eye-tracking equipment was 21, with an average age of 32.7 years (SD= 16.3), including nine men, eleven women, and one who preferred not to answer. The final analyzed sample for the GSR equipment was 22, with an average age of 35.0 years (SD= 16.1), including six men, thirteen women, two non-binary persons, and one who preferred not to answer. The final analyzed sample sizes and demographics for bicycling participants are shown in table 5.4.

Table 5.4 Final Analyzed Sample Size

Source	Data Lost	Final Analyzed Sample	Average Age (years)	Male	Female	Non-Binary	Prefer Not to Answer
SimObserver	6 (16.7%)	30	29.9	12 (40%)	15 (50%)	3 (10%)	
Eye-Tracker	15 (42%)	21	32.7	9 (43%)	11 (52%)		1 (5%)
GSR	14 (61%)	22	35.0	6 (27%)	13 (59%)	2 (9%)	1 (5%)
Qualtrics Survey	1 (3%)	35		12 (34%)	19 (54%)	3 (9%)	1 (3%)

5.6.2. Pre-Simulator Bicycling Questionnaire

The pre-simulator questionnaire for the bicycling portion of the experiment focused on participant demographics and bicycling experience. The final analyzed sample shown in table 5.5 was for 35 participants (one participant's responses were not recorded in Qualtrics). Within each category, participants were predominantly 18 to 24 years old (37.1 percent), had some college education (28.6 percent), were White (74.3 percent), and made less than $25,000 annually (34.3 percent).

For bicycling experience, participants generally used their bicycle primarily for recreation and leisure (31.4 percent) and spent one to two hours per week bicycling in bicycle riding seasons (34.3 percent). Participants were asked to identify their bicycling typology, with results shown in figure 5.7. Generally, participants identified as Enthused and Confident (66.7 percent).

Table 5.5 Pre-simulator Bicycling Questionnaire Results

Category	Demographic Variable	Count	Percentage
Gender	Male	12	34.3
	Female	19	54.3
	Non-Binary	3	8.6
	Prefer Not to Answer	1	2.9
Age	18-24	13	37.1
	25-34	8	22.9
	35-44	4	11.4

Category	Demographic Variable	Count	Percentage
	45-54	7	20.0
	55-64	2	5.7
	65+	1	2.9
Race	American Indian or Alaska Native	0	0.0
	Asian	0	0.0
	Black or African American	0	0.0
	Hispanic or Latino/a/x	0	0.0
	White or Caucasian	26	74.3
	Other	2	5.7
	Prefer Not to Answer	0	0.0
Income	Less than $25,000	12	34.3
	$25,000 to less than $50,000	4	11.4
	$50,000 to less than $75,000	1	2.9
	$75,000 to less than $100,000	5	14.3
	$100,000 to less than $200,000	10	28.6
	$200,000 or more	0	0.0
	Prefer Not to Answer	3	8.6
Education	Some high school or less	1	2.9
	High school diploma or GED	2	5.7
	Some college	10	28.6
	Trade/vocational school	0	0.0
	Associate Degree	3	8.6
	Four-year Degree	6	17.1
	Master’s Degree	9	25.7
	PhD Degree	3	8.6
	Prefer Not to Answer	1	2.9
Typology and Bicycling Behavior	Strong and Fearless: Willing to bicycle with limited or no bicycle-specific infrastructure	7	20.0
	Enthused and Confident: Willing to bicycle if some bicycle-specific infrastructure is in place	23	65.7
	Interested but Concerned: Willing to bicycle if high-quality bicycle infrastructure is in place	5	14.3
	No Way, Now How: Unwilling to bicycle even if high-quality bicycle infrastructure is in place	0	0.0
Primary Use of Bicycle	I currently do not ride a bike	3	8.6
	Commuting to work	7	20.0
	General transportation	8	22.9
	Recreation and leisure	11	31.4
	Exercise or sport	6	17.1
Bicycling Hours per Week	0 to less than 1 hour	9	25.7
	1 to less than 2 hours	12	34.3
	2 to less than 3 hours	7	20.0
	3 to less than 4 hours	1	2.9
	More than 4 hours	6	17.1

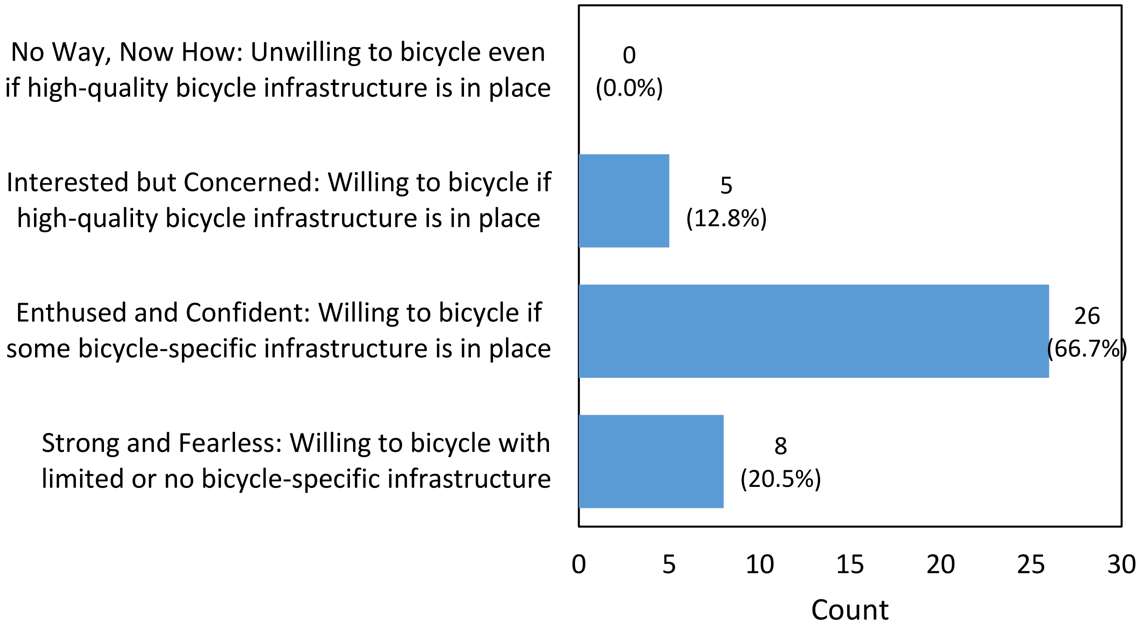


Figure 5.7 Self-Identification of Bicycling Typology

5.6.3. Post-Simulator Bicycling Questionnaire

The post-simulator questionnaire for the bicycling portion of the experiment focused on knowledge and influence of the BRS law, safety, and perception of the safety of bicyclists as they approached intersections in the built environment and in the simulator experiment. The questions used a scale response method, and 36 participants' responses are reflected in table 5.6.

The majority of participants were completely unfamiliar with BRS laws before participating in the experiment (58.3 percent), with only a small number feeling completely familiar with the BRS law (13.9 percent), as shown in figure 5.8. Participants were generally comfortable approaching intersections in the built environment (41.7 percent) and in the virtual environment (38.9 percent). More participants were very comfortable approaching intersections in the virtual environment (30.6 percent) than in the built environment (19.4 percent). Most of the participants found that knowledge of the BRS law influenced their behavior and decisions (77.3 percent).

Table 5.6 Post-Simulator Bicycling Questionnaire Results

Question	Options	Count	Percentage
How familiar were you with the Bicycle Rolling Stop law prior to participating in this experiment?	Completely Unfamiliar	21	58.3
	Somewhat unfamiliar	4	11.1
	Neither Unfamiliar or Familiar	1	2.8
	Somewhat Familiar	5	13.9
	Completely familiar	5	13.9
How comfortable do you typically feel approaching intersections while bicycling in everyday life?	Very Uncomfortable	1	2.8
	Uncomfortable	6	16.7
	Neutral	7	19.4
	Comfortable	15	41.7
	Very Comfortable	7	19.4
How comfortable did you feel approaching intersections during the experiment?	Very Uncomfortable	1	2.8
	Uncomfortable	6	16.7
	Neutral	4	11.1
	Comfortable	14	38.9
	Very Comfortable	11	30.6
Please indicate your level of agreement with the following statement: " I was concerned about my safety as approaching intersections."	Strongly Disagree	8	22.2
	Disagree	14	38.9
	Neutral	7	19.4
	Agree	7	19.4
	Strongly agree	0	0.0
Did you know about the Bicycle Rolling Stop law before beginning this experiment?	Yes	14	38.9
	No	22	61.1
Did knowledge of the Bicycle Rolling Stop law influence your behavior or decisions?	Yes	17	77.3
	No	5	22.7

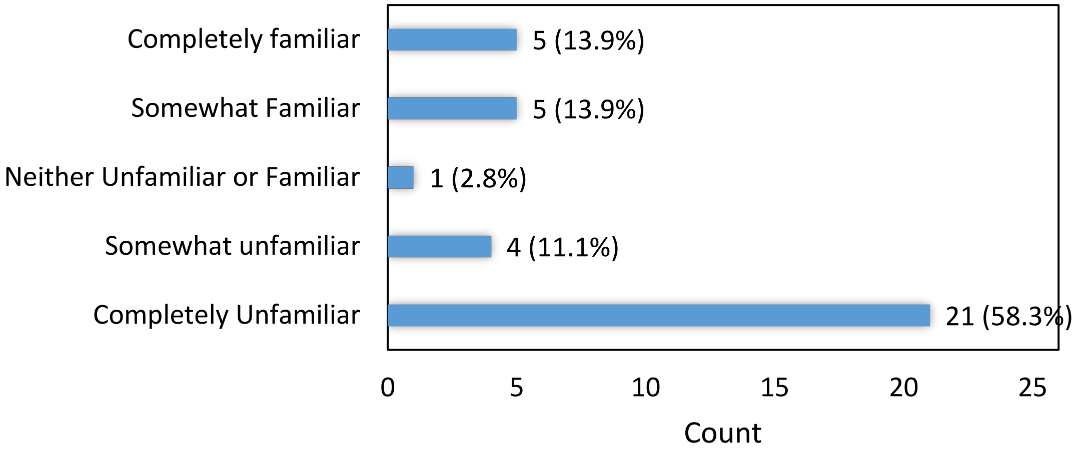


Figure 5.8 Familiarity of BRS law prior to participation

After each question, participants were asked to explain their responses in further detail. Direct quotes from those participants who were familiar with the BRS law before participation included, “I ride my bike everyday as my main mode of transportation and make use of this law as I ride to my destinations,” “I ride my bike as transportation and this law is helpful to me,” and “It is a behavior I usually practiced while cycling before this was legal (always within safe situations) and felt relieved to know that it was no longer illegal.”

Direct quotes from participants explaining how knowledge of the BRS influenced their behavior and decisions included, “I stop less knowing the law,” “I took note from when I was further back and saw a greater distance and would decide not to stop so I could more quickly cross when I didn't think traffic was approaching,” and “I didn't know about the law but that has always been how I ride a bike in town.”

5.6.4. Bicycle Speed

Speed data were collected from the SimObserver and evaluated with Microsoft Excel. As a bicycling participant rode through the virtual world, they were confronted with 16 test scenarios distributed across four tracks. The mean speed at each of these intersections was calculated by looking at all speeds as each participant approached the intersection of interest. Calculations began approximately 30 meters upstream of the stop sign at an intersection and continued until the bicyclist left the intersection, as seen in figure 5.9.

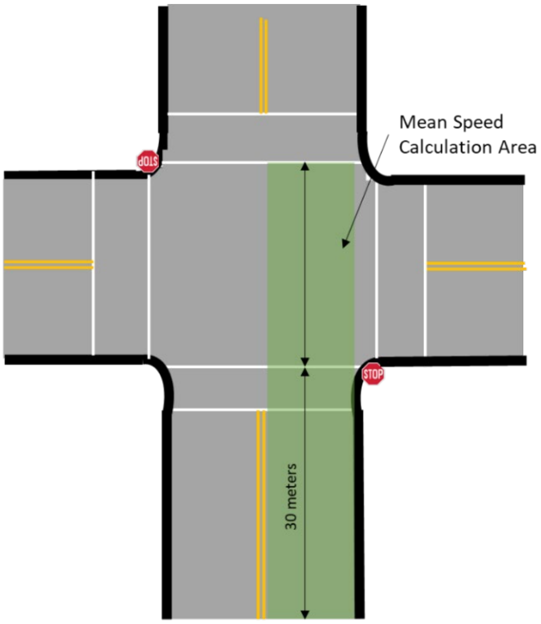


Figure 5.9 Mean Speed Calculation Area

Figures 5.10 and 5.11 show the mean speed of bicyclists before and after education for Track 1 and Track 2, respectively. For bike lane and shared roadway, the mean speed increased after education in all scenarios.

