AN ABSTRACT OF THE DISSERTATION OF

Mafruhatul Jannat for the degree of Doctor of Philosophy in Civil Engineering presented on December 16, 2014.

Title: Right-Hook Crash Causality at Signalized Intersections.

Abstract approved: ____

David S. Hurwitz

A Right-hook (RH) crash is a common type of bicycle-motor vehicle crash that occurs between a right-turning vehicle and through-moving bicycle at an intersection. At signalized intersections, RH crashes can occur at the onset of the green or during the latter portion of the green phase. In spite of the frequency and severity of this crash type, no experimental studies have provided compelling evidence as to the root causes of RH crashes at signalized intersections. This research provided improved understanding of RH crash causal factors during the latter portion of the green phase through an online survey and driving simulator experiment. From the 209 self-reported online survey responses, it was found that 78% of bicyclists were unaware of their stopping position with respect to stopped vehicles queued at an intersection during a red indication, and 19% of motorists (n = 246) reported that they would not yield to the adjacent bicyclist approaching from behind if they were detected in rear-view or side-view mirrors. The driving simulator experiment (n = 51) investigated RH crash causal factors related to the motorist and built environment using three different motorist performance measures: i) visual attention, ii)

situation awareness (SA) and iii) crash avoidance behavior. Motorist's visual attention measure revealed that in the presence of oncoming vehicular traffic, motorists spent the majority of their visual attention looking at the oncoming traffic that posed immediate hazard to them and failed to detect a bicyclist approaching from behind. Motorists' SA measure indicated that motorists detect a bicyclist riding in their forward field of view more successfully than a bicyclist approaching from behind in the vehicle's blind spot. Motorist's crash avoidance behavior revealed that 92% of 26 observed crashes occurred with a bicyclist approaching from behind in the vehicle's blind spot and oncoming vehicles were present in 88% of those crashes. Also, 81% of observed crashes occurred due to inadequate surveillance.

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Right-Hook Crash Causality at Signalized Intersections

by
Mafruhatul Jannat

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APPROVED:

Major Professor, representing Civil Engineering

Head of the School of Civil and Construction Engineering

Dean of the Graduate School

I understand that my dissertation will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my dissertation to any reader upon request.

Mafruhatul Jannat, Author

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LIST OF ABBREVIATIONS

AAA: American Automobile Association

AOI: Areas of Interest

ATFD: Average Total Fixation Duration

BMV: Bicycle-Motor Vehicle

CI: Confidence Interval

ISTEA: Intermodal Surface Transportation Efficiency Act

ITTE: Institute of Transportation and Traffic Engineering

FHWA: Federal Highway Administration

HSRC: Highway Safety Research Center

MAP-21: Moving Ahead for Progress in the 21st Century

NHTS: National Household Travel Surveys

NHTSA: National Highway Traffic Safety Administration

NMVCCS: National Motor Vehicle Crash Causation Survey

NPTS: National Personal Transportation Surveys

ODOT: Oregon Department of Transportation

PBCAT: Pedestrian and Bicycle Crash Analysis Tool

ITTE: Institute of Transportation and Traffic Engineering NCHS: National Center for Health Statistics

NEISS: National Electronic Injury Surveillance System

RH: Right-Hook

SA: Situation Awareness

LIST OF ABBREVIATIONS (Continued)

SAFETEA-LU: Safe, Accountable, Flexible Efficient Transportation Equity Act: A Legacy for Users

SAGAT: Situation Awareness Global Assessment Technique

TEA 21: Transportation Equity Act for the Twenty-First Century

USDOT: US Department of Transportation

Chapter 1 Introduction

With public interest seemingly increasing in sustainable transportation solutions—in part motivated by rising fuel prices and other concerns—bicycling has gradually become a more integral component of the multimodal transportation system in the US. As cities have made investments in the non-motorized transportation infrastructure, bicycling has become a meaningful alternative mode of transportation for commuting to activities such as school, work, shopping, and recreation (Pucher et al., 1999, 2011; SAFETEA-LU Section 1807, 2012). According to the National Personal Transportation Surveys (NPTS) of 1977 through 1995 and the National Household Travel Surveys (NHTS) of 2001 and 2009, the number of trips made by bicycle in the US has more than tripled from 1977 to 2009 while the bike share of total trips almost doubled, rising from 0.6% to 1.0% (NHTSA 2009; Pucher et al., 2011; PBIC and FHWA, 2010). Bicycle sales in the US have also increased from $15 million in 1973 to $6 billion in 2009 (National Bicycle Dealers Association, 2010).

Increased levels of bicycling has the potential to improve overall levels of public health, reduce emissions, alleviate parking demand as well as enhancing the livability of the community by providing an alternative to driving (FHWA, 1997; PBIC and FHWA, 2010). Since 50% of trips made by all modes in US cities are shorter than 3 miles and 40% are shorter than 2 miles, there is tremendous potential for replacing those trips with bicycling. From the context of health benefits, studies have found that adults who bike to work have healthier weight, blood pressure, and insulin levels and adolescents who bike are 48% less likely to be overweight as adults (Menschik et al., 2008; Gordon-Larsen et al., 2009). According to the Bureau of Transportation Statistics (2010), the annual cost of owning and driving a car for an average American household is estimated to be $7,179. Compared to that, for a round-trip commute of 10 miles, bicyclists save around $10 daily, or $3,650 annually (Bikes Belong, 2013). It has also been found that by replacing 1 mile of driving with 1 mile of bicycling can prevent the production of nearly 1 pound of CO_2 (0.88 lbs) (EPA, 2013).

Still, previous research has shown that safety is a primary concern for many people when considering bicycling as a mode choice. For the most recent year available (2011), the National Highway Traffic Safety Administration (NHTSA) reports that there were 677 fatal bicycle-related crashes in 2011 which accounted for 2% of transportation related fatalities in the US (NHTSA, 2011). As shown in the Table 1-1, the largest number of bicyclist fatalities, 786, was recorded in 2005.

Table 1-1: Total Fatalities and Bicyclists Fatalities, 2002-2011 (NHTSA)

Year	**Total Fatalities**	**Bicyclist Fatalities**	**Percent of Total Fatalities**
2002	43,005	665	1.5
2003	42,884	629	1.5
2004	42,836	727	1.7
2005	43,510	786	1.8
2006	42,708	772	1.8
2007	41,259	701	1.7
2008	37,423	718	1.9
2009	33,883	628	1.9
2010	32,999	623	1.9
2011	32,367	677	2.1

1.1 Right-Hook Crashes

Most bicycle-motor vehicle (BMV) crashes occur at intersections in urban areas—with crashes involving right-turning vehicles and through moving bicycles, which are commonly termed as “right-hook (RH) crashes”(Figure 1-1). According to the Oregon (OR) Bicycle Manual, “A RH occurs when a right-turning motorist crosses the path of a through bicyclist at an intersection” (ODOT, 2010).

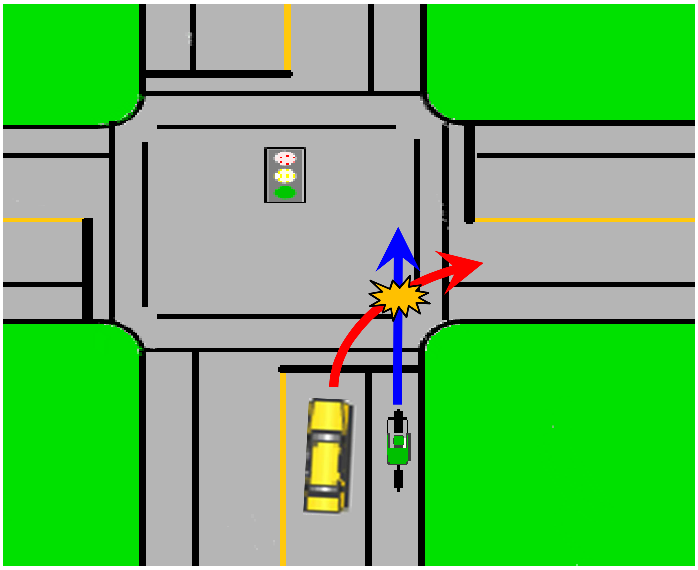


Figure 1-1: RH Crash

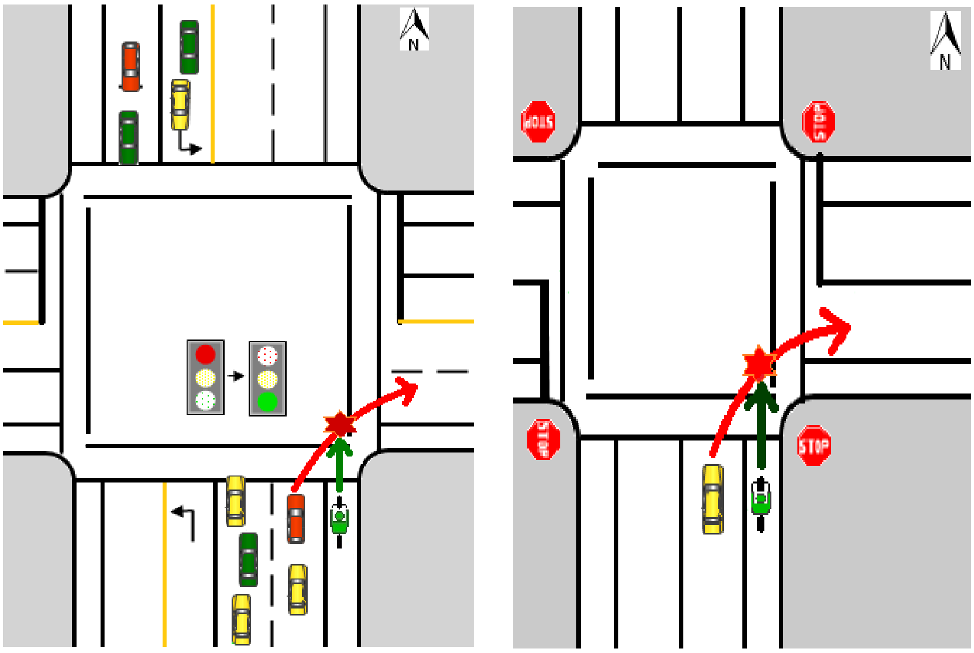
RH crashes at intersections can occur as the result of several scenarios:

1) A RH at the onset of the green indication or at a stop sign can occur when a bicyclist stops to the right of a vehicle that is waiting at a red indication or STOP sign and fails to notice the bicyclist, who may be occluded in the vehicle’s blind spot (Figure 1-3). Immediately after the signal turns green simultaneously the bicyclist proceeds through the intersection and the motorist turns right, leading to

a conflict and possible collision. Some literature has termed this a RH during the start-up green (City of Fort Collins, 2013; bikeportland.org, 2012).

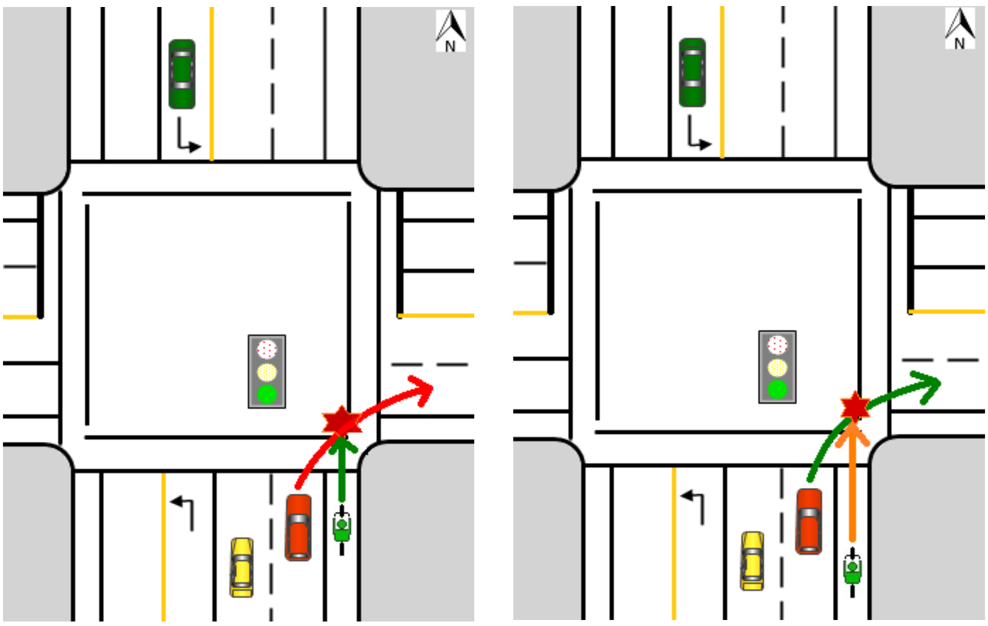
2) A RH can also occur at an intersection several seconds after the signal turns green when there is relative motion between the right-turning motorist and the through moving bicyclist. Some literature has termed this a RH during the “stale” green (City of Fort Collins, 2013; bikeportland.org, 2012) or RH during the latter portion of the green phase. A RH crash in this condition can occur in two ways: 1) when a bicyclist overtakes a slow-moving vehicle from the right and the vehicle unexpectedly makes a right-turn (Figure 1-2a); and, 2) when a fast moving vehicle overtakes the bicyclist and then tries to make a right-turn directly in front of the bicyclist, who simultaneously proceeds through the intersection (Figure 1-2b).

Crash data analysis has indicated that RH crashes were one of the most frequent BMV crashes in OR from 2007 to 2011. A study by Kittelson and Associates (2013) revealed that of the 2,711 crashes at intersections, 507 crashes were recorded where one vehicle was turning right and the bike was traveling straight (18%). Forty-eight percent of the 616 BMV crashes that occurred at signalized intersections in the Portland Metro area from 2007 to 2011 were categorized as RH crashes (Kittelson and Associates, 2013). In terms of severity, there were 12 severe RH crashes comprising 26% of the 46 total severe crashes at intersections in the Portland Metro from 2007 to 2011. However, in spite of the severity and increased frequency of RH crashes at signalized intersections, no experimental studies have yet to provide compelling evidence as to the root causes of RH crashes at signalized intersections.



(a) RH at Start-up Green (b) RH at STOP Sign

Figure 1-3 : RH Crash at STOP or Beginning of the Green Signal Phase



(a) Bicyclist Passing Slow-Moving Car (b) Motorist Passing Bicyclist

Figure 1-2: RH Crash at the Latter Portion of Green Phase

1.2 Objectives and Scope of the Study

To identify potential countermeasures for mitigating any crash type, a better understanding of crash causality, the factors contributing to and reasons for a type of crash, is critically important. An in-depth understanding of crash causality helps to identify effective crash mitigation strategies which may be in the form of user education, or improving the vehicle-human interface, or through implementing design treatment in the road environment. However, in order to analyze the reasons for a crash, it is important to identify whether a crash occurred due to human error, the vehicle, or the driving environment (Fisher et al., 2011). The objective of this research is to contribute to the body of knowledge by providing a better understanding of the causal factors of RH crashes at signalized intersections during the latter portion of the green phase.

During a RH crash at the onset of the green phase, both the bicyclist and the motorist start from a stopped position, i.e. there is no relative motion between them. However, during a RH crash in the latter portion of the green phase, both the bicyclist and the motorist are at motion and their relative positions vary while approaching the signalized intersection. Also, previous studies have examined mitigation strategies for RH crash at the onset of green indication (Loskorn et al., 2013; Dill et al., 2012). However, the causes and corresponding mitigation strategies of a RH crash occurring at the latter portion of green phase have yet to be identified. Therefore, a critical first step and the focus of this research effort is to identify the causal factors of RH crashes during the latter portion of the green phase at signalized intersection. The specific objectives of this research are to:

1. Conduct a comprehensive literature review on the crash contributing factors for BMV crashes at intersections,
2. Gain insight on the behaviors of conflicting motorists and bicyclists at intersections in the US, with a particular focus on RH crashes,
3. Analyze motorist performance using several performance measures during a simulated driving task, and
4. Identify the motorist related and driving environment related causal factors of RH crashes.

1.3 Organization of the Study

This dissertation is organized into several chapters. Chapter 2 describes a comprehensive literature review on the contributing factors of BMV crashes and motorist performance measures during a driving task. Chapter 3 presents an online survey conducted to assess motorist and bicyclist self-reported behavior during their interactions at intersections. Chapter 4 provides a detailed methodology of a driving simulator experiment conducted to measure motorist performance using several performance measures, during right-turning maneuvers during the latter portion of the green phase at signalized intersections. The three performance measures including motorist's visual attention, situational awareness (SA), and crash avoidance behavior are examined in detail in Chapters 5, 6, and 7, respectively. Finally, Chapter 8 provides a summary of the findings of this experiment and directions for future work.

Chapter 2 Literature Review

In order to determine the potential causes of RH crashes and their countermeasures, it is essential to understand the characteristics of bicyclist-motorist interaction at intersections. Therefore, the review of the literature focuses on crashes at intersections.

2.1 Bicycle Crashes at Intersections

According to the NHTSA, (2010), "Crashes often occur at intersections because these are the locations where two or more roads cross each other and activities such as turning left, crossing over, and turning right have the potential for conflicts resulting in crashes." Although intersections constitute only a small fraction of the overall area comprised by the surface transportation system, a comparatively large number of crashes occur at intersections, since a variety of modes directly interact, sometimes in conflicting ways, at these locations. NHTSA reported that 69% of fatal crashes in the US occurred in urban areas in 2011. Of all US bicycle-involved fatal crashes, 33% occurred at intersections, 57% at non intersections and 8% other locations. National crash data shows that in 2010, 618 bicyclists were killed in crashes with motor vehicles 33% of which occurred at intersections (NHTSA, 2010). In OR, 4,124 bicycle-motor vehicle crashes occurred from 2007-2010 and 66% of those crashes took place at intersections (ODOT, 2011 and Muttarta et al, 2011). This intersection related safety issue has been repeatedly identified in the literature (Weigand et al., 2008; Wang et al, 2004; Korve et al., 2002; and Wachtel et al, 1994). Wachtel et al. (1994) and Wang et al. (2004) stated in their studies that most bicycle-motor vehicle related crashes occur at intersection. This safety issue is potentially even more significant at urban intersections due to the increased number of motor vehicles and bicyclists. In an analysis of police reported bicycle crashes in Palo Alto, California from 1981 to 1990, Wachtel et al. (1994) found that 74% of 314 bicycle-motor vehicle related crashes occurred at intersection.

2.2 Oregon Crash Overview

According to Oregon Department of Transportation (ODOT), 56 bicyclists were involved in fatal bicycle-motor vehicle crashes 2007-2011 in OR as shown in Table 2-1. Inspection of the table reveals that reported bicycle crash data are severity-biased (meaning that very few non-injury crashes are reported). Only 3% (29/823) of the bicycle crashes are non-injury as opposed to motor vehicle crashes, which have approximately 50% of the total crashes property damage only. This is because of the reporting requirements of motor vehicle involvement and the relative severity of BMV crashes. Miranda-Moreno et al. (2011) studied injury count data reported at 623 signalized intersections on the island of Montreal, Canada. The injury data was reported by the ambulance services that had less underreporting and misallocation, according to authors. This study reported that from 1999 to 2003, 4,751 bicyclists were injured on the island of Montreal, an average of 950 bicyclists per year, almost 60% of which occurred at an intersection (Miranda-Moreno et al., 2011).

To identify candidate safety projects for OR, Kittleson and Associates (2013) complied data from 2007-2011 that is summarized in Table 2-2. In the table, the yellow-shaded cells sum to the total in each column as well as the larger categories in the grey shade (intersections and segments). Their analysis indicates that of 4,124 bicycle-vehicle crashes 66% occur at intersections. Of the severe crashes (defined as fatal or injury A), approximately 61% happened at intersections. At intersections, bicycle crashes are clearly an urban problem. In the urbanized area, more crashes occurred at unsignalized intersections.

Table 2-1: ODOT Crash Summary

Crashes	Type	2011	2010	2009	2008	2007	5 Year Avg
Bicycle	Fatal	15	7	8	11	15	11
	Injury (A+B+C)	917	872	759	754	614	783
	PDO	30	31	35	20	28	29
	Total	962	910	802	785	657	823
Pedestrian	Fatal	48	60	38	51	50	49
	Injury (A+B+C)	795	730	613	555	526	644
	PDO	6	2	11	4	4	5
	Total	849	792	662	610	580	699
Motor Vehicle	Fatal	247	225	285	307	346	282
	Injury (A+B+C)	2,175	19,277	17,681	16,731	17,360	18,645
	PDO	24,820	22,890	21,841	23,382	25,219	23,630
	Total	47,242	42,392	39,807	40,420	42,925	42,557

At the request of ODOT, Kittelson and Associates, explored the number of crashes where the motor vehicle was recorded as turning right and the cyclists was going straight. They reported that of the 2,711 crashes at intersections there were 507 crashes were recorded where one vehicle was turning right and the bike was traveling straight (18%). Four involved a bus, six were “truck with non-detachable bed, panel, self-propelled crane, tow truck, fire truck”, and five were truck tractor with trailer/mobile home in tow (Kittelson and Associates, 2013).

As part of the analysis, the crash data were parsed by the vehicle movements for some spatial subsets in Table 2-2. Figure 2-1 shows the movement of both vehicles at signalized intersections in the Portland Metro. The dark grey bars are non-severe crashes and the light grey slices are severe crashes. In the data used to create the figure, the bicycle movement was always straight. As shown in Figure 2-1, the largest number of crashes involve a bicycle moving straight – vehicle turning right (283+12 = 295). These potentially RH crashes are 48% of total 616 crashes. In terms of severity, the 12 severe crashes are 26% of the 46 total severe crashes at intersections in the Portland Metro.

Table 2-2: Bicycle Crashes, 2007-2011 by Category

	Portland Metro		**Non State Highways**		**State Highways**		**Statewide**		**Row Percent of Total**	
	Total	Severe	Total	Severe	Total	Severe	Total	Severe	Total	Severe
Intersections	1460	118	849	66	402	37	2711	221	66%	61%
Urban	1460	118	792	56	354	31	2606	205	63%	56%
Signalized	624	46	258	20	197	20	1079	86	26%	24%
Unsignalized	836	72	534	36	157	11	1527	119	37%	33%
Rural			57	10	48	6	105	16	3%	4%
Signalized			2	0	9	1	11	1	0%	0%
Unsignalized			55	10	39	5	94	15	2%	4%
Segment	634	54	574	61	205	27	1413	142	34%	39%
Urban	634	54	491	44	157	14	1282	112	31%	31%
Rural			83	17	48	13	131	30	3%	8%
Total	2094	172	1423	127	607	64	4124	363		

Source: Kittelson and Associates, Inc. OR Pedestrian and Bicycle Safety Implementation Plan, Stakeholder Workshop Handouts for Breakout Session #1

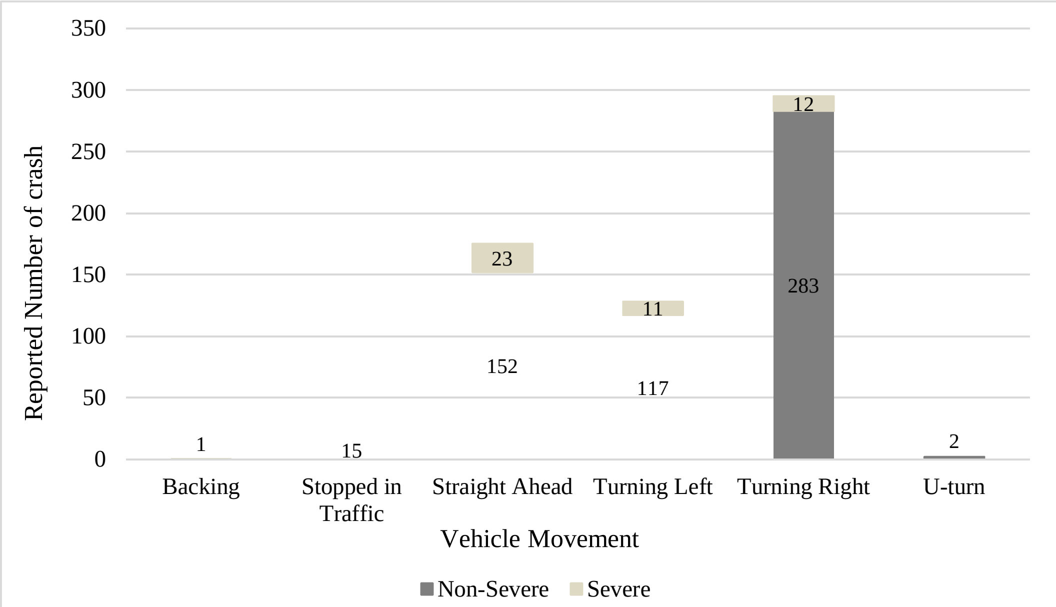


Figure 2-1: Crash Breakout by Vehicle Movements at Urban Intersection in the Portland Metro

In terms of relative risk, the crash type with highest risk is the straight ahead movements of both bicycle and vehicle where the proportion of severe crashes is 23/152=15.1%. When the vehicle is turning left, the risk 9.4% and the "RH" crash type has a lower risk 4.2%.

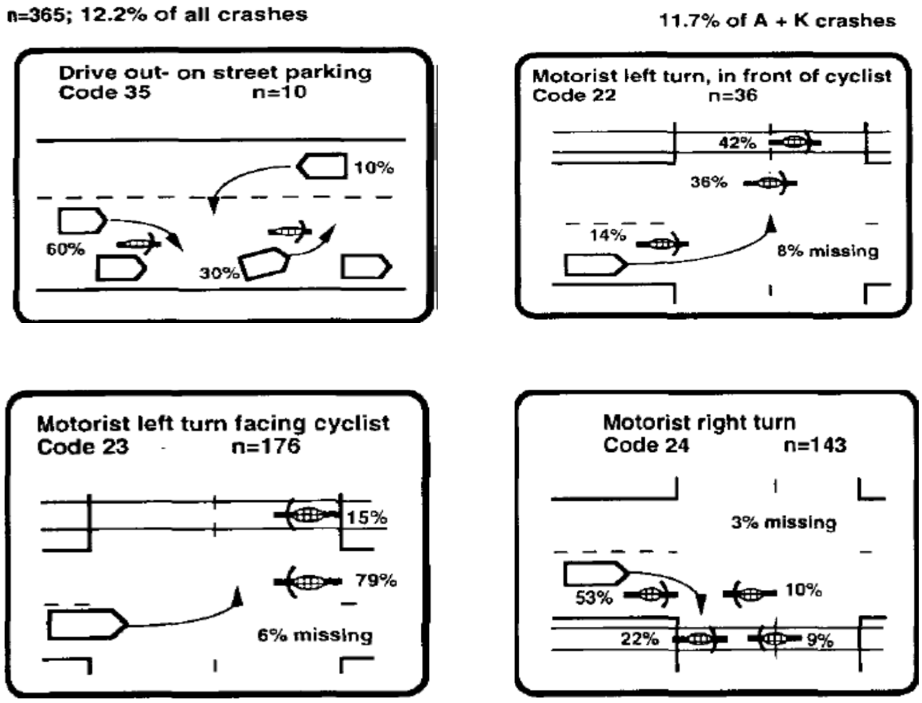
2.3 Crash Typologies

Crash typology or crash-typing system is an effective method to consider the behavior of bicyclist and motorist in different mixed mode crash scenarios. According to NHTSA, "Crash-typing system is a method for assigning a crash to one of several categories based on common crash characteristics (Karsch et al., 2012)". It helps researchers to determine the relative frequencies of different types of crashes, to analyze the scenarios and countermeasures for different crash types. It also helps to compare regional differences and trends over time for specific crash types.

The concept of pedestrian-motor vehicle crash typing was introduced in the early 1970s, and following that, Cross and Fisher developed a similar crash typing for bicycle crashes (Hunter et al., 1996, 1997*;* Zeibots et al., 2012). Cross and Fisher's typing was known as "problem types," where they categorized crashes into seven classes (A-G) that were subdivided into a total of 37 problem types (Karsch et al., 2012).

NHTSA adopted the similar crash-typing methodology and developed the NHTSA Manual Accident Typing (MAT) for Bicyclist Accidents Coder's Handbook, which identified a total of 45 distinct bicycle-motor vehicle crash configurations (Karsch et al., 2012; Hunter et al., 1996). The initial classification step considers vehicle movements: parallel paths, crossing paths, and special circumstances. Each crash type is then characterized by a specific sequence of events, and each has precipitating actions; predisposing factors; and characteristic populations, locations, or both that can be targeted for interventions (Hunter et al., 1996). The *parallel path* crash describes the situation where a motor vehicle and bicycle approach each other on parallel paths, either heading in the same or opposite directions, whereas in a *crossing path* crash the bicycle and motor vehicle are oriented on intersecting paths. *Specific circumstance* crashes include the following four groups of events: non-roadway location like parking lots, a motor vehicle that is backing, bicyclist riding a play vehicle such as a "big wheel" type tricycle and "weird" crashes, for example bicyclist struck by falling cargo. For each crash type, the Highway Safety Research Center (HSRC) 3-digit code, with the last digit was omitted was used. For example HSRC 361 is equivalent to NHTSA code 36, HSRC 220 equals NHTSA 22, and so on (Hunter et al., 1996).

To illustrate, one of the subgroups in the parallel path case was, "*motorist turn/merge into path of bicyclist*". Four different kinds of events were included in this subgroup. Those included motorist driving out from on street parking (Code 35), motorist turning left in front of a bicyclist going in the same direction as the motorist (Code 22), motorist turning left in front of a bicyclist coming toward the motorist (Code 23), and motorist turning right and striking a bicyclist going either in the same or opposing direction (Code 24). Figure 2-2 shows each of the four different events that are included in the motorist turn/merge into the path of bicyclist subgroup (Hunter et al., 1996).



Overrepresented Variables

Bicyclist Age	20-24; 25-44
Driver Age	65+
Location	urban
Time of Day	6-10am; 10am-2pm
Road Class	State roads
Number of Lanes	4,5,6+
Traffic Control	signal

Figure 2-2: Crash Typologies for Parallel Paths (Hunter et al., 1996)

In order to illustrate this crash typing, 3,000 BMV crash records collected from the states of California, Florida, Maryland, Minnesota, North Carolina, and Utah in the years of 1991 and 1992 were analyzed. Table 2-3 shows a summary of those crashes and Table 2-4 shows the top 10 most frequent crash types.

Table 2-3: Summary of Crash Typing (Hunter et al., 1996)

Crash Typing	Percent of total crashes
Crossing path crashes	58
Parallel path crashes	36
Specific circumstance crashes	6

Results also showed that the most common parallel path crashes were motorists turning or merging into a bicyclist's path (34.4% of all parallel path crashes). A common example of those parallel path crashes was when the motorist was making a right-turn and the bicyclist was riding in the same or opposite direction of traffic, which occurred in 143 cases (4.7%). However, in most of the cases (79% of those parallel path crashes), the bicyclist was riding the same direction as traffic. This crash (motorist right turn) scenario is similar to the *RH crash* scenario. It was also found that immediately before those crashes the motorist was overtaking the bicyclist 74% of the time, the bicyclist was overtaking the motorist on the right 11% of the time, and the overtaking action was unknown in the remaining 15% of cases. The crash summary also determined that bicyclists from 20 to 24 and 25 to 44 years old were more likely to be involved in this crash type, which primarily took place mostly on multilane roads (cross sections of four, five, six or more lanes). The regulatory speed limits of those roads ranged from between 31 mph to 37 mph. The crashes were 77% in urban areas and 23% in rural areas. It was reported that 11% of these crashes resulted in fatal or serious injuries. Bicyclists were riding in a bicycle lane only in 8% of these crashes (Hunter et al., 1996).

Table 2-4: Top 10 Most Frequent Crash Summary of Crash Typing (Hunter et al., 1996)

Crash type description	n	Percent of Total	Percent of Crash Type, Fatal or Serious Injury
Ride out at stop sign	290	9.7%	23%
Drive out at stop sign	277	9.3%	10%
Ride out at intersection-other	211	7.1%	16%
Drive out at midblock	207	6.9%	7%
Motorist left turn-facing bicyclist	176	5.9%	24%
Ride out at residential driveway	153	5.1%	24%
Motorist right turn	143	4.7%	11%
Ride out at midblock	132	4.4%	20%
Bicyclist left turn in front of traffic	130	4.3%	28%
Motorist overtaking-other	117	3.9%	28%

This early work by Hunter laid the foundation for the development of the Pedestrian and Bicycle Crash Analysis Tool (PBCAT) through the Highway Safety Research Center at the University of North Carolina sponsored by FHWA, in cooperation with NHTSA. The PBCAT software was developed based on the NHTSA crash typing scheme. It can be used by planners and engineers to develop and analyze a database containing the crash type and other details of crashes between motor vehicles and bicyclists or pedestrian crashes (Harkey et al., 1999; FHWA, 2013). This software can also be used to assist transportation safety practitioners in selecting countermeasures to mitigate the crash problems identified.

The crash typing approach has been applied by others. In the study of 188 bicycle-motor vehicle crashes in four cities in Finland, Räsänen et al. (1998) developed a new crash-typing scheme for crashes in order to reconstruct the actual movements of those involved and to analyze the detection of the motorist or the bicyclist by one another. They aggregated crashes into four major categories, which were further organized into 3 or 4 subcategories. Table 2-5 and Figure 2-3 show the Räsänen and Summala crash-typing scheme. The most common crashes were categorized as group II, where the motorist turned right and the bicyclist appeared from the right. This crash type especially 1B1 and 1B2 in Figure 2-3 are similar to the RH crash type, with the exception that there is buffer space between bicyclists' travel path and the major road. Although these figures (Figure 2-3, Figure 2-4, and Figure 2-5) describe a European centric design standard, those can be used to explain causes the BMV crashes at intersections in the US. Räsänen et al. (1998) concluded that the misallocation of attention of motorist resulting in failures to detect others, and unjustified expectations about the behavior of others were the two major reasons behind this crash type. It was also found that sight obstacles could be a contributing factor to many crashes.