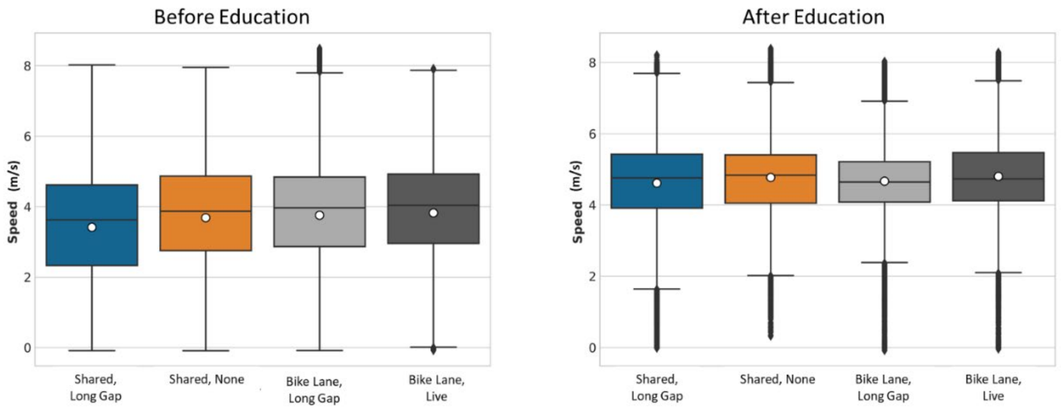


Figure 5.10 Mean Speed Before Education and After Education for All Participants, Track 1

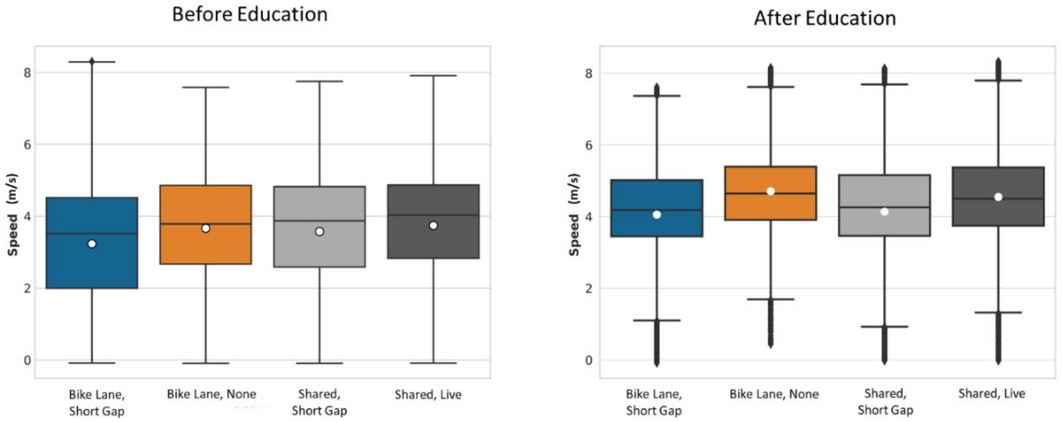


Figure 5.11 Mean Speed Before Education and After Education for All Participants, Track 2

Figure 5.12 shows combined speed profiles for participants for the scenario with a shared roadway and no conflicting vehicle movements. After participants had been educated about the BRS law, the speed profile showed few to no full stops at the stop sign, indicating that bicyclists performed yielding maneuvers rather than stops. Additionally, the speed profile showed a greater range of speeds when bicyclsts approached the intersection after education. Generally, the range of speeds 30 meters upstream of the stop sign before education was from 3.0 to 7.5 m/s, and after education the range increased slightly to 3.5 to 8.0 m/s.

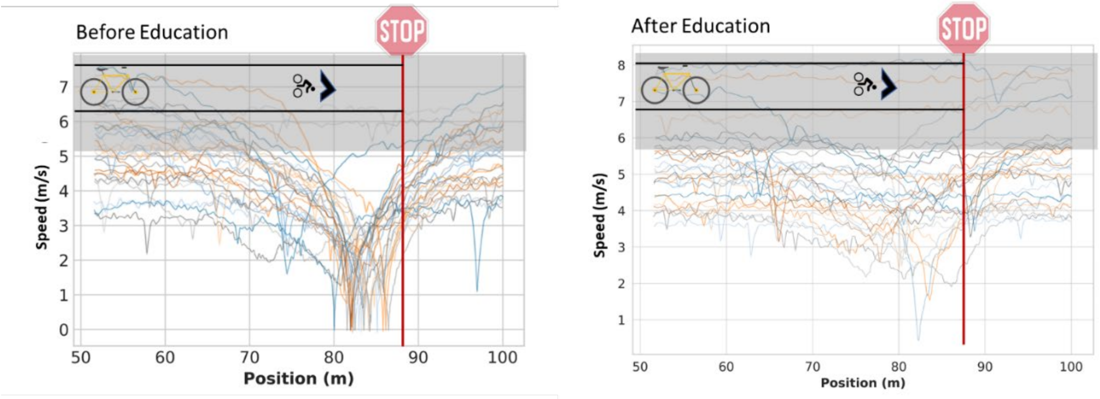


Figure 5.12 Speed Profiles, Before and After Education, Bike Lane, No Passenger Cars

Generally, for a scenario with a bike lane and two passenger cars arriving at the intersection 5 seconds apart (Short Gap), bicyclists approached the intersection 30 meters upstream of the stop sign with speeds ranging from approximately 3 to 8 m/s, before and after education. However, more bicyclists came to a stop at the intersection before education, as seen in figure 5.13.

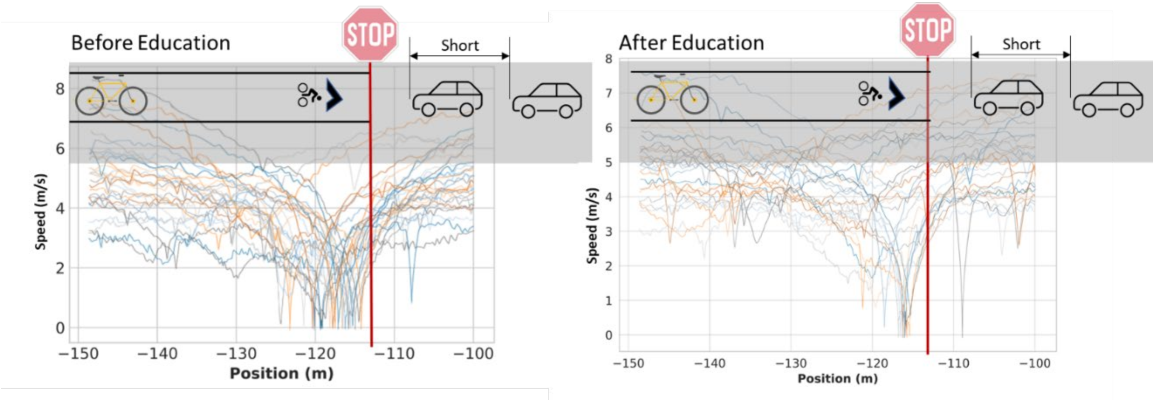


Figure 5.13 Speed Profiles, Before and After Education, Bike Lane, Short Gap Passenger Cars

Figures 5.14 and 5.15 show speed profiles with similar trends. Generally, bicyclists advanced through the intersection at greater speeds after education about the BRS law, when the roadway was shared with passenger cars approaching with Short Gaps between them, and a similar trend was seen in the live interaction.

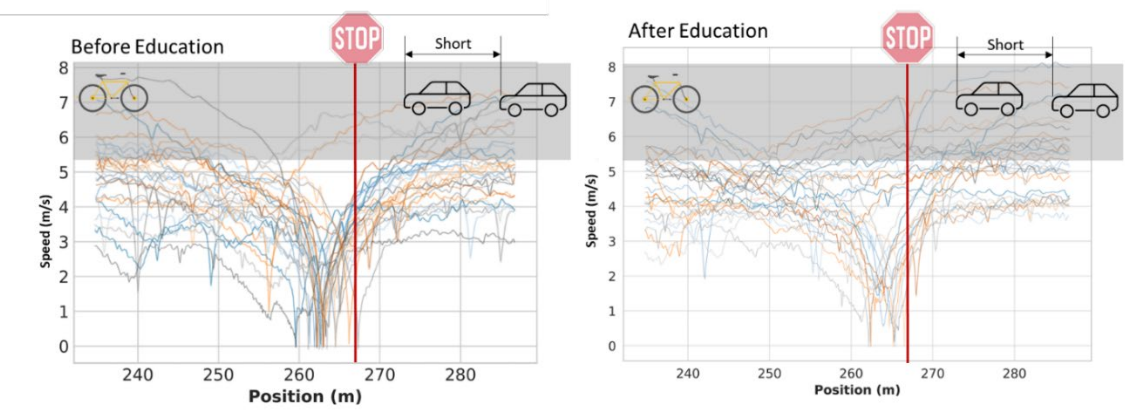


Figure 5.14 Speed Profiles, Before and After Education, Shared Roadway, Short Gap Passenger Cars

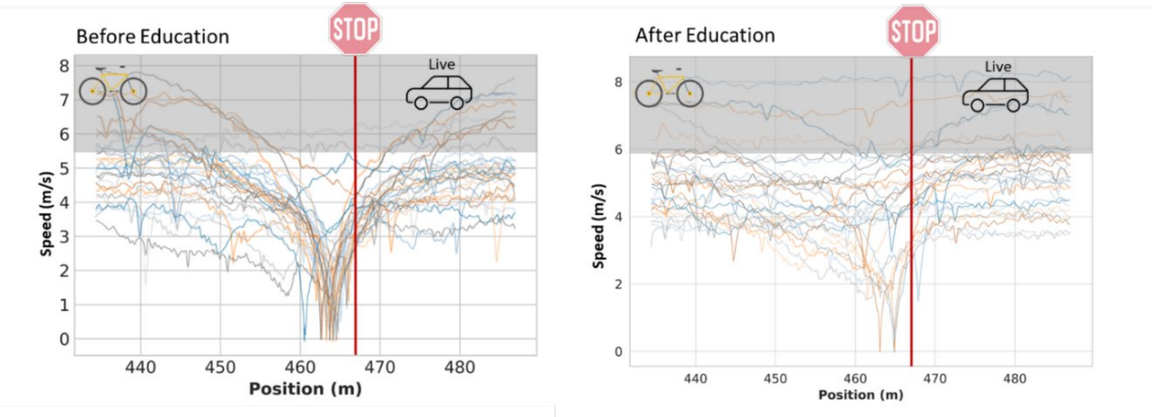


Figure 5.15 Speed Profiles, Before and After Education, Shared Roadway, Live Interaction

Comparing speed profiles for all scenarios showed that when passenger cars were performing conflicting movements at an intersection, more bicycles stopped at the stop sign than when there were no conflicting passenger cars present.

Descriptive statistics were calculated for bicycle speeds at intersections for all scenarios, and these results are shown in table 5.7. Speeds were taken as the bicycle approached an intersection starting 3 meters upstream of the stop sign and ending at the stop sign, as seen in figure 5.16.

Table 5.7 Descriptive Statistics for Bicycle Speed for All Scenarios Before and After Education

Bicycle Speed (m/s)	Conflicting Movements	None		Long Gap		Short Gap		Live	
	Education	Before	After	Before	After	Before	After	Before	After
Bike Lane	Mean	1.8	4.1	2.0	3.9	1.9	2.5	2.0	4.0
	SD	1.3	1.5	1.4	1.7	1.5	2.0	1.4	1.8
	Median	1.8	4.1	2.0	4.1	1.8	2.4	1.9	4.4
	Minimum	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0
	Conflicting Movements	None		Long Gap		Short Gap		Live	
	Education	Before	After	Before	After	Before	After	Before	After
Shared Roadway	Mean	1.7	4.3	1.6	3.5	1.7	2.4	1.7	3.4
	SD	1.4	1.5	1.4	1.8	1.4	1.9	1.4	1.9
	Median	1.7	4.5	1.4	3.9	1.6	2.0	1.7	3.6
	Minimum	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0