Table 2-5: Räsänen and Summala Crash-typing Scheme (Karsch et al., 2012)

Group:	**Definition:**
I	Car turns, cycle path crosses street before road crossing – the bicycle may approach from the left or the right and the car may be turning either left or right (4 subtypes)
II	Car turns, cycle path crosses street after road crossing – the bicycle may be appearing from in front of or behind the car and the car may be turning left or right (4 subtypes)
III	Car drives straight ahead, cyclist comes from the left – the bicycle crossing is on the far side of a 3-way (T type) or 4-way intersection or the bicycle crossing is on the near side of a 3-way (T) intersection (3 subtypes)
IV	Car drives straight ahead, cyclist comes from the right – the bicycle crossing is on the far side of a 3-way (T) intersection, on the near side of a 3-way (T) intersection with one leg of the T going off to the right or to the left or the bicycle crossing is on the far side of a 4-way intersection

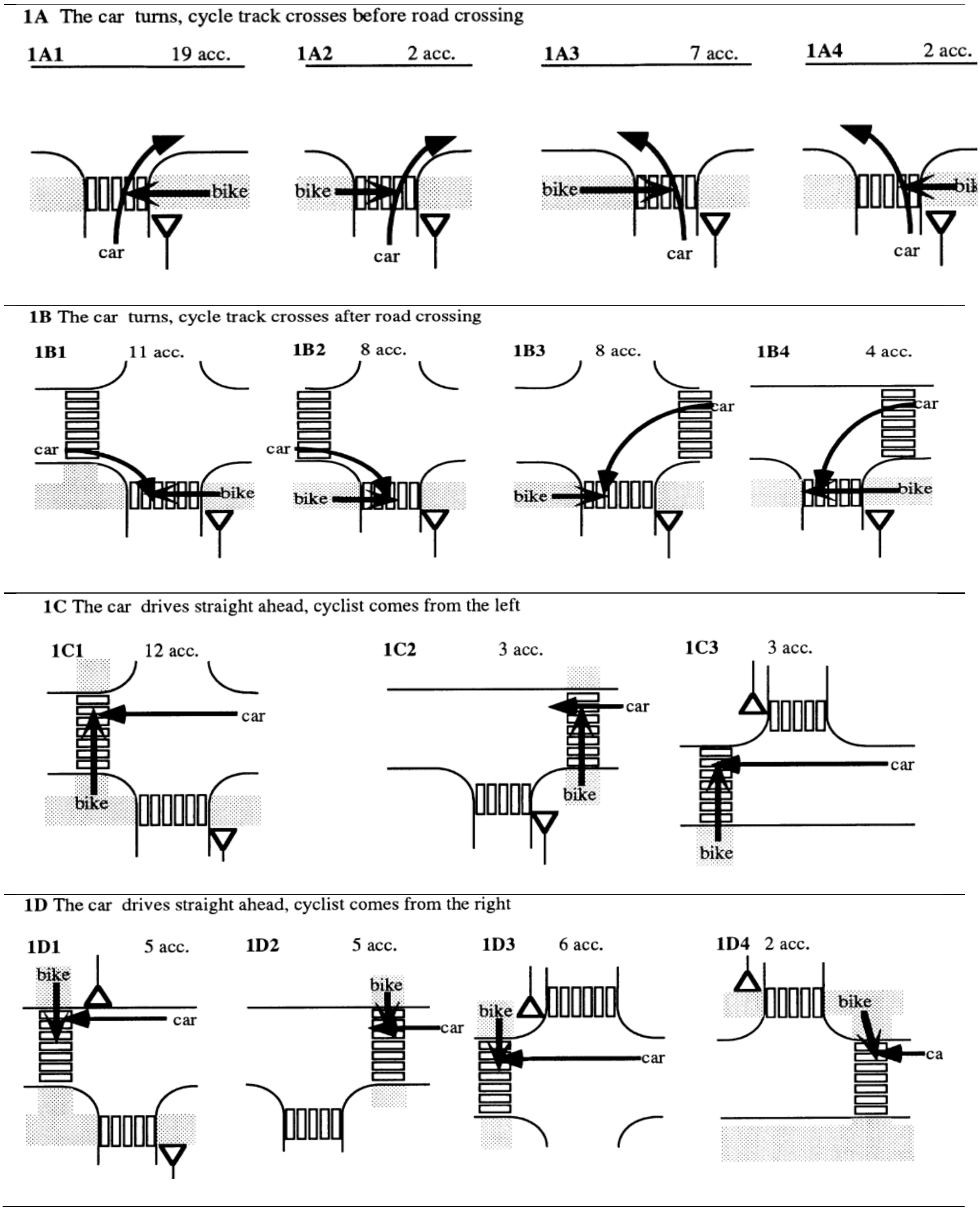
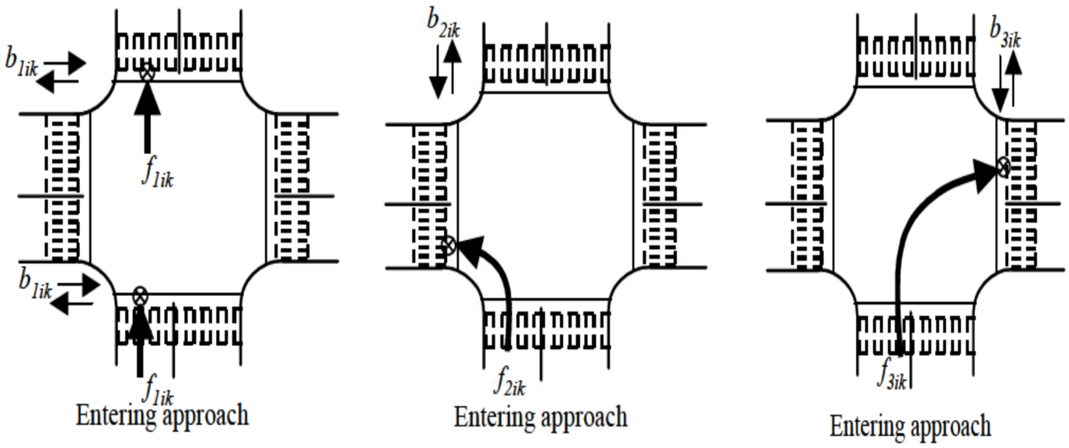


Figure 2-3: Räsänen and Summala Crash-typing Scheme, Four Intersections in 1B1 and 1B2 were Signalized; Two in 1B3; Three in 1C1 and One in 1C2 (Räsänen et al., 1998)

To relate the risk of a specific BMV crash type to bicycle and motor vehicle volumes, Wang et al. (2004) classified crashes at four-legged signalized intersection into three groups: through motor vehicle, left-turning motor vehicle, and right-turning motor vehicle related collisions (Figure 2-4) (Wang et al., 2004). They abbreviated the phrase bicycle-motor vehicle as BMV and used 4 years of crash data collected from 115 randomly selected intersections in the Tokyo Metropolitan area to estimate the expected accident risk of the three BMV crash types by the maximum likelihood method using a negative binomial probability formulation. The explanatory variables in the models included traffic and bicyclist volume, intersection location, visual noise, pedestrian overbridges, and median width.



(a) BMV Crash Type -1 (b) BMV Crash Type- 2 (c) BMV Crash Type - 3

Figure 2-4: Wang et al. Crash-typing Scheme (2004)

2.4 Contributing Crash Factors

Vehicle collisions often result from the loss of control by one or more of the parties involved, and are often due to the loss of attention or a failure to detect the other party (Korve et al., 2002*;* Summala, 1988, Summala et al., 1996; Räsänen, 1998; Rumar, 1990). The first most thorough investigation of the contributing factors for crashes was conducted in 1970's by a research team from Indiana University for the NHTSA, known as the "Tri-Level Study of Accident Causes" (Treat et al., 1979). This study investigated 2,258 different types of police-reported crashes. Results from this study reported that improper lookout and inattention were the two leading direct human causes of those crashes. Improper lookout consisted both of "failed to look" and "looked but failed to see" (Treat, 1980). In the first large-scale naturalistic study of 100 instrumented cars conducted by NHTSA in 2006, 241 motorists 18-years old and above were filmed inside their vehicles to study motorists' visual gazes from the video images of their face (Klauer et al., 2006). Detailed data were collected on vehicle, event, environmental, motorist state, e.g. eye behavior, drowsiness and narrative data, on events in the data base: Crashes, near-crashes and incidents. Based on the analysis of motorists' behavior, this study reported that motorists' inattention contributed to 78% of the recorded crashes and 65% of the near-crashes. Neyens et al. (2007) analyzed the relationship among three types of crashes (angular, rear-end, fixed object) and four types of distractions (cognitive, cell phone, in vehicle, passenger-related) among young motorists. Self-reported descriptions by motorists involved in crashes also confirmed attentional inefficiency expressed in the language "looked but failed to see mainly was responsible for crashes (Castro, 2008).

In a BMV crash, either the motorist or the bicyclist can be "at fault"; this section will review if the above mentioned motorist related factors are responsible for vehicle crashes with bicyclist at an intersection. In the context of a bicycle-motor vehicle crash, Räsänen et al. (1998) stated that a motorist's learned routine may result in a failure to actively search for an adjacent bicyclist before turning, while bicyclists' expectations may be violated if they misinterpret motorists' behavior before crossing an intersection. This potential failure of user perceptions is a common feature characterizing RH crashes at intersection. In order to understand the RH crash scenario in better detail, this section reviews BMV related crash factors by analyzing motorists' and bicyclists' perceptions during crashes.

2.4.1 Factors Attributable to Motorist

In a study of 39 BMV crashes, Summala et al. (1996) observed that one of the most frequent crash types was a motorist turning right and bicyclist coming from the right (on the left side of road) along a bike path (Figure 2-5), which accounted for 70% of the observed crashes (Summala et al., 1996). The authors determined that one of the contributing factors of this crash type is the improper allocation of motorist's visual attention while making turns at an intersection, which is similar to the "improper lookout" cause found in the crash study of "Tri-Level Study of Accident Causes" (Treat et al., 1979). In this study, Summala et al. (1996) found that before making a right turn, motorists focus their visual attention on the cars coming from the left, and fail to detect the bicyclist coming from their right early enough to respond safely.

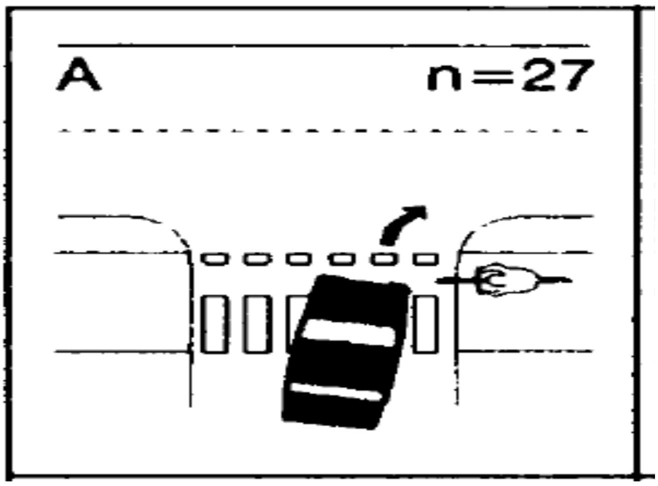


Figure 2-5: Vehicle Turning Right at Intersection (Summala et al., 1996)

Räsänen et al. (1998) studied 188 police-reported BMV crashes from four major cities in Finland. In this study, estimates about parties' behavior were based on structured interviews made by a police officer after the crash. Based on their analysis, the authors confirmed that attention misallocation among motorists may lead to a situation where they may not notice a bicyclist coming from an unexpected direction. Even if motorists look in the relevant direction and notice the bicyclist, often times the identification is too late to effectively stop or yield. This study concluded that only 11% of the motorists noticed the bicyclist before impact and in 37% of the crashes, neither motorist nor bicyclist realized the hazard or had time to yield. Wachtel et al. (1994) found the similar trend in a study of 371 police-reported bicycle-motor vehicle crashes in Palo Alto, California (Wachtel et al., 1994). Analyzing the crash data by bicyclists' age, sex, direction of travel and position on the road, the authors concluded that motorists turning right at an intersection scanned to the left for approaching traffic on the new road, and failed to detect or anticipate a fast moving wrong-way bicyclist approaching from the right, which is one of the most common type of BMV crash in Palo Alto. The Wachtel study included many sidewalk riding crashes which are known to be an elevated risk scenario for bicyclists. This crash scenario is similar to one of the crash scenarios described by Räsänen et al. (1998), where motorists turning right focus their attention on the cars coming from the left, and fail to detect the bicyclist coming from their right, as depicted in Figure 2-3 (Räsänen et al., 1998).

NHTSA conducted a study to examine the general characteristics of motor vehicle traffic crashes at intersections using the National Motor Vehicle Crash Causation Survey (NMVCCS) from 2005 to 2007 (NHTSA, 2010). The NMVCCS data is a nationally representative sample of crashes that occurred between 6 a.m. and midnight that contains on-scene information on the events and associated factors leading up to a crash. Among those records, there were 756,570 intersection-related crashes, 55.7% of the crashes occurred due to motorists’ recognition error, such as inattention, internal and external distractions, inadequate surveillance, etc. and 29.2% crashes were due to decision errors, such as driving too fast for conditions or aggressive driving, false assumption of other’s actions, illegal maneuver, and misjudgment of gap or other’s speed. The most frequently assigned critical reason was found to be inadequate surveillance, which constituted 44.1% of total intersection related crashes. Inadequate surveillance occurs when the motorist is in a situation where he needs to scan a certain location to safely complete a maneuver and either fails to look in the appropriate place or looks, but does not see. This failure can occur at an intersection when the motorist looks at the required direction before making a turn, but fails to see the approaching traffic (Dingus et al., 2006).

The NHTSA study (2010) also attempted to identify patterns of motorist-attributed characteristics for intersection-related crashes such as motorist's age and sex. Aggregating the crashes according to motorist's age group, it was determined that 33% of crashes involving a motorist 20 years old or younger were intersection related. However, among all crashes where motorists were 65 and older, 53.9% were intersection related. Overall it was found that the proportion of intersection-related crashes showed an increasing trend as the age of motorists involved increased. It was postulated that the contributing factors for crashes at signalized intersection involving motorists 24 years old and younger were "internal distraction," "false assumption of other's action," "too fast for conditions or aggressive driving," or "external distraction." In contrast, the contributing factors for crashes involving motorists 25 to 54 years old were "critical non-performance error," "illegal maneuver," "inattention," and "too fast for conditions or aggressive driving." Additionally, for crashes at stop- controlled intersections involving motorists 55 and older, the contributing factors included "inadequate surveillance" and "misjudgment of gap or other's speed," while for motorists 24 years old and younger the primary contributing factor was "turned with obstructed view" (NHTSA, 2010).

While analyzing intersection-related crashes according to gender, the study found that of all the crashes involving female motorists, 41.1% occurred at intersections, while only 32.2 % of crashes involving male motorists were intersection related. The study stated that male motorists of all ages were likely to be involved in intersection-related crashes due to "illegal maneuvers," "aggressive driving," or "driving too fast for conditions."

Again, for both male and female motorists 55 and older, crash factors were found to be "misjudgment of gap or other's speed" and "inadequate surveillance." For female motorists involved in intersection related crashes, the contributing factors included "internal distraction" or "inattention," whereas those were "illegal maneuver," "false assumption of other's action," "too fast for conditions or aggressive driving" for male motorists. Of particular interest for right-hook crashes, the study found that male motorists were much more likely to have false assumption of other's action as a contributing factor to crash (NHTSA, 2010).

2.4.2 Factors Attributable to Bicyclists

In a study of bicycle crashes at intersections, the Institute of Transportation and Traffic Engineering (ITTE) at the University of California, LA concluded that in the vicinity of intersections, bicyclists are often involved in crashes because they cannot clearly perceive dangers (Chao et al., 1978). Bicyclists assumed that the motorist would give way as required by the law. This becomes more severe when bicyclists ride on familiar routes. The combination studies have assumed that bicyclists who make a left-turn are exposed to the greatest danger (Summala et al., 1996; Räsänen et al., 1998), bicyclists turning right or travelling straight, are also exposed to risk. As explained in those studies, bicyclists may be less vigilant in searching for hazards as they perceive the right side of the road to be safer due to fewer potential conflicts (but this is just speculation). Räsänen and Summala (1998) determined that one of the contributing factors to BMV crashes at intersections was bicyclists' misplaced attention on a familiar route, i.e. not focusing attention in the appropriate direction and the assumption of right-of-way may result in a situation where bicyclists do not actively search for motor vehicles coming from their left, contributing to RH crashes.

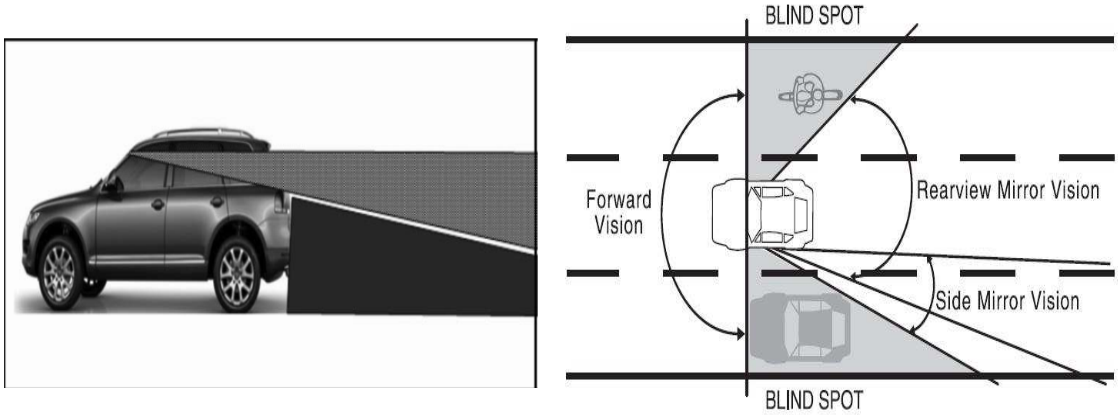
Karsch et al. (2012) reviewed the pedestrian and bicyclist safety research literature from 1991 to 2007 in US stated that for all the BMV crashes in 2009, the most common bicyclist contributing factors were failure to yield to motorist (21%), and riding against traffic (15%). Stop sign violations and safe movement violations represented another 7.8% and 6.1%, respectively (Karsch et al., 2012).

NHTSA (2011) data showed that in 2010, 534 male bicyclists were killed, resulting in a fatality rate of 3.51 fatalities per million people. In contrast, there were 84 female bicyclist fatalities resulting in a fatality rate of 0.53 per million people, seven times lower than men. The highest number of male bicyclist fatalities was for bicyclists between the ages of 45 and 54. This result suggested that the overrepresentation of male bicyclists in injuries and fatalities may be due to riding in more dangerous situations or engaging in riskier riding behaviors than females respectively (Karsch et al., 2012).

However, per capita rates as a measure of exposure can be misleading since it fails to account for the fact that the observed cycling gender splits do not mirror the population (observed splits are typically 70% male even in bicycle-friendly cities like Portland, OR. In a study by Li et al. (2000) analyzing data from the National Center for Health Statistics (NCHS), the National Electronic Injury Surveillance System (NEISS) and the NPTS reported that male bicyclists were overrepresented in bicycling fatalities due to their higher number of trips by bicycle. Furthermore, the study revealed that when involved in a crash, male bicyclists tended to sustain more severe injuries than female bicyclists respectively (Karsch et al., 2012). However, when analyzing the data on a per trip basis, men were found to be at a slightly lower injury risk than women (Li et al., 1996).

Studies showed that bicyclists on a sidewalk or bicycle path were 1.8 times more likely to get involved in intersection crash than those riding on the road, most probably due to blind spot conflicts at intersection respectively (Karsch et al., 2012). Blind spot conflicts occur when a bicyclist is located in the blind point of a vehicle, i.e. the areas on the road that cannot be seen in the mirrors on either or both sides of the vehicle (Figure 2-6). Paine et al. (2011) stated that even when the entire field of view available to the motorist in a vehicle, such as the rear window, the interior rear view mirror and the external rear view mirrors, are used in combination to see the area behind the vehicle, there are still blind spots behind the vehicle. The extent of these blind spots depends on the characteristics of the vehicle, together with the size of the motorist (mainly eye height when seated) and the height of the object to be detected. Based on the research on blind spots of different vehicle types, it was found that 1.97 foot object was not visible any closer than 15 to 30 feet from the rear of most station wagons and SUVs (Paine et al., 2001). Measuring the blind spots of different vehicle types, Consumer Reports mentioned that the average blind spot of a sedan ranged from 10 to 35 feet, whereas for SUVs and pickups, the average blind spot was up to 50 feet (Consumer Reports, 2005). Due to the size and height, trucks or buses have four blind spots or “no-zones” (Figure 2-7). No-Zones are actual blind spots where vehicles “disappears” or become invisible from the view of the truck or bus driver (WHAT IS NO ZONE; NCDOT, 2007). As stated in the American Automobile Association (AAA), the front no-zone extends to 10- to- 20 feet in front of the truck cab and the rear no-zone extends to 200 feet behind a truck, which is compared to two-thirds the length of a football field (Share with Care Brochure, AAA newsroom, 2011). Regarding side no-zones, trucks have extremely large blind spots on both sides, even with large side-view mirror - much larger than the blind spots motorist experience while driving a car (Share with Care Brochure, AAA newsroom, 2011). Therefore for side no-zones the message is don't "hang out" on either side of trucks, or if very necessary to pass, then it is recommended to allow plenty of space and extra time while passing a truck (Share with Care Brochure, AAA newsroom, 2011; NO-ZONES AND BLIND SPOTS, UDOT).

The probability of bicyclists on sidewalk to be obscured by parked cars, buildings, fences, and shrubbery is more likely than bicyclists on the road. Due to the likelihood of blind spot conflicts, this obscured bicyclist at the blind spot of the vehicles poses greater risk for a right-turning vehicle at an intersection since their required stopping distance is much longer than a pedestrian's and they have less maneuverability (Wachtel et al., 1994). Several studies have been conducted to evaluate mitigation strategies to mitigate run-over backing crashes with objects or young children obscured in the vehicle's blind spots (Hurwitz et al., 2009; Muttarta et al., 2011; Paine et al., 2011). With the aim to reduce backing crashes, Hurwitz et al. (2009) evaluated whether the integration of rear-view cameras with an audible warning system can reduce backing crash rates. Muttart et al. (2011) proposed a backing warning system based upon motorist's response times and backing acceleration at different backing scenarios. Paine et al. (2011) evaluated possible technical solutions including proximity sensors and visual aids to reduce the risk of backing crash injuries for young children. Their evaluation involved determining blind spots to the rear of the vehicle through 'Blind Spot' test and evaluating whether visual aids and/or sensor systems can effectively cover these blind spots.



a) The cone of visibility (lighter shaded region) and obscured (darker shaded region) areas behind a high profile vehicle (Muttart et al., 2011)

(b) Blind spot of passenger vehicle

Figure 2-6: Typical Areas of a Driver’s Blind Spot

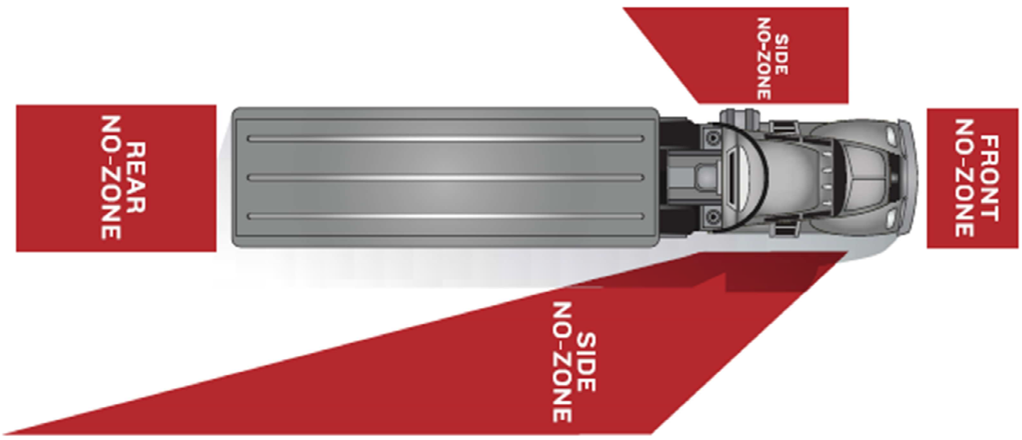


Figure 2-7: Blind Spot or “No-zones” of Truck

2.5 Measuring Motorist's Driving Performance

In support of measuring driver performance in a driving simulator, this section reviews some of the critical research. Given the clear contribution of motorist attention in crash causations, empirical measures are needed.

2.5.1 Acquisition of Visual Information

Gibson et al. (1938) stated that, "of all the abilities that contemporary civilization requires of us, driving is the most important for individuals in the sense that errors in this ability translate into the greatest threat to human life". This statement indicates the importance of safe driving, and the correlation between errors in motorist performance and safety. Shinar (2007) described driving as an information processing task in which most of the information is received through the visual channel.

While driving can be considered an information processing task, the most critical component of the information processing model is attention (Klauer et al., 2006). Addressing the motorist as an active information processor, Castro (2008) presented the following statistics to underline the importance of motorists' perception and attention during driving: 1) more than 90% of traffic crashes are due to human error (Fell, 1976; Castro 2008); 2) more than 90% of those are due to problems with visual information acquisition (Hills, 1980; Olson, 1993); and 3) the majority of motorists reported that the causes of crashes were of the, "I looked, but I didn't see it", i.e. inattention blindness type (Castro, 2008).

Numerous studies agree that inattention and distraction are major contributing factors for motor vehicle related crashes (Fisher et al., 2011). To identify the role of inattention and distraction on the causes of crashes, early studies often used estimates from police crash reports (Sabey et al., 1975; Treat, et al., 1979; Fisher et al., 2011). However, with the change in the technology regarding information acquisition over the last five years, eye behaviors are contributing significantly to identify the cause of crashes due to distraction and inattention (Fisher et al., 2011). Therefore, information regarding motorists' eye movement and visual attention, in particular information on where the motorist was looking at and for how long immediately before a crash occurred can explain whether it was the motorist or the environment that the motorist was exposed to, was likely to responsible for the crash (Fisher et al., 2011).

Motorists' eye movements and visual attention can be directly related to crash causality. For example, motorists may fail to anticipate hazards or fail to scan locations on roadway that may contain threats which could materialize suddenly, which can lead to crashes (Fisher et al., 2011). As reported by McKnight et al. (2003), the majority of crashes are caused by failures to scan the roadway adequately. Crashes may also occur when a motorist fails to perceive or identify a threat on the road in spite of directly looking at that threat. In the psychological literature, this is termed as *inattention blindness* (Mack et al., 1998; Simons et al., 1999), which is the failure to notice something when the observer directly looks at it. Cognitive distraction is a common cause of inattention blindness. According to NHTSA, cognitive distraction are as tasks that are defined as the mental workload associated with a task that involves thinking about something other than the driving task" (NHTSA Distracted Driving Research Plan, NHTSA, 2010).

2.5.1.1 Measuring Eye Movement

This section describes different parameters and techniques for measuring eye movement.

Parameters

SAE (Society of Automotive Engineers, 2000) and ISO (International Standards Organization, 2002) publications have defined standardized terms for eye movement in automotive contexts. One category of eye movements is the fixation, which occurs when the gaze is directed towards a particular location and remains still for some period of time, typically around 0.20-0.35 seconds (Green, 2007; Fisher et al., 2011). Fixations are separated by rapid eye movements called saccades. Although sometimes saccades (movements within regions) and transitions (movements between regions) are used synonymously, the SAE Recommended Practice (12396) recommends distinguishing them. Again, some literature used the terms fixation and glance synonymously, whereas a glance consists of all consecutive fixations on a target plus the preceding transitions. Figure 2-8 is a "Transition Diagram" that distinguishes the eye movement terms described above.

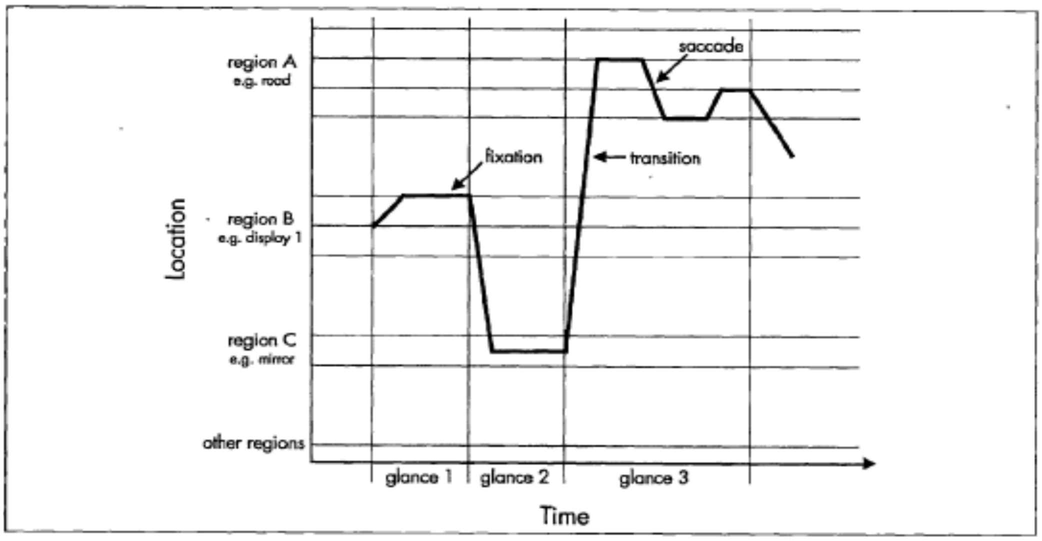


Figure 2-8: Transition Diagram (Green, 2007)

Very little new information is obtained during saccades and transitions due to the phenomenon known as saccadic suppression (Matin, 1986). People are unaware of the blurry moving image on the retina during the saccade, mostly due to the reason that it is backwardly masked by the visual information from the fixation following the saccade. Therefore, the fixation is of primary measure of interest. It is very unlikely that objects not fixated will be encoded, and longer times fixating on an object indicate difficulty processing an object. Therefore, the duration and location of fixations both indicate that and object that is being fixated on is being processed (Fisher et al., 2011). While fixation and saccades are measures of eye movement for static images, smooth pursuit movements are measures of eye movement when the object is moving with respect to observer, such as a pedestrian, or when the observer is moving, such as reading a speed limit sign during driving (Fisher et al., 2011).

Fisher et al. (2011) have also classified the measures of eye movement according to spatial and temporal characteristics. Spatial parameters of eye movement provide information on whether an object or area in the scene has been processed, such as a fixation or gaze location. Spatial parameters are of particular interest to determine novice and older motorists' behavior, given their optimal fixation pattern is known (Fisher et al., 2011). The sequence of fixations is another important spatial parameter with respect to eye movement and the concept of areas of interest (AOIs) is of particular interest in this regard. Since driving is a dynamic task, motorists must monitor a series of dynamic processes at known locations, such as gauges, roadways, and traffic signals etc. - each mapping onto respective AOI defined by the scenario. The proportion of glances on each AOI is then measured and compared across group or conditions to gain information on when and where motorists looked (Maltz & Shinar, 1999). In addition, the scan path of motorists can also be measured, which is defined by the sequence of gazes in different locations or different AOIs. Temporal parameters of eye movements provide information on what useful information can be extracted from the duration of fixations and glance duration can be a useful measure in this regard (Fisher et al., 2011).

Many researchers have studied motorists' eye movement in order to determine how likely a motorist is to crash (Scholl et al., 2003), and how differences in eye behavior appear to be related to crash rates (Mourant et al., 1972; Underwood et al., 2003; Pollatsek et al., 2006). Studying the anticipatory glances to areas of the roadways where potential threat might appear, Pradhan et al. (2005) found that novice motorists can be around six times less likely to glance at potential threat areas. Again, based on previous experimentation, the mean glance duration is typically 10 to 50 milliseconds shorter for experienced motorists than novice motorists (Laya, 1998; Crundall et al. 1998). Other than experience as probable reason for this difference, Fisher et al. (2011) hypothesized that novice motorists simply fail to recognize the need to scan for the potential threat on roadways (Fisher et al., 2011). An alternative hypothesis proposed by the author was that novice motorists are overloaded with the demands of driving and therefore do not have the spare capacity left to make the prediction that they need to launch the anticipatory eye movement. Using an eye tracker and a driving simulator, Garay-Vega et al. (2007) conducted experiments to evaluate these two hypotheses. Findings from those experiments showed that although load appeared to contribute somewhat to the depressed anticipatory glances for novice motorists, the difference mostly occurred because novice motorists were not aware of the necessity of making such eye movements. Thus it was determined that without knowledge of eye behavior, it would not have been possible to test those hypotheses or produce results. Studies also found that experienced motorists look at their mirrors more than novices and look farther down the road than novices who tend to focus close to the front of the vehicle (Chapman et al., 1998; Mourant et al., 1972). Therefore, knowledge of eye behavior is critical to gain real insights on the causes of crashes and also how the design of the interface with the motorist, such as signs, music retrieval systems, and so on, can be improved to minimize crash risk.

Techniques

Using an early model eye movement camera, Rockwell et al. (1968) developed the first eye tracking system that monitored and recorded motorists' on-road visual scanning behavior. In recent days, motorists’ eye behavior can be measured either in a driving simulator or on the road in an instrumented car (Chrysler et al., 2004) either directly from the recording of a camera aimed at a motorist's face known as the direct observation method, or by using special electronic devices often referred to as "gaze trackers" or "eye movement recorders" (Green, 1992; Williams et al., 1994). Direct observations are labor intensive and time consuming to process; the video tapes must be played back frame-by frame, so often only a small fraction of the data collected is analyzed (Green, 2007). For standard video equipment (operating at 30 frames per second), times are accurate to the nearest 33 milliseconds. Electronic devices typically record (1) the reflection of a beam of light off of the cornea, (2) the electrical signals of the muscles controlling the eye, or (3) the location of the boundary between the white and dark parts of the eye. None of these methods are ideal and each technology has limitations (use in daylight, vertical accuracy, wearer discomfort, and so on) for particular conditions. Currently, the most widely used technology for in-vehicle studies (off-head cameras that track the eyes) utilizes the white/dark boundary of the eyes. Further, glasses or contacts may interfere with measurements, a consideration of special relevance to older motorists, almost all of whom wear corrective eye wear.

Eye movement data collected with eye tracker technology provides direct evidence whether potential hazards were being anticipated in most cases (Fisher et al., 2011). Eye trackers can also provide reliable information about motorists’ eye movement during instances when motorists look but fail to identify threats or inattention blindness if a crash occurs. But in the absence of a crash, it is difficult to definitely determine if a motorist is looking but not seeing exclusively with an eye tracker (Fisher et al., 2011).

However, as argued by Fisher et al., an increase in inattention blindness will increase the likelihood of crashes. Therefore information on the occurrence of inattention blindness in the more general driving environment collected by eye trackers can be very useful in this regard. Strayer et al. (2003) used an eye tracker and driving simulator to assess whether cell phone conversation affect motorists' driving performance by distracting visual attention, yielding a form of inattention blindness. Their results are consistent with the earlier findings by Rumar (1990) that motorists fail to see objects in the driving environment even while directly gazing at them due to inattention blindness during cell phone conversations.

2.6 Situational Awareness (SA)

As discussed in the previous section, perception and attention are very important factors for safe driving (Moore, 1969; Rumar, 1982; Castro, 2009; Gugerty, 2011). Therefore it is essential to measure motorists' attention correctly to gain insight on the driving task, and also to evaluate the effects of different factors such as cell phone use, fatigue and drunk driving (Gugerty, 2011). Suggesting that motorists' situational awareness (SA) is similar to motorists' attention, Gugerty (2011) has defined SA as, "the updated, meaningful knowledge of an unpredictably-changing, multifaceted situation that operators use to guide choice and action when engaged in real-time multitasking." In the context of the driving task, this meaningful knowledge can include the motorists' route location, roadway alignment, location of nearby traffic and pedestrians, fuel level, and so on. Gugerty (2011) also categorized the perceptual and cognitive processes required to maintain SA into three levels:

- Level 1: automatic, a preattentive process that occurs unconsciously and places almost no demands on cognitive resources;
- Level 2: recognition-primed, a decision processes that may be conscious for brief periods (< 1 s) and place few demands on cognitive resources; and
- Level 3: conscious, a controlled process that place heavy demands on cognitive resources.

From the context of driving, Gugerty described vehicle control, such as maintaining speed and lane position as mostly an automated processes, but other tasks requiring some regular conscious decisions during driving, such as lane changing or stopping at a red indication are recognition-primed processes. At the final level, he described hazard anticipation and making navigational decisions in an unfamiliar environment during heavy traffic as requiring a controlled, conscious process (Gugerty, 2011).

To safely accomplish the dynamic and multifaceted driving task, motorists need to perceive, identify, and correctly interpret the elements of the current traffic situation including immediately adjacent traffic, road signs, route direction, and other inputs, while being vigilant for obstacles and making predictions of near future traffic conditions to maintain control, guidance, and navigation of the vehicle (Baumann, 2007). Endsley's definition of SA incorporates the great variability of information that needs to be processed in dynamic real time tasks such as driving, air traffic control, or flying. Endsley (1988) states that, "Situation awareness is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future". Endsley's (1995) definition of SA was expanded into three hierarchical phases:

- Level 1 SA involves *perception* of the elements in the environment;
- Level 2 SA is the *comprehension* of the current situation by integrating various pieces of data and information collected in Level 1 SA in conjunction with operator goals; and
- Level 3 SA involves in the *projection* of future status from the knowledge of the elements and comprehension of the situation achieved in Level 1 and Level 2 SA. Level 3 SA allows the motorist to perform timely and effective decision making.

During driving, motorists need to perceive the continuously changing driving environment including road, traffic and vehicle conditions, understand the current situations, and finally predict the near future, motorists need to make conscious and effective decisions to avoid hazard based on the knowledge gained in previous two levels. Although two models are conceptually different, Gugerty (2011) has compared his three levels of perceptual and cognitive processes with Endsley's (1995) three levels of SA in the way that perceiving the elements of a situation (Endsley's Level 1 SA) is mostly highly automated, while comprehension and projection (Level 2 and 3) mostly use recognition-primed and controlled processes (Gugerty, 2011).

The above discussion underlines the importance of SA which is required for hazard anticipation and safe driving. A high degree of SA generally helps motorists to accomplish these goals as well as provides a basis for subsequent decision making and good performance in the driving task. In the context of right-hook crash scenarios, a high degree of SA could help motorists to be aware of bicyclists in the adjacent lane, predict their future maneuvers and make decisions based on this information to safely accomplish right-turn maneuvers at signalized intersections.

2.6.1 Focal and Ambient Vision

Vision is closely related with attention and the driving task. Schneider (1967) and others have distinguished between two modes of vision: focal vision and ambient vision. Focal vision uses foveal input and serial processing for object identification. It is much more dependent on inference and higher-level cognition. The visual receptors of ambient vision are distributed across all of the visual field and retina, both in the fovea and periphery (Leibowitz, 1988; Previc, 1998, 2002). Ambient vision is relatively automatic and unconscious (Gugerty, 2011). Leibowitz and Owens (1977) suggested that the main subtasks of driving, vehicle control or guidance uses the automated processes of the ambient vision; while other important driving subtasks, such as identifying hazards and navigation in heavy traffic, use focal vision.

Both ambient and focal vision is important for attention capturing, good SA and safe driving. It has been found that causes of night time crashes can be explained by these two modes of vision (Owens et al., 1999; Brooks et al., 2005). Leibowitz et al. (1977) hypothesized that, at night, focal vision degrades much more rapidly than ambient vision. The ambient vision allows the motorist to perform the main subtask of vehicle. However, motorists are unaware of the severe degradation of their focal vision that helps to identify hazards. As stated by the authors (Owens et al., 1999; Brooks et al., 2005), the issue with the selective degradation of the two visual modes is that motorists become overconfident in their ability to perform the overall task of driving at night, which ultimately leads them to drive too fast increasing crash rates.

2.6.2 Measuring Situation Awareness (SA)

SA plays an important role in human interaction with a dynamic and changing environment in a real time task such as driving, air traffic control, or flying. (Gugerty, 2011). Although the concept of SA is better developed and applied in the aviation domain, a similar concept of SA has been applied to the driving condition as well; since they share similar dynamic environment characteristics where system input variables change over time (Ruiqi, 2011). Over the past decade, several techniques have been developed to measure SA. Gugerty classified SA measurement techniques into two groups – i) Online where motorist behavior is measured in a simulated driving environment with little or no interruption and, ii) offline when driving scenario is not visible during behavior measurement (Gugerty, 2011). Examples of online SA measurement include eye tracking measures, Situation Present Awareness Method (SPAM), and Useful Field of View (UFOV) test, while offline measures include the Situation Awareness Global Assessment Technique (SAGAT) proposed and validated by Endsley (1995). Other classifications to measure SA include direct and indirect measures or subjective and objective measures. In direct measures participants are asked to recall events from their experience (Gugerty, 2011), whereas indirect measures assess SA from subject's performance. For example, Sarter & Woods described an indirect measure of SA where the time to detect irregularities in an environment was the measure of SA (Gonzalez et al., 2007; Sarter et al., 1992). Subjective measures involve assigning numerical value to the quality of SA during a particular period and rely on a subject's self-assessment of SA (Jones, 2000*)*. Conversely, objective measures rely on querying participants to recognize a situation and then comparing their views of the situation with reality (Gonzalez et al. 2007; Endsley, 2001). SAGAT by Endsley is an example of a direct and objective measure of SA.

Physiological techniques, such as P300 and eye-tracking devices have been used for almost 40 years to monitor and measure motorist's glance patterns and determine whether information is registered cognitively. Researchers mostly record saccades or overt eye movements and fixations with the eye tracker as a proxy for determining the focus of the motorist's attention. The most common variable measured in this system is dwell time or percentage of time fixating on specific area of interest (AOI). Gugerty (2011) justified that fixation is an acceptable measure to track motorists' focal attention because while driving motorists need to gather information from about 270° around them with head movements and large saccades . However, the drawback with eye tracking is that it provides information on whether elements in the environment are perceived and processed by subjects, but it cannot determine how much information remains in memory, whether the information is registered correctly, or what comprehension the subject has of those elements (Endsley, 1995).

The most widely used offline SA technique is the SAGAT, which provides an evaluation of SA based on the operator's objective opinion. In SAGAT, all of the operator's displays are made temporality blank during periodic, randomly-timed freezes in a simulation scenario and memory based queries are directed at the operator to assess his knowledge of what was happening at that time. Queries are determined based on an in-depth cognitive task analysis across all three levels of SA defined by Endsley (1998). The main advantage of SAGAT is that it measures operator SA across a wide range of elements that are important for SA in a particular system giving an unbiased index of SA. However, the main disadvantage of SAGAT is the issue of intrusiveness that it may change the phenomenon of interest, and therefore fail to provide data about the natural character and occurrence of SA. Also, this method relies on operator’s memory and therefore may not reflect a true representation of the operator’s SA. Using SAGAT, Gugerty (1997; Gugerty et al., 2004) assessed SA of motorists in a low fidelity driving simulator. During the experiment, participants viewed driving scenarios that was blanked periodically and responded to questions assessing their awareness of cars about to collide with them and of cars in the blind spot.

In contrast to the offline SA measurement techniques such as SAGAT, the online techniques such as SPAM measures motorists’ SA while keeping the driving scenario visible. In SPAM an ongoing driving scenario in a simulator is paused at unpredictable times and the motorist is asked to respond to one or two questions about the scenario keeping the scenario visible (Durso et al., 2006). Response time is the main variable is response time in measure.

The Situation Awareness Rating Technique (SART) provides a subjective rating of SA by operators (Taylor, 1989). Through a series of bipolar scales SART allows operators to rate a system design based on the degree to which they perceive the amount of demand on attentional resources, supply of attentional resources, and understanding of the situation provided. These scales are then combined to give an overall SART score for a given system. SART considers operators' perceived workload in addition to their perceived understanding of the situation. The main advantage of SART is the ease of use and low cost. It does not require customization for different domains and can be used both in simulation and real world tasks. However, this method suffers from the possible influence of perceived performance and expected performance. Again, though SART was shown to be correlated with performance measures (Selcon et al., 1990), it is unclear whether this is attributable to the workload or the understanding components (Endsley, 1995).

2.7 Summary

It is worth noting that although the incident of right-turning vehicle crashes with bicycles appears in the literature with some frequency (Wachtel et al., 1994; Weigand, 2008; Summal, 1988), little substantive research has been conducted on this topic. The reason for limited research on this specific crash type could be explained in several ways, including:

- National crash statistics and hospital records are quite limited regarding variables necessary to fully understanding this crash scenario (Thom et al., 1993). They typically involve persons killed or injured; accident time (month, day, week, hour); vehicle type (large truck, passenger car, light truck, motorcycle), site (province, municipality, type of road and junction); speed limit; restraints used, circumstances of accident (weather, light condition); participants (sex, road user and age group), influence of alcohol, type of driving license and diagrams and classification of crash types (Thom et al., 1993; NHTSA, 2011). It is at best, very difficult to infer the behavior of each party (their paths, directions, and turns) from data sets of this type. Therefore, the total number of RH crashes occurring every year in US cannot be determined with certainty from the existing data sources.

- Although state based crash analysis and reporting systems provide crash data for bicycle fatalities and injuries including their types at different intersections around the state, the frequency of reported crashes can be low (ODOT, 2011; Hunter et al., 1996). Since the motorists involved in crashes are responsible to submit the of crash report forms it is not always guaranteed that all the qualifying crashes are reported to the recordkeeping authorities (ODOT, 2011). One study found that less than two thirds of bicycle-motor vehicle crashes were reported in state motor vehicle files though all of those were serious enough to require emergency room treatment (Hunter et al., 1996). For example, in 2009, nearly 200,500 people were treated for bicycle-related injuries occurring in traffic, representing a rate of 66 injuries per 100,000 people, but 518,750 people were transferred to hospital emergency rooms or hospitalized for bicycle-related injuries occurring in public and non-public roadways, representing a rate of 175 injuries per 100,000 people (Centers for Disease Control and Prevention, 2011). Therefore the correct frequency of this crash type is unknown in state level data as well.

- The history of bicycling in the US as a mode of travel is fairly recent when compared to Europe and many other countries in the world. As bicycling is becoming more popular in US cities, more safety related issues are emerging, motivating new research needs (Korve et al., 2002 and Weigand, 2008).

This literature review can be summarized into the following key points that reveal important gaps in the existing research on RH crashes at signalized intersections.

- In Oregon, the reported crash data indicates that the RH crash is a common BMV crash type at urban intersections; many of these crashes do result in severe injury.
- Although some studies analyzed motorist and bicyclists' behavior during crashes with right-turning vehicles, as interpreted by crash data, no in-depth study was found that specifically analyzed various factors contributing to RH crashes and potential countermeasures. In addition, there is a gap in the literature that could assess motorists' and bicyclists' SA in the crash environment, which can shed light on causal factors behind this crash type.
- A better understanding of crash causality is very important to identify potential countermeasures for mitigating that crash type. However, due to the limitations of crash data at both the national and state level, the actual characteristics of RH crash are predominantly unknown. Therefore, in depth analysis of the causal factors of this crash type is necessary. Driving simulator and eye tracker technology can be used in this regard. Driving simulator can place motorists into crash likely scenarios without causing any potential harm. Eye tracker technology can provide information on motorists' eye movement. Eye movement data

collected through the eye tracker technology provides reliable information whether motorists could detect and perceive potential hazards during driving to avoid crash.

- Motorists' SA and visual attention are very important for hazard anticipation and safe driving, which in turn are good measures of motorists' driving performance. Driving simulators can be used effectively to measure motorists' SA and attention, and assess motorist driving performance.
- Studies on BMV crashes at intersection shows that before turning right, motorists tend to focus their attention on the opposing oncoming vehicular traffic, and fail to detect the bicyclist coming from their right. Research also found that the higher speed of bicyclists overtaking the right-turning vehicle was a contributing factor to the RH crash. Based on that, this literature review identified that the volume of oncoming vehicular traffic, speed of bicyclists and relative position of bicyclist in the adjacent lane can potentially contribute to RH crashes at intersection.
- This literature review could not identify any intersection treatment implemented in the US to date, that has produced evidence of significantly reducing RH crashes at signalized intersections, except bike box for RH conflicts at the onset of the green indication. The efficacy of different intersection treatments can be evaluated using the driving simulator.

Chapter 3 Online Survey: Predictive Behavior of Bicyclist and Motorist

As identified in the Literature Review chapter, since a RH crash can result from the loss of control by either the motorist or the bicyclist, or both, it is essential to understand the characteristics of bicyclist-motorist interaction at intersections. While analyzing the behavior of bicyclist or motorist during their interaction at intersection, a significant amount of research has been found on the elements of built environment and bicycling (Wardman et al., 1997; Abraham et al., 2002; Stinson et al. 2005; Monsere et al. 2012) or the relationship between trip distance and bicycling (Moritz, 1998; Pucher et al., 2006, Cervero, 1996; Timperio et al., 2006, Parkin et al., 2008). However, it was found that very limited amount of research has been conducted on the relationship between attitudes, norms and bicycling (E. Heinen et al., 2010). In particular, no significant study has been found that can reveal any characteristics of bicyclists or motorist during their interaction at intersections leading to a RH crash. Therefore, a web-based survey was conducted in an effort to understand motorists' and bicyclists' behavior during interactions at an intersection, with a particular focus on the RH crash scenario. This chapter presents the web-based survey study that provided valuable insights on the potential causes of RH crashes at intersections. Findings from this chapter also helped to design the driving simulator experiments for identifying RH crash causal factors described in the following chapters.

3.1 Survey Approaches

Surveys conducted to analyze bicyclists' behavior can be categorized into three primary types, revealed preference (RP) surveys, stated preference (SP) surveys, and the Delphi technique (Stinson et al., 2003). RP surveys evaluate the users' travel behavior by presenting an actual choice environment. By assessing individual's actual experience of a trip, the RP survey may be able to provide more accurate result of travel behavior (Stinson et al., 2003). However, this method is time and resource intensive and limits the potential sample size and geographic scope of data collection. Previous bicycle studies that used RP surveys include studies by Aultman-Hall et al. (1997), Hyodo et al., (2000) and Howard et al. (2001). A SP survey evaluates the user's choice responses by presenting them a series of hypothetical choice scenarios. The major advantage of SP surveys is the ability to obtain a large sample size, low cost of data collection, and not having multi-collinearity among attributes (Stinson et al., 2003). Using this survey technique, Stinson et al. (2003) found that travel times, roadway functional classification, hilliness, roadway pavement condition, and number of STOP signs are some of the important factors influencing bicyclists' route choice behavior. Bovy et al. (1985), and Abraham et al. (2002) also used the SP survey in their study on bicyclists' route choice behavior. The Delphi technique analyzes expert opinions to identify the relative weight of the factors in bicyclists' route choice behavior. Delphi results may not be universally consistent with the data from RP and SP surveys (Stinson et al., 2003).

Given the advantages of SP survey over the other two survey methods stated above, this study used the SP survey technique to understand the behavior of motorists and bicyclists at an intersection. The road users were presented with hypothetical intersection scenarios in the survey questionnaire and were asked how they would behave in those scenarios.

3.2 Survey Goal

Following a SP approach, this survey aims to a) gain insight on the behaviors of motorists and bicyclists at intersections in the US, in particular from the perspective of RH crashes, b) collect information on motorist's visual attention when completing a right-turn at an intersection, and c) to gain knowledge on user's perception of the RH crash. The knowledge gained from this survey will be used to develop the follow-up driving simulator experiments pertaining to motorist related causal factors for RH crashes.

3.3 Survey Distributions

The survey was designed and administered through a web based survey tool. It was primarily distributed through a variety of email list serves with a direct web link of the survey. The survey link was also distributed through online social networking service, such as Facebook, and also posted to the environment-friendly group of Corvallis, OR known as "Car-free Corvallis".

The survey asked respondents to provide their current state of residence. Table 3-1 shows the states and their 2013 "bikeability" ranking rated by the League of American Bicyclists (2013) of the survey respondents. The highest number of responses were obtained from Oregon.

Table 3-1: Geographic Location of the Respondents, and State Ranking of "Bikeability" Rated by the League of American Bicyclists (League of American Bicyclists, 2013)

US State	Number of Responses	2013 Bicycle Friendly State ranking
Oregon	145	3
Alabama	4	49
California	28	19
Colorado	1	2
Connecticut	2	18
District of Columbia	1	51
Florida	1	31
Georgia	2	24
Idaho	1	26
Illinois	7	9
Indiana	17	42
Iowa	1	21
Louisiana	1	29
Massachusetts	13	6
Michigan	4	12
Montana	1	39
New Jersey	2	7
Ohio	2	32
Pennsylvania	2	15
South Carolina	2	34
Tennessee	3	17
Texas	5	22
Virginia	1	16
Washington	3	1

3.4 Survey Limitations

Due to the survey distribution technique, all the respondents were enthusiastic motorists and bicyclists with good access to computers. Therefore, self-selection bias might exist in the survey population. A potential shortcoming of self-reported survey results is that the respondents' perceptions may not necessarily reflect the perceptions of the road user group at large (Stinson et al., 2005, Jannat et al., 2011). Again, the computerized distribution of the survey may not reach the group of respondents who do not use computers such as older group and/or lower income group of the road users.

3.5 Survey Design

The exclusion criteria for the online survey prevented participants outside the ages of 18 through 75 or with less than one year of driving or bicycling experience. The exclusion criteria were the first question presented after the instruction to the participants. If either exclusion criteria was met participants were directed to the end of the survey and they were thanked for their participation.

The survey included the following five sections of questions:

A. Demographics: This section included standard demographics questions related to age, gender, race, education level, driver's license status, transit pass or car share membership, location of residence; as well as questions on how many working motor vehicles or working bicycle their household owns providing insight on access to certain modes of transportation.
B. Travel behavior: This section included question on the transportation modes used by respondents on a weekly basis.
C. Bicyclists' behavior at intersections: Respondents who reported that they had ridden a bicycle in the past year, were presented with this series of questions to have a better understanding of their behavior approaching an intersection. Questions regarding bicyclists' glance pattern and how they would interact with vehicles while approaching at intersections were included.

D. Motorists' behavior at intersections: To gain insight on how motorist's behavior may contribute to the RH crash, questions concerning motorists' actions in different intersection scenarios with bicycle traffic were presented. Specific questions considered motorists glance pattern, and lateral position at the onset of a right-turn at a signalized intersection.

E. Familiarity of RH crashes: Respondents were asked if they had previously heard the phrase RH crash before, and if they could describe what type of crash this phrase referred to. Respondents were also asked about their perceptions of what factors might contribute to this crash type and which intersection treatments they thought would be effective to reduce this RH crash at intersections.

A copy of the complete survey questionnaire has been included in Appendix A.

3.6 Survey Analysis

The completed surveys were downloaded from the web-based survey tool to the Microsoft Excel (Microsoft Office Excel, 2010), and then imported into R (R Development Core Team, 2013) Statistical Software to perform a variety of statistical analyses. For questions in which one option was requested to select from a set of options, the fraction of every option was calculated and expressed as a percentage of total responses. Tests for statistical significance were performed using the Chi-Square test or the Fisher's Exact test, when sample size was small. A Nonparametric Mann-Whitney U-test (also known as the Wilcoxon-Matt-Whitney test, Mann-Whitney-Wilcoxon test or Wilcoxon rank-sum test) and Kruskal-Wallis rank sum test were conducted to analyze the Likert scale data obtained from the respondents.

3.6.1 General Demographic Information

In total, 250 people started this online survey and 246 people completed the survey, representing a 1.6% dropout rate. While the survey results may not be a true population sample, the findings from this survey can provide valuable insight on the transportation system user behavior at intersections, and users' perceptions towards RH crashes. The survey results showed that all the respondents, who completed the survey (n=246), have driven a car the last year and 94% of them have a valid driver license. For the purpose of analysis, respondents were divided into two groups- 'motorists who are cyclists (M-C)', if they had ridden a bicycle in the last year, and 'motorists who are non-cyclists ((M-NC)', if they had not ridden a bicycle in the past year. Eighty-five percent of the respondents was listed in the 'M-C' group while 15% of the respondents were in the 'M-NC' group (Table 3-2).

Table 3-2: Respondents According to Motorists and Bicyclists

	M-C	M-NC	Total
Response	209	37	246
Percent	85%	15%	100%

Table 3-3 presents the general demographic information of the survey respondents, aggregated by the two motorist groups described above. Sixty-eight percent of the survey respondents were male and 32% were female. Also, men (71%) were more likely to ride bicycle than women (29%). 41% of the respondents were between the ages of 26 to 35. There was an over representation of respondents who had four-year college degree or more (85%). 65% of the respondents were White or Caucasian, while 27% were Asian. It was also found that majority (71%) of the bicyclists were White or Caucasian, while only

35% of the motorists were Caucasian. 94% of the respondents had a driver’s license whereas only 11% had a transit pass and another 11% had a carshare membership. More than half of the respondents (52%) had more than one car in their household, whereas almost two-third of the respondents (63%) had more than one bicycle in their household. The majority of the motorists (76%) had less than one bicycle per household. However, more than half of the bicyclists have more than one vehicle per household (53%).

Chi-square tests were conducted to see if there was any statistically significant association between each respondent category and two different motorist groups presented in Table 3-3. A p-value of less than 0.05 indicates a statistically significant association, which has been marked in **bold** in the table. When the sample size is small (less than 5), a Fisher’s Exact test was used instead to determine the significant association between the respondent category and motorist group. It was found that there is a statistically significant association between respondent’s race and motorist group (p-value < 0.001). A statistically significant association was also found between bicycle ownership and motorist group (p-value < 0.001).

Table 3-3: Survey Participant Demographics

Category	M-C	M-NC	Total	Percent
Gender				
Male	147 (71%)	20 (54%)	167	68%
Female	61 (29%)	17 (46%)	78	32%
Total	208	37	245	100%
Chi-square test not significant, (p > 0.05)				
Age				
18-25	53 (27%)	5 (14%)	58	25%
26-35	73 (38%)	21 (60%)	94	41%
36-49	29 (15%)	3 (9%)	32	14%
50-59	19 (10%)	4 (11%)	23	10%
60-75	20 (10%)	2 (6%)	22	10%
Total	194	35	229	100%
Fisher's Exact test not significant (p > 0.05)				
Education level				
Some high school or less	0 (0%)	0 (0%)	0	0%
High school diploma or GED	2 (1%)	2 (5%)	4	2%
Some College	25 (12%)	2 (5%)	27	11%
Trade/Vocational School	1 (0%)	0 (0%)	1	0%
Associate Degree	3 (1%)	1 (1%)	4	2%
Four-year college degree or more	177 (85%)	32 (86%)	209	85%
Others	1 (0%)	0 (0%)	1	0%
Total	209	37	246	100%
Fisher's Exact test not significant (p > 0.05)				
Race				
American Indian or Alaska Native	0 (0%)	0 (0%)	0	0%
Asian	45 ((22%)	21 (57%)	66	27%
Black or African American	3 (1%)	1 (3%)	4	2%
Hispanic or Latino	7 (3%)	0 (0%)	7	3%
White or Caucasian	146 (71%)	13 (35%)	159	65%
Other	6 (3%)	2 (5%)	8	3%
Total	207	37	244	100%
Fisher's Exact test significant (p < 0.05)				
Do you have				
Driver's license	194 (93%)	37 (100%)	231	94%
Transit pass	23 (11%)	3 (8%)	26	11%
Carshare Membership	26 (12%)	0 (0%)	26	11%
Fisher's Exact test not significant (p > 0.05)				
Vehicle Ownership				
More than 1 vehicle per household	111 (53%)	16 (43%)	127	52%
1 or less vehicle per household	98 (47%)	21 (57%)	119	48%
Total	209	37	246	100%
Chi-square test not significant, (p > 0.05)				
Bicycle Ownership				
More than 1 bicycle per household	145 (69%)	9 (24%)	154	63%
1 or less bicycles per household	64 (31%)	28 (76%)	92	37%
Total	209	37	246	100%
Chi-square test significant, (p < 0.05)				

3.6.2 Travel Behavior

As reported, motorists who ride bicycles (MC) used a motor vehicle for 47% of their weekly travel, while motorist who do not ride bicycle (M-NC) made 77% of their weekly travel by motor vehicle (Figure 3-1). Again, (M-NC) used more public transportation (9%) than M-C group (6%) for weekly travel. However, M-C group (18%) walk more during weekly travel than M-NC group (14%). A Chi-square test indicated that the distribution of responses to different travel mode was statistically significantly (p-value < 0.001).

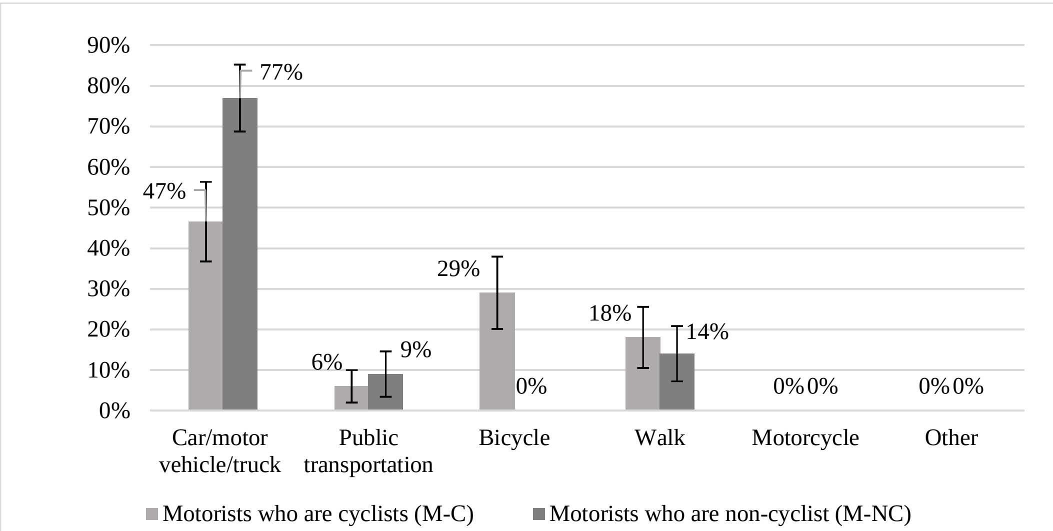


Figure 3-1: Respondent's Percent Weekly Travel Mode

3.6.3 Behavior of Bicyclists at Intersections

This section analyzes the behavior of bicyclists approaching an intersection from the self-reported response of the M-C group.

Bicyclist's scanning behavior during green signal phase at intersection

Bicyclists were presented with a scenario including an exclusive right-turn lane while approaching a signalized intersection. Respondents were asked about their glance patterns while moving through the intersection during a green phase. It was found that more than two-third of the bicyclist (71%) responded that they will scan left, right and left again, and pass when it is safe (Figure 3-2). Twenty-two percent of bicyclists reported that they would *not* yield to vehicles before crossing (19% would scan for vehicles, 3% would not scan) assuming vehicles would yield. The most common response in the ‘other’ category (5%) was that bicyclists would check over their left shoulder to merge with the through traffic lane to their left and proceed through the intersection while riding in the through traffic lane.

A Chi-square test of goodness-of-fit was conducted to identify if the distribution of responses in each category fits an expected distribution. A Chi-square test of goodness-of-fit is used when there is one categorical variable with two or more categories and to assess whether the number of observations in each category fits an expected distribution (McDonald, 2009). A statistically significant difference was identified indicating that the distribution of the responses in each category was not uniform, i.e. responses were not equal (p-value < 0.001). Another Chi-square test also indicated that the distribution of the correct response *scan left, right and left again, and pass when it is safe* was statistically significantly different (p-value < 0.001) when compared with the distribution of other options in the question. A 95% confidence intervals (CI) were calculated for each response category as well (Figure 3-2).

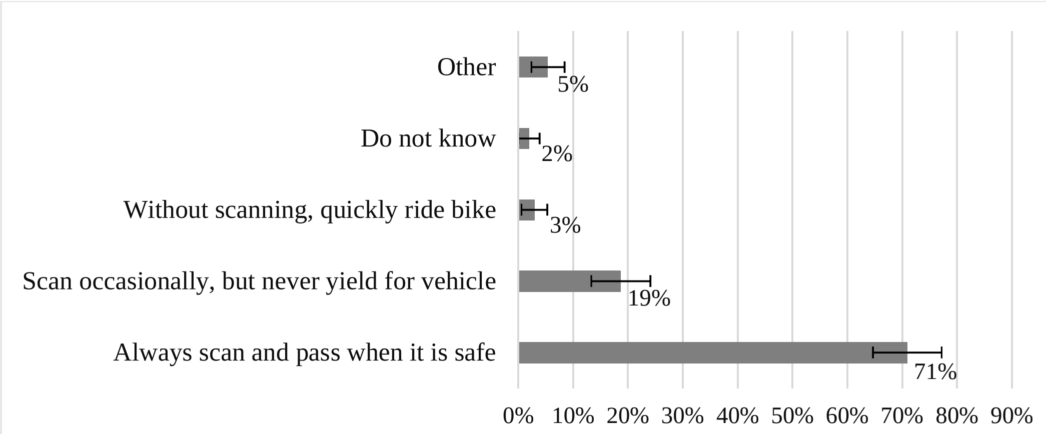


Figure 3-2: Bicyclist Scanning Behavior at A Signalized Intersection (n=203)

Bicyclist's self-reported action when a car is turning right

In another scenario, a car was going to turn right from the left of bicyclist, while the bicyclist was approaching the intersection. Bicyclists were asked what they would do if they wanted to proceed straight through the intersection in this scenario. More than two-thirds of the bicyclists (69%) responded that they would slow and yield for the turning vehicle (Figure 3-3). However, nearly one-fourth (21%) of the bicyclist reported that they would try to pass the vehicle assuming the driver would yield to them. Among those bicyclists who would pass, 14% would maintain their approaching speed to pass, while 7% said they would accelerate to pass the turning vehicle.

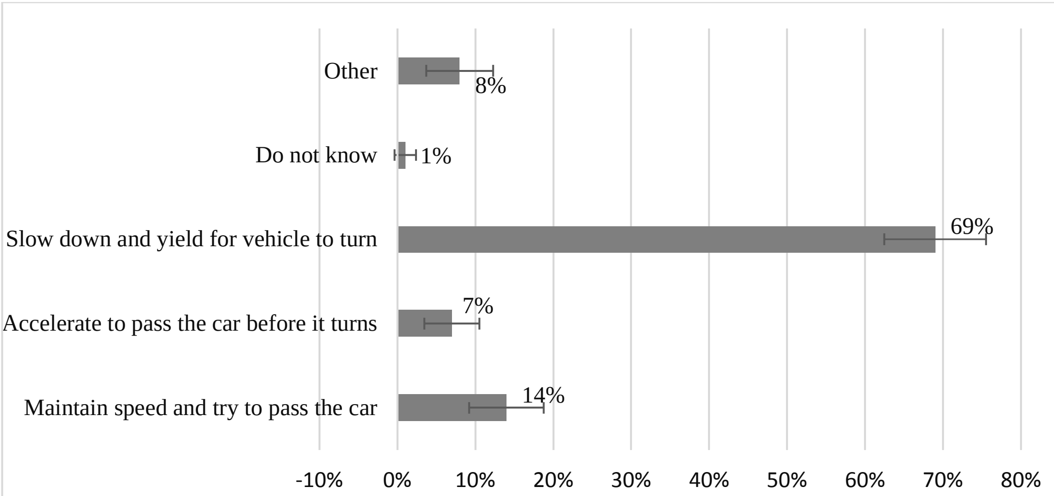


Figure 3-3: Bicyclists' Self-Reported Action When Motorist Is Turning Right (n=202)

A Chi-square test of goodness-of-fit indicated that the distribution of responses in each category does not fit an expected distribution, indicating that the distribution of the responses in each category was not uniform (p-value < 0.001). The Chi-square test also indicated that the distribution of the ideal response *slow down and yield for the vehicle to turn* was different than other options with statistical significance (p-value < 0.001).

Bicyclist's direction of passing a right-turning vehicle at intersection

Bicyclists were asked in which direction they would pass the right-turning vehicle at an intersection. It is recommended for bicyclists not to pass a right-turning vehicle on the right of the vehicle (OR Bicyclist's Manual, 2010). The recommended practice is- i) either stay behind the car to let it turn or, ii) pass on the car's left when safe. More than half of the bicyclists (57%) responded that they would stay behind the vehicle to let it turn (Figure 3-4). The next most common response (28%) was to either *pass the vehicle on the left at intersection or stay behind the vehicle to let it turn.* 10% of the bicyclists reported they would pass the vehicle on its left. However, 3% of the bicyclists responded that they would pass the vehicle on its right (the incorrect maneuver).