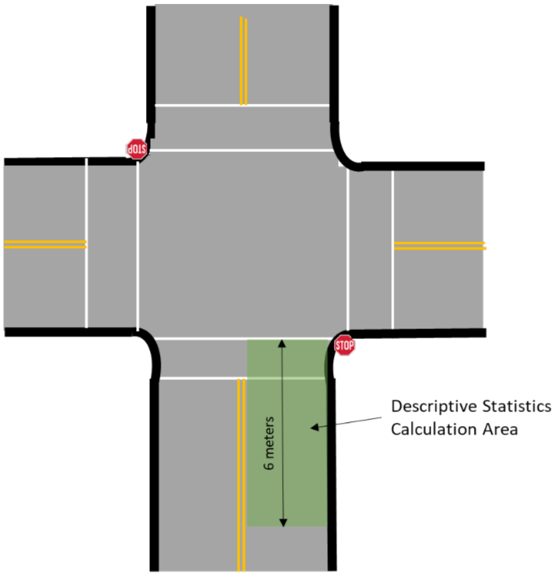
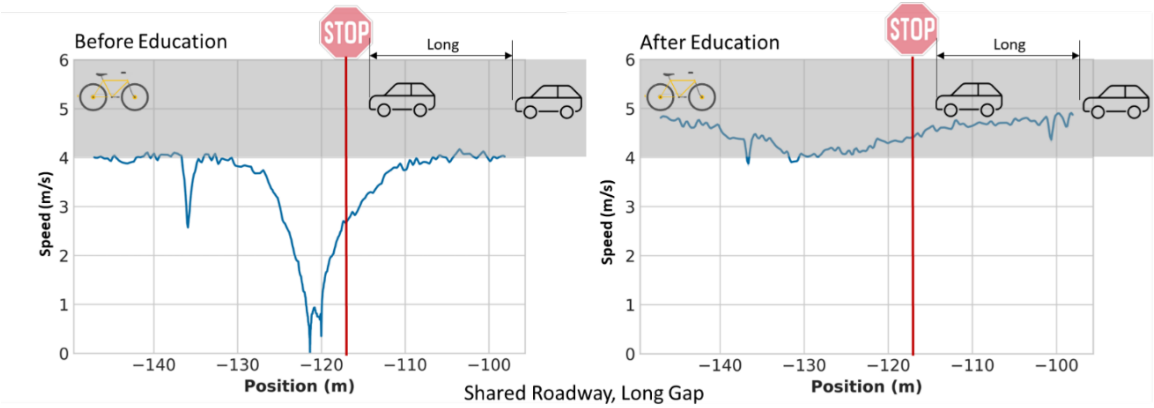


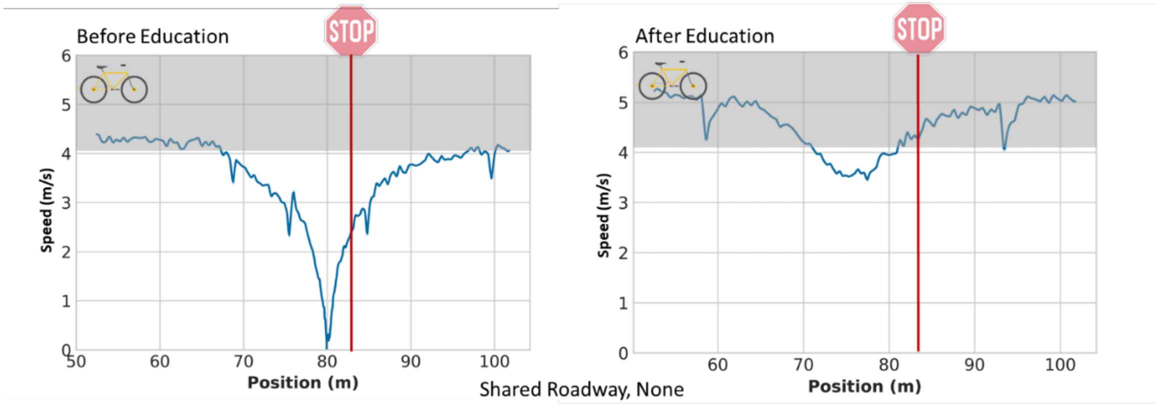
Figure 5.16 Descriptive Statistics Calculation Area

For all scenarios, including for a dedicated bike lane and a shared roadway, the mean speed for bicyclists increased after education. The greatest mean speed increase was 2.6 m/s for a shared roadway with no passenger cars, the minimum speed increase after education was from 0 m/s to 0.3 m/s, and the median speed also increased from 1.7 to 4.5 m/s.

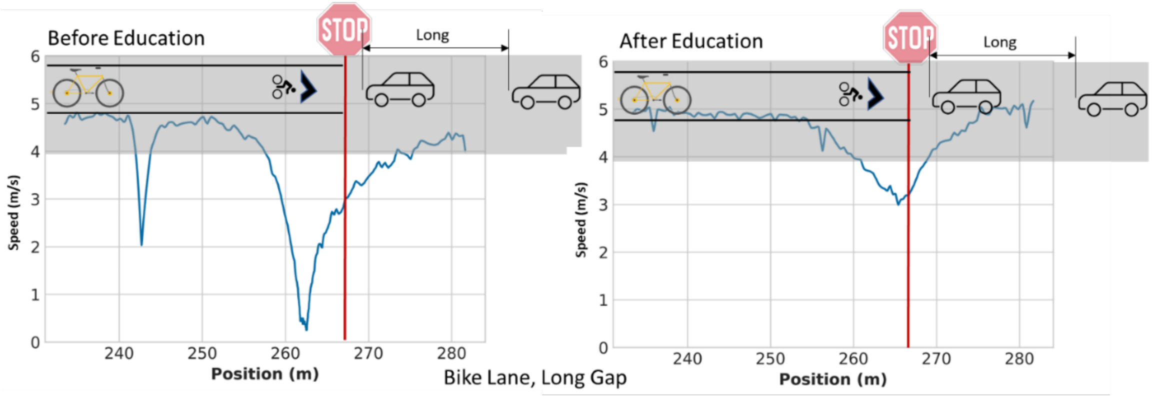
Figure 5.17 shows speed profiles for one participant in four different scenarios before and after education. In all scenarios, the participant came to a stop before education and yielded after education. When there was a shared roadway with no conflicting passenger car movements, the lowest speed 30 meters from the intersection was approximately 4.5 m/s before education and was over 5 m/s after education.



Shared Roadway, Long Gap



Shared Roadway, None



Bike Lane, Long Gap

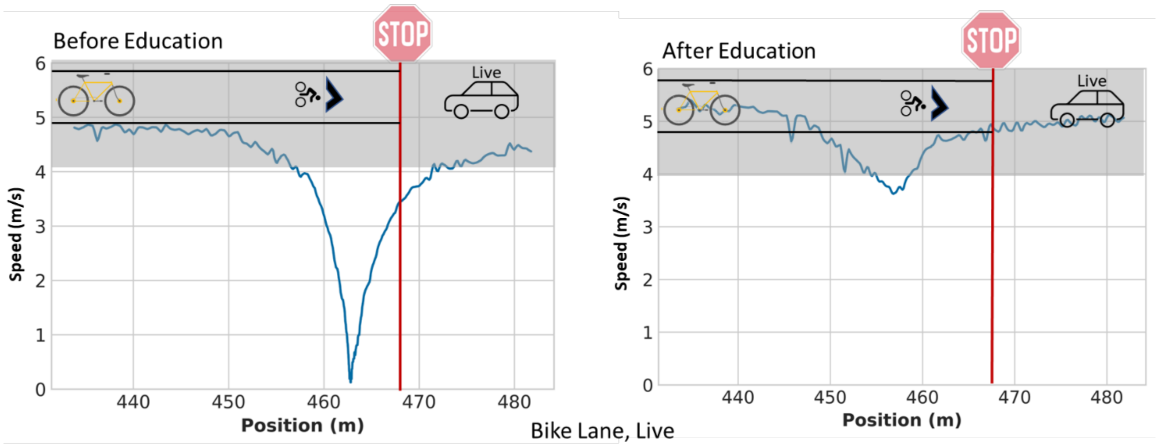


Figure 5.17 Speed Profile for a Participant in Four Different Scenarios

Next, to further understand bicyclists' speeding behaviors and to account for confounding variables, a statistical analysis was conducted. The results of the LMM model are shown in table 5.8. The random effect was significant (Wald Z=3.62, p <0.001), which suggests that it was necessary to treat the participant as a random factor in the model.

Table 5.8 Summary of the Estimated Model for Mean Speed

Variable	**Estimate**	**SE**	**T-Value**	**P-Value**
Participant random effect (Var)	1.29	0.36	3.62	**0.000**
Constant	2.35	0.24	9.86	**0.000**
Education				
Before	Baseline			
After	1.99	0.10	20.92	**0.000**
Movement of Conflicting Vehicle				
None	Baseline			
Long gap	0.00	0.13	0.01	0.996
Short gap	-0.21	0.13	-1.59	**0.113**
Live	-0.03	0.13	-0.19	0.847
Roadway Treatment				
Shared Roadway	Baseline			
Bike Lane	0.21	0.09	2.23	**0.026**
Summary Statistics				
R2	*70%*			
-2 log likelihood	*1482.36*			

Bold p-values: Significant at the 85% confidence level

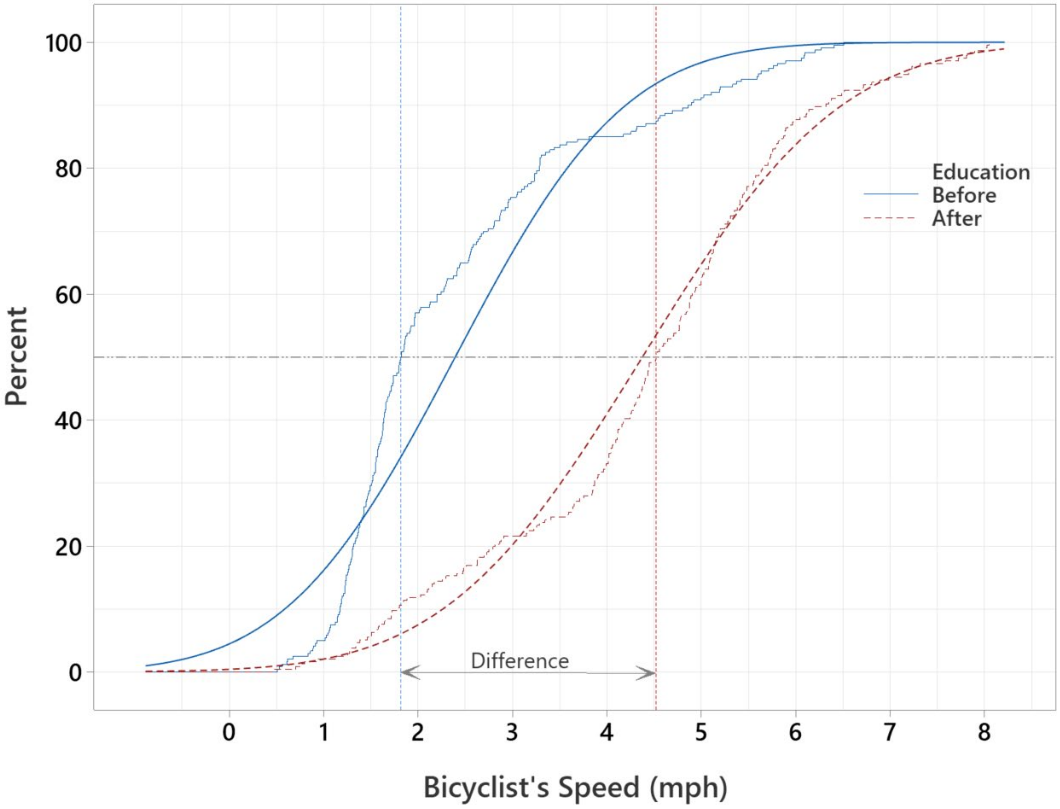


Figure 5.18 Cumulative Distribution of Bicyclists' Speeds Before and After Education.

One important objective was to determine whether or not bicyclists used the BRS law to make safer decisions at stop-controlled intersections. To answer this question, the researchers looked at behavior after BRS education. For the purposes of this experiment, it was assumed that a complete stop for a bicycling participant happened at 0.22 m/s (0.5 mph) and below, as recorded by the SimObserver. Thirty participants had the opportunity to stop at the following:

- 60 stop-controlled intersections with no cars;
- 60 stop-controlled intersections with cars arriving at the intersection with 5-second headways;
- 60 stop-controlled intersections with dynamically coded cars arriving at the intersections with 10-second headways; and,
- 60 stop-controlled intersections with a live conflicting vehicle interaction.

When no cars were present, participants stopped at the stop sign 0 percent of the time, but when cars were arriving with a 5-second headway, participants stopped 15 percent of the time, and when cars were arriving with a 10-second headway, participants stopped 7 percent of the time.

5.6.5. Bicycle Visual Attention

Visual attention was collected from 21 participants using the Tobii Pro Glasses 3 and iMotions software, and Microsoft Excel was used for visualization and analysis of these data. Areas of interest (AOI) were generated by drawing polygons around objects to which visual attention was expected from participants. The first defined AOI was the stop sign located on the intersection approach of interest. The second AOI (Car 1) was defined as the first passenger car performing a conflicting movement as the bicyclists approached the intersection. The third AOI (Car 2) was defined as the second passenger car indicating a conflicting movement as the bicyclist approached the intersection. Intersections were defined with movements of conflicting vehicles that arrived in succession with a Short Gap or Long Gap. None was a variable representing no passenger cars at the intersection, and Live was a variable representing the interaction between a participant in the driving simulator and a participant in the bicycling simulator. Time spent fixating on AOIs could indicate the objects to which participants were allocating visual attention while making decisions both before and after education about the BRS law.

The visual “dwell time” on a given AOI, in seconds, was calculated by using the fixation rate defined as any gaze at a single AOI with a minimum duration of 100 milliseconds. “Dwell time” describes the total fixation duration (TFD) of each participant on each AOI.