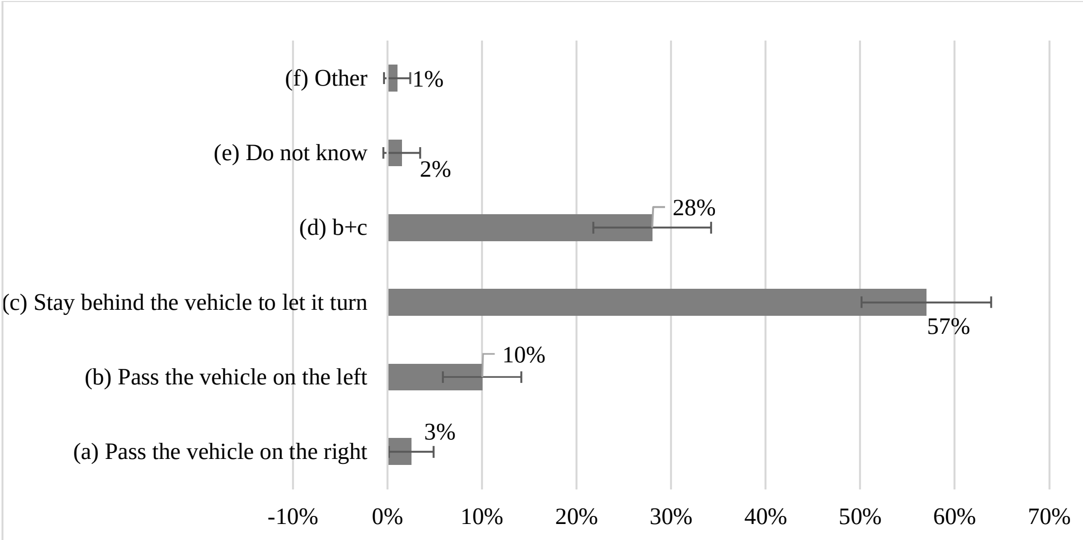


Figure 3-4: Bicyclist’s Position While Passing A Right-Turning Vehicle (n=200)

A Chi-square test of goodness-of-fit indicated that the distribution of responses in each category does not fit an expected distribution, indicating that the distribution of the responses in each category was not uniform (p-value < 0.001). A statistically significant difference (p-value < 0.001) was also found between the distributions of the correct responses *pass the vehicle on the left at intersection, stay behind the vehicle to let it turn or combination of both.*

Bicyclist’s stopping position in relation to queued cars

Bicyclists were asked where they would stop in response to a red indication at an intersection with a queue of vehicles (Figure 3-5). It is recommended that bicyclists should stop in the bike lane either ahead of or behind the first stopped vehicle at an intersection (OR Bicyclist’s Manual, 2010). Bicyclists may not see the turn signals of a vehicle directly beside them just as the adjacent motorist may not detect the bicyclist. As stated in the OR Bicyclist's Manual, "While it is legal to pass a line of stopped cars on streets with a bike lane, it is advisable to stop behind the first vehicle". However, only 22% of the bicyclists provided correct responses *behind the first stopped vehicle* (9%), *in front of the first stopped vehicle* (10%) or *combination of both* (3%). Most of the bicyclists (45%) reported that they would stop to the *right of the first stopped car*. Almost one-fourth of the bicyclists (24%) reported they would *stop anywhere in the bike lane*.

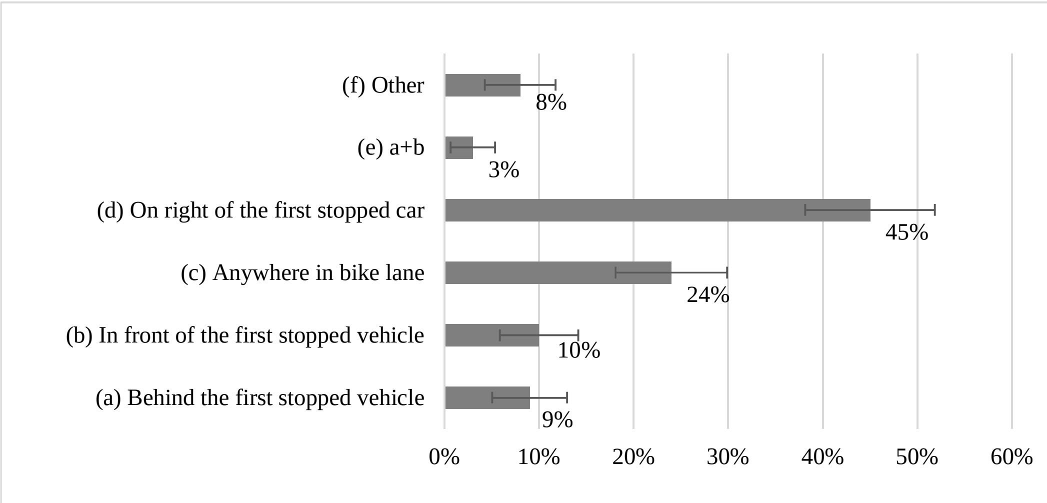


Figure 3-5: Bicyclists' Position With Respect To Queued Cars (n=203)

A Chi-square test of goodness-of-fit indicated that the distribution of responses in each category does not fit an expected distribution, indicating that the distribution of the responses in each category was not uniform (p-value < 0.001). Another Chi-square test showed that the distributions of the correct responses were statistically significant different (p-value = 0.02) from the distribution of other incorrect responses in the question at 0.05 significant level. These results indicate that some bicyclists were unaware of or disregard recommended safe stopping positions with respect to the position of stopped cars at an intersection, which might make them vulnerable to RH crashes at the onset of the green indication.

3.6.4 Behavior of Motorists at Intersections

This section analyzes the behavior of motorists at an intersection with bicycle traffic.

Motorist's visual scanning at intersection

To gain insight on motorists' visual attention at an intersection before turning right, motorists' were asked to rate how often they look for different objects at the intersection. Instead of using a 5-point or 7-point Likert scale, search frequency was rated in a 4-point Likert-type rating scale where the mid-point or 'neutral' option of a 5-point Likert scale was omitted (Worcester et al., 1975). While collecting responses in the 4-point Likert scale by the web-based survey tool, 'never' was rated being one, 'sometimes' being two, 'often' being four and 'always' was rated being six. Table 3-4 shows that there was no difference in the mode (6) and median (6) responses to the frequency respondents look for different objects at an intersection (Table 3-4). However, when the mean responses for the *always* category were examined, it was found that 84% of the motorists responded they would *always* look for the traffic signal status (mean = 5.63), 76% responded they would *always* look for crossing pedestrians (mean = 5.44), 68% responded they would *always* look for oncoming vehicular traffic (mean = 5.00), and 56% would *always* look for bicyclists at their right (mean=4.87). Results indicated that the mean responses to the frequency respondents look for bicyclists was the lowest compared to that for the traffic signal status, oncoming vehicular traffic, and crossing pedestrians. Chi-square test of goodness-of-fit indicated there was no statistically significant difference in the distribution of responses for *always look for* category among traffic signal status, oncoming vehicular traffic, and crossing pedestrians, however those three were found to be statistically different from the response to *always look for* bicyclists to the right side of the driver (p-value = 0.004).

Table 3-4: Frequencies That Motorists Search For Targets at an Intersection

Question	Never	Sometimes	Often	Always	n	μ	*Mo*	*Md*
Oncoming traffic	4%	4%	17%	68%	225	*5.00*	*6*	*6*
Crossing Pedestrian	0%	0%	20%	76%	225	*5.44*	*6*	*6*
Bicyclist(s)	2%	2%	32%	56%	225	*4.87*	*6*	*6*
Traffic signal	0%	0%	14%	84%	225	*5.63*	*6*	*6*
Other	13%	13%	13%	69%	16	*4.88*	*6*	*6*

n = total, μ = Mean, *Mo* = Mode, *Md* = Median

Motorists were also asked how frequently they check different locations to detect the presence of a bicyclist before turning right at an intersection. Motorists rated the frequency in a 5-point Likert scale, from ‘never’ (one) to ‘all the time’ (five). However for the analysis purpose, the ‘never’ and ‘rarely’ responses were aggregated and termed as ‘infrequently’ and the responses of “often” and “all the time” were aggregated and termed ‘frequently’ categories.

Table 3-5: Frequencies That Motorists Scan Different Checked Spots

Question	Infrequently	Sometimes	Frequently	n	μ	*Mo*	*Md*
Rear view mirror	20%	21%	59%	225	*3.55*	*4*	*4*
Passenger side mirror	7%	12%	81%	225	*4.20*	*5*	*4*
Driver side mirror	61%	17%	22%	223	*2.47*	*2*	*2*
Front Passenger side	8%	19%	73%	224	*4.02*	*5*	*4*
Driver side window	64%	16%	20%	221	*2.36*	*2*	*2*
Rear passenger side	28%	19%	52%	223	*3.32*	*4*	*4*
Looking over shoulder	12%	20%	68%	225	*3.87*	*5*	*4*
Other	1%	1%	1%	7	*3.29*	*3*	*3*

n = total, μ = Mean, *Mo* = Mode, *Md* = Median

Kruskal-Wallis rank sum test significant, p-value < 0.05

Table 3-5 indicates that the most frequently checked spot (81%) was the *passenger side mirror* (mean = 4.20, mode = 5, median = 4), followed by the *front passenger side window* (mean = 4.02, mode = 5, median = 4). 68% percent of motorists reported that they frequently *look over their shoulder* (mean = 3.87, mode = 5, median = 4) to detect the presence of bicyclists to their right. Also, 59% of motorists responded that they frequently check *the rear view* mirror (mean = 3.55, mode = 4, median = 4) and 52% reported they frequently check the *rear passenger side window* (mean = 3.32, mode = 4, median = 4) to detect the presence of bicyclists to their right. The least frequently checked spots were reported as the *driver side mirror* (22% motorists frequently check, mean = 2.47, mode = 2, median = 2) and the *driver side window* (20% motorists frequently check, mean = 2.36, mode = 2, median = 2). A Kruskal-Wallis rank sum test indicated that the median responses from all different checked spots were not equal (p-value = 0.03). However, no statistically significant difference was found in the median responses of the most frequently checked spots (median=4).

Motorists' Self-Reported Action when They Detect a Bicyclist

This section analyzes motorist's self-reported action when they detected the bicyclist approaching the intersection at their right in two different positions- bicyclist riding ahead of the motorist and bicyclist approaching from behind the motorist at their blind spot.

Bicyclist approaching from behind the motorist

Motorists were asked what they would do if they detected a bicyclist approaching from behind in the right-side mirror before turning right at an intersection (Figure 3-6). More than two-thirds of motorists (72%) reported that they would yield and let the bicyclist pass before turning. 10% of the motorists said they would accelerate and turn right before the bicyclist reaches the intersection, whereas 9% of motorists reported that they would make the right-turn at their current speed assuming the bicyclist would yield. The most common 'Other' response was that the relative speed and position of the bicyclist approaching the intersection would govern the decision to turn before or yield to the bicycle.

A Chi-square test of goodness-of-fit indicated that a statistically significant difference exists between the most common response of *motorist would yield and let the bicyclist pass* and the other alternate responses (p value < 0.001).

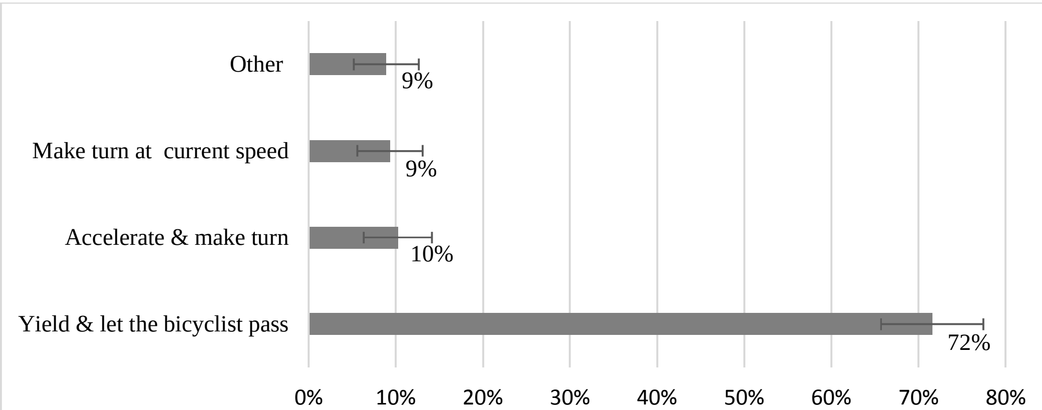


Figure 3-6: Motorist's Action When a Bicyclist Is Detected in Side Mirror (n=225)

Bicyclist riding ahead the motorist

Motorists were asked what they would do before turning right at an intersection if they detect a bicyclist riding ahead on the right of their vehicle (Figure 3-7). Ninety five percent of the motorists reported that they would *slow down* and another 4% said they would *stop* to let the bicyclist pass before they make the turn. However, 1% of the motorists said they would *accelerate* past the bicyclist and turn right. A Chi-square test of goodness-of-fit indicated that the distribution of responses in each category does not fit an expected distribution, indicating that the distribution of the responses in each category was not uniform (p-value < 0.001).

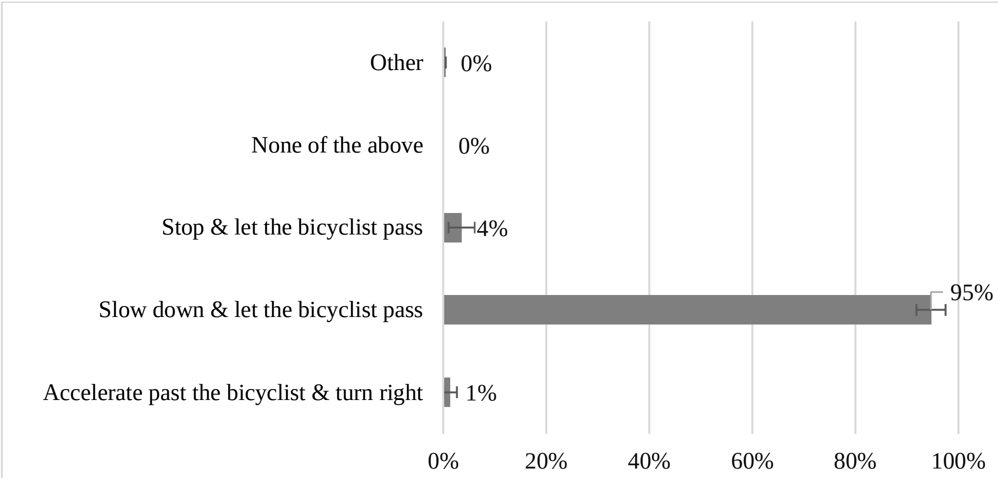


Figure 3-7: Motorists’ Action When Bicyclist Riding Ahead (n=225)

Comparisons were made to determine if there is any change in motorists’ turning behavior at an intersection based on the relative position of bicyclists, i.e. when bicyclist is approaching from behind detected in the right-side mirror vs. when the bicyclist is riding ahead (Table 3-6). 99% of the motorists reported that they would either slow down (95%) or yield (4%) to let the bicyclist pass if they detected a bicyclist riding ahead before their turning. Only 1% of motorists reported that they would turn right *not* yielding the right of way to bicyclist by accelerating or maintaining their current speed. However, when the bicyclist was approaching from behind detected in motorist’s right-side mirror, 19% of motorists reported that they would not yield the right of way to bicyclists and would turn right by either accelerating (10%) or maintaining their current speed (9%). A Chi- square test of independence confirmed that there was a statistically significant association between the motorist's predictive action and the relative position of bicyclists approaching the intersection (p-value < 0.001).

Table 3-6: Motorist's Decision to Turn Right w.r.t Bicyclist Relative Position

Motorist's self-reported action	**Bicyclists approaching from behind**	**Bicyclists riding ahead**
Stop or slow down to let the bicyclist pass	72%	99%
Make turn before the bicyclist by accelerating or at current speed	19%	1%
Other	9%	0%

Chi-square test significant, p-value < 0.05

3.6.5 Comprehension and Experience of RH Crashes

Among 234 respondents, only 35% were familiar with the phrase "Right-hook" crash (Table 3-7). However, when respondents were asked to anticipate what type of crash the phrase "Right-hook" refers to from four given multiple choice options, 68% of the respondents correctly responded. Also, 9% of the total respondents reported that they had been involved in a RH crash.

Table 3-7: Familiarity and Occurrence of the Phrase "Right-Hook"

Response	**Number**	**Percentage**	**n**
Familiar with the phrase	83	35%	234
Could anticipate the meaning of the phrase	159	68%	234
Involved with the RH crash	20	9%	234

The RH crashes reported in the survey according to transportation user and location (Table 3-8) were further considered. 95% of the respondents involved in RH crashes (n=20) reported that they were riding bicycle during the crash. More than half of the RH crash (55%) occurred at intersections, among which 30% occurred at intersections with a traffic signal, and 25% occurred at intersections with a STOP sign. Another 30% of RH crashes occurred in a driveway, while 15% crashes occurred in a parking lot.

Table 3-8: Number of RH Crash by Transportation User and Facility Type (n=20)

Location	**Riding bike**	**Driving car**	**Total**
Intersection with a traffic signal	30%	0%	30%
Intersection with a STOP sign	25%	0%	25%
Driveway	25%	5%	30%
Parking lot	15%	0%	15%
Other	0%	0%	0%
Total	**95%**	**5%**	**100%**

Respondents were asked to describe the type of bicycle treatments at the locations of the RH crashes they were involved in (Table 3-9). As reported, half of the RH crash (50%) occurred *on commercial streets with a striped bike lane*, while 20% of those crashes occurred *on a commercial street with on-street car parking, and No bike lane*. Thirty percent of the respondents involved in a RH crash reported that the crash occurred on a residential street (listed in o*ther* type), and 20% of those residential streets had no bike lanes.

Table 3-9: Type of Bicycle Treatment at the RH Crash Location (n=20)

Bicycle treatment	**Riding bike**	**Driving car**	**Total**
A commercial street w/ painted buffer and parked cars	0%	0%	0%
A commercial street w/ on-street car parking, NO bike	20%	0%	20%
A commercial street w/ striped bike lane	50%	0%	50%
A commercial street w/physically separated bike lane	0%	0%	0%
Other	25%	5%	30%
Total	**95%**	**5%**	**100%**

Perceptions of RH Crash Contributing Factors

Respondents were asked to assess how significantly different factors that contribute to the occurrence of RH crashes at an intersection. They rated their opinion on a 5-point Likert scale, from ‘strongly disagree’ (1) to ‘strongly agree’ (5) (Figure 3-8).

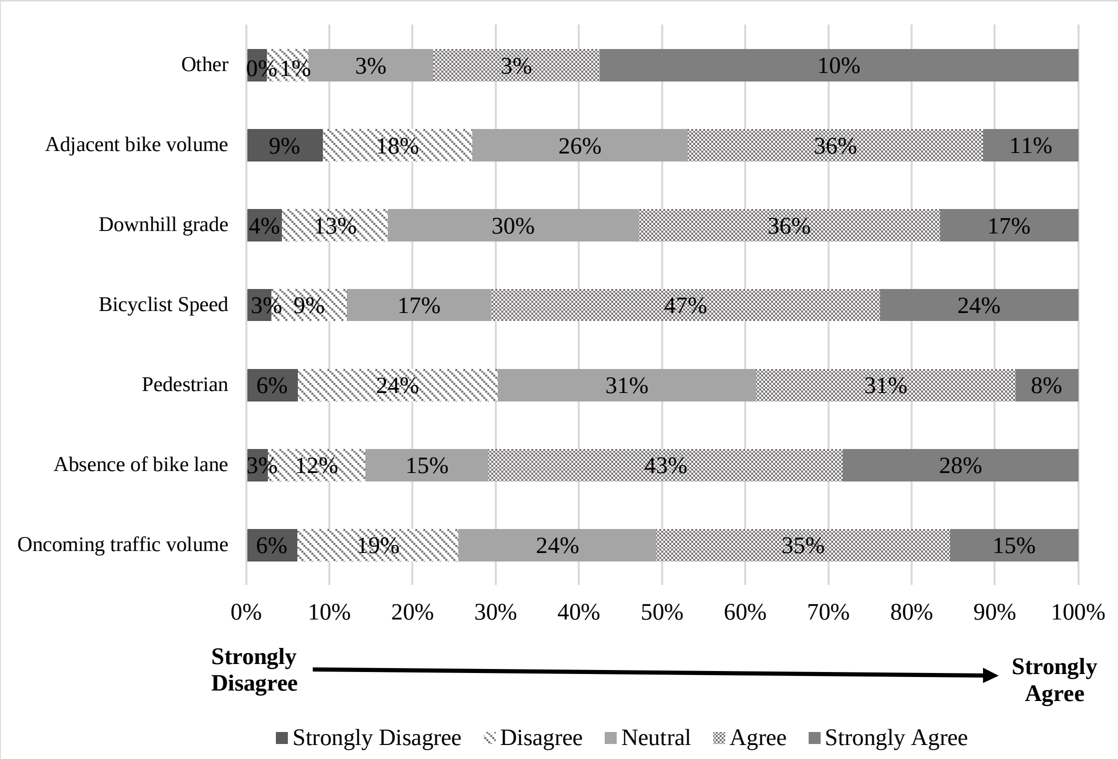


Figure 3-8: Opinions of RH Crash Contributing Factors

To analyze this question, the responses of “strongly disagree” and “disagree” were combined and termed “disagree” and the responses of “agree” and “strongly agree” were combined and termed “agree”. Descriptive statistics were also calculated (Table 3-10). The majority of respondents (71%) agreed that *bicyclist speed* and *absence of bike lane* were significant factors contributing to RH crashes. More than half of the respondents also reported that *downhill grade* (53%) and *oncoming traffic volume* (51%) also may contribute to RH crashes at intersections. 47% of respondents agreed that the *adjacent bicyclist volume* might contribute to the RH crash, and 39% reported that the *presence of pedestrian* might be a contributing factor. Respondents also reported *other* RH crash contributing factors, mostly motorist related, such as *motorists not looking in the right mirror or blind spot before turning, distracted driving, misjudging of bicyclist's speed, not correctly yielding the right of way to bicyclists, unpredictable riding behavior of bicyclists, bicyclist attitude towards motorists* and *bad weather*. Kruskal-Wallis rank sum test showed that there was a statistically significant difference in the median responses to the opinion of different RH crash contributing factors (p-value < 0.001).

Table 3-10: Opinions of Different RH Crash Contributing Factors

Question	**Disagree**	**Neutral**	**Agree**	**n**	***μ***	***Mo***	***Md***
Oncoming traffic volume	26%	24%	51%	227	*3.34*	*4*	*4*
Absence of bike lane	14%	15%	71%	230	*3.82*	*4*	*4*
Pedestrian	30%	31%	39%	225	*3.10*	*4*	*3*
Bicyclist Speed	12%	17%	71%	231	*3.79*	*4*	*4*
Downhill grade	17%	30%	53%	229	*3.48*	*4*	*4*
Adjacent bike volume	27%	26%	47%	228	*3.22*	*4*	*3*
Oncoming traffic volume	1%	3%	14%	40	*4.24*	*5*	*5*

n = total, μ = Mean, *Mo* = Mode, *Md* = Median

Kruskal-Wallis rank sum test significant, p-value < 0.05

Respondent's opinions of RH crash contributing factors were further categorized by two motorist's groups, M-C vs. M-NC to see if there was any difference between their opinions (Table 3-11). Differences were found in the level of agreement with different causal factors between the two motorist groups, although not statistically significant (Chi-square test, p-value > 0.05). The highest percentage of M-C (70%) respondents ranked the a*bsence of bike lane* as the most agreed contributing factor, whereas the highest percent of M-NC respondents ranked (80%) that the *bicyclists speed* was the most agreed contributing factor. *Presence of pedestrian* was ranked as the lowest in the 'agree' category in both motorist groups (37% vs. 48%).

Descriptive statistics were calculated for each motorist group (Table 3-12). The table shows that median responses to the level agreement with different RH crash contributing factors were equal for both motorist groups except for *oncoming traffic volume* and *adjacent bicyclist volume*.

Table 3-11: Opinions of RH Crash Contributing Factors by Two Motorist Groups

	Disagree		**Neutral**		**Agree**		**n**	
Question	*M-C*	*M-NC*	*M-C*	*M-NC*	*M-C*	*M-NC*	*M-C*	*M-NC*
Oncoming traffic	27%	18%	24%	21%	49%	61%	193	33
Absence of bike lane	15%	14%	16%	8%	70%	78%	193	36
Pedestrian	30%	30%	33%	21%	37%	48%	191	33
Bicyclist Speed	14%	3%	17%	17%	69%	80%	195	35
Downhill grade	17%	18%	32%	21%	51%	62%	194	34
Adjacent bike volume	29%	14%	29%	11%	42%	74%	191	35

A Mann-Whitney U-test was used to statistically compare the median responses for different RH crash contributing factors between the two motorist groups. The p-value indicated that there was no statistically significant difference between the median responses of two motorists groups at 0.05 significance level, except for the *adjacent bicyclist volume* factor (p value = 0.003).

Table 3-12: Descriptive Statistics of Opinions of RH Crash Contributing Factors

Question	*μ*		*Mo*		*Md*		*p-value*
	M-C	*M-NC*	*M-C*	*M-NC*	*M-C*	*M-NC*	
Oncoming traffic volume	3.30	3.61	4	4	3	4	0.18
Absence of bike lane	3.81	3.86	4	4	4	4	0.84
Pedestrian	3.08	3.18	3	4	3	3	0.54
Bicyclist Speed	3.76	3.97	4	4	4	4	0.47
Downhill grade	3.48	3.50	4	4	4	4	0.84
Adjacent bike volume	3.13	3.71	4	4	3	4	**0.003**

n = total, *μ* = Mean, *Mo* = Mode, *Md* = Median
***Bold** indicates a Mann-Whitney U-test significant difference, p-value<0.05*

Perceptions of Different RH Crash Mitigation Treatments

Respondents were asked to rate different intersection treatments based on how effective they would be reducing RH crashes at intersections. They rated the treatments on a 5-point Likert scale, from ‘very ineffective’ (one) to ‘very effective’ (five). To analyze this question, responses of “very ineffective” and “ineffective” were combined and termed “ineffective” and responses of “effective” and “very effective” were combined and termed “effective” (Table 3-13).

The most respondents rated *bike box with bike lane extension* as effective (68%, mean=3.68, median=4) treatment closely followed by *green pavement conflict markings* (59%, mean=3.46, median=4). *Shared lane* was the least commonly rated as an effective (32%, mean=2.81, median=3) treatment. Respondents also proposed *separate bike paths* and *exclusive bike signal phasing* as very effective treatments to reduce RH crashes in the *other* category.

A Kruskal-Wallis rank sum test was performed to determine if the median responses to the efficacy of different intersection treatments were equal. A p-value < 0.001 showed that there was statistically significant difference in the median responses.

Table 3-13: Efficacy of Different RH Crash Mitigation Treatments

Question	**Ineffective**	**No opinion**	**Effective**	***n***	***μ***	***Mo***	***Md***
Green pavement conflict	18%	23%	59%	*223*	*3.46*	*4*	*4*
Bike box with bike lane	16%	16%	68%	*225*	*3.68*	*4*	*4*
Specific bicycle signal head	27%	20%	52%	*225*	*3.32*	*4*	*4*
Shared lane	45%	23%	32%	*222*	*2.81*	*2*	*3*
Combined bicycle lane/turn	28%	20%	52%	*223*	*3.29*	*4*	*4*
Dutch Intersection Design	19%	32%	50%	*219*	*3.44*	*3*	*3*
Other	0%	7%	7%	*30*	*3.87*	*3*	*3*

n = total, *μ* = Mean, *Mo* = Mode, *Md* = Median
Kruskal-Wallis rank sum test significant, p-value<0.001

3.7 Discussion

This survey provides preliminary evidence on factors contributing to the occurrence of RH crashes. This is the only study, according to author's knowledge based on a review of more than 150 related documents, exclusively designed with a focus on RH crashes and their relation to the behavior of motorists and bicyclists at signalized intersections. The key findings of this study are summarized below:

Demographics

- Men (71%) were found to be more likely to ride bicycles than women (29%). This finding is consistent with numerous previous bicycle studies (Räsänen et al., 1998; Banister and Gallant, 1999; Pucher et al., 1999; McDonald et al., 2001; Dill et al, 2007). There was an over representation of respondents with higher education, specifically those who had four-year college degree or more (85%).

The highest percentage of both bicyclists and motorists were between the ages of 26 to 35. This finding is consistent with the Moudon et al. (2005) study that stated that people between the ages of 25-45 rode more than those between the ages of 18-21.

- While the majority of bicyclists were White or Caucasian (71%), only 35% of the motorists were White or Caucasian. This finding is also consistent with the study by Moudon et al. (2005) who found bicycling increased for white, middle-aged, male respondents.
- The majority of the motorists (76%) had less than one bicycle per household. However, more than half of the bicyclists had more than one vehicle per household (53%). This finding is also consistent with the study by Moudon et al. (2005) who found bicycling increased for people who have more than one car per adult.
- Statistically significant associations were found between respondent's race and motorist groups who ride bicycles vs. those who do not; and also between bicycle ownership and these two motorist group (p value < 0.05).
- Motorist who do not bike used public transportation more (9%) than the motorist who ride bicycles (6%) for their weekly travel. However, respondents of M-C group walk more (18%) than M-NC group (14%) for their weekly travel.

Behavior of Bicyclists at Intersections

- In response to the scanning for vehicles while making through movement at an intersection, almost one-fourth (22%) of the bicyclists reported that they would *not* yield to vehicles before crossing (19% would scan for vehicles, 3% would not scan) assuming vehicles would yield. A similar response was observed when bicyclists were asked what they would do if a car was going to turn right immediately from their left. Almost one-fourth (21%) of the bicyclists reported that they would try to pass the vehicle assuming the driver will yield the right of way. This interpretation of motorists' behavior may increase the vulnerability of bicyclists to RH crashes at intersections. This finding on bicyclist's behavior is consistent with the finding of Karsch et al. (2012), where he reviewed the pedestrian and bicyclist safety research literature from 1991 to 2007 in US and stated that for all the BMV crashes in 2009, the most common bicyclist contributing factors were failure to yield to motorist (21%).

- Most bicyclists (78%) were unaware of their stopping position with respect to stopped vehicles queued at an intersection in response to a red traffic indication. Only 22% of bicyclists provided the correct response with respect to their stopping position.

Behavior of Motorists at Intersections

- In response to visual scanning of the objects at an intersection, 84% of motorists (n=225) said they would *always* look for the traffic signal status, 76% would *always* look for crossing pedestrians, and 68% would *always* look for oncoming vehicular traffic, only 56% reported that they would *always* look for bicyclists at their right before turning right at the intersection. This indicates that motorists may search less frequently for bicyclist to their right than other targets before turning right at the intersection. This could potential contribute to the occurrence of RH crashes.

- A statistically significant difference was found in motorists' turning behavior at an intersection with respect to bicyclist's relative position in the adjacent bicycle lane. Only 1% of motorists reported that they would *not* yield to the bicyclist that was riding ahead and would accelerate to pass the bicyclist before turning at an intersection. However, 19% of motorists reported that they would *not* yield to the adjacent bicyclist approaching from the behind, whom the motorist detected in the rear- or side-view mirror and would turn right at the intersection assuming the bicyclist would yield. Motorist's *not* yielding the right of way to bicyclists can potentially cause a RH crash later in the green phase, since motorists may not always be able to correctly judge bicyclist's speed.

Familiarity with RH crashes

- Among 234 respondents, only 35% were familiar with the phrase "Right-hook". However, 68% of the respondents correctly interpreted what type of crash "Right-hook (RH)" refers to when presented with four multiple choice options. 9% of the total respondents had been previously involved in a RH crash.
- Among the respondents involved in a RH crash, 95% were riding bicycles during the crash. Again, more than half of the RH crashes (55%) occurred at intersections, among which 30% occurred at intersections with a traffic signal, and 25% occurred at intersections with a STOP sign. Half of the RH crash (50%) occurred on commercial streets with a striped bike lane.
- While respondents were asked about their perception of RH crash contributing factors, the majority of the respondents (71%) agreed that the high speed of bicyclist and absence of bike lanes were major contributing factors followed by

the downhill grade (53%) and volume of oncoming vehicular traffic (51%). 47% of respondents also reported that volume of adjacent bicyclists might contribute to the RH crash, whereas 39% reported that presence of pedestrian might be a contributing factor.

- Respondents were asked to rate different intersection treatments as being effective or ineffective in reducing RH crashes at the intersection. Respondents rated bike box with a bike lane extension to be the most effective treatment (68%) followed by green pavement conflict marking (59%).

It can be concluded that factors revealed from this survey analysis should provide useful in future research and implementation aimed at preventing RH crashes. Specifically, motorist behavior related factors found from this survey analysis will be considered during the development of following driving simulator experiments pertaining to RH crashes.

Chapter 4 Driving Simulator Experiment Methodology

To better understand RH crash casualty, the self-reported interactions between motorists' and bicyclists' behavior at signalized intersections were examined through an online survey (Chapter 3). However, to more accurately assess crash risk, it is important to understand driving performance and behavior in the larger context of the driving environment (Dingus, 2011). The classic inferential approach of diagnosing crashes using police-reported crash records appears to pose several problems (Brown, 1992). In addition to the fact that crashes are rare events, police-reported crash records contain little specific information on the behavior of road users and traffic hazards during the crash. Due to the limitation of crash databases, simulation has emerged as a leading research tool for exploring the contribution of human driving behavior on traffic crashes (Durkee, 2010). This research leveraged the OSU high-fidelity driving simulator to investigate the causal factors of RH crashes related to motorist behavior. While a RH crash can theoretically result from errors made by motorists or bicyclists, this research effort evaluated motorist and roadway related factors of RH crashes.

This chapter provides a detailed description of the experimental design, selection of participants, task selection and implementation, and experimental procedure of this driving simulator study.

4.1 Research Scope

As documented in the literature review chapter, improper allocation of motorists' visual attention was proven as one of the factors contributing to crashes between a motorist turning right and a bicyclist coming from the right (on the left side of road) along a bicycle path at an intersection (Räsänen et al., 1998). Inadequate surveillance was another contributing factor to bicycle-motor vehicle crashes at intersection, when motorists look to where a conflicting vehicle might be present (adjacent and to the right of the vehicle) before making a turn, but fails to detect the bicyclist (NHTSA, 2010). Therefore, a safe right-turning maneuver requires that the motorist complete at least two independent tasks: (i) look and detect the bicyclist, (ii) make the appropriate decision based on that information and corresponding conditions at the intersection. In this regard, SA can help to explain motorists' behavior by exploring several key factors: anticipation, attention, perception, expectations, and risk (Endsley, 1998). SA is the term given to the awareness that a person has of a situation, an operator's dynamic understanding of 'what is going on' (Endsley, 1995a). Therefore, to analyze motorist related crash factors, this experiment measured motorist's performance during right-turn maneuvers at signalized intersection in the presence of a through-moving bicyclist in an adjacent bicycle lane through their (i) visual attention, (ii) SA, and (iii) crash avoidance behavior.

4.2 Research Design

This research is divided into three components, where each component addresses a specific set of research questions associated with the three performance measures stated above, i.e. right-turning motorist's visual attention, SA, and crash avoidance behavior.

For this purpose, four independent variables were included in the experiment: relative position of bicyclist, bicyclist approach speed, oncoming left-turning vehicular traffic and, pedestrian presence in the conflicting crosswalk. The first independent variable “relative position of bicyclist” had three levels – 1) no bicyclists, 2) bicyclist approaching from behind the motorist, which placed the bicyclist in the blind spot to the right and behind the subject vehicle and 3) bicyclist riding ahead of the motorist where the motorist would overtake the bicyclist (overtaking scenario). The second independent variable, bicyclist’s speed had two levels – 1) low (12 miles per hour (mph), and 2) high (16 mph). The third independent variable was the “presence of oncoming left-turning vehicular traffic”, which had two levels – 1) no oncoming (zero) vehicles and 2) three oncoming vehicles. The last factor was the “presence of a conflicting pedestrian in the crosswalk, which also had two levels – 1) no (zero) pedestrian and 2) one conflicting pedestrian walking towards the participant. Table 4-1 shows different experiment factors and their levels. The factorial design resulted in 24 scenarios for inclusion in the experiment, which were manipulated within-subjects. The within-subject design provides the advantage of greater statistical power and reduction in error variance associated with individual differences (Cobb, 1998). However, one fundamental disadvantage of the within-subjects’ design is "Practice effects”, which are caused by the participants' practice and growing experience as they move through the sequence of conditions. This effect is due to the participants' growing general familiarity with the procedures. To control for this effect, the order of the presentation of the scenarios to the participants need to be random ordered or counterbalanced. A more detail treatment of this topic appears in section “4.3.2 Scenario Layout”.

Table 4-1: Experimental Factors and Levels

Name of the Variable	**Category**	**Levels**
Bicyclist relative position	Nominal (Categorical)	None
		One (1) bicyclist riding in front of the motorist in an adjacent bicycle lane to the right
		One (1) bicyclist coming from behind the motorist in an adjacent bicycle lane to the right
Speed of bicyclist	Discrete	Low (12 mph)
		High (16 mph)
Presence of oncoming vehicular traffic	Dichotomous (Categorical)	None
		Three (3) Vehicles
Presence of conflicting pedestrian	Dichotomous (Categorical)	None
		One (1) pedestrian walking towards the motorist

4.3 Research Questions

The overarching research questions associated with the assessment of the visual attention, SA, and crash avoidance behavior of motorists are included in this section. However, specific research hypothesis, data analysis, results and discussions are organized in subsequent chapters (Table 4-2).

Table 4-2: Corresponding Chapters of Right-Turning Motorist’s Performance Measures

Performance Measures	**Chapter #**	**Title**
Visual attention	5	Analysis & Result-Visual attention
SA	6	Analysis & Result-SA
Crash Avoidance	7	Analysis & Result-Crash Avoidance

4.3.1 Research Question - Visual Attention

The visual attention of motorists was measured by eye movement data collected with eye tracker technology. Fisher et al. (2011) stated that eye movement data provides direct evidence whether potential hazards are being anticipated in most cases. As such, participants' eye movement data were collected to investigate if they detect potential RH crash hazards, i.e. the through-moving bicyclist in the adjacent bicycle lane before turning right at a signalized intersection. The potential influence of the experimental factors (Table 4-1) on right-turning motorist's eye movement formed the basis of the research questions regarding the visual attention of motorists.

> *Research Question 1 (RQ_1)*: Is the visual attention of a right-turning motorist influenced by the relative position of the adjacent bicyclist?

> *Research Question 2 (RQ_2)*: Is the visual attention of a right-turning motorist influenced by bicyclist's approaching speeds at a signalized intersection?

> *Research Question 3 (RQ_3)*: Is the visual attention of a right-turning motorist influenced by the presence of oncoming left-turning traffic at the intersection?

> *Research Question 4 (RQ_4)*: Is the visual attention of a right-turning motorist influenced by the presence of conflicting pedestrian crossing the intersection?

Subsequently, research hypotheses were formulated to statistically analyze the eye movement data of right-turning motorists. As mentioned in Table 4-2, the research hypothesis, data analysis and results for this set of experiment are detailed in the "Chapter 5: Analysis & Result-Visual attention".

4.3.2 Research Question – SA

The Situation Awareness Global Assessment Technique (SAGAT) (Endsley, 1995) was used to measure a right-turning motorist's SA in the presence of a through-moving bicyclist in an adjacent bicycle lane during the latter portion of the green phase at a signalized intersection. SAGAT is the most widely used measure of SA. It was developed and validated by Endsley (1995) to assess operator's SA using queries for each of the three levels of SA proposed in the Endsley's three-level model. The three-level model is a cognitive theory that uses an information processing approach where the three levels are, level 1 SA (perception of the elements), level 2 SA (comprehension of their meaning), and level 3 SA (projection of future status) (Endsley, 1995). The research questions associated with SA were formulated to assess the influence of the relative position of bicyclists and the presence of oncoming left-turning traffic on motorist's SA while turning right during the latter portion of green phase at an intersection with bicycle traffic.

Research Question 5 (RQ_5): Does the relative position of a through-moving bicyclist in the adjacent bicycle lane influence right-turning motorists' SA at the latter portion of green phase at an intersection?

Research Question 6 (RQ_6): Does the presence of oncoming left-turning traffic influence right-turning motorists' SA at the latter portion of green phase at an intersection?

Research Question 7 (RQ_7): Do the combination of the presence of oncoming left-turning traffic and relative position of bicyclist influence right-turning motorists' SA at the latter portion of green phase at an intersection?

Research Question 8 (RQ8): Is there any correlation between the number of correct responses and crash avoidance behavior of right-turning motorist in a driving simulator environment?

The research hypothesis, data analysis and results for this set of experiment are detailed in "Chapter 6: Analysis & Result-SA" (Table 4-2).

4.3.3 Research Question – Crash Avoidance Behavior

Although SA is key to decision making in a dynamic environment, it does not necessarily guarantee successful task performance (Salmon, 2009). Therefore, in addition to the explicit recall measures of SA, it is also important to assess operator's SA with indirect performance-based measures (Gugerty, 1997). In this experimental component, motorist's performance was measured through the global performance measure of crash avoidance during right-turning maneuvers at the latter portion of the green indication and in the presence of bicyclists at a signalized intersection. Crash avoidance behavior helped to determine if a motorist was able to notice a bicyclist in a timely manner, decide to avoid the collision, and execute an evasive maneuver to ultimately avoid a RH crash at a simulated signalized intersection. The following research questions were established to guide the assessment of crash avoidance behavior:

Research Question 9 (RQ_9): What are the driving environment causal factors leading to the occurrence of a RH crash at the latter portion of a green phase observed in the simulated intersections?

Research Question 10 (RQ_{10}): What are the human causal factors leading to the occurrence of a RH crash at the latter portion of a green phase observed in the simulated intersections?

4.4 Driving Simulator Study

The OSU Driving Simulator, design of the virtual environment and the pilot study conducted for this experiment are described in this section.

4.4.1 OSU Driving Simulator Description

The OSU Driving Simulator is a high-fidelity, motion-based simulator, consisting of a full 2009 Ford Fusion cab mounted above an electric pitch motion system capable of rotating ±4 degrees. The vehicle cab is mounted on the pitch motion system with the driver's eye-point located at the center of the viewing volume. The pitch motion system allows for the accurate representation of acceleration or deceleration (OSU Driving Simulator, 2011). Researchers build the environment and track subject drivers from within the operator workstation shown in Figure 4-1, which is out of view from participants within the vehicle.

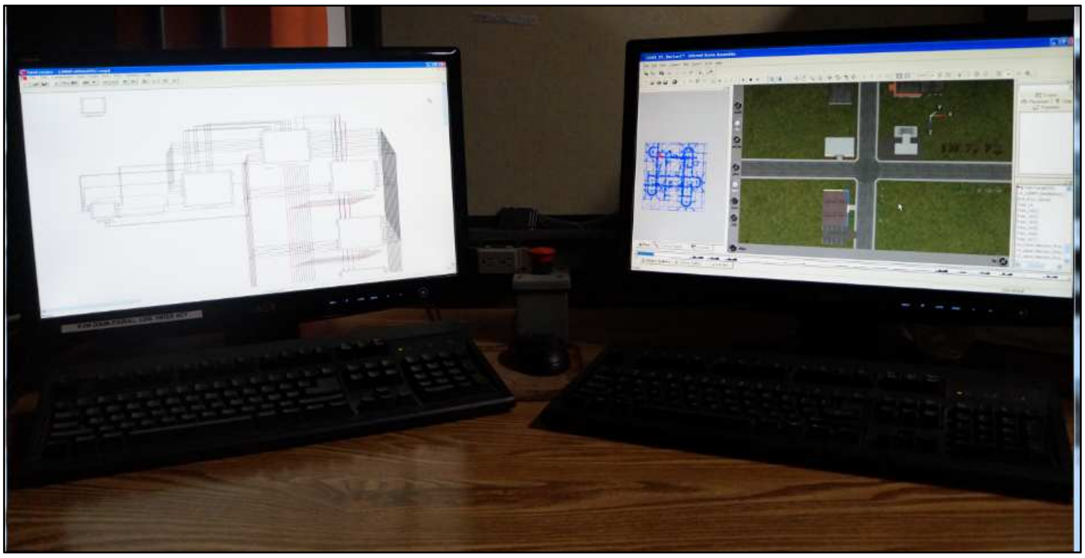


Figure 4-1: Operator Workstation for the Driving Simulator

Three liquid crystals on silicon projectors with a resolution of 1,400 by 1,050 are used to project a front view of 180 degrees by 40 degrees. These front screens measure 11 feet by 7.5 feet. A digital light-processing projector is used to display a rear image for the driver's center mirror. The two side mirrors have embedded LCD displays. The update rate for the projected graphics is 60 Hz. Ambient sounds around the vehicle and internal sounds to the vehicle are modeled with a surround sound system. The computer system consists of a quad core host running Realtime Technologies SimCreator Software with an update rate for the graphics of 60 Hz. The simulator software is capable of capturing and outputting highly accurate values for performance measures such as speed, position, brake, and acceleration. Figure 4-2 shows views of the simulated environment created for this experiment from inside (left) and outside (right) the vehicle.

Figure 4-2: Simulated Environment in OSU Driving Simulator

The virtual environment were developed using Simulator software packages, including Internet Scene Assembler (ISA), Simcreator and Google Sketchup. The simulated test track were developed in ISA using Java Script based sensors on the test tracks to change the signal indication and display dynamic objects, such as a bicyclist approaching the intersection in the adjacent bicycle lane, an oncoming vehicle turning left or a conflicting pedestrian crossing the intersection, based on the subject vehicle's presence. The following parameters on both subject vehicle and dynamic objects were recorded at roughly 10 Hz (10 times a second) throughout the duration of the experiment:

- Time – To map the change in speed and acceleration with the position on the roadway
- Instantaneous Speed of subject vehicle – To identify changes in speed approaching an intersection

- Instantaneous Position of subject vehicle – To estimate the headways and distance upstream from the stop line
- Instantaneous Acceleration/Deceleration – To identify any acceleration or deceleration approaching the intersection
- Instantaneous Speed of dynamic vehicle – To record the speed approaching an intersection
- Instantaneous Position of dynamic object– To locate the distance upstream from the stop line and also to calculate the headway between subject vehicle

4.4.2 Scenario Layout

The simulated environment was designed to put the motorist in situations where observations could be made to address specific research questions and hypotheses. As mentioned in subsection 4.2 Research Design, the four independent variables and variable levels resulted in 24 different independent variable combinations that needed to be presented to the motorist to address the research questions of interest. In these combinations, when there was no bicyclist present, the bicyclist speed variable was not considered. Therefore, 20 right-turning scenarios were presented to participants in the driving simulator experiment. To differentiate from the crash-likely scenario described below, this 20 right-turning scenarios were termed as “typical intersections” in this experiment. While the visual attention of the motorist was observed in all 20 scenarios, the second performance measure, motorist’s SA was measured immediately after six scenarios. Additionally, to measure the crash avoidance behavior of participants, they were exposed to a crash-likely scenario at the last intersection configuration. The worst possible combination of the four experimental factors, i.e. bicyclist approaching from the behind at 16 mph, three oncoming vehicles and one conflicting pedestrian were presented in this crash-likely scenario. Therefore, in total 21 scenarios were included in this experiment.

The design and sequencing of the 21 scenarios was influenced by a need to minimize the occurrence of simulator sickness and to provide opportunities to freeze the simulation six times to measure motorists' SA. Therefore, the experimental driving was divided into seven individual grids of intersections, and the crash-likely scenario was presented at the last intersection of the seventh grid. The number of right-turning scenarios included in each grid was varied so that the simulation could be stopped at various intervals, a recommended best practice for measuring SA (Endsley, 1995b). Each scenario was assigned a position on a grid based on the assignment of random number generation, except for the crash likely scenario which had to appear last. The order of presentation of Grids 1 to 6 was counterbalanced to minimize the practice effect on driver performance. This arrangement also introduced "random nature" to the experiment, which helped to reduce the "practice effect" limitation of the within-subject design, and made it more difficult for participants to predict when the simulation would stop, which was necessary for the SA measurement. Five grids consisted of three right-turning maneuvers, and the other two grids consisted of two or four right-turning maneuvers each. This distribution of 21 scenarios across seven grids provided participants with the opportunity to take small breaks between clusters of scenarios. Table 4-3 presents the layout of seven grids with 21 scenarios, where the crash-likely scenario is marked with asterisk (*) symbol.

Table 4-3: Grid and Right-turning Intersection Layout

RT #	Bicyclist Relative position	Oncoming Traffic	Bicyclist Speed (mph)	Crossing pedestrian
		Grid 1		
1	1 bicyclist ahead	No vehicles	16	1 pedestrian towards the subject
2	1 bicyclist ahead	3 vehicles	12	1 pedestrian towards the subject
3	1 bicyclist behind	No vehicles	16	No pedestrian
		Grid 2		
1	1 bicyclist behind	No vehicles	12	No pedestrian
2	1 bicyclist behind	No vehicles	16	1 pedestrian towards the subject
3	1 bicyclist ahead	3 vehicles	16	No pedestrian
		Grid 3		
1	1 bicyclist ahead	No vehicles	12	1 pedestrian towards the subject
2	No bicyclists	No vehicles	N/A	1 pedestrian towards the subject
3	1 bicyclist ahead	3 vehicles	16	1 pedestrian towards the subject
4	1 bicyclist behind	3 vehicles	16	No pedestrian
		Grid 4		
1	1 bicyclist ahead	No vehicles	12	No pedestrian
2	1 bicyclist behind	3 vehicles	16	1 pedestrian towards the subject
3	No bicyclists	No vehicles	N/A	No pedestrian
		Grid 5		
1	1 bicyclist behind	3 vehicles	12	No pedestrian
2	No bicyclists	3 vehicles	N/A	No pedestrian
		Grid 6		
1	1 bicyclist behind	No vehicles	12	1 pedestrian towards the subject
2	1 bicyclist behind	3 vehicles	12	1 pedestrian towards the subject
3	1 bicyclist ahead	No vehicles	16	No pedestrian
		Grid 7		
1	No bicyclists	3 vehicles	N/A	1 pedestrian towards the subject
2	1 bicyclist ahead	3 vehicles	12	No pedestrian
3*	1 bicyclist behind	3 vehicles	16	1 pedestrian towards the subject

* Crash-likely scenario

Grids 1, 2, 4, 6 and 7 are comprised of three right-turning intersections. To provide more variability in the grid presentation, the start and finish locations of these grids were not consistent. Also, the right-turning scenarios were interrupted by through movements at intersections that were not experimental scenarios to prevent participants anticipating the motivation for the study and to reduce simulator sickness. Figure 4-3 shows an example of grid layout of three right-turning scenarios- grid 1, 2 and 7. The “Path” in the figure indicates the sequence of intersections participants were asked to drive through. The layout of other grids with two, three, and four right-turning scenarios are included in Appendix B.

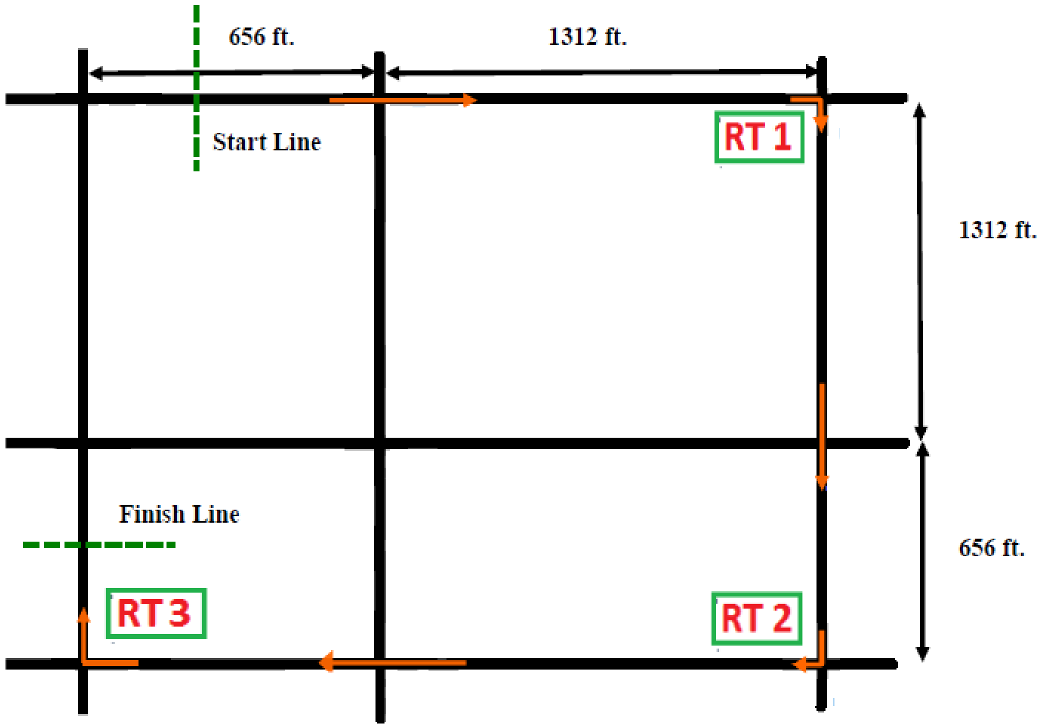


Figure 4-3: Example of Grid Layout of Grid 1, 2 and 7 with Three Right-Turning (RT) Scenarios – Path Start-Thru-Right-Thru-Right-Thru-Right-Finish

Participants were given the instruction to turn right at an intersection through an automated voice command saying “*Turn Right at the Next Intersection*”. This voice command was automatically generated using a Java Script based sensor placed at the right-turning intersection approach, which was triggered by the presence of the participant vehicle on the sensor.

The tangent sections between intersections measured approximately 1,968 (656+1312) feet. The cross section of the roadway included three 12-foot traffic lanes with 5.5-foot bicycle lanes each direction. The intersection approaches included a single shared lane and a single receiving lane, whereas the opposing direction had two lanes. No exclusive left-turn or right-turn bay was provided at the intersection. The intersection approaches had a posted speed limit of 35 mph. Figure 4-4 shows an example of an intersection approach in the simulated environment as it was presented to the participants. This particular scenario includes the presence of oncoming left-turning vehicles waiting in the queue, and a bicyclist riding ahead of the right-turning motorist at the latter portion of green phase.

Figure 4-4: Screen Capture of Intersection Approach in Simulated Environment

Counterbalancing

To control for the practice or carry over effect, the order of the intersection grids were counterbalanced, i.e. presented in random order. Counterbalancing can be complete or partial. Complete counterbalancing uses all possible treatment sequences an equal number of times, therefore the number of possible orders (and thus the number of participants required) is N! (Goodwin, 2009). This method is infeasible for this 20 factorial design, as it requires 20! (2.43 X 10^{18}) different treatment sequences. When complete counterbalancing is not feasible, partial counterbalancing is used, which uses some subset of the available order sequences. Various procedures are available for partial counterbalancing including Latin square, balanced Latin square, and randomized partial counterbalancing. Latin square counterbalancing ensures that each condition appears only once in a given ordinal position of the sequence and requires an equal number of participants assigned to each sequence. However, this methodology does not account for carryover effects. Balanced Latin square methodology controls for order effects and carryover effects, but similarly requires that equal number of participants be assigned to each sequence. Statistical calculations are also problematic for Latin square designs with missing or lost data (Durkee, 2010).

Randomized partial counterbalancing is used when the number of conditions (or trial orders) is far larger than the number of participants. It involves randomly selecting as many sequences of treatment conditions as there are participants for the experiment (Goodwin, 2009). This design allows for simple statistical calculations even in the presence of missing or lost data. It is also the most flexible design in terms of number of required participants (Goodwin, 2009). Any number of participants can be chosen. This method of randomization has been used many simulator studies (Fisher et al., 2011; Akinwuntan, 2005; Ashton, 1972). Randomized partial counterbalancing was chosen for this study due to the simplicity and flexibility it regarded in terms of statistical analysis and number of required participants.

In this randomized partial counterbalancing procedure, four different grid sequences were chosen depending on the two-, three- or four-intersection grid layout. The grid sequences were *6-3-4-2-5-1-7*, *2-3-1-6-5-4-7*, *1-2-3-5-4-6-7*, and *4-6-5-2-3-1-7*, which were randomly presented to the participants. Three of these grid sequences were randomly assigned 17 times and one sequence was randomly assigned 16 times to the 67 participants in this driving simulator study (Table 4-4).

Table 4-4: Random Assignment of Grid Sequence to Participants

Grid Sequence	Frequency of presentation
6-3-4-2-5-1-7	17
2-3-1-6-5-4-7	17
1-2-3-5-4-6-7	16
4-6-5-2-3-1-7	17

4.4.3 Pilot Study

Before conducting the full-scale experiment, a pilot study was conducted with five participants (two males and three females) in order to receive feedback on experimental procedures and the experimental scenarios. Valuable insight was provided on the effectiveness of the planned research design. Feedback from pilot study participants were used to modify the wording of the task command and SA questionnaire. Data analysis also helped to calibrate the worst case experimental factor combination to be used in the crash-likely scenario.

4.5 Experimental Protocol

The experimental procedure was carefully designed to reduce the occurrence of simulation sickness, for example, by providing long tangent sections between right-turns or providing small breaks between driving of successive grids while asking the SA questionnaire. The entire data collection process was designed to insure that all necessary information was recorded efficiently. This section describes the step-by-step procedures of the driving simulator study, as conducted, for each individual participant.

4.5.1 Step 1: Informed Consent and compensation

Upon the test participant's arrival to the laboratory, the informed consent document that was approved by the Institutional Review Board (IRB) of OSU was presented explained. It provided the participant with the opportunity to have an overall idea of the entire experiment and ask any questions regarding the test. The informed consent document included the reasoning behind the study and the importance of participant's participation. In addition, the document explained the risks and benefits to the participant associated with the test. Participants were given $20 compensation in cash for participating in an experimental trial after signing the informed consent document. Participants were also clearly informed that they could stop the experiment at any time for any reason and still receive full compensation. Participants were not told of the specific research objective or the associated hypotheses.

4.5.2 Step 2: Prescreening Survey

The second step of the simulator test was a prescreening survey targeting participants' demographics, such as age, gender, driving experience, and highest level of education, as well as their prior experience with driving simulators and motion sickness. In addition to the demographic information, the survey included questions in the following areas:

- Vision – Participant's vision was crucial for the test. Participants' were asked if they use corrective glasses or contact lenses while driving. It was insured during the test drive that the participants were able to clearly see the driving environment and read the visual instruction displayed on the screen to stop the driving.
- Simulation sickness – Participants with previous driving simulation experience were asked about any simulation sickness they experienced. If they had previously experience simulator sickness, they were encouraged not to participate.
- Motion sickness – Participants were surveyed about any kind of motion sickness they had experienced in the past. If an individual had a strong tendency towards any kind of motion sickness, they were encouraged not to participate in the experiment.

4.5.3 Step 3: Calibration Drive

A test drive followed the completion of the prescreening survey. At this stage, motorists were required to perform a 3 to 5 minute calibration drive to acclimate to the operational characteristics of the driving simulator, and to confirm if they were prone to simulator sickness. Once seated in the vehicle for the test drive, participants were allowed to adjust the seat, rear-view mirror and steering wheel to maximize comfort and performance while driving in the experiment. Participants were also instructed to drive and follow all traffic laws that they normally would. The test drive was conducted on a generic city environment track with turning maneuvers similar to this experiment, so that participants could become accustomed to both the vehicle's mechanics and the virtual reality of the simulator.

Simulation sickness is a phenomenon where a person exhibits symptoms similar to motion sickness caused by a simulator (Fisher, 2011; Owen, 1999). The symptoms are often described as very similar to that of motion sickness, and can include headache, nausea, dizziness, sweating, and in extreme situations, vomiting. While there is no definitive explanation for simulation sickness, one widely accepted theory, cue conflict theory, suggests that it arises from the mismatch of visual motion cues and physical motion cues, as perceived by the vestibular system (Owen, 1999). In the case that a participant reported simulation sickness during or after the calibration drive, they were excluded from the experimental drives.

4.5.4 Step 4: Eye-tracking Calibration

After the participants met the inclusion criteria and acclimated to the operational characteristics of the driving simulator during the calibration drive, then the researchers instrumented them with a head mounted eye tracker. Participants were directed to look at different locations on a calibration image projected on the forward screen of the driving simulator (Figure 4-5). If the eye-tracking equipment was unable to perform the calibration, which depended on eye position and other physical attributes, then the experiment was not continued.

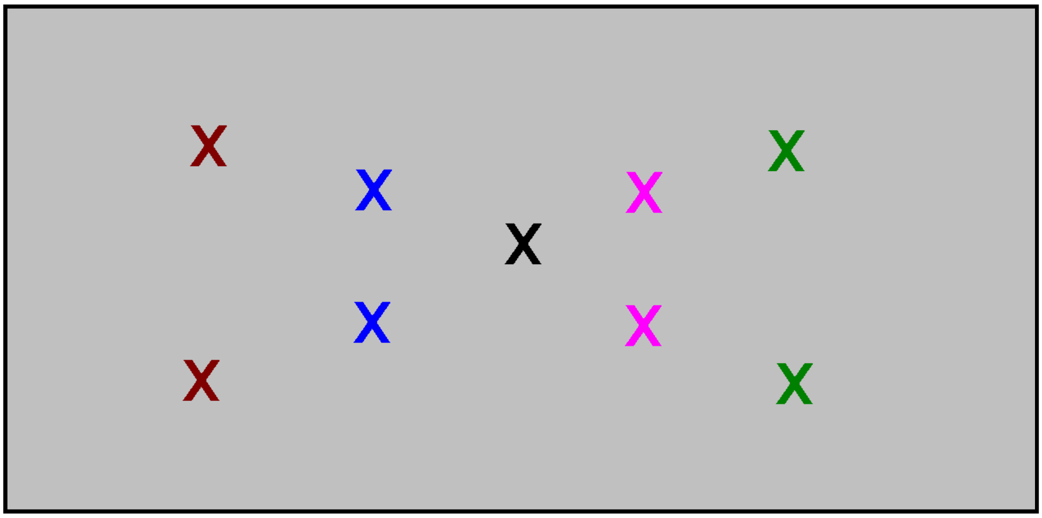


Figure 4-5: Eye-Tracking Calibration Image

4.5.5 Step 5: Experimental Drive

After the motorist's eyes were calibrated to the driving simulator screens, they were given a brief instruction about the test environment and the tasks they were required to perform. As stated in the previous section, the entire experiment was divided into seven grids. Participant were asked to fill out the SA questionnaire at the end of first six grids. The virtual driving course itself was designed to take the participant 20 to 30 minutes to complete. The entire experiment, including the consent process, eye tracker calibration and post-drive questionnaire, lasted approximately 50 minutes.

4.5.6 Step 6: Post-Drive Survey

As the final step of the experiment, drivers were asked to respond to several questions in a post-drive online-survey. After providing a consistent definition for a RH crash, the post-drive survey focuses on the following categories of questions:

- Familiarity with RH crash – Had motorists heard the phrase, “RH crash” before participating in this study and have they ever been involved in a RH crash while driving a car or riding a bicycle?
- Motorist behavior at intersections – Do they commonly look for bicyclists in an adjacent bicycle lane when turning right at an intersection and if so how do they scan for the bicyclist?

4.6 Diving Simulator Participant Demographics

This section describes the process by which participants in the experiment were recruited and their demographics.

4.6.1 Recruitment

A total of 67 individuals, primarily from the community surrounding Corvallis, OR, participated as test participants in the driving simulator study. The population of interest was licensed Oregon drivers; therefore, only licensed Oregon drivers with at least one year driving experience were recruited for the experiment.

In addition to Oregon licensure, participants were required to not have vision problems, and be physically and mentally capable of legally operating a vehicle. Participants also needed to be deemed competent to provide written, informed consent. Recruitment of participants was accomplished through the use of flyers posted around campus and emailed to different campus organizations and a wide range of listservs. Older participants were specifically recruited by emails using the Center for Healthy Aging

Research (CHAR) registry (LIFE Registry). This registry includes people aged 50 or over who reside in the State of Oregon and wish to volunteer for research studies.

Researchers did not screen interested participants based on gender until the quota for either males or females had been reached, at which point only the gender with the unmet quota was allowed to participate. Although it was expected that many participants would be OSU students, an effort was made to incorporate participants of all ages within the specified range of 18 to 75 years. Throughout the entire study, information related to the participants was kept under double-lock security in compliance with accepted IRB procedures. Each participant was randomly assigned a number to remove any uniquely identifiable information from the recorded data.

4.6.2 Demographics

Sixty seven participants (35 male and 32 female) participated in the simulator study. Approximately 24 percent (11 female and 5 male) of participants reported simulation sickness at various stages of the experiment (Table 4-5). All responses recorded from the participants who exhibited simulator sickness, were excluded from the original data set. Thus, the final data set comprised of 51 participants; 30 male (45 % of total) and 21 female (31 % of total) (Table 4-5). Table 4-6 demonstrates the participants' demographics of this simulator experiment.

Table 4-5: Summary of Participant Population

Categories	Total	Male	Female
Total	67 (100%)	35 (52%)	32 (48%)
Sim Sick (%)	16 (24%)	5(7%)	11(16%)
Participated (%)	51 (76%)	30 (45%)	21(31%)

Table 4-6: Participant Demographics

Category	Possible Responses	Number of Participants	Percentage of Participants
What is your highest completed level of education?	High School Diploma	2	4 %
	Some College	17	33 %
	Associates Degree	6	12 %
	4-year Degree	13	25 %
	Master's Degree	11	22 %
	PhD Degree	2	4 %
	Other	0	0 %
How many years have you been licensed?	1 - 5 years	19	37%
	6 - 10 years	14	27 %
	11 - 15 years	4	8 %
	16 - 20 years	2	4%
	More than 20 years	12	24 %
What corrective lenses do you wear while driving?	Glasses	0	0 %
	Contacts	13	25 %
	None	38	75%
Do you experience motion sickness?	Yes	6	12 %
	No	45	88 %
Gender	Male	30	59 %
	Female	21	41 %
Age	**Minimum**	**Average**	**Maximum**
	19	30.24	69

4.7 Results of the Post-Drive Survey

This section includes the results from post drive survey in the driving simulator. The responses from the driving simulator experiment participants were statistically compared with the responses collected in the online survey in the previous Chapter 3. The statistical analysis was conducted in the R software.

4.7.1 Responses on Motorist Behavior

Driving simulator participants were asked if they commonly check for the presence of bicyclists in adjacent bicycle lanes and if so, where do they usually look to detect the bicyclist. It was found that, 44 of 51 driving simulator participants (86%) commonly check for bicyclist before turning right. Comparing that with the driving simulator participants, it was found that 88% of the online survey participants also self-reported that they check for bicyclists in the adjacent bicycle lane before turning right (Table 4-7). No statistical significant was found between the distributions of responses of the two participant groups.

Table 4-7: Comparison of the Frequency of Motorists Check for Bicyclists between Simulator Post-Drive Survey and Online Survey

Commonly look for bicyclists	Simulator Study (n=51)	Online Survey (n=234)
Yes	86%	88%
No	14%	12%

Table 4-8 shows responses of both driving simulator participants and the online-survey participants about where they commonly check for the bicyclist before turning right at an intersection. It was found that side view mirror is the most commonly checked location for the adjacent bicyclist in both response groups. Chi-square test of homogeneity (p-value = 0.001) indicated statistically significant difference in the distribution of the responses between the two groups.

Table 4-8: Comparison between the Simulator Post-Drive Survey and Online Survey Responses for Bicyclist Checking Location

Checking Locations	Simulator Study (n=51)	Online Survey (n=234)
Rear view mirror	61%	59%
Side view mirror	61%	81%
Passenger side window	51%	73%
Rear window	14%	52%

4.7.2 Responses on RH crash information

After presenting the definition of a RH crash, driving simulator participants were asked if they were familiar with the “RH crash” phrase and if they had ever been involved in a crash of this type. As Table 4-9 indicates, only 14% of the driving simulator participants were familiar with the phrase, RH crash, whereas 35 % of the online survey participants were familiar with the phrase. A Chi-square test of homogeneity (p-value = 0.01) showed a statistically significant difference in the distribution of responses between these two groups of participants at 0.05 significant level. However, only 8% of the driving simulator participants were involved with a RH crash and 9% of the online survey participants were involved with a RH crash in real-world driving. No statistical significant difference was found in this case (p-value >0.05).

Table 4-9: Comparison of Simulator Post-Drive Survey and Online Survey Responses on RH crash

Responses	Simulator Study (n=51)	Online Survey (n=234)
Familiar with RH phrase	7(14%)	83 (35%)
Involved with the RH crash	4(8%)	20(9%)

The hypotheses, data analysis, and results related to each of three performance measure collected in this experiment, i.e. visual attention, SA, and crash avoidance behavior have been documented in the following chapters of “Chapter 5: Analysis & Result-Visual Attention”, “Chapter 6: Analysis & Result-SA”, and “Chapter 7:Analysis & Result-Crash Avoidance”, respectively.

Chapter 5 Analysis & Result - Visual Attention

A significant number of traffic crashes have been found to be caused by deficiencies in visual attention (McKnight, 2003; Chapman, 1998; Sabey et al., 1980) of parties involved. As mentioned in Chapter 2, with improvements in eye-tracking technology over the last five years, eye behaviors are contributing significantly to identifying the cause of crashes due to distraction and inattention (Fisher et al., 2011). Eye movement data collected with eye tracker technology provides direct empirical evidence of whether potential hazards were being anticipated in most cases (Fisher et al., 2011). Many researchers have studied motorists' visual attention to determine how likely a motorist is to crash (Scholl et al., 2003), and how differences in eye behavior appear to be related to crash rates (Mourant et al., 1972; Underwood et al., 2003; Pollatsek et al., 2006). Therefore, to identify the causal factors of RH crashes, this chapter investigates the visual attention of right-turning motorists to determine if they scan correctly for the potential threat of a RH crash, i.e. the bicyclist before turning right at a signalized intersection. This chapter will also examine how motorist's visual attention for bicyclists changes with changes in the surrounding traffic, potentially contributing to a RH crash.

5.1 Experimental Procedure

Participants were asked to perform right-turning maneuvers at signalized intersections during the latter portion of the green phase. Participant's eye tracking data were collected with an eye tracker with head mounted optics while driving in 20 typical right-turning intersections in the simulated environment. For a detailed description of the experimental design refer to section 4.4 of the Chapter 4.

5.1.1 Eye Glance Data

Eye-tracking data were collected with the Mobile Eye-XG platform from Applied Science Laboratories (ASL) as displayed in Figure 5-1. This platform allows the user to have both unconstrained eye and head movement. A sampling rate of 30 Hz was used, with an accuracy of 0.5-1.0 degrees (OSU Driving Simulator, 2011). The participant's gaze was calculated based on the correlation between the participant's pupil position and the reflection of three infrared lights on the eyeball. Eye movement consists of fixations and saccades. Fixations occurs when the gaze is directed towards a particular location and remains still for some period of time (Green, 2007; Fisher et al., 2011). Saccades occur when the eye moves to another point. The Mobile Eye-XG system records a fixation when the participant's eyes pause in a certain position for more than 100 milliseconds. Quick movements to another position (saccades) are not recorded directly but are calculated based on the dwell time between fixations. For this research, the saccades were not analyzed due to the research questions being considered.