The descriptive statistics and visualization in table 5.9 and figure 5.19 are for the Stop Sign AOI, including 21 participants grouped by movement of conflicting vehicles (i.e., None, Long Gap, Short Gap, and Live). In almost all scenarios, for the bike lane and shared roadway, the mean TFD spent on the stop sign decreased after BRS law education. In the scenario for shared roadway with a Short Gap, the mean TFD slightly increased after education; however, the median was 0 seconds, indicating that half the participants did not fixate significantly on the stop sign.

Table 5.9 Descriptive Statistics for the Stop Sign AOI Before and After Education about the BRS Law

Stop Sign AOI	Conflicting Movements	None		Long Gap		Short Gap		Live	
	Education	**Before**	**After**	**Before**	**After**	**Before**	**After**	**Before**	**After**
Bike Lane	Mean	1.34	0.64	0.38	0.24	1.01	0.88	0.45	0.18
	SD	2.77	0.58	0.27	0.27	3.81	3.32	0.69	0.21
	Median	0.28	0.52	0.34	0.16	0.06	0.00	0.22	0.12

	Conflicting Movements	None		Long Gap		Short Gap		Live	
	Education	**Before**	**After**	**Before**	**After**	**Before**	**After**	**Before**	**After**
Shared Roadway	Mean	0.92	0.30	0.36	0.07	0.14	0.18	0.49	0.26
	SD	2.30	0.59	0.47	0.20	0.26	0.50	0.51	0.36
	Median	0.38	0.06	0.18	0.00	0.00	0.00	0.26	0.10

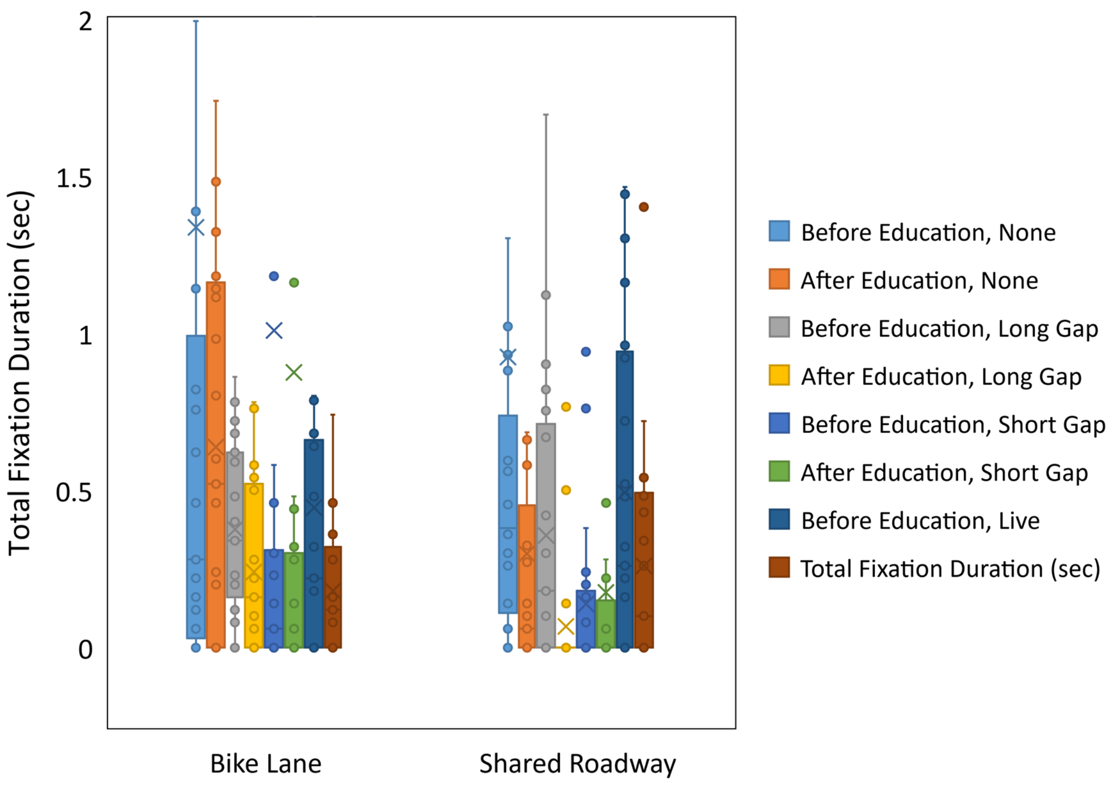


Figure 5.19 The Stop Sign AOI

The descriptive statistics in table 5.10 and visualization in figure 5.20 include 21 participants. They are for the AOI Stop Sign in comparison to the AOI Car 1 and AOI Car 2 when conflicting movements were present with a Short Gap as the bicycling participant approached the intersection, with a bike lane and shared roadway. When there was a bike lane, the mean TFD for Stop Sign decreased after education but increased for Car 1 and decreased for Car 2. The mean TFD spent on Car 1 increased by 0.90 seconds, whereas the mean TFD spent on Car 2 decreased by 1.37 seconds after education. When there was a shared roadway, the mean TFD for Stop Sign increased after education and decreased for Car 1 and Car 2. The mean TFD decreased by 0.13 seconds for Car 1 and by 1.45 seconds for Car 2 after education.

Table 5.10 Descriptive Statistics for the AOIs Stop Sign, Car 1, and Car 2 Before and After Education

	AOI	**AOI Stop Sign**		**AOI Car 1**		**AOI Car 2**	
Short Gap	**Education**	**Before**	**After**	**Before**	**After**	**Before**	**After**
Bike Lane	Mean	1.01	0.82	0.95	1.85	4.44	3.07
	SD	3.81	3.32	1.17	2.49	4.92	2.80
	Median	0.06	0.00	0.56	1.37	2.48	2.20
	AOI	**AOI Stop Sign**		**AOI Car 1**		**AOI Car 2**	
	Education	**Before**	**After**	**Before**	**After**	**Before**	**After**
Shared Roadway	Mean	0.14	0.88	1.01	0.88	4.86	3.41
	SD	0.26	1.11	0.86	1.11	3.81	3.00
	Median	0.00	0.38	0.98	0.38	5.13	2.58

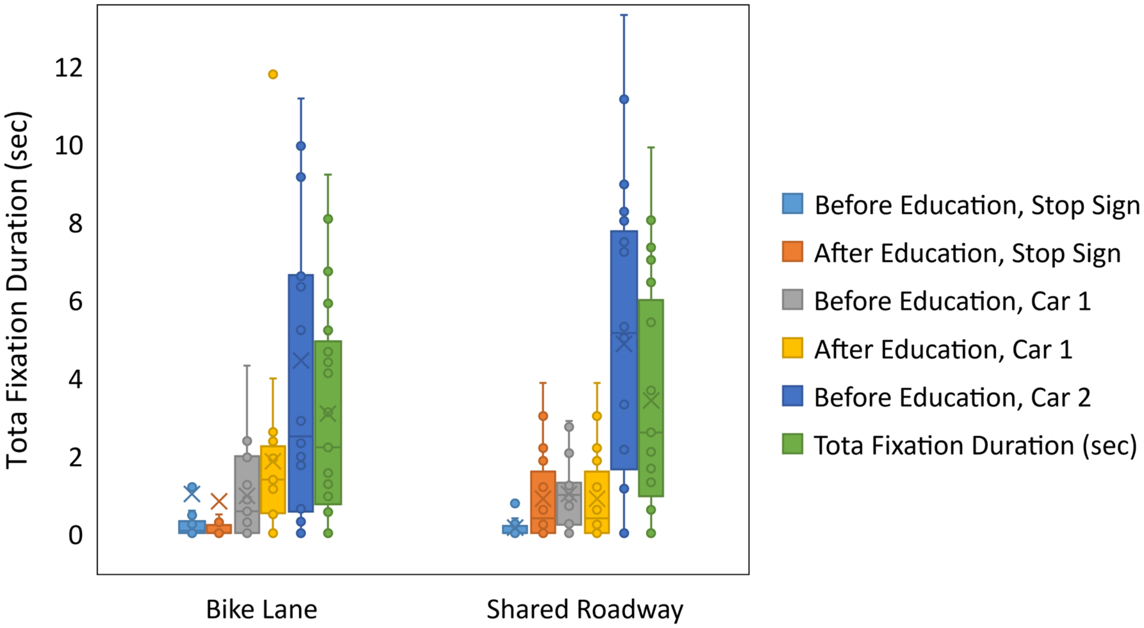


Figure 5.20 The AOIs Stop Sign, Car 1, Car 2, Short Gap

The researchers looked at the fixation behavior of 21 participants for scenarios in which conflicting car movements arrived with a Long Gap, with a bike lane and shared roadway. In these cases, the bicycling participant arrived at the intersection after Car 1 had completed the conflicting movement and Car 2 was arriving at the intersection. The descriptive statistics in table 5.11 and visualization in figure 5.21 compare the AOIs for Stop Sign and Car 2, before and after education. With a bike lane, the mean TFD for Car 2 slightly increased after education; however, the median after education was 0.18 seconds. With a shared roadway, the mean TFD for Car 2 decreased.

Table 5.11 Descriptive Statistics for the AOIs Stop Sign, Car 2, Long Gap, Before and After Education

	AOI	**AOI Stop Sign**		**AOI Car 2**	
Long Gap	**Education**	**Before**	**After**	**Before**	**After**
Bike Lane	Mean	0.38	0.24	0.32	0.45
	SD	0.27	0.27	0.47	0.52
	Median	0.34	0.16	0.10	0.18
	AOI	**AOI Stop Sign**		**AOI Car 2**	
	Education	**Before**	**After**	**Before**	**After**
Shared Roadway	Mean	0.36	0.07	3.83	3.26
	SD	0.47	0.20	3.48	3.58
	Median	0.18	0.00	3.60	2.12

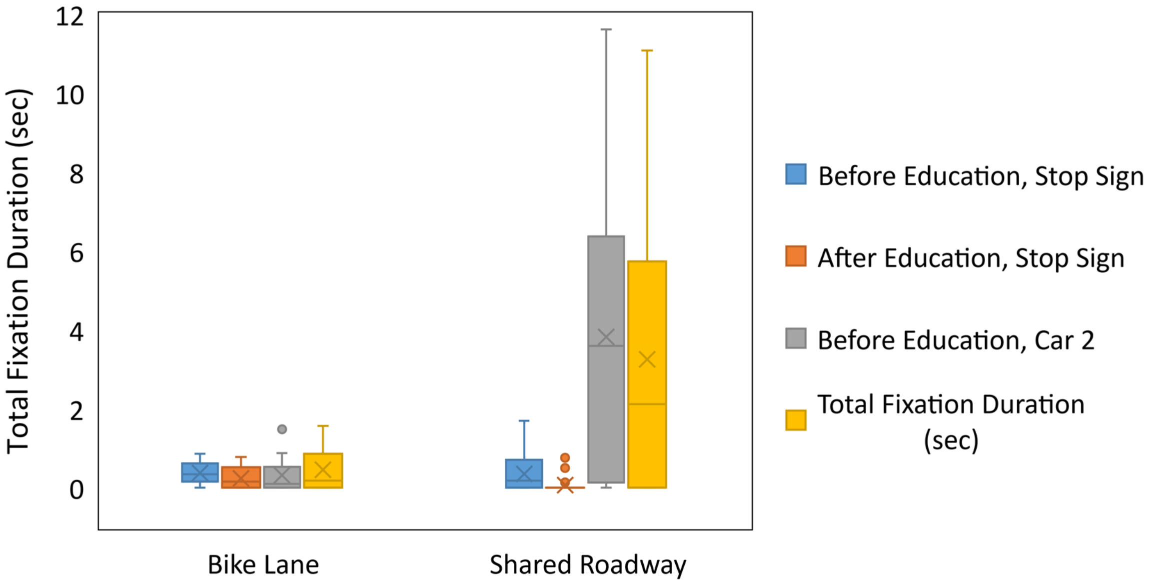


Figure 5.21 The AOIs Stop Sign, Car 2, Long Gap

Live Interaction indicates the intersection wherethe bicycling participant and the driving participant met at the same time. The driving participant was told to drive straight through the intersection after adhering to all traffic laws. The live interaction was dependent upon the speed of both the bicycling and driving participants; therefore, the interaction was not completed in all cases. Out of 21 participants attempting the live interaction, 12 before education and eight after education were considered complete. The AOIs for Stop Sign and Car-Live were used to calculate the descriptive statistics and visualization shown in table 5.12 and figure 5.22 for the Live Interactions that were completed with a bike lane and shared roadway. For bike lane and shared roadway, the mean TFD spent on the stop sign decreased after education. In the bike lane scenario, the mean TFD spent on the AOI Car-Live increased by 0.33 seconds; in the shared roadway scenario, the mean TFD spent on the AOI Car-Live decreased only very slightly, by 0.04 seconds.