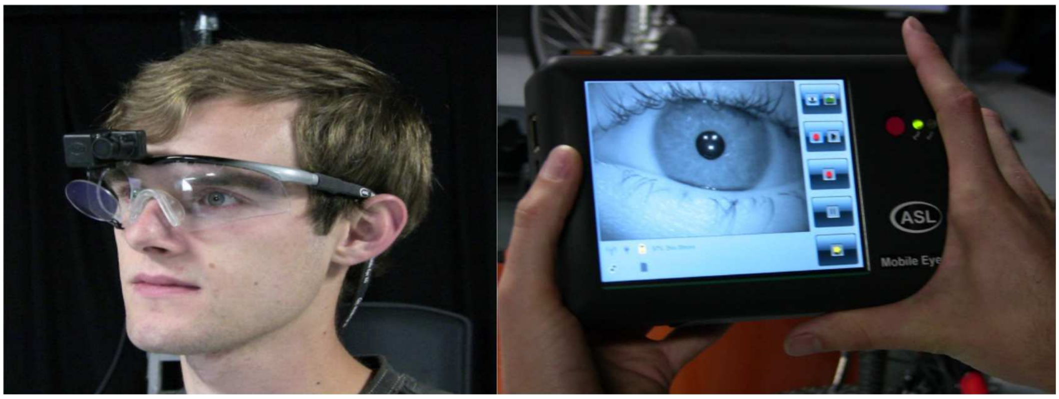


Figure 5-1: OSU Researcher Demonstrating the Mobile Eye XG Glasses (Left) and Mobile Recording Unit (Right)

5.2 Research Objective and Hypotheses

The objective and hypotheses of this experiment have been detailed in this section. As mentioned in "4.3 Research Questions" section of Chapter 4, the research hypotheses were formulated to address the research questions on right-turning motorist's visual attention through statistical analysis of eye movement data.

5.2.1 Research Objective

The primary objective of this experiment is to determine the effect of various experimental factors on the likelihood of motorists scanning for the presence of bicyclists before turning right at a signalized intersection during the latter portion of the green phase.

5.2.2 Research Hypotheses

One of the common features of BMV crashes at intersections includes motorists' learned routine of failing to account for an adjacent bicyclist before turning (Räsänen et al., 1998). We hypothesized that right-turning motorist's visual search will be influenced by the relative position of bicyclists. We inferred that motorist would fail to detect the bicyclist when approaching from behind in the motorist's blind spot as compared to when the bicyclist is riding in front of the motorist in his focal vision. Two hypotheses were formulated to address this:

$H_{0\ (VSP1)}$: Relative positions of adjacent bicyclists' have no effect on the right-turning motorists' mean total fixation duration on areas of interest in the driving environment.

$H_{0\ (VSP2)}$: There is no difference in the proportion of motorists who fixate on an adjacent bicyclist during the right-turn maneuver at signalized intersections as the relative position of the bicyclist changes.

It has also been suggested that before turning right, motorists tend to focus their attention on the cars coming from the left, and fail to notice bicycles coming from their right early enough to respond safely (Summala et al., 1996). Therefore, we hypothesized that motorist's visual attention will be influenced when an oncoming car turns left in front of the motorist. Also, a study on bike boxes in Portland, OR suggested that the speed of bicyclists overtaking the right-turning vehicle was a contributing factor to the occurrence RH crash (Dill et al., 2010). We inferred that bicyclist's speed would have an effect on the visual attention of motorists while turning right during the latter portion of the green phase. Again the Institute of Transportation Engineers (ITE) *Transportation Planning Handbook* states that one of the most common pedestrian crashes is the vehicle turn/merge conflict type (Meyer, 2009). This conflict type occurs when a pedestrian and vehicle collide while the vehicle is conducting, preparing, or has just completed a turning movement (Hurwitz et al., 2013). Considering this finding, we also hypothesized that the presence of a pedestrian in the conflicting crosswalk might influence the visual attention of a right-turning motorist.

$H_{0\ (VSP3)}$: *The speed of adjacent bicyclists have no effect on right-turning motorists' mean total fixation duration on areas of interest in the driving environment*.

$H_{0\ (VSP4)}$: *The presence of oncoming left-turning vehicular traffic has no effect on the right-turning motorists' mean total fixation duration on areas of interest in the driving environment*.

$H_{0\ (VSP5)}$: *The presence of pedestrian in the conflicting crosswalk have no effect on the right-turning motorists' mean total fixation duration on areas of interest in the driving environment*.

5.3 Variables of Interest

This section illustrates the independent and dependent variables included in this experiment.

5.3.1 Independent Variables

The relative position and speed of bicyclist, presence of oncoming left-turning vehicular traffic, and conflicting pedestrian in the crosswalk may influence motorists' visual attention while turning right. Therefore, all these factors were included as independent variables. It should be noted that although other factors, for example motorists' experience level, age or conspicuity of bicyclist may also influence motorist visual search task at an intersection, those factors are outside the scope of this study.

The first independent variable “relative position of bicyclist” had three levels – 1) no bicyclists, 2) bicyclist approaching from behind the motorist, and 3) bicyclist riding ahead of the motorist. The second independent variable, bicyclist’s speed had two levels – 1) lower (12 mph), and 2) high (16 mph). The third independent variable was the “presence of oncoming left-turning vehicular traffic”, which had two levels – 1) no oncoming (zero) vehicles and 2) three oncoming vehicles. The last independent variable was the “presence of a conflicting pedestrian in the crosswalk, which also had two levels – 1) no (zero) pedestrian and 2) one conflicting pedestrian walking towards the participant. These options resulted in 20 individual right-turning scenarios for the experiment, as described in the Chapter 4.

5.3.2 Dependent Variables

The primary dependent variable of this experiment was the visual attention of motorists during the right-turn maneuver at signalized intersections. Average total fixation duration (ATFD) was documented for each Area of Interest (AOI) as it provided a quantitative measure of how motorist visual attention was distributed across targets (Fisher et al., 2011).

5.4 Data Analysis and Result

Fifty-one participants successfully completed this driving simulator experiment. However, due to the eye-tracker calibration issues, completely usable data was collected for 41 participants representing a total of 820 (41*20) right-turn maneuvers.

5.4.1 Data Reduction

After collecting participant's eye movement data with the eye-tracker, fixation data were analyzed by AOI polygons with the ASL Results Plus software suite. For this process, researchers watched each collected approach video (20 per participant) and drew AOI polygons on individual video frames in a sequence separated by intervals of approximately five to 10 frames. Once the researcher manually situated each AOI, an "Anchor" was created within the software. The distance and size differences of the AOIs between these Anchors was interpolated by the Results Plus software, to ensure that all fixations on the AOIa (i.e., pedestrians, bicyclists, mirrors and oncoming vehicles) were captured.

Figure 5-2 is a screen shot of the ASL Results Plus software. This is an example of a video that has been coded with AOIs. At this particular moment in time, the motorist was fixating on a bicyclist who he was initially detected in the rear-view mirror before turning right (right edge of the figure identified by a yellow rectangular AOI and red cross hairs).This figure also includes heat maps (orange-yellow circular patterns) for the conflicting pedestrian AOI crossing the intersection and the side traffic signal AOI with green indication in motorist's field of view.

Figure 5-2: Participant Fixating on the Bicyclist before Turning Right

Another example of a participant fixating on a conflicting pedestrian AOI (center of the figure identified by a pink rectangular AOI and red cross hairs) at the crosswalk is shown in Figure 5-3. This figure exemplifies a complex driving scenario where the motorist had to scan for the oncoming vehicular traffic, a crossing pedestrian in the conflicting cross walk, and the bicyclist riding in front of him before turning right at the intersection. Figure 5-4 demonstrates different AOIs, such as rear-view (RV) mirror, traffic signal, that motorists fixated before turning right at an intersection.

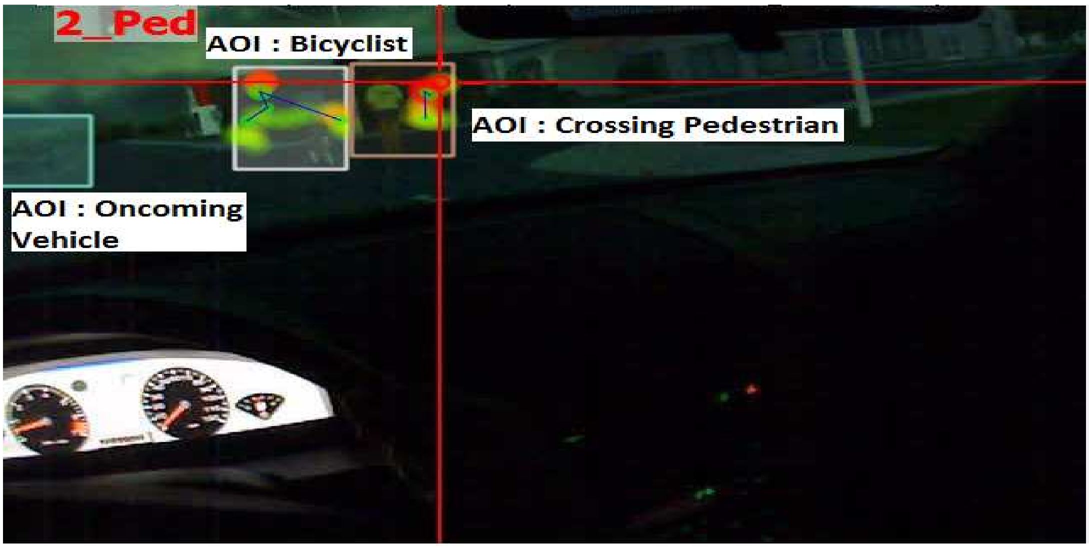


Figure 5-3: Participant Fixation Pattern in Presence of Bicyclist, Pedestrian and Oncoming Vehicle before Initiating a Right-Turn

Figure 5-4: Examples of AOIs Participants Fixated on Before Turning Right

Researchers analyzed motorist's eye-tracking data starting from the point when the participant approached the intersection and continued until the participant completed the right-turn maneuver. Therefore, all of the objects of concern related to the current research questions appear before the right-turning maneuvers were completed.

Once the AOIs were coded for each individual video file, output spreadsheets of all the fixations and their corresponding AOIs were produced using the ASL Results Plus software. Fixations outside of coded AOIs were universally defined as OUTSIDE and were not analyzed further. Researchers exported these .txt spreadsheets and imported them into different analysis packages (e.g., Excel and SPSS) for further analysis. Table 5-1 presents an example of a portion of one participant's summary data set exported from the Results Plus software at a single approach with oncoming vehicles, a pedestrian crossing in the conflicting crosswalk, and a bicyclist approaching from the behind the motorist. This table summarizes the fixations during a single 25-second approach video and includes the number of fixations, total fixation durations, average fixation durations, and time of the first fixation within each AOI created during an intersection approach and right-turn maneuver. Saccades were not analyzed. A 25-second approach video was analyzed for every participant at every intersection. Figure 5-5 shows examples of different AOIs that motorists fixated on during the experiment.

Table 5-1: Example AOI Summary Table

AOI Name	Description	Fixation Count	Total Fixation Duration (s)	Average Fixation Duration (s)	First Fixation Time (s)
Bike_Bk	Bicyclist approaching from the behind	2	0.43	0.215	106.8
Ped	Conflicting pedestrian at the crosswalk	12	5.47	0.456	88.09
Car	Oncoming vehicle turning left at intersection	6	2.51	0.837	94.7
Signal_main	Overhead traffic signal	1	0.16	0.16	107.86
Signal_side	Right-side traffic signal	0	0	0	0
RV_Mirror	Rear-view mirror	4	0.58	0.145	81.74
Side_Mirror	Right-side mirror	8	1.84	0.23	79.97
Outside	Any other area	282	88.19	0.313	2.156

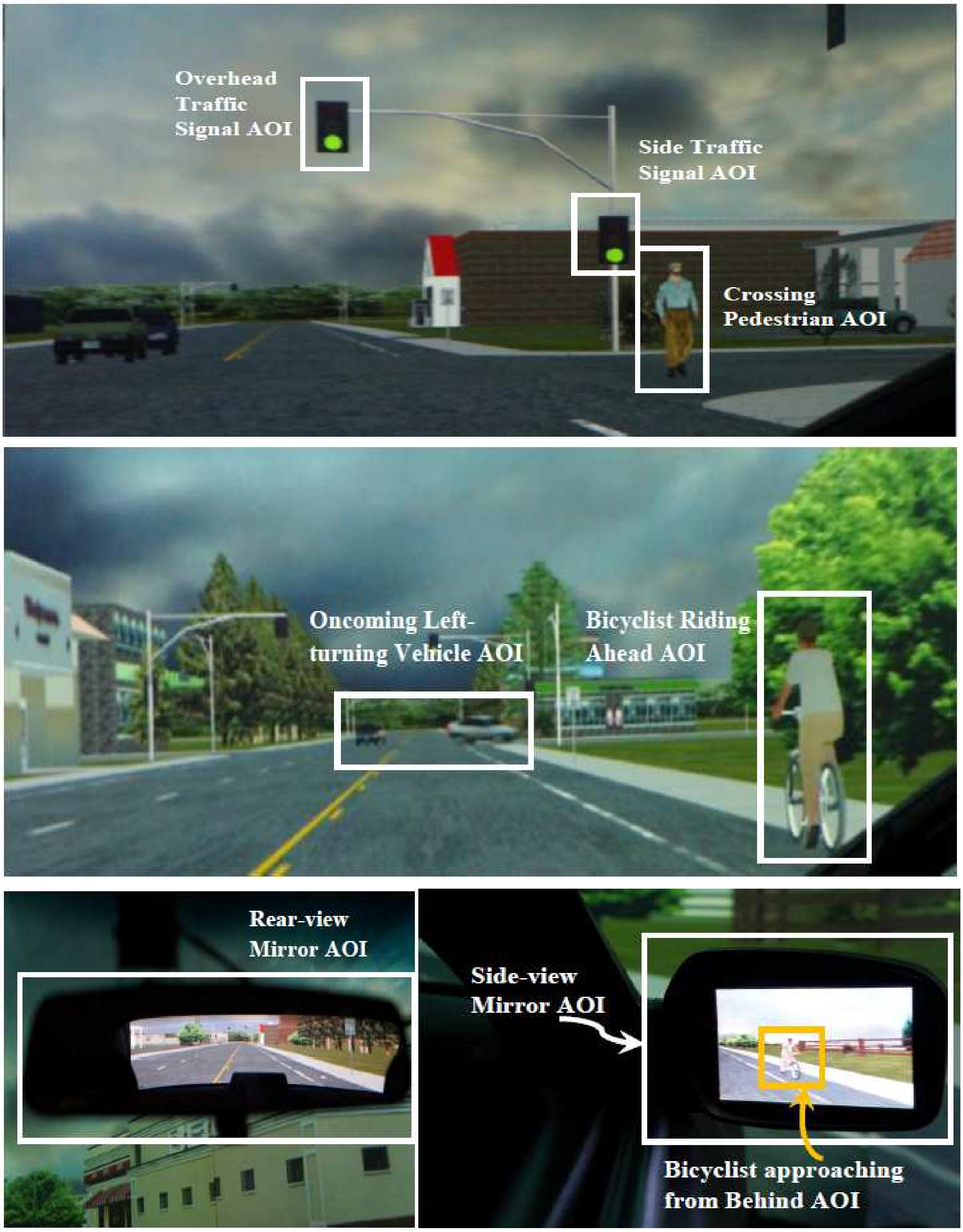


Figure 5-5: Examples of Different AOIs Motorists Fixated On During the Experiment

5.4.2 Preliminary Data Analysis

Various descriptive statistics and statistical tests were conducted using the ATFDs from all participants for each defined AOI. Table 5-2 summarizes the ATFDs of each AOI collected at the 20 right-turn experimental scenarios.

Table 5-2: Summary of AOI Fixations by Intersection

Scenario	Intersection Information				ATFD (s)							
	Bicyclist Relative Position	**Oncoming Vehicle**	**Bicyclist Speed (MPH)**	**Crossing pedestrian**	**Ped**	**Bicyclist Ahead**	**Bicyclist Behind**	**Signal Overhead**	**Signal Side**	**RV Mirror**	**Side Mirror**	**Oncoming veh**
Grid 1_1	Bicyclist ahead	No veh	16	1 ped	4.54	1.51	N/A	0.09	0.21	0.31	0.42	N/A
Grid 1_2	Bicyclist ahead	3 veh	12	1 ped	3.24	1.20	N/A	0.19	0.21	0.61	0.55	1.29
Grid 1_3	Bicyclist behind	No veh	16	No ped	N/A	N/A	0.06	0.09	0.12	0.32	0.58	N/A
Grid 2_1	Bicyclist behind	No veh	12	No ped	N/A	N/A	0.19	0.12	0.13	0.38	0.52	N/A
Grid 2_2	Bicyclist behind	No veh	16	1 ped	4.24	N/A	0.34	0.12	0.27	0.70	0.50	N/A
Grid 2_3	Bicyclist ahead	3 veh	16	No ped	N/A	1.34	N/A	0.25	0.12	0.28	0.29	1.97
Grid 3_1	Bicyclist ahead	No veh	12	1 ped	3.34	1.80	N/A	0.12	0.16	0.57	0.40	N/A
Grid 3_2	No bicyclist	No veh	N/A	1 ped	4.61	N/A	N/A	0.11	0.28	0.57	0.32	N/A
Grid 3_3	Bicyclist ahead	3 veh	16	1 ped	1.99	1.06	N/A	0.10	0.10	0.27	0.26	1.33
Grid 3_4	Bicyclist behind	3 veh	16	No ped	N/A	N/A	0.08	0.19	0.04	0.34	0.30	1.98
Grid 4_1	Bicyclist ahead	No veh	12	No ped	N/A	1.37	N/A	0.08	0.12	0.56	0.37	N/A
Grid 4_2	Bicyclist behind	3 veh	16	1 ped	3.69	N/A	0.32	0.23	0.11	0.34	0.46	2.26
Grid 4_3	No bicyclist	No veh	N/A	No ped	N/A	N/A	N/A	0.43	0.09	0.42	0.23	N/A
Grid 5_1	Bicyclist behind	3 veh	12	No ped	N/A	N/A	0.16	0.21	0.10	0.31	0.57	1.79
Grid 5_2	No bicyclist	3 veh	N/A	No ped	N/A	N/A	N/A	0.08	0.07	0.25	0.19	1.52
Grid 6_1	Bicyclist behind	No veh	12	1 ped	4.58	N/A	0.57	0.21	0.10	0.40	0.39	N/A
Grid 6_2	Bicyclist behind	3 veh	12	1 ped	3.56	N/A	0.28	0.10	0.15	0.42	0.30	2.01
Grid 6_3	Bicyclist ahead	No veh	16	No ped	N/A	1.75	N/A	0.06	0.12	0.34	0.27	N/A
Grid 7_1	No bicyclist	3 veh	N/A	1 ped	3.08	N/A	N/A	0.12	0.11	0.48	0.43	1.44
Grid 7_2	Bicyclist ahead	3 veh	12	No ped	N/A	1.16	N/A	0.11	0.10	0.53	0.56	1.07

Figure 5-6 shows the ATFD values and 95% CIs for four AOIs at an intersection scenario where the motorist was presented with no pedestrians, no oncoming vehicles, and no bicyclists. This particular intersection is the most basic of all intersections shown to the participants. This scenario presented the simplest driving scenario to the motorist.

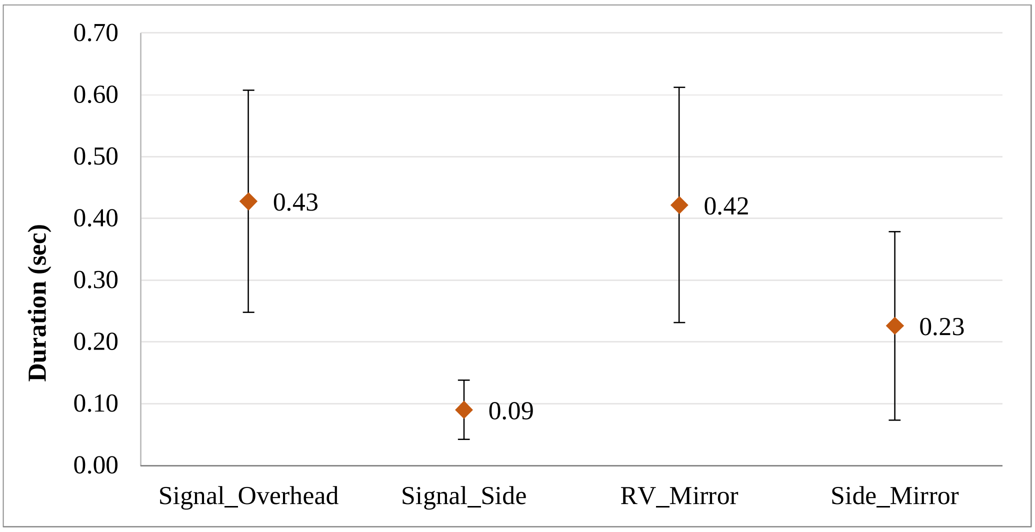


Figure 5-6: ATFDs with 95% CIs for Control Case (No Bicyclists, No Vehicles, No Pedestrians)

Figure 5-7 shows the ATFDs from all participants at an intersection where the bicyclist was approaching from behind the motorist at 16 mph, oncoming vehicles were present, and a pedestrian was present in the conflicting crosswalk. This case includes the greatest number of experimental variables, and is one of the most visually complex scenario.

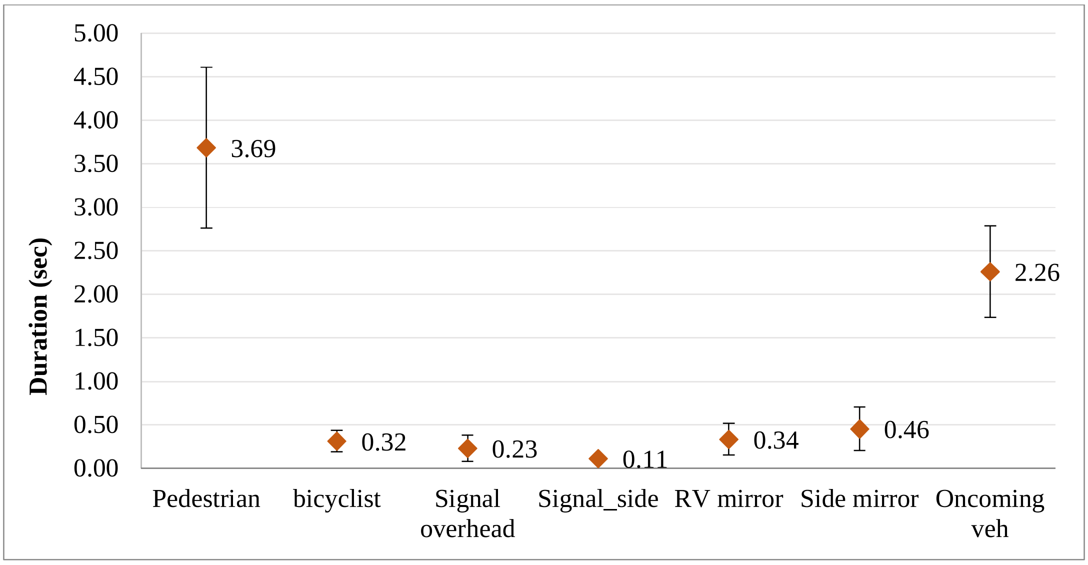


Figure 5-7: ATFD with 95% CIs for One of the Most Visually Complex Scenarios (Bicyclist Approaching From Behind at 16 mph, Three Vehicles, One Conflicting Pedestrian)

While Figure 5-7 represents one of the most visually complex scenarios, Figure 5-8 represents the ATFDs from all participants for the other most visually complex scenario where the bicyclist was riding ahead of the motorist at 16 mph. The other two variables were identical to those described in Figure 5-7. Appendix C contains figures showing the ATFDs and 95% CIs for all 20 experimental scenarios.

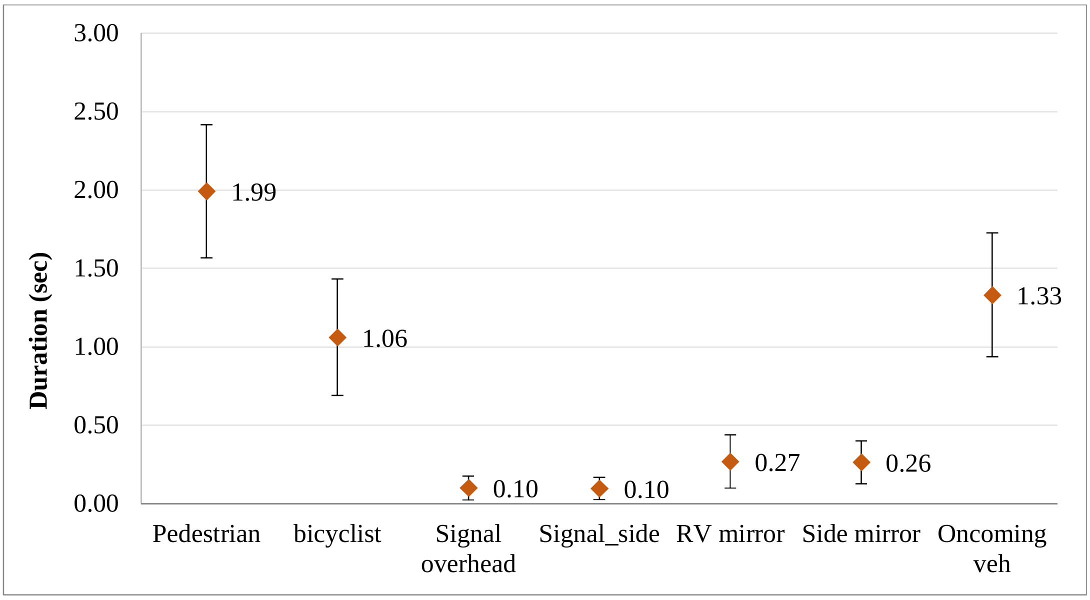


Figure 5-8: ATFD with 95% CIs for the Other Most Visually Complex Scenario (Bicyclist Riding in the Front at 16 mph, Three Vehicles, One Conflicting Pedestrian)

Figure 5-9 shows the ATFDs of five AOIs for two experimental scenarios in which all factors were kept constant (one pedestrian crossing the intersection and three oncoming vehicles) except for the relative position of bicyclists (Ahead vs Behind) riding at 16 MPH. As described in Chapter 4, Grid 3-3 represents the intersection where the bicyclist was riding in front of the motorist at 16 MPH, whereas Grid 4-2 represents the intersection where the bicyclist was approaching from behind the motorist at 16 MPH. The graphical comparison shows that the 95% CIs of the ATFDs for the bicyclist's position, crossing pedestrian, and the oncoming vehicle do not overlap with respect to different bicyclist position. This finding suggests that when a bicyclist is in the motorist's blind zone (behind), right-turning motorist spends less time (0.32 sec) scanning for the bicyclist as compared to when the bicyclist is riding at the motorist's forward field of view (1.06 sec). A two-sample Welch's *t*-test (determined by Levene's Homogeneity of

Variance test) resulted in a two-tailed p-value of less than 0.001 for this comparison. The graphical comparison also shows that when a bicyclist was riding in the motorist's forward field of view, the motorist spend less time fixating on the pedestrian (1.99 sec vs 3.69 sec) and oncoming vehicles (1.33 sec vs 2.26 sec) compared to when the bicyclist was riding behind. Two-sample Welch's *t*-tests (determined by Levene's Homogeneity of Variance test) resulted in two-tailed p-values of less than 0.001 and 0.007 for these comparisons, respectively.

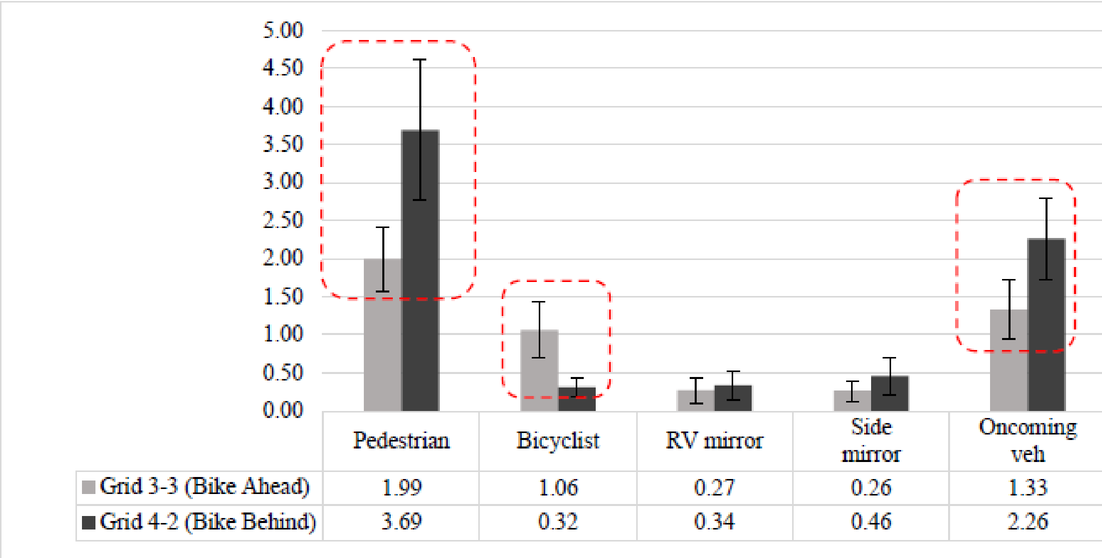


Figure 5-9: Bar Plots of ATFD (s) for Two Similar Intersections with Different Bicyclist Positions

5.4.3 Statistical Analysis

Fixation data for different AOIs were statistically analyzed to answer the research hypotheses using SPSS (IBM SPSS Statistics, V22.0).

5.4.3.1 Relative Position of Bicyclist

To answer the first research hypothesis ($H_{0\ (VSP1)}$) regarding the relative position of the bicyclist with respect to the motorist, the dataset was split by the three levels of bicyclist position - 1) bicyclist riding in the front, 2) bicyclist approaching from the behind, and 3) no bicyclist.

The first two levels were included in eight experimental scenarios each and the third level resulted in four experimental scenarios. The dataset was aggregated this way to isolate the impact of individual variable levels. Figure 5-10 shows the ATFDs with 95% CIs on AOI by bicyclist position.

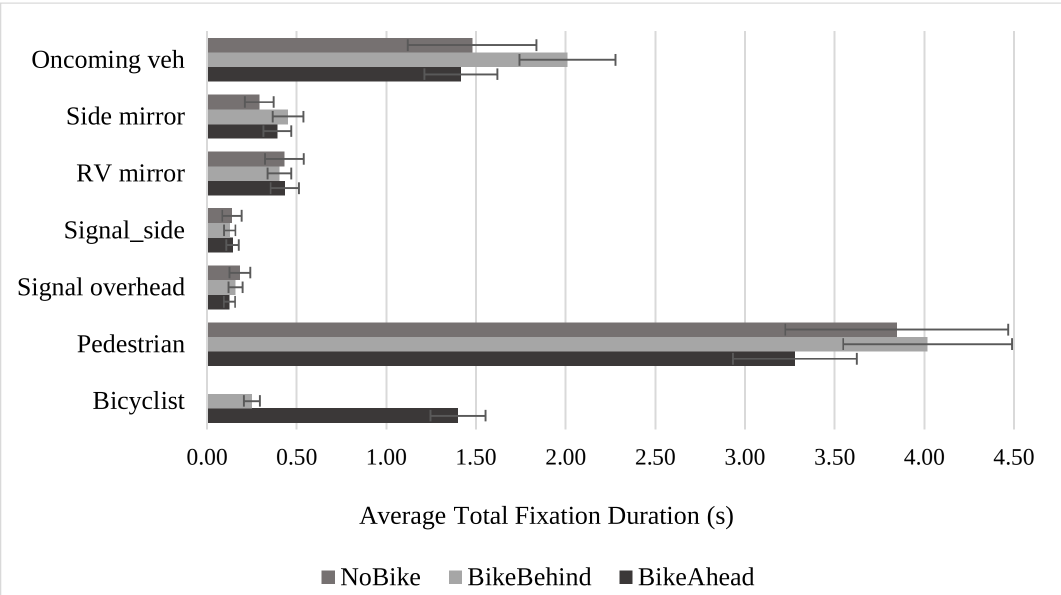


Figure 5-10: Bar Plot of ATFDs at All Intersections by Bicyclist Position

Analysis of variance (ANOVA) was used to statistically determine if there is any difference in the ATFDs with respect to bicyclist's position. However, when the variances were not equal (determined by Levene's test) indicating the violation of the assumption of homogeneity of variance, the Welch's Robust test or Omnibus F were used to interpret the *F*-statistic. Finally, pairwise comparisons were calculated with Tukey's Honest Significant Difference (HSD) test. Table 5-3 presents the results of these tests, with statistically significant p-values shown in bold.

Table 5-3: ANOVA Analysis of Difference in ATFDs by Bicyclist Position

Area of Interest	**Relative position of bicyclist**			**ANOVA**	**Tukey's HSD for pairwise comparisons of means w.r.t bicyclist positions**								
	Ahead	**Behind**	**None**	**All**	**Ahead vs Behind**			**Ahead vs None**			**Behind vs None**		
	ATFD			p-value	p-value	Sig	Diff	p-value	Sig	Diff	p-value	Sig	Diff
Bicyclist	1.40	0.25	N/A	N/A	**<0.001** †	**Yes**	1.15	N/A			N/A		
Pedestrian	3.28	4.02	3.85	**0.03** *	**0.039**	**Yes**	-0.74	0.28	No	-0.57	0.89	No	0.17
Signal overhead	0.13	0.16	0.18	0.16 *	0.4	No	-0.03	0.17	No	-0.06	0.74	No	-0.02
Signal_side	0.14	0.13	0.14	0.83	0.82	No	0.014	0.99	No	0	0.95	No	-0.01
RV mirror	0.43	0.40	0.43	0.82	0.83	No	0.03	0.99	No	0	0.9	No	-0.03
Side mirror	0.39	0.45	0.29	**0.03***	0.53	No	-0.06	0.302	No	0.1	**0.049**	**Yes**	0.16
Oncoming veh	1.42	2.01	1.48	**0.002** *	**0.002**	**Yes**	-0.59	0.95	No	-0.06	0.53	No	-0.03

† No multiple comparisons required. P-value reflects a two-sided Welch's two sample *t*-test

* P-value reflects a Welch *F* test

The ANOVA analysis showed that fixations on the bicyclist, pedestrian, right-side mirror, and oncoming vehicles had statistically significant differences as measured by ATFDs. A two-sided Welch's two sample *t*-test indicated a statistically significant difference in the ATFDs on bicyclists with respect to bicyclists' position. It revealed that motorists spent more time fixating on the bicyclist when it was riding in the forward field of view as compared to when the bicyclist was approaching from behind the motorist. The ATFD for the pedestrian AOIs was different when bicyclist was riding in the front vs when bicyclist was approaching from the behind with statistical significance. This finding revealed that in the presence of a bicyclist in the forward field of view, motorists spent less time fixating on the pedestrian compared to when the bicyclist was approaching from the behind. Similar findings were observed in the case of the oncoming vehicle AOI. However, a statistically significant difference in the ATFDs on the right-side mirror and corresponding pairwise comparison showed that motorists spent more time fixation on the right-side mirror when a bicyclist was approaching from behind compared to when there was no bicyclist present at the intersection. No other significant differences were found with 95% confidence.