Table 5.12 Descriptive Statistics for Stop Sign and Car-Live AOIs, Before and After Education

Live Interaction	AOI	AOI Stop Sign		AOI Car-Live	
	Education	**Before**	**After**	**Before**	**After**
Bike Lane	Mean	0.58	0.18	1.94	2.27
	SD	0.72	0.20	1.54	1.69
	Median	0.41	0.14	2.02	2.89
	AOI	**AOI Stop Sign**		**AOI Car-Live**	
	Education	**Before**	**After**	**Before**	**After**
Shared Roadway	Mean	0.52	0.31	2.12	2.08
	SD	0.44	0.25	1.62	1.91
	Median	0.42	0.34	1.99	1.28

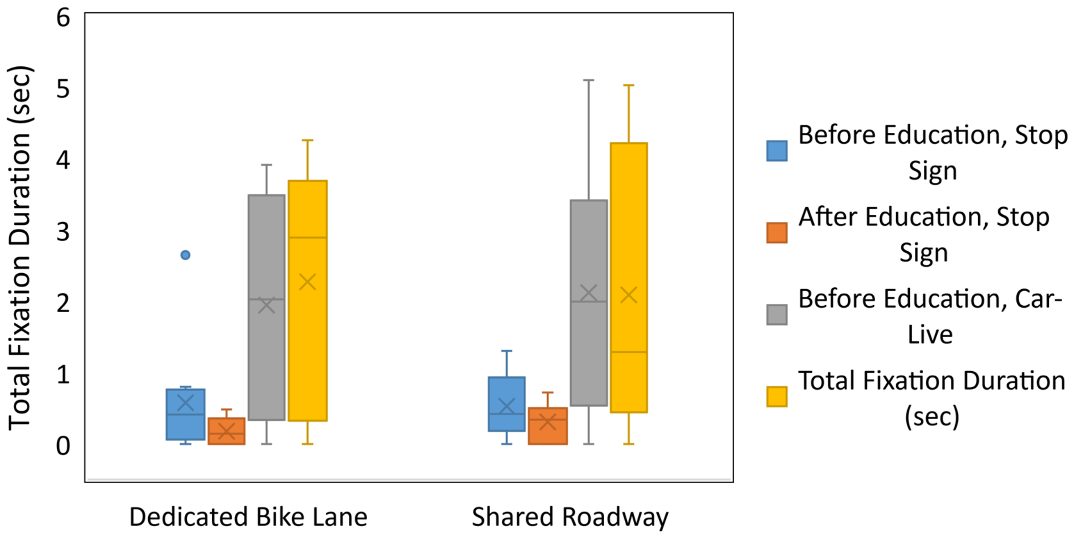


Figure 5.22 Live Interaction AOIs

Next, to better understand the participants' total fixation duration and account for any confounding variables, a statistical analysis was conducted. The results of the LMM model are shown in table 5.13. The random effect was significant (Wald Z=2.46, *p* =0.007), which suggests that it was necessary to treat the participant as a random factor in the model.

Table 5.13 Summary of Estimated Model for Mean TFD (AOI: sStop Sign)

Variable	**Estimate**	**SE**	**T-Value**	**P-Value**
Participant random effect (Var)	0.03	0.01	2.46	**0.007**
Constant	0.49	0.07	7.53	**0.000**
Education				
Before	Baseline			
After	-0.11	0.04	-2.63	**0.009**
Movement of Conflicting Vehicle				
None	Baseline			
Long gap	-0.20	0.06	-3.35	**0.001**
Short gap	-0.30	0.06	-4.91	**0.000**
Live	-0.12	0.06	-1.96	**0.051**
Roadway Treatment				
Shared Roadway	Baseline			
Bike Lane	0.06	0.04	1.42	**0.156**
Summary Statistics				
R2	*28%*			
-2 log likelihood	*368.00*			

Bold p-values: Significant at the 85 percent confidence level

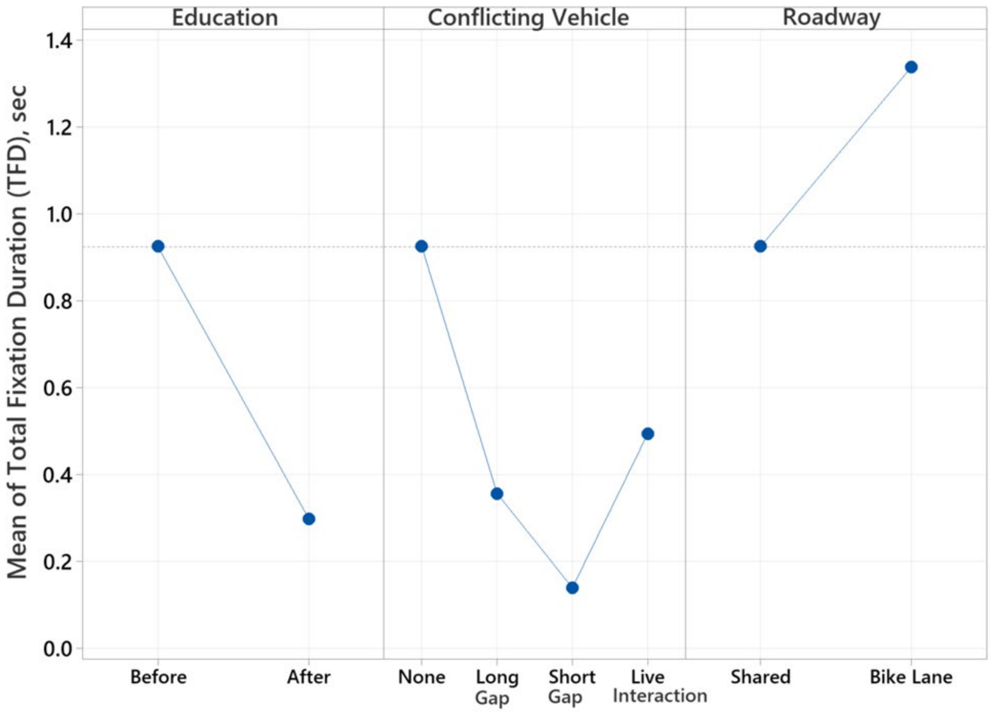


Figure 5.23 Plot of the Primary Effects of the Selected Factors on Mean TFD

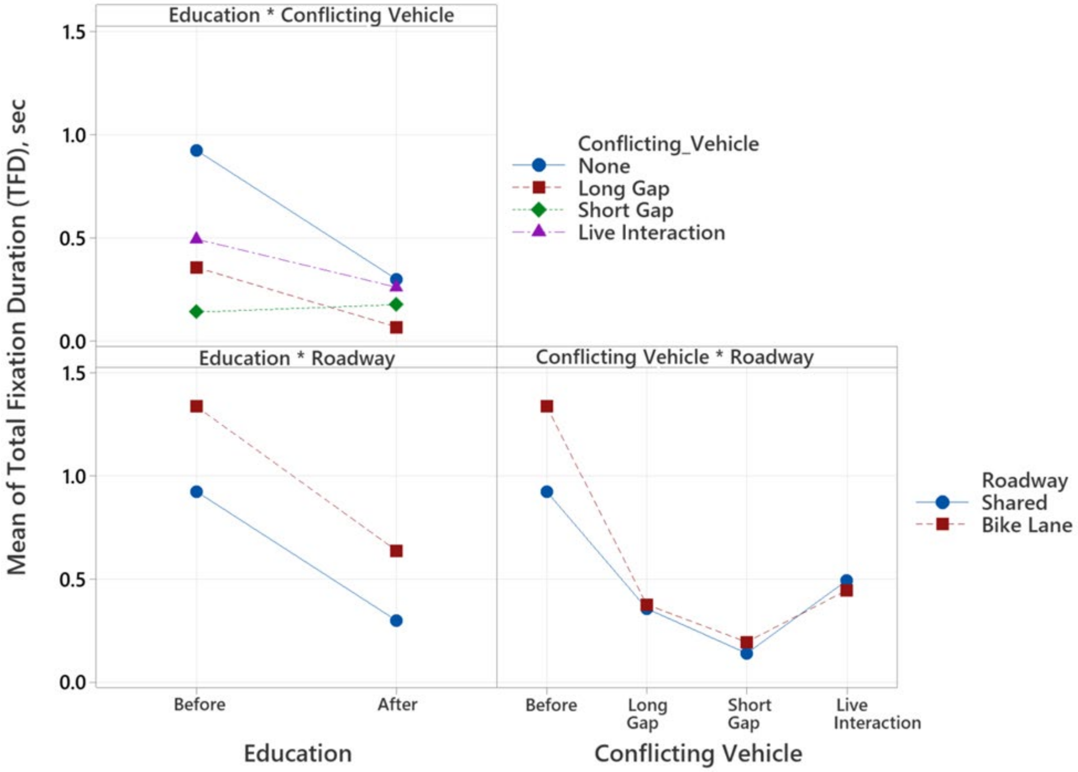


Figure 5.24 Plot of Two-Way Interactions of the Selected Factors on Mean TFD

5.6.6. Bicycle GSR

Galvanic skin response (GSR) data were collected from 22 participants, and the average number of peaks per minute was calculated. A higher number of peaks per minute indicated increased stress for drivers and bicyclists. Figure 5.25 and table 5.14 show the box plot and descriptive statistics, respectively, of the GSR readings for all intersections in the experiment, with a bike lane and shared roadway treatments, including those without passenger cars (None) and those with passenger cars performing conflicting movements (Long Gap, Short Gap, Live), both before and after education about the BRS law. The mean GSR in peaks per minute before education was higher than that after education. The mean GSR for each scenario before education was higher than the overall mean GSR after education. For each scenario, except a dedicated bike lane with passenger cars arriving with a Long Gap distance, the mean GSR after education was lower than the overall mean GSR before education.

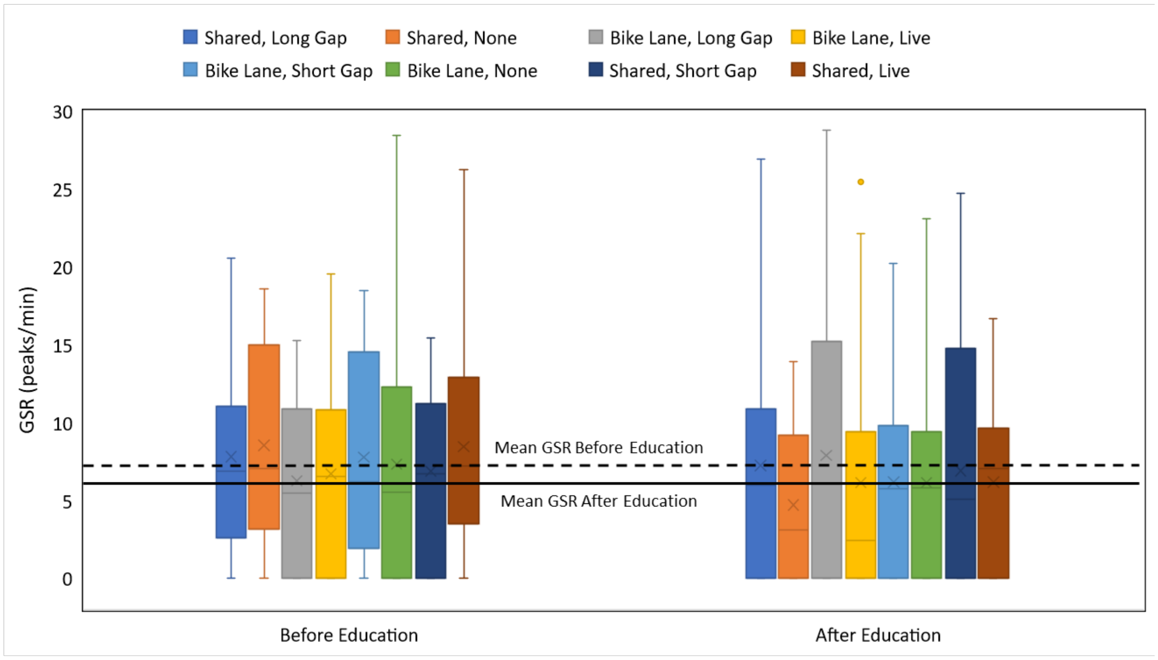


Figure 5.25 GSR for All Scenarios Before Education and After Education

Table 5.14 GSR Descriptive Statistics for All Scenarios Before Education and After Education

	Conflicting Movements	**None**		**Short Gap**		**Long Gap**		**Live**	
GSR	**Education**	**Before**	**After**	**Before**	**After**	**Before**	**After**	**Before**	**After**
Bike Lane	Mean	7.35	6.16	7.79	6.18	6.26	7.90	6.71	6.15
	SD	7.66	6.66	6.53	6.99	5.09	8.78	5.92	7.90
	Median	5.56	5.82	6.19	5.76	5.48	6.02	6.56	2.42
	Conflicting Movements	**None**		**Short Gap**		**Long Gap**		**Live**	
	Education	**Before**	**After**	**Before**	**After**	**Before**	**After**	**Before**	**After**
Shared Roadway	Mean	8.54	4.72	6.88	6.92	7.83	7.24	8.46	6.19
	SD	6.49	5.03	5.25	8.16	6.29	7.97	6.98	5.70
	Median	7.04	3.12	6.72	5.11	6.88	5.97	7.21	7.08

When there were no passenger cars at an intersection, the mean GSR decreased after education in comparison to that when passenger cars were performing conflicting movements. This happened both where there were dedicated bike lanes and shared roadways, as shown in figure 5.25. When passenger cars were present, and they arrived in both short and long gaps, the mean GSR remained nearly the same before and after education. Before education, the mean GSR was slightly higher when there were no passenger cars present than when passenger cars were present in the intersection for both roadway treatments. However, after education, the mean GSR was greater when passenger cars were present at the intersection than when there were no passenger cars. Figure 5.26 excludes the scenario involving the live interaction. figure 5.27 shows that the mean GSR decreased after education in the Live Interaction scenario.