5.4.3.2 Motorists Not Fixating on Bicyclist

In addition to the assessment of the ATFDs on the bicyclist with respect to different bicyclist positions, another research interest ($H_{0\ (VSP2)}$) was to investigate the percentage of motorists who fixated on the bicyclist before turning right at an intersection. Individual motorist fixation behavior was examined for two different bicyclist positions (approaching the intersection in front of or behind the motorist) for this purpose. Since the target where the eyes are pointing is a good indication of what is being processed (Fisher et al., 2011), a fixation on a bicyclist will likely indicate if he was scanned or detected by the motorist during a right-turn maneuver. Therefore the determination of the detection of a bicyclist was limited to when a motorist fixated directly on the bicyclist. For example, a motorist who fixated on the RV or side mirror, but did not fixate on the bicyclist coming from behind and afterwards turned-right without yielding to the bicyclist - these cases indicated that motorist failed to detect the bicyclist and were coded as “not fixated” in the analysis.

As depicted in Table 5-4, there were 328 (41 participants*8 turns) right-turns scenarios for each bicyclist position. When the bicyclist was riding ahead of the motorist in his forward field of view, in 87% of the cases the motorists fixated on the bicyclist, i.e. actively scanned for the bicyclist before turning right. However, when a bicyclist was approaching from behind in the motorist's blind zone, in only 44% of the scenarios did a motorist fixate on the bicyclist before turning right. A Chi-square test revealed a statistically significant difference (p-value < 0.001) between the frequencies of motorist fixation on the bicyclist with different bicyclist positions.

Table 5-4: Frequency of Motorist Fixation on Bicyclists before Turning Right

Frequency of fixation	**Bicyclist position**	
	Ahead	*Behind*
Total (n)	328	328
Fixated	284	145
%	87%	44%

5.4.3.3 Speed of Adjacent Bicyclist

A comparison of all ATFDs with respect to the bicyclist's speed in the adjacent bike lane was also conducted. To address $H_{0\,(VSP3)}$, the dataset was divided by the two levels of bicyclist speed of 16 mph and 12 mph. These two groups consisted of eight experimental scenarios each. Figure 5-11 shows the ATFDs with 95% CIs on AOIs by bicyclists speed.

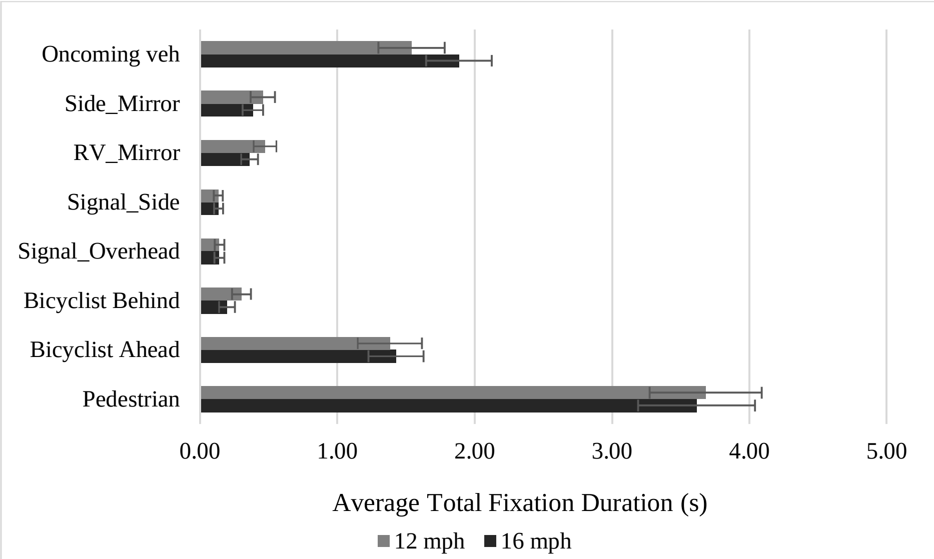


Figure 5-11: Bar Plot of ATFDs at All Intersections, According to Bicyclist's Speed

Table 5-5 presents the results of a two-sample, two-sided *t*-tests that was conducted to determine the difference in the ATFDs with respect to bicyclist's speed. As stated before, when the variances were not equal (determined by Levene's test) indicating the violation of the assumption of homogeneity of variance, the Welch's *t*-test were used instead of the Student's *t*-test summary table to interpret the *t*-statistic. A statistically significant difference was found in the ATFDs on the RV mirror AOI with changes in the bicyclist's speed. When bicyclist's speed was lower (12 mph), motorists spent more time scanning the RV mirror compared to higher (16 mph) speed scenarios. This was likely because the bicyclist required more time to travel the same distance before reaching the intersection at lower speed compared to higher speed, while the motorist yielded for him to pass. Since the motorist had to wait longer for the bicyclist to pass when at the lower speed, the time spent fixating on the RV mirror searching for bicyclist at lower speed was greater than when bicyclist was at higher speed.

Table 5-5: Two-sample *t*-test of ATFDs by Bicyclist Speed

Areas of Interest	**Speed of Bicyclist**		**Two sample two tail *t*-test**	
	16 mph	12 mph	*16 mph vs 12 mph*	
	ATFD (sec)		p-value	Significant
Pedestrian	3.61	3.68	0.83	No
Bicyclist Ahead	1.43	1.38	0.78	No
Bicyclist Behind	0.20	0.30	0.98	No
Signal_Overhead	0.14	0.14	1.00	No
Signal_Side	0.14	0.13	0.91	No
RV_Mirror	0.36	0.47	**0.03 †**	**Yes**
Side_Mirror	0.39	0.46	0.23 †	No
Oncoming veh	1.89	1.54	0.06	No/Suggestive

† P-value reflects a two-sided Welch's two sample *t*-test

5.4.3.4 Presence of Oncoming Vehicle

To address ($H_{0\ (VSP4)}$), which was related to the presence of oncoming vehicular traffic, the dataset was divided by the two levels of oncoming vehicles (No vehicles and 3 vehicles). These two groups consisted of 10 experimental scenarios each.

Figure 5-12 shows the ATFDs with 95% CIs on AOIs by the presence of oncoming vehicular traffic.

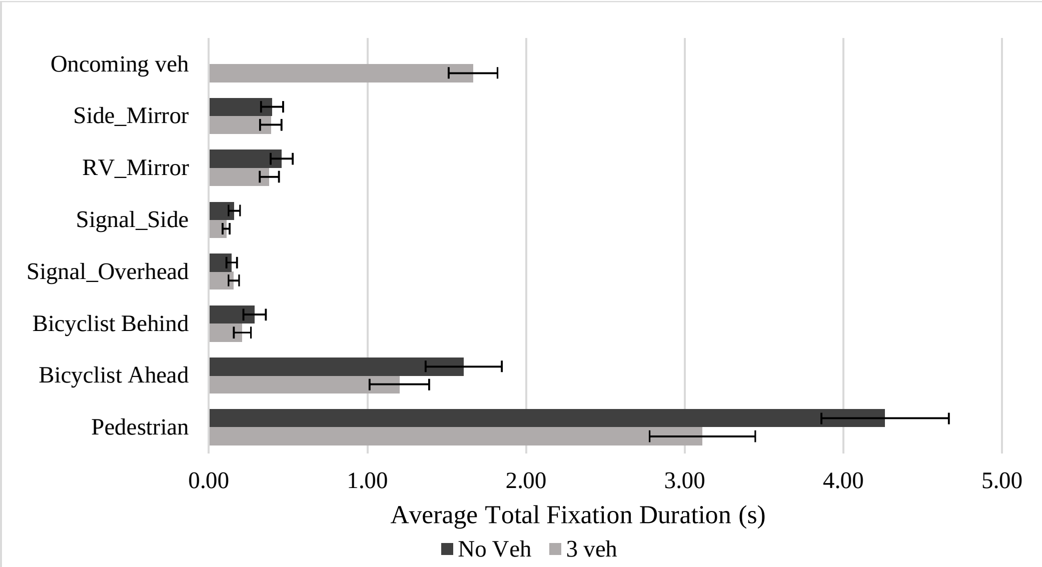


Figure 5-12: Bar Plot of ATFDs at All Intersections, According to the Presence of Oncoming Vehicle

Two-sample, two-sided Students or Welch's (when variances were not equal) *t*-tests were conducted to determine whether the ATFDs on specific AOIs varied with the presence of oncoming vehicle (Table 5-6). Statistically significant differences were identified in cases of Pedestrian, Bicyclist riding ahead of the motorist, and Side traffic signal AOIs with the presence of oncoming vehicles. Statistical difference indicated that motorist spent less time fixating on pedestrian, on bicyclist that was riding ahead of the motorist, and the side signal when there were oncoming vehicles as compared to when there was no oncoming vehicle present. The reason can be explained by motorist's limited capacity for visual attention. The presence of oncoming vehicles posed more of a threat to the motorist as compared to other objects in his field of view and as such the motorist spent more time fixating on the oncoming vehicles.

Table 5-6: Two-sample *t*-test of ATFDs Comparing AOIs by Oncoming Vehicles

Areas of Interest	**Oncoming Vehicle**		**Two sample two tail *t*-test**	
	3 Veh	No Veh	*3 Veh vs No Veh*	
	ATFD (sec)		p-value	Significant
Pedestrian	3.11	4.26	**<0.001 †**	**Yes**
Bicyclist Ahead	1.20	1.61	**0.01 †**	**Yes**
Bicyclist Behind	0.21	0.29	0.09 †	No
Signal_Overhead	0.16	0.14	0.57	No
Signal_Side	0.11	0.16	**0.02 †**	**Yes**
RV_Mirror	0.38	0.46	0.11 †	No
Side_Mirror	0.39	0.40	0.87	No
Oncoming veh	1.67	N/A	N/A	N/A

† P-value reflects a two-sided Welch's two sample *t*-test

5.4.3.5 Presence of Pedestrian

The influence of a pedestrian was considered to address $H_{0\ (VSP5)}$. For this analysis, the dataset was split by the two levels of conflicting pedestrian in the crosswalk no pedestrian or one pedestrian walking towards the motorist. These two groups consisted of ten experimental scenarios each. Figure 5-13 shows the ATFDs with 95% CIs on AOIs by the presence of conflicting pedestrian.

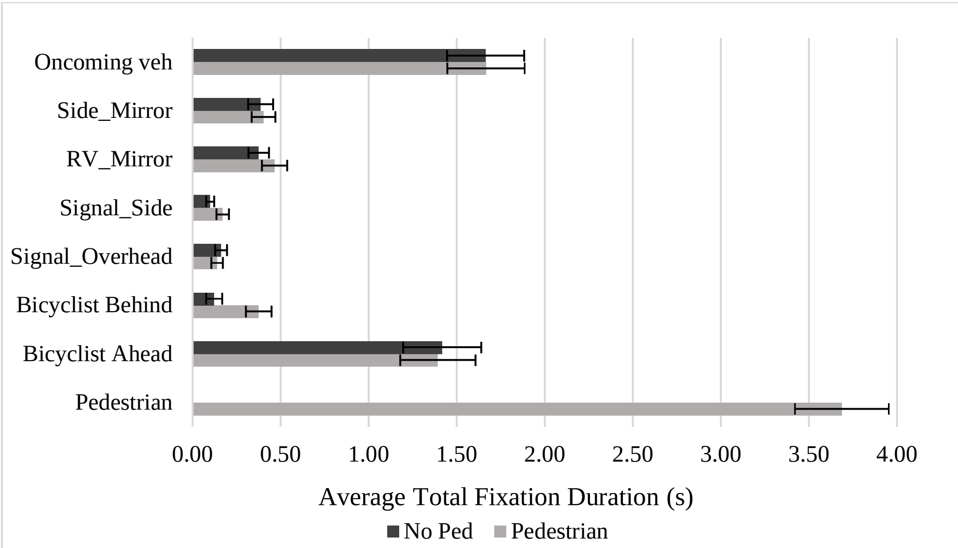


Figure 5-13: Bar Plot of ATFDs at all Intersections by the Presence of Pedestrians

From the result of two-sample, two-sided Students or Welch's *t*-tests (when variances were not equal) (Table 5-7), the only statistical significant different was found between the ATFD of the Bicyclist behind AOI with the presence of a pedestrian. Results indicated that motorist spent less time fixating on the bicyclist approaching from behind when a conflicting pedestrian was present in the crosswalk as compared to when no pedestrian present.

Table 5-7: Two-sample *t*-test of ATFDs comparing AOIs by Conflicting Pedestrian

Areas of Interest	**Pedestrian**		**Two sample two tail *t*-test**	
	Ped	No Ped	*Ped vs No Ped*	
	ATFD (sec)		p-value	Significant
Pedestrian	3.69	N/A	N/A	N/A
Bicyclist Ahead	1.39	1.42	0.88	No
Bicyclist Behind	0.38	0.12	**<0.001 †**	**Yes**
Signal_Overhead	0.14	0.16	0.35	No
Signal_Side	0.17	0.10	0.72	No
RV_Mirror	0.47	0.38	0.06 †	Suggestive
Side_Mirror	0.40	0.39	0.76	No
Oncoming veh	1.67	1.66	0.99	No

† P-value reflects a two-sided Welch's two sample *t*-test

5.5 Discussion

This study investigated motorists' visual attention to assess if motorists actively search for bicyclists before turning right at a signalized intersection- an important condition to avoid a RH crash. This chapter also examined the effect of various elements of adjacent traffic, such as pedestrian and oncoming vehicles, on the visual attention of motorist that may contribute to RH crashes.

When a bicyclist was approaching from behind the motorist, they were less likely to be observed by the motorist compared to when bicyclists were riding ahead of the motorist (p-value < 0.001). This finding is consistent with the finding of Falzetta (2004). In a simulator-based study, she assessed how the location and the type of events influence motorist attention allocation using an event detection task. The events occurred either ahead of the motorist in the same or the oncoming lane, or behind the motorist. She found that participants detected forward events more successfully than rear events, and the location effect was consistent with an attention allocation strategy that gave higher priority to the road ahead.

For a similar reason, a statistically significant difference (p-value < 0.001) was observed between the frequencies of motorist fixations on the bicyclist when the bicyclist was approaching from the behind vs when bicyclist was riding ahead. Eighty-seven percent of the time motorists fixated on a bicyclist that was riding ahead, whereas the motorist fixated on a bicyclist approaching from the behind only 44% of the time.

A statistically significant difference was also observed in the ATFDs on the conflicting pedestrian (p-value = 0.039) and oncoming vehicles (p-value = 0.002) with respect to bicyclist's position. This finding suggests that when a bicyclist was riding ahead in motorist's focal vision, motorists anticipated them as a potential threat. Therefore, motorist spent less time fixating on other traffic elements, such as pedestrian or oncoming left-turning traffic in the presence of bicyclist in the focal vision. However, in the absence of the bicyclist in the focal vision, i.e. when the bicyclist was approaching from behind, motorist spent more time fixating on other traffic elements immediately relevant to safe operation of the vehicle.

Another statistically significant finding (p-value = 0.049) was observed in the ATFDs on the right-side mirror when the bicyclist was approaching from the behind compared to when there was no bicyclist. This suggests that when motorists detected a bicyclist approaching from behind in the right-side mirror, he spent more time fixating on the right-side mirror while waiting for the bicyclist to pass at the intersection compared to when there was no bicyclist present.

Bicyclist's speed had a statistically significant effect only on the ATFDs on the RV mirror (p-value = 0.03). A bicyclist that was detected in the RV mirror would require more time to travel the same distance before reaching the intersection at lower speed compared to higher speed. Therefore, the total fixation duration spent on checking the RV mirror in search of bicyclist was higher when the bicyclist traveled at a lower speed.

Statistically significant differences in the ATFDs were found on crossing pedestrians (p-value < 0.001), side traffic signal (p-value = 0.022) and bicyclist riding ahead of the motorist (p-value = 0.01) between all intersections with the presence of oncoming left-turning traffic vs no oncoming traffic. Results suggest that in the absence of oncoming traffic, motorists spent more time fixating on other traffic elements in their focal vision, such as scanning for the pedestrian, checking for the traffic signal status, or fixating on the bicyclist ahead. However, in the presence of oncoming vehicular traffic, motorists spent the majority of their time fixating on the oncoming traffic and comparatively less time on the other traffic elements. These findings are similar to the findings in Hurwitz et al. (2013), Knodler et al. (2005), and Summala et al. (1996). Hurwitz et al (2013) studied the effects of the oncoming traffic, the presence and walking direction of pedestrians, and three of four section verdical displays for the Flashing Yellow Arrow (FYA) on driver performance, and found that the oncoming volume of vehicles released from the queue affects the focus of pedestrians on pedestrians. In another experiment to identify sources of information used by left-turning drivers at signalized intersections, Knodler et al (2005) found that in the absence of opposing vehicles, drivers were more likely to seek out additional cues. While analyzing bicycle-car collisions at non-signalized intersections in the Helsinki City area, Finland by assessing the visual scanning behavior of motorist, Summala et al (1996) found that motorist develop a visual scanning strategy which concentrates on detection of more frequent and major dangers, such as conflicting vehicles but ignores and may even mask visual information on less frequent dangers, such as bicyclists.

The presence of a pedestrian had statistically significant effect on the ATFDs of the Bicyclist Behind AOI (p-value <0.001). Results suggest that when a conflicting pedestrian was crossing the intersection in the motorist’s focal vision, that posed immediate threat to motorists and they spent more time to fixate on the pedestrian. Consequently, they failed to fixate on the bicyclist that was approaching from behind in the blind zone.

All these findings indicate that bicyclist approaching from behind the motorist in the blind spot is the most vulnerable to a right-turning motorist and failure to detect this bicyclist may potentially lead to a RH crash. The presence of oncoming left-turning traffic and pedestrian at the crosswalk are likely to increase the risk of RH crash.

Chapter 6 Analysis & Result - SA

SA has been shown to influence both decision making and task performance of the operator during the tasks of driving and flying. While the issue with SA is most pronounced in the aviation domain, other complex real-time tasks, such as driving also suffer the consequence of poor SA. An investigation of 2,258 motor vehicle crashes by Treat et al. (1980) revealed that improper lookout and inattention, which are two important aspects of SA, were found to be leading causes. Improper lookout or inadequate surveillance consisted both of "failed to look" and "looked but failed to see" (Treat, 1980). Gugerty (2011) found that improper lookout and inattention, were cited as causes of more crashes than factors related to decision making (e.g., excessive speed) and psychomotor ability (e.g., improper driving technique). Therefore, measuring the SA of motorists during a right-turning maneuver at an intersection can be useful in the sense that it can provide important insight towards the identification of causal factors of RH crashes involving human error. Therefore, this chapter will investigate the SA of motorists completing a right-turn maneuver at a signalized intersection during the latter portion of the green phase.

6.1 Experimental Procedure

This section describes the procedures and tasks followed in the driving simulator experiment to assess motorist's SA while performing a right-turn maneuver during the latter potion of the green phase at a signalized intersection.

6.1.1 Experimental Task

The experiment consisted of a three (bicyclist's relative position) X two (presence of oncoming left-turning vehicle) within-subject factorial design. The task in this experiment used the same experimental design described in the Chapter 4. Participants (n=51) were exposed to different combinations of relative positions of bicyclist and presence of the oncoming left-turning traffic at the last intersection of first six grids (Table 6-1). Participants were asked to follow the speed limit of the roads during driving, which was posted as 35 mph. The average speed of the bicyclist for this experiment was 16 mph at all intersections.

Table 6-1: Layout of the Last Intersection of Each Grid

Grid #	Relative position of bicyclists	Oncoming Traffic
1	1 bicyclist behind	No vehicles
2	1 bicyclist ahead	3 vehicles
3	1 bicyclist behind	3 vehicles
4	No bicyclists	No vehicles
5	No bicyclists	3 vehicles
6	1 bicyclist ahead	No vehicles

6.1.2 Procedure

Motorist SA was assessed after completing the right-turning maneuver at the last intersection of each of six grids, as described in Chapter 4. Endsley (1995) identified three general components or levels of SA, including perception of elements in the environment (Level 1 SA), comprehension of their meaning in relation to task goals (Level 2 SA), and projection of their status in the near future (Level 3 SA). Each of these SA levels were measured using an adaptation of the SA global assessment technique, SAGAT (Endsley, 1987, 1990, 1995). The SAGAT is a simulation freeze technique in which SA queries are presented to complex system operators (i.e. pilot, motorist) on the system status and relevant features of the external environment at random intervals (Endsley, 1995b). In this experiment, the simulation was frozen as soon as the motorist complete the last right-turn maneuver in each grid at various points in times. As stated in the "Driving Simulator Study" section in Chapter 4, the grids consisted of varying numbers (two, three or four) of total right-turns and the simulation was frozen at the end of each grid. The total number of right-turns for different grids were not equal so that the simulation could be frozen at various intervals and participants could not predict in advance when the simulation would freeze. During a freeze, the simulation was stopped and the display was blanked out while assessing motorist SA. As soon as the simulation froze, participants were presented with the SA questionnaire for assessing their SA using a small laptop, and administered through an online survey tool. This procedure was followed to minimize intrusiveness since participants did not need to move to a different workstation to respond to the SA questionnaire. In addition, the computerized versions of SAGAT queries helped to reduce data collection and reduction time when compared to the paper version of queries. There was no time constraint placed on participants to complete the SA questionnaire. After participants completed a questionnaire, the simulation was activated with a new grid of driving scenarios. Participants were not provided with feedback on their responses to the queries during or immediately after the survey.

SAGAT was chosen for this study because it employs objectivity and directedness, and is a well-documented measure of SA (Gonzalez et al, 2007). This deterministic SA measurement has been validated for assessing how aware individuals are about elements in the environment (Salmon, 2009), which was one of the important objectives of this experiment. SAGAT does not require user self-assessment or any inferences of user behavior. It is also seemingly unintrusive on the participant's performance because of the short (usually less than 1 min) and random interruptions it employs (Bolstad & Endsley, 1990). Further, no significant effect on participant's performance were found with number of stops (as many as 3 for up to 2 min) or duration of stops of up to 5 minutes (Endsley, 1995) in the simulation.

In addition to the explicit recall measures of SA, it is also important to assess operator's SA with indirect performance-based measures since many real-time tasks require well-practiced automatic processes (Gugerty, 1997). The percentage of times a motorist can avoid hitting an adjacent car positioned in the blind spot during driving is an example of a performance-based measure during the driving task. In this experiment, participant's task performance was measured by investigating if they could avoid a crash with a through-moving adjacent bicyclist to their right while turning right at a signalized intersection during the latter portion of the green phase. As stated in Chapter 4, this performance measure was termed as crash avoidance behavior of motorists and detailed analysis of this performance measure has been provided in Chapter 7.

6.1.3 SA Questions

Participants were asked a total of nine SA queries selected from a pool of queries, targeting three questions for each level of motorist SA (perception, comprehension, and projection). Each participant received the same nine queries every time, but in a randomized order. The queries were presented in a random so that the participant could not associate any particular question with a particular portion of the driving task while turning at each intersection. The complete SA questionnaire used in this experiment has been included in Appendix D.

Level 1 SA - Perception of the elements in the environment

The first step in achieving SA is to perceive the status, attributes, and dynamics of relevant elements in the environment (Endsley, 2001). To assess Level 1 SA, participants were asked queries to recall the relevant elements in their driving environments, such as the last road sign they saw, the number of bicyclists that was present in the adjacent bicycle lane and the number of oncoming vehicles that turned left just before the simulation freeze.

Level 2 SA - Comprehension of the current situation

This level of SA requires the comprehension of the significance of objects and events through the synthesis and integration of disjointed Level 1 elements in conjunction with operator goals (Endsley, 2001). Assessment of Level 2 SA included queries that addressed motorists' comprehension of the overall driving environment by investigating whether they could integrate various elements in the built environment, such as the turning signal indicator of the oncoming left-turning vehicles that were waiting in the queue to turn left or the current location of motorist's vehicle with respect to the location where they started driving.

Level 3 SA - Projection of future status

The third and highest level of SA requires the ability to project the future actions of elements in the environment, achieved through the knowledge and comprehension of Level 1 and Level 2 SA. To assess Level 3 SA, participants were asked queries if they could project times to certain events, such as the time required to reach the approaching intersection, or project the location of their vehicle relative to the crossing pedestrian in order to avoid a collision.

Participant's SA was measured by assessing the average percent of correct responses to Level 1, Level 2 and Level 3 queries and an overall SA score (sum of up all three SA level scores) across all questionnaires. Participants were not aware of the scoring system.

6.2 Research Objective and Hypotheses

The overarching objective and the research hypotheses of this experiment are detailed in this section. The research hypotheses were formulated to address the research questions on right-turning motorist's SA, stated in the "4.3 Research Question" section of Chapter 4, through the statistical analysis of the motorist's SA responses.

6.2.1 Research Objective

The overarching research objective of this experiment was to assess if right-turning motorist have the necessary knowledge for safely executing a right-turning maneuver, which is important to avoid a potential RH crash with adjacent bicyclist.

6.2.2 Research Hypotheses

We hypothesized that right-turning motorist's SA will be affected by the relative position of bicyclist. We inferred that when a bicyclist approaches from the behind a motorist in the adjacent bike lane, the motorist would have comparatively poor knowledge of the presence of bicyclist as compared to the scenario where a bicyclist is riding ahead of the motorist in the adjacent bike lane. In particular, Level 1 and Level 2 SA would be poor when bicyclists approach the intersection from behind the motorist as compared to when bicyclists approach the intersection ahead of the motorist due to motorist's poor detection and perception of the traffic element in the driving environment. We also hypothesized that motorist's SA will be reduced when oncoming cars turn left in front of the motorist as they will compete for limited mental resources and will increase motorists' perceptual workload, which will eventually decrease SA (Gugerty et al, 2000). Finally, we hypothesized that the interaction effect of the presence of oncoming vehicles and relative positions of bicyclists will reduce right-turning motorists' SA due to greater demand on working memory load.

We also inferred that a right-turning motorist who will not be able avoid a crash with a through-moving bicyclist has poor knowledge of the bicyclist's location in the adjacent bike lane. Since the SA questionnaire in this experiment involves queries on bicyclist position, we hypothesized that there would be a correlation between motorists' crash avoidance behavior and their SA score, in particular the Level 1 SA score that explicitly assess the detection of bicyclist location.

$H_{0\ (SA1)}$: Relative positions of adjacent bicyclists' have no effect on right-turning motorists' SA in a driving simulator environment.

$H_{0\ (SA2)}$: Presence of oncoming left-turning traffic has no effect on right-turning motorists' SA in a driving simulator environment.

$H_{0\ (SA3)}$: The interaction of left-turning oncoming traffic and relative position of bicyclists' have no effect on right-turning motorists' SA in a driving simulator environment.

$H_{0\ (SA4)}$: There is no correlation between the number of correct responses and crash avoidance behavior of right-turning motorist in a driving simulator environment.

6.3 Variables of Interest

This section illustrates the independent and dependent variables of this experiment.

6.3.1 Independent Variables

The research hypotheses suggest that two independent variables were selected from four experimental factors described in the "4.2 Research Design" section of Chapter 4 to assess motorists' SA. The independent variable were the relative position of bicyclists while approaching the intersection and the presence of oncoming vehicular traffic. Although, additional factors, such as presence of a pedestrian in the conflicting crosswalk, volume of adjacent vehicular traffic, and motorists' experience level may influence SA, those factors are outside the scope of the current study.

As stated in the “4.2 Research Design” section, the first independent variable was the “relative position of bicyclist”, which was manipulated within-subjects. It had three levels – 1) no bicyclists, 2) bicyclist approaching from behind the motorist (bicyclist in the blind spot) and 3) bicyclist riding ahead of the motorist (overtaking scenario).) The other independent variable was the “presence of oncoming vehicular traffic”, which was also manipulated as a within-subject variable. It had two levels – 1) no oncoming (zero) vehicles and 2) three oncoming vehicles. The levels of each independent variable are listed in Table 6-2.

Table 6-2 Levels of Independent Variables

Name of the Variable	Category	Levels
Relative position of bicyclists	Nominal (Categorical)	None
		One (1) bicyclist riding in front of the motorist in an adjacent bike lane to the right
		One (1) bicyclist coming from behind the motorist in an adjacent bike lane to the right
Volume of oncoming vehicular traffic	Dichotomous (Categorical)	None
		Three (3) Vehicles

6.3.2 Dependent Variables

The dependent variables for the experiment were motorists SA measured through their responses to SAGAT queries in perception (Level 1 SA), comprehension (Level 2 SA) and projection (Level 3 SA) queries and overall SA score across all questionnaires. SAGAT scoring of SA response are based on binomial data, e.g. correct or incorrect responses when compared to what was actually happening in the simulation at the time of freeze.

6.4 Data Analysis and Results

Participant responses to the SA queries were scored either as 1 (correct) or 0 (incorrect). Participant's overall SAGAT scores for a specific query were calculated by summing all correct responses in Level 1, Level 2, and Level 3 SA queries. Data reduction and visualization was performed in both Microsoft Excel (Microsoft 2013) and SPSS (IBM SPSS Statistics, V22.0), and the statistical analysis was performed in SPSS.

6.4.1 Result

Figure 5-2 presents the mean SA scores to the Level 1, Level 2, Level 3 queries and the mean of overall SA scores as a function of relative position of bicyclist and volume of oncoming vehicular traffic. The plot reveals that, on average, right-turning motorists exhibited better overall SA in the base condition, i.e. when there was no bicyclist or oncoming vehicle present (M = 4.88, SD = 1.56) at the intersection and exhibited the worst overall SA when the bicyclist was approaching from behind the motorist, but no oncoming vehicles were present (M = 3.63, SD = 1.76).

The mean scores in both Level 1 SA (M = 1.41, SD = 0.75) and Level 2 (M = 0.90, SD = 0.76) SA were the lowest when oncoming vehicle was turning in front of the motorist and a bicyclist was approaching from behind. The plot also reveals that right-turning motorist's Level 1 and Level 2 SA scores degraded for the base condition, i.e. when no bicyclist and oncoming vehicles were present.

Unlike the Level 1 and Level 2 SA, the right-turning motorist's Level 3 SA score was the lowest when a bicyclists was riding ahead of the motorist while no oncoming traffic were present (M = 1.14, SD = 0.92).

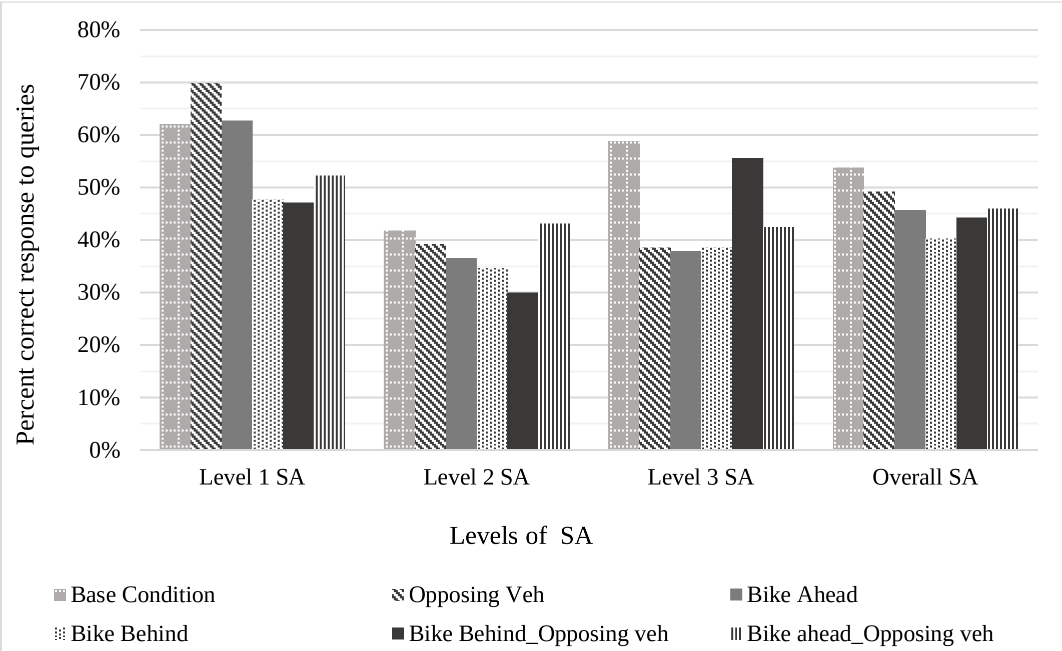


Figure 6-1: Mean Percent Correct Responses to SA Queries for Bicyclist's Position and presence of Oncoming Vehicles

Statistical Analysis

A repeated-measure general linear model (GLM) was used for this data analysis. Since the measurements were taken on each participant under each of several conditions, there was a violation of the "independence of observation" condition (Weinfurt, 2000). Therefore, a "repeated-measures" approach was considered for this data analysis. To control for the experiment-wide error rate associated with conducting multiple analyses of variance (ANOVA) on different dependent variables, a multivariate analysis of variance (MANOVA) was performed (Kass et al., 2007). MANOVA accounts for the correlation between the dependent variables (Mayers, 2013). In addition a repeated-measures ANOVA is sensitive to the violation of the compound symmetry assumption and the assumption of sphericity (Weinfurt, 2000). The compound symmetry assumption requires that the variances of the measures (pooled within-group) and covariances between the measures (between-group) at each level of the repeated factor are equal. The sphericity assumption states that the variances of the differences within all combinations of related groups (levels) are equal. When these two assumptions are violated, MANOVA is a more valid and statistically powerful procedure over repeated-measures ANOVA (Weinfurt, 2000). Considering this, a repeated-measures MANOVA approach was selected to statistically analyze this experimental data set.

In order to perform a MANOVA, the assumptions required for MANOVA were verified for the data set. The independent variables in this data set were categorical, and the dependent variables (SA scores) were interval data. The dependent variables were reasonably normally distributed (skewness and kurtosis z-values between -1.96 to 1.96) and were reasonable correlated (for negative correlation, $r < -0.40$ and for positive correlation, $r < 0.90$). Therefore, it was concluded that the data set met the assumption criteria to perform a repeated-measures MANOVA.