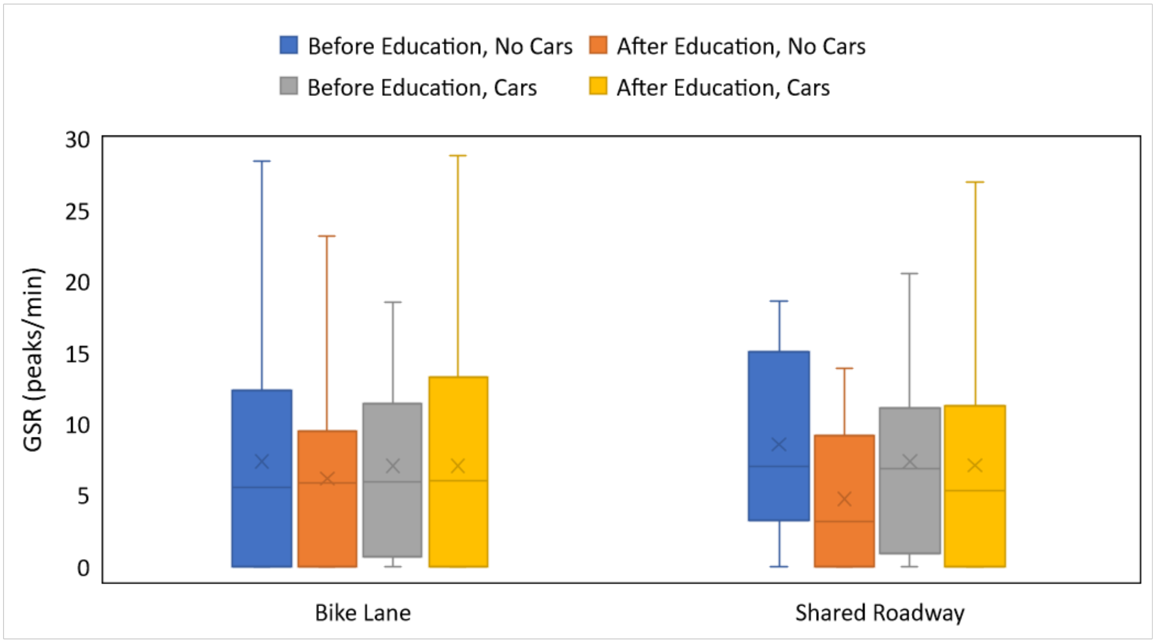


Figure 5.26 GSR for Scenarios in Which Cars Were Present and No Cars Were Present, Before and After Education

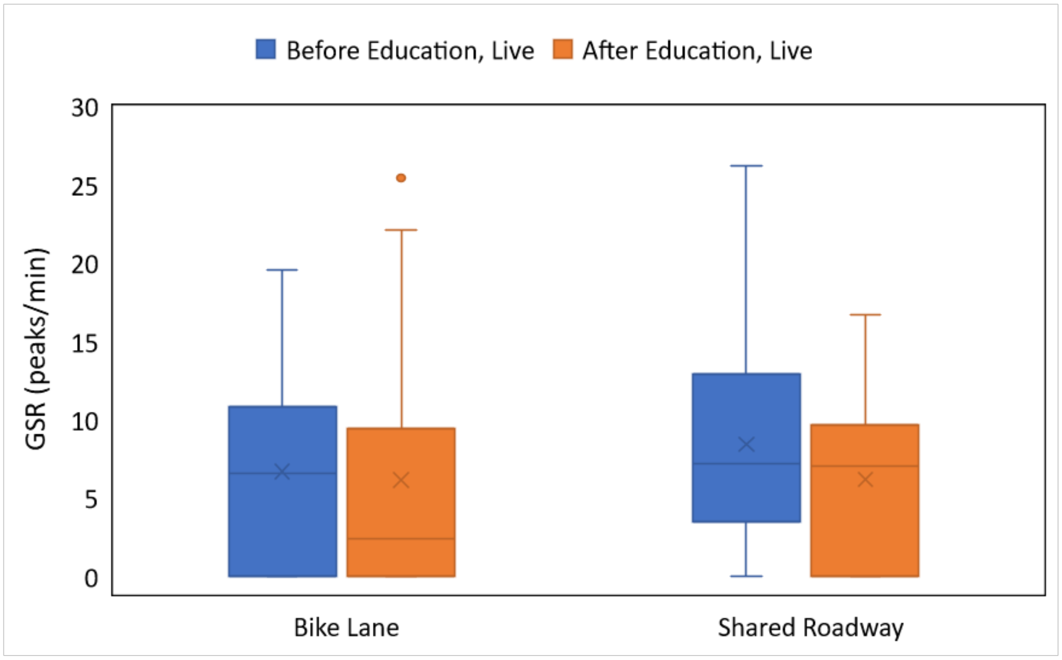


Figure 5.27 GSR for Scenarios with Live Interaction Before and After Education

Galvanic skin response data were collected from 22 participants, and the average peaks per minute are shown and compared in figure 5.28 for all scenarios for men and women. Two participants identifying as non-binary and one who preferred not to answer were excluded from the data. In all scenarios, women had higher GSR readings than men.

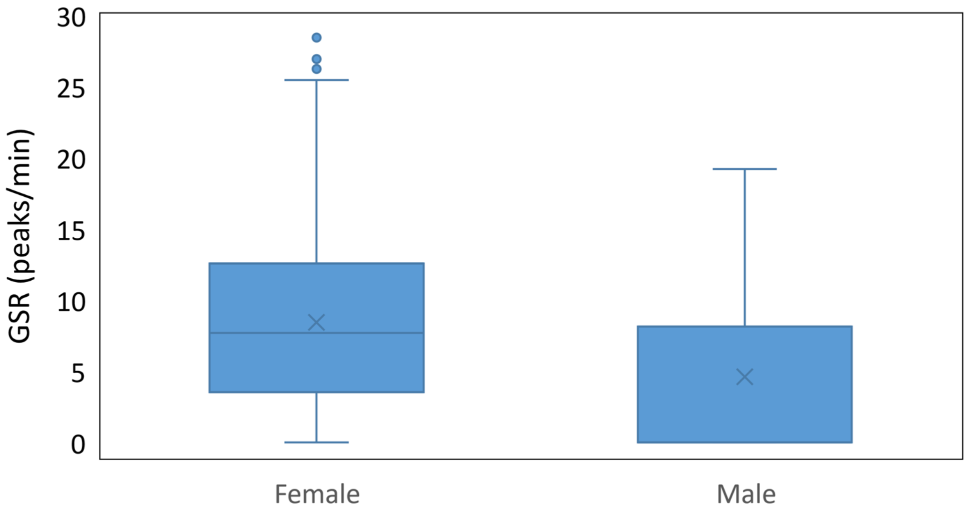


Figure 5.28 GSR Results by Gender

5.7. Driving Performance Results

5.7.1. Driving Participant Demographics

A total of 40 participants were recruited for the driving portion of this networked experiment; however, one recruited participant did not show at the time of the experiment, leaving 39 participants. All participants were recruited from Corvallis and the surrounding area, including 20 men, 18 women, and one who preferred not to answer. No one identified as non-binary for the driving portion of the experiment. The participants' ages ranged from 18 to 68 years, with an average age of 32.8 years (SD= 14.1). Six (15 percent) participants were not able to complete the experiment because of simulator sickness in the driving simulator, and three participants were not able to complete the experiment because of simulator sickness in the bicycling simulator. In the networked experiment, if the bicycling participant exhibited simulator sickness, the experiment ended for both participants. These cases of simulator sickness brought the sample size down to 30 participants; however, one set of data was lost with the SimObserver, thus reducing the final analyzed sample size to 29 participants with an average age of 29.7 years (SD= 13.5), including 15 men (average age= 26.3, SD= 10.4 years), 13 women (average age= 32.3, SD= 16.3 years), and one who preferred not to answer (age= 39 years).

Although data were collected for the passenger car participants on the eye-tracker and GSR, for the purposes of this report, the data were not analyzed. It is expected that some data were lost during the experiment, resulting in different final analyzed sample sets for data collected with the SimObserver, eye-tracker, and GSR. The total analyzed sample sizes and demographics for driving participants are shown in table 5.15.

Table 5.15 Driving Participants and Sample Sizes

	Total	Male	Female	Non-Binary	Prefer Not to Answer
Total Enrolled	39 (100%)	20 (51%)	18 (46%)		1 (3%)
Simulation Sickness	6 (15%)	3 (50%)	3 (50%)		
Data Not Collected	3 (8%)	2 (67%)	1 (33%)		
Data Lost	1 (3%)		1 (100%)		
Total Sample	29 (74%)	15 (52%)	13 (45%)		1 (3%)
Age Range			18	- 68	

5.7.2. *Pre-Simulator Driving Questionnaire*

The pre-simulator questionnaire for the driving portion of the experiment focused on participant demographics and driving experience. The final analyzed samples shown in table 5.16 are for 30 participants. Within each category, participants were predominantly 1824 years old (50.0 percent), had some college education (40.0 percent), were White or Caucasian (80.0 percent), and made between $25,000 and $49,999 annually (30.0 percent). For driving experience, participants generally had been a licensed driver for between one and six years (40.0 percent) and drove two to four times per week (43.3 percent).

Table 5.16 Pre-Simulator Driving Questionnaire Results

Category	Demographic Variable	Count	Percentage
Gender	Male	15	50.0
	Female	14	46.7
	Non-Binary	0	0.0
	Prefer Not to Answer	1	3.3
Age	18-24	15	50.0
	25-34	7	23.3
	35-44	4	13.3
	45-54	2	6.7
	55-64	1	3.3
	65+	1	3.3
Race	American Indian or Alaska Native	1	3.3

Category	Demographic Variable	Count	Percentage
	Asian	2	6.7
	Black or African American	0	0.0
	Hispanic or Latino/a/x	2	6.7
	White or Caucasian	24	80.0
	Other	1	3.3
	Prefer Not to Answer	0	0.0
Income	Less than $25,000	8	26.7
	$25,000 to less than $50,000	9	30.0
	$50,000 to less than $75,000	2	6.7
	$75,000 to less than $100,000	4	13.3
	$100,000 to less than $200,000	4	13.3
	$200,000 or more	1	3.3
	Prefer Not to Answer	2	6.7
Education	Some high school or less	0	0.0
	High school diploma or GED	2	6.7
	Some college	12	40.0
	Trade/vocational school	0	0.0
	Associate Degree	2	6.7
	Four-year Degree	6	20.0
	Master's Degree	6	20.0
	PhD Degree	2	6.7
	Prefer Not to Answer	0	0.0
Driving Experience	Less than 1 year	0	0.0
	1 to less than 6 years	12	40.0
	6 to less than 20 years	10	33.3
	20 years or more	8	26.7
	I am not currently licensed	0	0.0
Driving Hours per Week	1 time per week	2	6.7
	2 to 4 times per week	13	43.3
	5 to 10 times per week	7	23.3
	More than 10 times per week	5	16.7
	0 – Do not currently drive	3	10.0

5.7.3. Post-Simulator Driving Questionnaire

The post-simulator questionnaire for the driving portion of the experiment focused on knowledge about and influence of the BRS law, safety, and perception of safety of the bicyclists as they approached intersections in the built environment and in the simulated environment. The questions used a scale response method, and 30 participants' responses are reflected in table 5.17.

Participants were generally completely unfamiliar with the BRS law before participating in the experiment (37.5 percent), they felt comfortable approaching intersections with bicycles present in the built environment (40.6 percent), and they felt neutral (40.6 percent) and comfortable (40.6 percent) approaching intersections in the simulated environment. Drivers generally felt that knowledge about the BRS law influenced their behavior and decisions (59.4 percent).

Table 5.17 Post-Simulator Driving Questionnaire Results

Question	Options	Count	Percentage
How familiar were you with the Bicycle Rolling Stop law prior to participating in this experiment?	Completely Unfamiliar	12	37.5
	Somewhat unfamiliar	4	12.5
	Neither Unfamiliar or Familiar	3	9.4
	Somewhat Familiar	5	15.6
	Completely familiar	8	25.0
As a driver, how comfortable do you typically feel approaching intersections with bicycles in everyday life?	Very Uncomfortable	0	0
	Uncomfortable	7	21.9
	Neutral	8	25.0
	Comfortable	13	40.6
	Very Comfortable	4	12.5
How comfortable did you feel approaching intersections with bicycles in during the experiment?	Very Uncomfortable	0	0.0
	Uncomfortable	5	15.6
	Neutral	13	40.6
	Comfortable	13	40.6
	Very Comfortable	1	3.1
Please indicate your level of agreement with the following statement: "As a driver, I was concerned about bicyclist safety when approaching an intersection where a bicyclist was present."	Strongly Disagree	2	6.3
	Disagree	4	12.5
	Neutral	4	12.5
	Agree	12	37.5
	Strongly agree	10	31.3
Did knowledge of the Bicycle Rolling Stop law influence your behavior or decisions?	Yes	19	59.4
	No	13	40.6

Participants were asked to explain their answers in their own words after each question. Some direct quotes from participants answering whether knowledge of the BRS law influenced their behavior or decision included, “knowing that the cyclists were not going to stop made me more cautious around them,” “I knew that bikes had a different priority so had to be more careful,” and “knowing about the BRS law made me wait longer at the intersections to be certain the biker could turn before I drove.”

5.7.4. Driving Speed

Driving speeds were recorded with SimObserver and analyzed with Microsoft Excel. The mean speed of drivers was calculated beginning 30 meters before they approached the stop sign until they left the intersection. Driving participants were confronted with eight scenarios in two tracks that were repeated after they had been educated about the BRS law.

Figure 5.29 shows the mean speeds of drivers before and after education for Track 1, which includes half the scenarios presented to participants. After education about the BRS law, the mean speeds were nearly the same as, or greater than, before education, as drivers approached the intersections for all scenarios, including those with the dedicated bike lane and shared roadway.

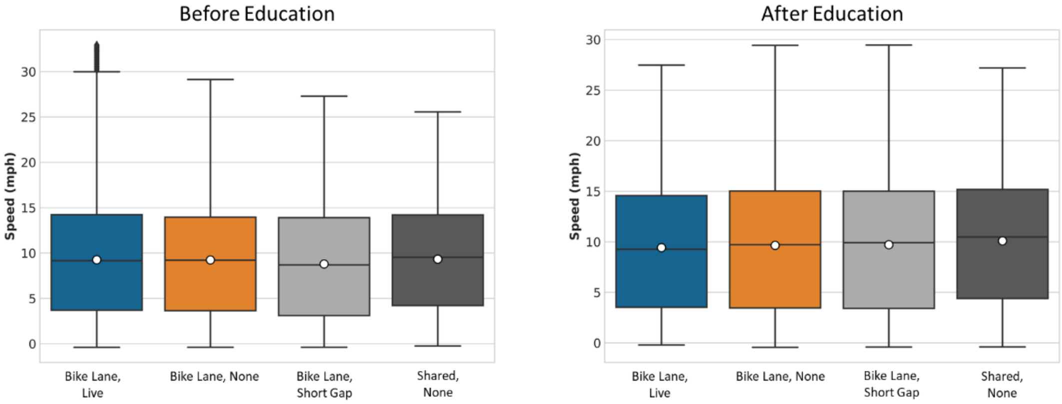


Figure 5.29 Mean Speed Before Education and After Education, Track 1

Figure 5.30 shows the mean speeds of drivers before and after education for Track 2. In the scenario with the dedicated bike lane and with virtual bicycles approaching the intersection while performing conflicting movements with a Long Gap between arrival of the next bicycle, the mean speed decreased slightly after education about the BRS law.

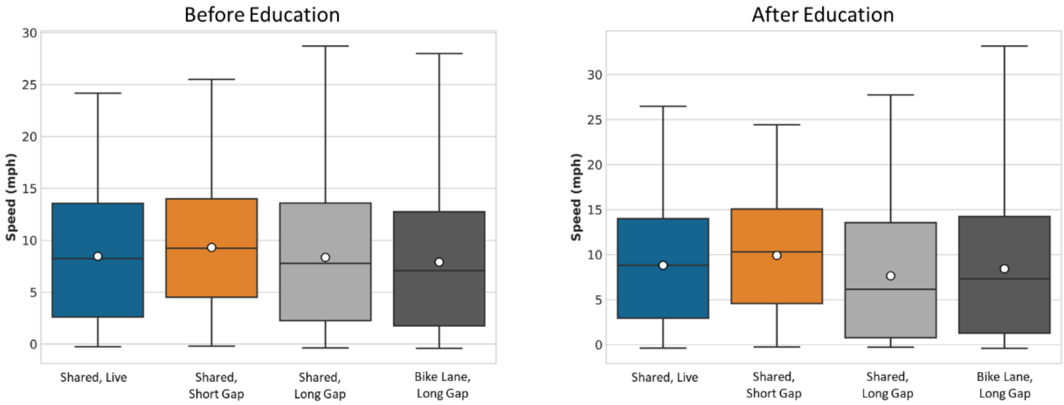


Figure 5.30 Mean Speeds Before Education and After Education, Track 2

Table 5.18 presents the descriptive statistics for the driving simulator speeds for all scenarios before and after BRS law education. These speeds were calculated as the driving participants approached the intersection of interest, starting 3 meters in front of the stop sign and stopping once the simulated passenger car had reached the stop sign. For the dedicated bike lane, with simulated bicycles performing conflicting movements at a Long Gap and Short Gap distance, the mean speed increased after education. For the dedicated bike lane with no conflicting bicycle movements, the mean speed decreased by 0.2 mph. In the live interaction scenario with a dedicated bike lane, the mean speed stayed nearly the same (3.37 and 3.36 mph) before and after education; however, the median speed increased after education by between 0.3 mph and 2.6 mph.

In scenarios with shared roadway conditions, no conflicting bicycle movements, and Long Gap bicycle conflicting movements, the mean and median speeds increased after education. The greatest increase was for the shared roadway with no conflicting bicycle movements, in which the mean speed increased 0.6 mph to 4.0 mph after education, and the median speed also increased 0.6 mph to 3.4 mph after education. In scenarios with a shared roadway and Long Gap bicycle conflicting movements and live interaction, the mean speed decreased after education. For Long Gap bicycle conflicting movements, the mean speed decreased by between 0.7 mph and 1.9 mph, and the median speed decreased between 0.7 mph and 1.1 mph.

Table 5.18 Descriptive Statistics for Passenger Car Speeds for All Scenarios Before and After Education

Passenger Car Speed (mph)	Conflicting Movements	None		Long Gap		Short Gap		Live	
	Education	**Before**	**After**	**Before**	**After**	**Before**	**After**	**Before**	**After**
Bike Lane	Mean	3.3	3.1	2.4	2.4	2.8	3.0	3.4	3.4
	SD	3.0	3.1	2.5	2.9	2.9	2.9	3.3	3.1
	Median	2.6	2.3	1.4	1.2	2.1	2.2	2.3	2.6
	Minimum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Conflicting Movements	**None**		**Long Gap**		**Short Gap**		**Live**	
	Education	**Before**	**After**	**Before**	**After**	**Before**	**After**	**Before**	**After**
Shared Roadway	Mean	3.4	4.0	2.7	1.9	3.3	3.4	3.0	2.8
	SD	3.0	3.5	2.7	2.5	2.8	2.9	3.0	2.9
	Median	2.7	3.4	1.9	0.7	2.7	3.0	2.0	1.9
	Minimum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Figure 5.31 shows the speed profile for 29 participants for the scenario with bike lanes and bicycles performing conflicting movements with a Long Gap. Each line represents the speed profile for one driving participant. When shown together, we see that all participants behaved similarly, obeying traffic laws as they understood them. The speed profiles show that drivers performed similarly before and after education about the BRS law. Before education, the slope of the speed profile was slightly steeper and less uniform than after education.

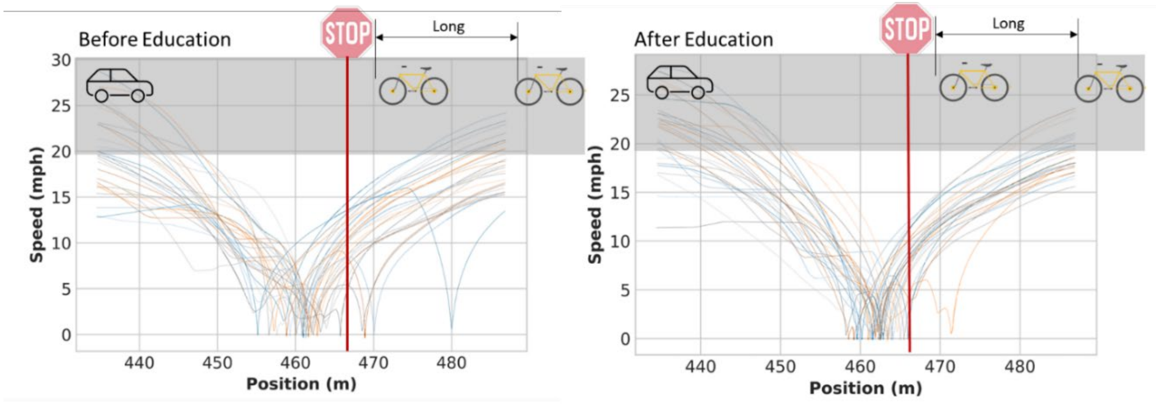


Figure 5.31 Speed Profiles, Before and After Education, Shared Roadway, Long Gap

Figure 5.32 shows the speed profile of one participant with a shared roadway treatment. Comparing speeds at a position 250 m before the intersection, before education, the travel speed was lower than the speed after education. However, after the participant had been educated about the BRS law, the driver decelerated at a faster rate and approaced the stop sign at a significantly lower speed when bicyles were performing conflicting movements with a Short Gap at the intersection.

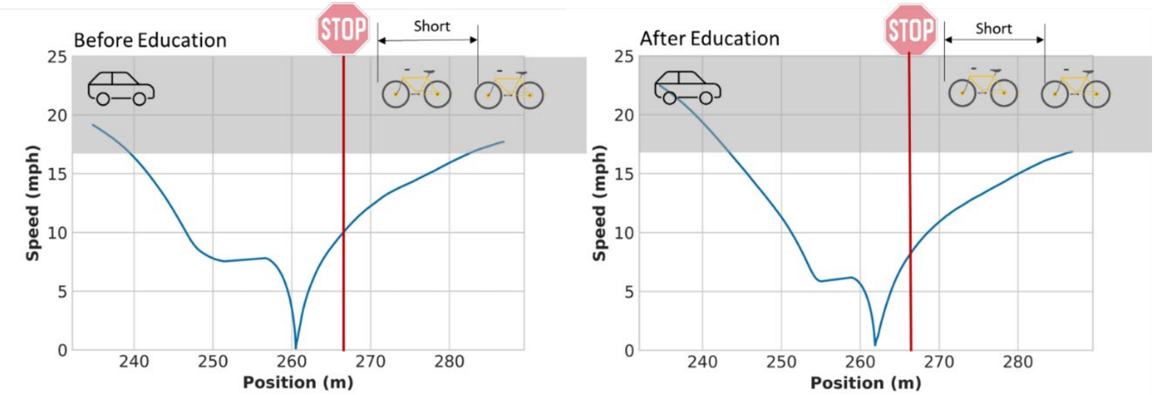


Figure 5.32 Speed Profile for a Participant: Before and After Education, Shared Roadway, Short Gap

Figure 5.33 is for one participant on a shared roadway with bicycles performing conflicting movements with a Long Gap separation. After education, the speed of the passenger car was greater than before education 30 meters from the intersection. However, as the participants drew closer to the stop, they decelerated at a faster rate and approached the stop at a slower speed after education.

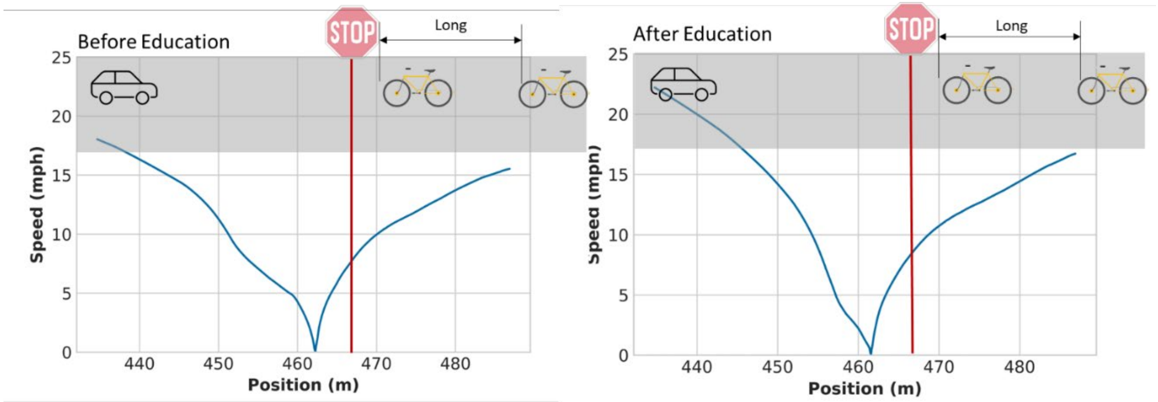


Figure 5.33 Speed Profile for a Participant: Before and After Education, Shared Roadway, Long Gap

To better understand drivers' speeds and account for any confounding variables, a statistical analysis was conducted. The results of the LMM model are shown in table 5.19. The random effect was significant (Wald Z=3.28, *p* =0.001), which suggests that it was necessary to treat the participant as a random factor in the model.

Table 5.19 Summary of Estimated Model for Mean Drivers' Speeds

Variable	Estimate	SE	T-Value	P-Value
Participant random effect (Var)	1.20	0.36	3.28	**0.001**
Constant	4.01	0.28	14.59	**0.000**
Education				
Before	Baseline			
After	-0.002	0.15	-0.02	0.987
Movement of Conflicting Vehicle				
None	Baseline			
Long gap	-0.88	0.22	-4.07	**0.000**
Short gap	-0.27	0.21	-1.26	**0.207**
Live	0.14	0.21	0.67	0.502
Roadway Treatment				
Shared Roadway	Baseline			
Bike Lane	-0.11	0.15	-0.70	0.487
Summary Statistics				
R2	*37%*			
-2 log likelihood	*1820.14*			

Bold p-values: Significant at the 80 percent confidence level

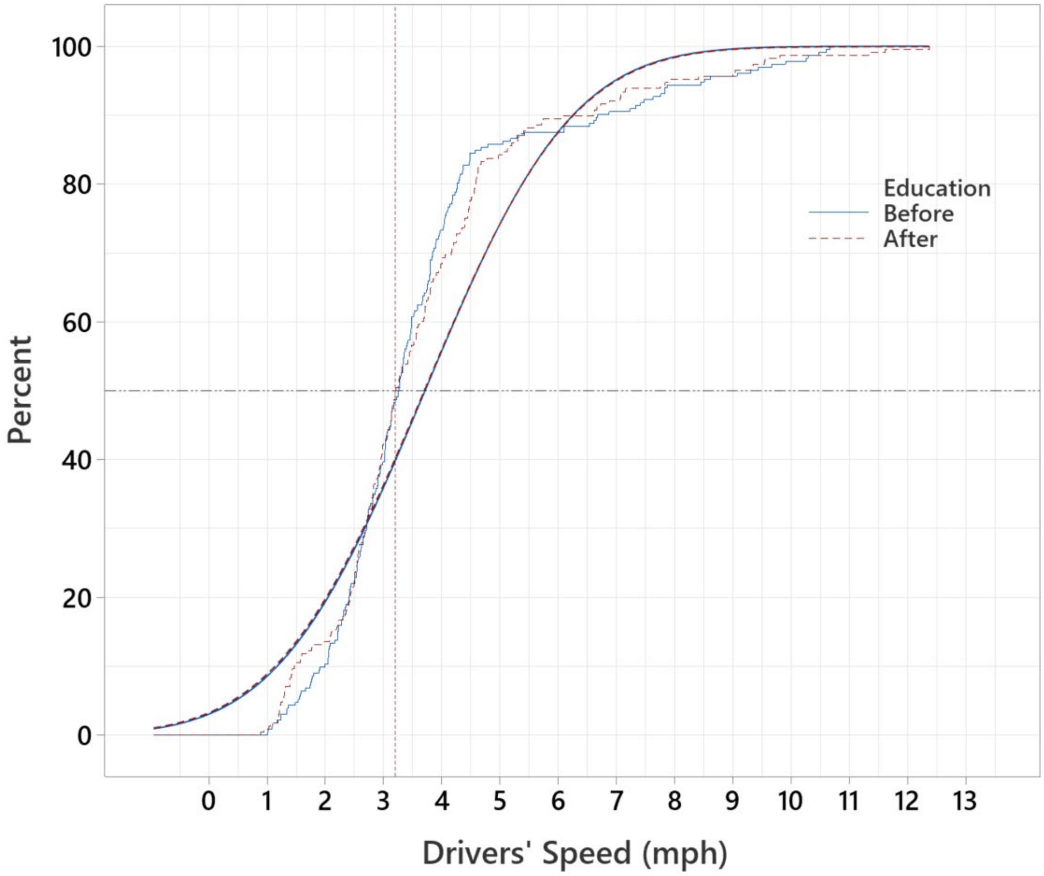


Figure 5.34 Cumulative Distribution of Drivers' Speeds Before and After Education

5.8. Live Interaction Results

The live interaction simulation was dependent upon the speeds of both participants in the simulation—the driver and the bicyclist. The methodology used to design the experiment with a live interaction in the simulated environment generally worked as intended, even though it was dependent upon the speed of the driver and the speed of the bicyclist (two variables). Whereas driver speed could be dictated with a design speed and speed limit signs throughout the simulation, the bicycle speed was up to the bicyclist. Even with the gears on the bicycle set for one speed, the participant could still speed up or slow down by pedaling the bike faster or slower.

To overcome this variability, in the networked simulator, dynamic coding was used to anticipate when a participant on the bicycling simulator would meet at an intersection with a participant in the driving simulator. Each participant had opportunities for four live interactions, including two before BRS education and two after BRS education. The total final analyzed sample for potential live interactions was 30 participants.

For the 30 participants analyzed, there was potential for 120 live interactions, including 60 before BRS education and 60 after BRS education. The live interaction was considered a success only if the driving participant arrived in view of the bicyclist when the bicyclist was approximately 100 feet from the stop sign. If this occurred, the car was considered to be in the area of interest for the bicyclist's decision making. Out of 120 potential live interactions, live interactions happened 71 times (59.2 percent); 37 (52.1 percent) of these instances were before BRS education, and 34 (47.9 percent) of these instances were after BRS education.

5.9. Conclusions

This section presents the researchers' conclusions related to knowledge of the BRS law and behavior of bicyclists with different roadway treatments and conflicting passenger car movements. These findings are based on the networked driving and bicycling simulator experiment.

5.9.1. Bicycling Simulator Findings

Bicyclists' performance in the simulator changed significantly after education concerning the BRS law. Before education, most of bicyclists generally stopped at all stop signs, while after education bicyclists generally yielded at stop signs and advanced through intersections at higher speeds. More bicyclists came to a stop at each stop sign after education when passenger cars were present in contrast to no passenger cars at the intersections. Additionally, over 75 percent of participants stated that knowledge of the BRS law influenced their behavior and decisions.

Presence of conflicting passenger car movements also had a significant effect on the visual attention of bicyclists in both lane treatments—bike lane and shared roadway. When there were no passenger cars at an intersection, bicyclists spent most of their time looking at the stop sign. When passenger cars were present, their visual attention was split between the stop sign and the passenger cars. This behavior was also different before and after BRS education. When there was a bike lane, after education of the law participants spent more time looking at the first car present at the intersection and less time looking at the second car arriving at the intersection. When there was a shared roadway, after education participants spent more time looking at the stop sign and less time looking at the second car arriving at the intersection. After education, participants also allocated more attention to passenger cars arriving at the intersection when they were deciding whether to accept a gap and enter the intersection. This may have also been influenced by bicyclists' evaluation of the safety of potential gaps during yielding maneuvers at stop signs.

Generally, the level of stress decreased after education for all users, and this could indicate increased comfort level with the simulator itself, or it could indicate increased comfort with decision making at intersections. Still, an increase in stress happened in scenarios with a bike lane and movements of conflicting vehicles with a Long Gap. One reason for an increased level of stress in this scenario may be that the decision zone for the participant was longer with cars arriving at a greater distance. Generally, the level of stress experienced by women was higher than that of men. The level of stress when cars were present increased for participants after education in comparison to when cars were not present. This may have been due to the fact that after education concerning the BRS law, participants had to *decide when to yield* at stop signs, rather than automatically stopping at each stop sign.

Generally, the researchers found that bicyclists were not contributing to dangerous behaviors when BRS was legal because participants exhibited different decision-making behavior when cars, which can be seen as immediate hazards, were present at a stop-controlled intersection as the bicyclist approached the intersection.

5.9.2. Driving Simulator Findings

Educating participants about the BRS law had significant effects on driving speeds. As driving participants approached the intersections, they decelerated faster and entered the intersection at slower speeds when bicyclists were present.

5.9.3. Live Interaction Findings

The live interaction findings were similar to the bicycling simulator findings. In cases where the live interaction was successful, participants spent significantly more time looking at the stop sign before BRS education in both the dedicated bike lane and shared roadway treatments. When there was a dedicated bike lane, participants spent more time after education looking at the approaching passenger car. When there was a shared roadway, participants spent slightly less time after education looking at the approaching passenger car. This might be because, typically, dedicated bike lanes are on higher speed roads, and bicyclists may be more concerned about approaching passenger cars on roads with higher speeds.

These results suggest that live interactions may validate the results seen with pre-programmed vehicle interactions in the virtual environment. The researchers believe that networked simulation, using the new methodology established with this experiment, could be useful for future research. In a simulation, participants are observed for their behavior relative to a known, dynamically coded entity. Networked simulation could become a way to observe behavior between two entities when decision making is a factor and behavior between the two entities is unknown.

CHAPTER 6. CONCLUSIONS

To fill a gap in existing knowledge, this research utilized stakeholder interviews, an online survey, and a networked driving and bicycling simulator experiment to evaluate the safety implications of the BRS law.

6.1. Recommendations

Outcomes from this research suggest that education and outreach opportunities regarding bicycle rolling stop laws need to be more actively pursued. One such opportunity would involve the incorporation of these laws into the driver handbook of each state where BRS legislation has been passed. For example, in the Idaho Driver's Handbook (ITD, 2016), Oregon Driver Manual (ODOT, 2020), and the Washington Driver Guide (WA DOL, n.d.), there are sections that describe driver and bicyclist interactions, but bicycle rolling stop laws are not specifically mentioned. Older drivers who use these resources during the standard license renewal process could, and should, be afforded an opportunity to learn about appropriate bicycle behaviors at intersections through the inclusion of a short section on bicycle rolling stop laws. Indeed, an informed driver might view bicyclists who (legally) roll through a stop sign or roll through a red light when making a right turn at an intersection in a more favorable manner. Defensive driving would also be encouraged through further education, in which motorists would more carefully look for cyclists at all intersections, knowing the rights afforded to them by BRS laws.

6.2. Limitations

The research results provided herein give valuable feedback for transportation professionals to consider when they design educational initiatives and make future legislative decisions. However, there are some limitations to this research, and future work has been identified that could further current understanding of BRS legislation.

While a reasonable saturation model was developed for the stakeholder interview process described in Chapter 3, only a limited number of stakeholders were interviewed, leaving the possibility of uncaptured opinions concerning BRS. Again, although the survey tool developed in Chapter 4 captured hundreds of responses from Idaho, Washington, and Oregon, it is possible that some voices were not heard, as is the nature of surveys.

The major limitation of the full-scale bicycling simulator described in Chapter 5 is that it only provided a forward-facing view for the cyclists, presented on a single 8-foot x 10-foot projection screen. It is important for vulnerable road users to have 360-degree view with no obstructions to make safe decisions in the built environment and to create realism in appearance and movement in the simulated environment. Such a surrounding view was provided for the motorist simulator.

6.3. Future Work

Existing research on the topic of BRS law is limited, and the researchers identified several future research topics, including those listed below.

- Research has shown that women comply with circular red signal indications at a higher rate than men, and women are also more likely to be injured or killed by trucks at intersections. This has led some to advocate for more training in “assertive cycling and road positioning,” especially for women. Future research could include variable bicycle positioning at intersections, yielding versus stopping behaviors for cyclists, and specific interactions with trucks. These variables could be studied in a networked bicycling and heavy vehicle simulator.
- The potential exists to collect crash data for comparison before and after passage of the BRS law, specifically concentrated on dense cities with high bicycle commuter percentages, such as seen in Portland, Oregon, and Seattle, Washington. However, care must be taken to recognize the date of legalization of the BRS law as a potential confounding variable because of the pandemic year, 2020, and changes in bicycling behavior during that time.
- The popularity of electric bicycles should be considered in conjunction with the implementation of BRS laws in the future, as the use of electric bicycles may change the balance of reasoning behind BRS legislation, tipping it away from discussion of cyclists’ convenience, effort, and instability.

Research could be conducted into potential added signs to be used at intersections where BRS is permitted. This research produced select data that were not able to be analyzed because of time constraints. Research has shown that drivers are more aggressive toward bicyclists when they believe the cyclists are breaking the law. GSR data were collected for driving participants and could be analyzed for stress levels before and after education of the BRS law. Along with survey data, these GSR data could be used to determine aggression levels for drivers. Positional data for the driving participants in the simulator study could also be analyzed for stopping behavior, thus answering the question of whether drivers would wait longer at stop signs for a bicycle to make a decision after BRS education.

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