The full model in the repeated-measures MANOVA included all of the variables as additive variables. Table 6-3 shows the output of the MANOVA analysis that includes different outcomes for measuring the multivariate significance. According to Bray and Maxwell (1985), Pillai's Trace (V) is the most powerful option when the samples are of equal size. Therefore, results from the Pillai's Trace (V) was considered to report the significance of the test in this experiment.

Repeated-measures MANOVA results (Table 6-3) revealed a significant main effect of the "bicyclist's position" on SA measures ($V = 0.227$, $F\ (2, 49) = 7.183$, p-value = 0.002). Therefore, we rejected the first null hypothesis ($H_{0\ (SA1)}$), which stated that the relative positions of adjacent bicyclists' have no effect on right-turning motorists' SA. There was no significant main effect of the "presence of oncoming vehicles". Also, there was no interaction effect of the "bicyclist's position" and "presence of oncoming vehicles". Therefore, we failed to reject the second ($H_{0\ (SA2)}$) and third null hypothesis ($H_{0\ (SA3)}$) of this experiment, which stated the effect of the presence of the oncoming vehicle and the interaction effect on right-turning motorists' SA respectively.

Table 6-3: Multivariate Statistics

Multivariate Tests[a]							
Effect		Value	F	Hypothesis df	Error df	Sig.	Partial eta squared
BikePos	*Pillai's Trace*	*.227*	*7.183*[b]	*2.000*	*49.000*	*.002*	*.227*
	Wilks' Lambda	.773	7.183[b]	2.000	49.000	.002	.227
	Hotelling's Trace	.293	7.183[b]	2.000	49.000	.002	.227
	Roy's Largest Root	.293	7.183[b]	2.000	49.000	.002	.227
VehVol	Pillai's Trace	.001	.073[b]	1.000	50.000	.789	.001
	Wilks' Lambda	.999	.073[b]	1.000	50.000	.789	.001
	Hotelling's Trace	.001	.073[b]	1.000	50.000	.789	.001
	Roy's Largest Root	.001	.073[b]	1.000	50.000	.789	.001
BikePos * VehVol	Pillai's Trace	.076	2.024[b]	2.000	49.000	.143	.076
	Wilks' Lambda	.924	2.024[b]	2.000	49.000	.143	.076
	Hotelling's Trace	.083	2.024[b]	2.000	49.000	.143	.076
	Roy's Largest Root	.083	2.024[b]	2.000	49.000	.143	.076

a. Design: Intercept
Within Subjects Design: BikePos + VehVol + BikePos * VehVol

Since the MANOVA main effects of bicyclist's position was found, a univariate analysis was examined for this variable. The analysis revealed that right-turning motorist's overall SA score was significantly degraded when a bicyclist was approaching from behind the motorist when compared to no bicyclist presence at the intersection (p-value = 0.001).

A repeated-measures ANOVA was conducted to analyze the Level 1 SA score. Results indicated that there was a significant interaction effect of the bicyclist's position and oncoming vehicular volume on the Level 1 SA score (F (2, 49) = 4.52, p-value=0.013). Motorist's perceptual knowledge of the driving environment was the lowest when a bicyclist approached from behind the motorist and oncoming vehicles were present.

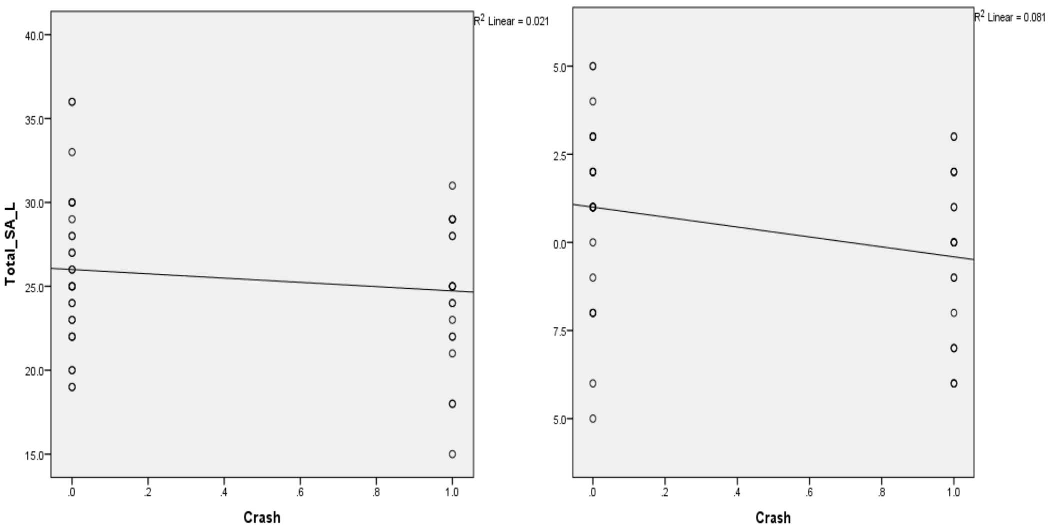
Repeated-measures ANOVA analysis on Level 2 SA scores revealed a significant effect of the bicyclist's position (F (2, 49) = 3.85, p-value = 0.016). No significant effect of the oncoming vehicular volume or interaction effect was found on the Level 2 SA score. A Bonferroni post-hoc analysis indicated that motorist's comprehension of the traffic elements degraded when a bicyclist was approaching from behind the motorist when compared with no bicyclist present (p-value = 0.045) or when the bicyclist was riding ahead of the motorist on the approach to the intersection (p-value = 0.048).

Similar to the Level 1 SA score, a repeated-measures ANOVA analysis on the Level 3 SA score revealed that there was a significant interaction effect of the bicyclist's position and oncoming vehicular volume on right-turning motorist's Level 3 SA score (F (2, 49) = 8.26, p-value < 0.001). However, unlike the Level 1 SA, motorists demonstrated significantly lower ability to project status of the driving environment when the bicyclist was riding in the front while oncoming vehicles were turning in front of the motorist as compared to when a bicyclist was approaching from the behind and oncoming vehicles turning in front of the motorist.

6.4.2 Correlation Analysis

Motorist's crash avoidance behavior was also used as an indicator of their SA while performing a right-turn maneuver at the intersection. In order to determine if there was any significant association between the number of correct responses, i.e. right-turning motorist's overall SA score and crash avoidance behavior, a Point biserial correlation analysis was conducted between participant's overall SA score and crash occurrence. Participant's crash avoidance behavior was measured in terms of crash occurrence, which was a dichotomous nominal variable and scored either as 1 (crash) or 0 (no crash). Since the Point biserial correlation coefficient (r_{pbi}) indicates the degree of relationship between a naturally occurring dichotomous nominal scale and an interval scale (Brown, 1988), it was chosen to calculate the association between crash occurrence (dichotomous variable) and motorist's overall SA score (interval scale).

The Point biserial correlation coefficient (r_{pbi}) indicated a reasonable negative linear association between overall SA scores and crash occurrence, although not statistically significant (r_{pbi}= *-0.14, ns)*. The negative association between overall SA score and crash occurrence (Figure 6-2 (a)) indicated that as a whole motorist having lower scores in overall correct responses to SA queries tended to show lower performance in avoiding a crash.



(a) (b)

Figure 6-2: Correlation between Crash Occurrence and (a) Overall SA Score, (b) Level 1 SA Score

Since perception and detection of the hazard is an important criterion of crash avoidance, the Point biserial correlation analysis was also conducted between participant's Level 1 SA score and crash occurrence. In this case, The Point biserial correlation coefficient (r_{pbi}) indicated a significant negative linear association (Figure 6-2(b)) between Level 1 SA score and crash occurrence (r_{pbi}= -0.3, p-value=0.043). This finding suggests that a common cause of the observed crashes was a failure to detect the presence of a conflicting bicycle.

In summary, the analyses indicated that on average the relative position of a bicyclist significantly influenced right-turning motorist's overall SA. The volume of oncoming vehicles was found not to have a statistically significant effect on right-turning motorist's overall SA. The interaction effect between bicyclist's relative position and oncoming vehicular volume was also found not to have a statistically significant influence on right-turning motorist's overall SA. However the interaction effect was found to be statistically significant for Level 1 and Level 3 SA. The Point biserial correlation coefficient indicated a reasonable negative linear association between right-turning motorist's crash avoidance behavior and overall SA, although not statistically significant. However, a significant negative linear relationship was found between right-turning motorist's crash avoidance behavior and Level 1 SA.

6.5 Discussion

This study investigated motorists' SA in the real-time complex task of simulated driving as a possible cause of RH crashes. Specifically, the objective was to determine if right-turning motorists had the knowledge needed for the driving subtask of monitoring and hazard avoidance, i.e. the knowledge of the traffic around them in order to successfully complete a safe right-turn maneuver at a signalized intersection during the latter portion of the green phase.

As expected, participant's overall SA scores indicated that before turning right, motorists were significantly less aware of the presence of bicyclists in the adjacent bike lane when the bicyclist was approaching in an adjacent bicycle lane from behind the motorists as compared to when the bicyclist was riding ahead of the motorist in an adjacent bicycle lane(p-value=0.002). This suggests that right-turning motorists used cues of the surrounding traffic to focus their attention during driving. For example an adjacent bicyclist riding ahead of the motorist posed an immediate driving hazard to motorists and they focused more attention to the bicyclist. However, when the bicyclist was approaching from behind in motorist's blind spot, motorists did not focus attention to the bicyclist in their peripheral vision. This may be due to the fact that tracking an object in the blind spot of a car demands greater working memory (Gugerty, 1997). This finding is also consistent with previous research by Gugerty (1997), Falzetta (2004) and Crundall et al. (1999). Gugerty (1997) measured motorist's SA through hazard detection, blocking car detection, and crash avoidance during a simulated driving task and found that participants focused more of their attention on nearby cars and cars in front of them that were perceived most likely to pose a hazard and focused less attention on cars in the blind spot. While assessing motorists' attention allocation by location and type of event, Falzetta (2004) found that participants detected forward events better than rear events, and generally allocated more attention to the road ahead. Crundall et al. (1999) also found that the frequency of detecting peripheral visual onsets decreased as the cognitive demand of the focal hazard-perception task increased.

Motorists' perception (Level 1) of traffic was found to be the lowest when oncoming vehicles were turning left in front of the motorist and the bicyclist was approaching from behind (p-value=0.013). This observation could be explained by the cue utilization study, which evaluated the extent to which participants' behavior is constrained by environmental cues (Brunswick, 1956; Hursch et al., 1964). In this experiment, motorists allocated attention to the oncoming vehicle that posed a potential driving hazard to them, not to the bicyclist in their peripheral vision. Since focal hazard-perception tasks compete for limited cognitive resources, which eventually decreased the frequency of detecting peripheral visual events (Crundall et al., 1999), as evidenced by decreased Level 1 SA.

Motorists' perception (Level 1 SA) and comprehension (Level 2 SA) of the driving environment was better when the bicyclist was riding ahead as compared to when the bicyclist was approaching from behind. However an opposing trend was found for Level 3 SA (projection queries), where motorists' projection of the driving environment significantly degraded when the bicyclist was riding ahead of the motorist and oncoming vehicles were turning left in front of the motorist (p-value < 0.001). This can be explained by the limitation of motorist's attentional capacity. With excessive demands on attention due to multiple environmental stimuli (e.g., presence of a bicycle and oncoming cars) to attend to in their focal vision, motorist's task performance declined corresponding to reduced SA.

In the simulated driving task, motorist's perception and comprehension of the driving environments, i.e. lower level SA also degraded in the scenario where there was no oncoming vehicle and no bicyclist present, although not statistically significant. This was likely because in the absence of any type of environmental stimuli (i.e. car, bicyclist), the motorist was not allocating much visual attention to the observation of the driving environment and their knowledge of surrounding traffic degraded.

A significant relationship between motorist's crash avoidance behavior and lower level of SA (perception) suggested that a motorist good at detecting adjacent traffic, might exhibit better crash avoidance behavior with a bicyclist situated in the vehicle's blind spot. This finding suggests that observed crashes were primarily due to the detection error. Gugerty (1997) similarly found that better explicit recall of car locations was associated with better performance in hazard detection and blocking car detection.

Appropriate caution should be maintained when interpreting the results from this experiment. Motorists with relatively high SA may not always complete the right-turn maneuver successfully by avoiding crashes with a bicycle, whilst relatively poor SA does not necessarily guarantee that a motorist will crash when turning at an intersection. Endsley (2000), for example, indicated that many other factors are involved in turning good SA into successful performance and it is possible to have bad performance with perfect SA and good performance with poor SA.

Chapter 7 Analysis & Result - Crash Avoidance

As previously discussed, national crash statistics and hospital records provide a variety of significant information about crash scenarios (e.g., time, vehicle type, road condition, and driver demographics). However, they include limited detail regarding motorist behavior, an element that is necessary to fully understand particular crash scenarios. In addition, the number of reported BMV crashes is relatively low introducing a challenge for the systematic analysis of their causal factors. Considering this, similar crash-likely scenarios were created in the driving simulator where motorists were exposed to different driving hazards (i.e. oncoming left-turning vehicle, bicyclist in the blind spot, and pedestrians in the conflicting crosswalk) without harming them, in order to analyze how motorist's behavior contributes to the occurrence of RH crashes.

According to Dingus et al. (2011), it is important to understand motorist behavior and performance in the larger context of the driving environment to assess crash risk. Previous chapters of this study described motorist's behavior while completing the right-turn maneuver at an intersection through their response in the online survey (Chapter 3), their visual attention (Chapter 5) and SA (Chapter 6). This chapter assesses the performance of a right-turning motorist through the global performance measure of crash avoidance.

7.1 Research Objective

The objective of this experiment was to assess right-turning motorists' behavior in a crash-likely scenarios. Specifically, to assess if motorists can detect the potential hazard, i.e. the bicyclist in the adjacent bicycle lane and avoid a crash with the bicyclist while performing a right-turn during the latter portion of the green phase at a signalized intersection.

7.2 Experimental Procedure

Crash avoidance is measured through the number of right-turning motorists who could not avoid crashes with a through-moving bicyclist to their immediate right in the bike lane at a signalized intersection. It is expected that this global performance measure will provide information on right-turning motorist's decision and response-execution processes, as found by Gugerty (1997).

In the experimental design as discussed in Chapter 4, a bicyclist that posed a hazard to the motorist was riding in an adjacent bike lane either ahead of the motorist or approaching from behind. The bicyclist approaching the intersection from behind the motorist was entirely within the motorist's blind spot. Since the three-dimensional display in the driving simulator did not show vehicles immediately to the right of the motorist, participants had a larger blind spot than in a real driving environment (Gugerty, 1997). Participant could avoid colliding with a bicyclist approaching from the behind by detecting it in the rear- or side-view mirror. Motorist's crash avoidance behavior was observed during every right-turn maneuver (n = 21), as described in Chapter 4. As previously described, among the 21 right-turning scenarios, a single scenario was designed to be a crash-likely, and other 20 scenarios replicated typical intersection scenarios in an urban environment, which were termed as “typical” intersections in this experiment.

While assessing motorists’ expectations and mental workload in critical intersection scenarios created in a driving simulator, Plavˇsi´c (2010) found that the driving simulator can be successfully deployed to design realistic critical scenarios in urban environments and to explore various driver errors. In this experiment, this crash-likely scenario was created by replicating a complex driving scenario with a significant density of information and variety of vulnerable road users. The crash-likely scenario was replicated at the last experimental intersection (the 21st intersection) of the last grid to avoid any potential impact on motorist’s driving task during other scenarios due to the occurrence of a crash. The worst possible condition, identified from the online survey (Chapter 3) and the pilot study (Chapter 4), was replicated in the crash-likely scenario. In this scenario, an oncoming vehicle made a permitted left-turn while the motorist approached the intersection followed immediately by two additional oncoming vehicles waiting in the queue in the opposing left turn lane, a pedestrian walked towards the motorist in the crosswalk and another vulnerable road user, a bicyclist, approached from behind the motorist in an adjacent bike lane at 16 mph. These traffic elements were situated such that the motorist would likely hit the bicyclist approaching from his vehicle’s blind spot unless he detected the bicyclist through his mirrors.

7.2.1 Detection

Motorist's driving in the simulated environment was observed continuously from the simulator's operator station and records were taken at the moment a crash occurred. Motorists were also verbally asked at the end of the experiment if they caused any crashes during the experiment. The recorded crash data was further validated by checking the locations of the subject vehicle and bicycle centroid, recorded as dynamic variable data in the driving simulator.

The causes of the crash were assessed through the analysis of participant's eye tracking data at the time of the crash. Additionally, at the end of the experiment, when participants were verbally asked if they were involved in a crash, at that time, they were also asked about the reason for the crash. The responses were then compared with the eye tracking data.

Data reduction and visualization was performed in both Microsoft Excel (Microsoft 2013) and SPSS (IBM SPSS Statistics, V22.0), and the statistical analysis was performed in R and SPSS statistical software.

7.3 Contributing Crash Factors

In this experiment, 51 participants each completed 21 right-turn maneuvers, in total 1,071 right-turns were made. Twenty six crashes were observed during 1071 right-turns.

Among these 26 crashes, 11 crashes were observed during the crash-likely scenario and the remaining 15 crashes were observed during the other 20 scenarios (Table 7-1).

Table 7-1: Total Number of Crashes

Intersection Type	Crash Number (%)
Typical intersection	15 (58%)
Crash-likely scenario	11 (42%)
Total	**26**

These 26 crashes were made by 23 participants, three of whom crashed twice. Two of these three participants realized they had been involved in a crash. They stated that although they detected the bicycle in the side-view mirror, the reason of the crash was their poor projection.

7.3.1 Driving Environmental Factor

The driving environmental factors during observed crashes included the presence of oncoming left-turning traffic, presence of pedestrian in the conflicting crosswalk, and the relative position of a bicyclist in motorist's adjacent bike lane. Table 7-2 describes the exact independent variables that were present in the driving scenario where a crash was observed. After the crash-likely intersection, the highest number of crashes occurred in the typical intersection scenario where the oncoming traffic was present in the conflicting left-turn lane, and a bicyclist was approaching from behind at 16 mph, but no pedestrian was present in the conflicting crosswalk.

Apart from the crash-likely intersection scenario, it was found that bicyclists approached from behind the motorist in 13 crash scenarios and bicyclists were riding ahead of the motorist in two crash scenarios. A Chi-square test revealed a statistically significant difference between these two bicyclist positions (p-value = 0.005) with respect to the occurrence of a crash. While the bicyclist’s speed was 16 mph in the crash-likely scenario, 12 typical intersection crash scenarios had bicyclists approaching at 16 mph speed and three crash scenarios had bicyclists approaching at 12 mph speed. A Chi-square test revealed a statistically significant difference between bicyclist speeds with respect to crash outcomes (p-value = 0.02). The average motorist speed during crashes at the crash-likely scenario was 12.6 mph ranging from a minimum of 7.2 mph to a maximum speed of 19.7 mph.

Thirteen crash scenarios had a pedestrian in the conflicting crosswalk, whereas 13 crashes occurred when no pedestrian was present. No statistically significant difference was found for the presence of pedestrian with respect to crash outcomes. Motorists caused 21 crashes when oncoming left-turning vehicles were present and, whereas seven crashes occurred when no oncoming vehicle was present. A statistically significant difference was found for the presence of oncoming vehicles with respect to crash outcome (p-value = 0.008).

Table 7-2: Independent Variable Levels during Observed Crashes

Intersection Type	Relative Position of Bicyclist	Oncoming Traffic Volume	Bicyclist Speed (mph)	Motorist Speed (mph)			Crossing Pedestrian	Total
				Mean	Max	Min		
Crash-Likely Intersection (n=11)	1 bicyclist behind	3 veh	16	12.6	19.7	7.2	1 ped	11
Typical Intersection (n=15)	1 bicyclist behind	3 veh	16	10.5	12.3	9.1	None	6
	1 bicyclist behind	None	16	11.9	12.5	11.4	None	3
	1 bicyclist ahead	None	16	11.9	11.9	11.9	None	1
	1 bicyclist behind	3 veh	16	8.9	8.9	8.9	1 ped	1
	1 bicyclist behind	3 veh	12	8.5	8.5	8.5	None	1
	1 bicyclist ahead	None	12	7.6	7.6	7.6	None	1
	1 bicyclist behind	None	12	9.5	9.5	9.5	None	1
	1 bicyclist behind	None	16	12.6	12.6	12.6	1 ped	1
	Total							**26**

7.3.2 Motorist Related Factors

Motorist related factors of crashes are categorized into two groups- factors attributes to motorist characteristics, such as gender, age, education, experience and factors attributes to motorist behavior characteristics, such as inadequate surveillance and poor projection.

Analysis of the participant demographics showed that male participants were more likely to be involved in crashes than female participants (Table 7-3). A Chi-square test revealed statistically significant differences between gender with respect to crash involvement (p-value = 0.02). Although the highest percentage of motorist had driving experience of 1-5 years (44%), no statistically significant difference on crash involvement was found with respect to driving experience. Table 7-3 also indicates the highest number of participants involved in a crash attended some college (31%) and were between the ages of 25-34 years (39%), no statistically significant effect on crash involvement was found with respect to education or age.

Table 7-3: Motorist Related Crash Causal Factors

Category	Level	Crash-Likely Scenario (n=11)	Other Scenarios (n=12)	Total (n=23)
Gender	Male	73%	75%	74%
	Female	27%	25%	26%
Experience (year)	1-5	45%	42%	44%
	6-10	27%	8%	17%
	11-20	9%	17%	13%
	20+	18%	33%	26%
Education	High School	0%	8%	4%
	Some College	27%	33%	31%
	Associates Degree	18%	8%	13%
	4 year degree	18%	33%	26%
	Master's Degree	18%	17%	17%
	PhD Degree	18%	0%	9%
Age (year)	18-24	36%	33%	35%
	25-34	45%	33%	39%
	35-44	9%	8%	9%
	45-54	0%	8%	4%
	55-64	9%	8%	9%
	65+	0%	8%	4%
Cause	Fails to look (Improper Lookout)	64%	67%	66%
	Look but did not see (Improper Lookout)	27%	7%	15%
	Poor Projection	9%	26%	19%

Factors Related to Motorist Behavior

Causal factors attributed to motorist behavior were categorized as either inadequate surveillance or poor projection. As stated in Chapter 2, inadequate surveillance occurs when a motorist either failed to look or looked but do not see (inattention blindness).

Analyzing motorist's glance data from the eye tracker, it was found that in most cases (66%) motorists did not check their mirrors before turning right and failed to detect the bicyclist in their blind spot (Table 7-3). This finding was consistent with responses to follow-up questions collected at the end of each experiment drive. However, 15% of the motorist who were involved in crashes said that they did not see any bicyclist before turning-right although their glance data revealed that they had checked at least one mirror before turning and the bicyclist was visible in that mirror. It indicated that those crashes may have been the result of a "look but did not see" failure.

Five of these 26 crashes (19%) occurred due to poor motorist projection (Table 7-3). In two of those crash scenarios, a bicyclist was riding ahead of the motorist; the motorist passed the bicyclist and then turned right at the intersection. By not yielding the right-of-way to the bicyclist, a crash resulted. In the other three cases, the bicyclist approached from behind the motorist and the motorists detected the bicyclist in one of the mirrors. Motorist's detection of the bicyclist was confirmed from their verbal statement and glance data. However, motorists reported that they assumed they would be able to complete the right-turning maneuver before the bicyclist reached the intersection. Due to motorist's poor projection, a crash with the bicyclist resulted during the turning maneuver.

7.3.3 Predictive Model

To predict the type of people most likely to have a crash with a bicyclist approaching from behind at the intersection with similar driving environment in this experiment, a binary logistic regression (commonly referred to as a logit model) was conducted. Binary logistic regression was used because this model is appropriate to analyze a dichotomous outcome variable (Sweet, 1999; Schwab, 2002; Hosmer et al., 2000; Long, 1997), which is crash occurrence in this experiment. In a logit model, the log odds of the outcome is modeled as a linear combination of the predictor variables.

The dependent variable of this model was the log-odds of the probability of crash occurrence, which had one of two possible values: 1 (crash) or 0 (no crash). The predictor variables of the model derived from the driving simulator experiment included the participant's gender, driving experience, age, and education level. As presented in Table 7-3, gender, education level, and driving experience were included as categorical predictor variables with two, six, and four levels respectively, whereas age was considered as a continuous predictor variable. The mathematical model (Equation 7-1) was as follows:

$$logit\ (\hat{p}) = lp \quad — \quad = p \quad + p \quad (gp \quad) + p \quad (\quad g \quad) + p \quad (p \quad tiop) + p \quad (p \quad i \quad) p$$ ……….Equation 7-1

Where,

$\hat{p}$= the probability of Y is 1,

1- $\hat{p}$= The probability that Y is 0

Equation 7-1 was considered the full model for the logistic regression. The output from the logistic regression analysis in SPSS has been provided in Appendix E. Results showed that a test of the full model against a constant-only reduced model was statistically significant. The Chi-square value of 16.6 with a p-value < 0.05 indicated that the predictors as a whole reliably distinguished between the occurrence of crash and no crash. The overall prediction success was 71.7% (83.3% for no crash and 57% for a crash). The Wald criterion demonstrated that only gender made a significant contribution to prediction (p-value = 0.026). Age, education and experience level were not statistically significant predictors. One unit change in gender, i.e. from female to male, is associated with an increase of 1.82 times in the log odds of a crash occurring. Therefore, the final model (Equation 7-2) was determined to be:

$logit(\hat{p}) = lp \; — = -1.48 + 1.82 * (gp \quad)p$ ……………. Equation 7-2

Interpretation of the final model

It is important to note that Equation 7-2 is only valid for a population with demographics similar to those described in the Chapter 4, who are exposed to similar levels of traffic during driving as described in Chapter 4. According to, the odds that the outcome will have a value 1 (i.e. crash) for a female participant is calculated as Exp(-1.48 + 1.82*1) = 1.40, while the odds for a male participant is 8.68. In other words, when there is one unit change in gender, i.e. from female to male, the odd ratio is 7 (exact 7.28) times as large and therefore the probability that males will occur a crash is 7 times as likely as a female will occur a crash when they are exposed to similar levels of traffic as presented in this experiment.

7.4 Collision Diagram

To aid in the preliminary data exploration, collision diagrams were created for each right-turning scenario that experienced crashes. The collision diagram focuses on right-turning vehicle trajectories and through-moving bicyclist trajectories at the intersection. The collision diagrams zoom in on the corner of the intersection where the right-turn maneuvers took place. Therefore, only the shared through right lane from the east and the shared receiving lane to the north including the bike lanes have been shown in the collision diagram. The diagram also identifies the location of the crashes, the crash sequence number, the traffic signal status, which was green during all crashes, and the speed of the motorists and bicyclists in mph at the time of collision.

Figure 7-1 presents a collision diagram of crashes that specifically occurred in the crash likely scenario. The diagram shows 12-foot wide vehicle approaching and receiving lanes, 5.5 foot bike lanes, vehicle trajectories, and bicyclist's speed (16 mph) and direction of travel. As the crash sequence number indicates in the diagram, there were 11 crashes at this intersection, with a variety of vehicle speeds. The diagram also indicates crash locations occurring from the edge (crash#7) to the middle of the intersection (crash#4).

Similar collision diagrams for eight alternative scenarios are included in Appendix F.

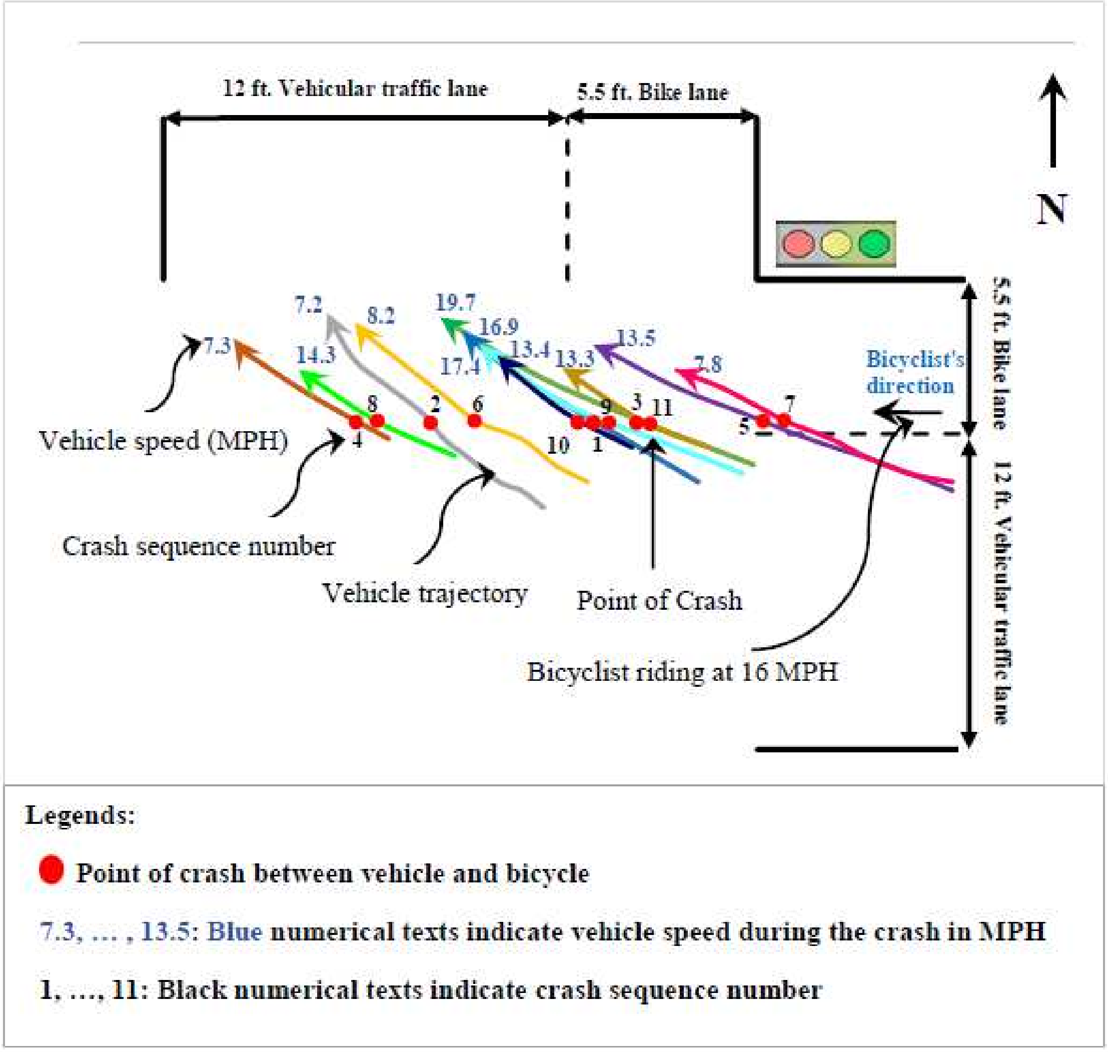


Figure 7-1: Collision Diagram of the Crashes Occurred in the Crash-Likely Intersection

7.5 Traffic Conflict

According to Amundsen and Hydén (1977), “a traffic conflict or near-crash is an observable situation in which two or more road users approach each other in space and time to such an extent that a collision is imminent if their movements remain unchanged”. A near miss is defined as a situation when two road users unintentionally pass each other with a very small margin, so that the general feeling is that a collision nearly occurred (Laureshyn, 2010). A commonly used severity indicator of traffic conflicts and near misses is the Time-to-Collision (TTC), which is defined as "the time required for two vehicles to collide if they continue at their present speeds and on the same path" (Hayward, 1971, and Hydén, 1987). Many studies have used TTC to estimate the number and severity conflicts (Hoffmann et al., 1994; Hyden, 1996; Minderhoud et al., 2001; Vogel, 2003). However, as Laureshyn (2010) stated that TTCs can be used as an indicator only if road users are on a collision course, i.e. if they continue without changes, a collision will occur. It is a continuous measure and can be calculated for any moment as long as the vehicles are on a collision course. The minimum time to collision is represented by the minimum TTC value (TTC_{min}) which is defined as "the minimum time distance between two vehicles during the collision avoidance process" (van der Horst, 1984). The TTC_{min} will be zero when a collision occurs.

The simplest application of TTC occurs for vehicle trajectories crossing at a right angle or in parallel. Describing the theoretical TTC curve discussed by Hayward (1971), Laureshyn (2010) stated a very basic estimation of the TTC (Equation 7-3) can be calculated with the distance S and the speed of the vehicle 2 (v_2) when the vehicles are in collision course (Figure 7-2).

$$= p -$$ …………Equation 7-3

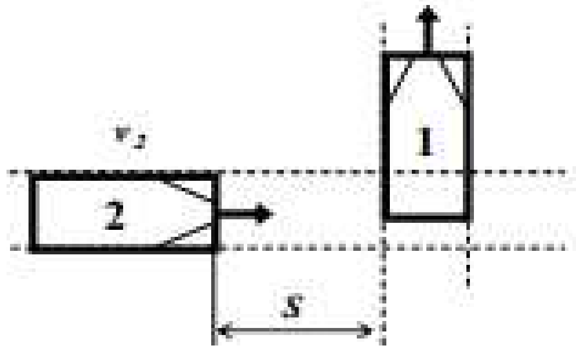


Figure 7-2: TTC When Perpendicular Vehicles are On a Collision Course (Laureshyn, 2010)

For a right-angle approach, van der Horst (1990) calculated TTC using the following equations:

=p— ,   *if* — < — < ——— ……… Equation 7-4

=p— ,   *if* — < — < ——— ………Equation 7-5

Where, d_1, d_2 = distances from the front of vehicles 1 and 2, respectively, to the area of intersection

l_1, l_2, w_1, w_2 = the lengths and widths of vehicles 1 and 2, respectively

v_1, v_2 = vehicle speeds

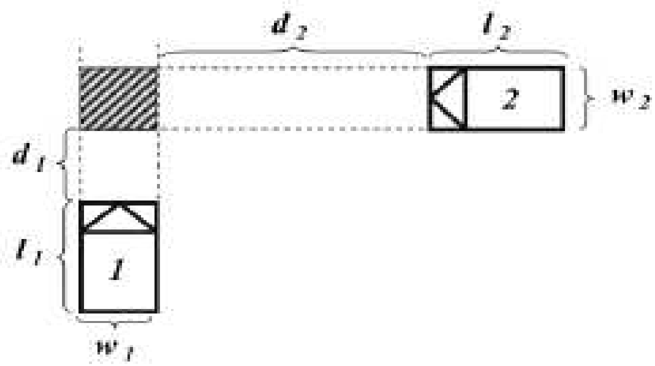


Figure 7-3: Calculation of TTC for Perpendicular Trajectories (van der Horst, 1990)

While evaluating the threshold value of TTC, Brown (1994) found that a TTC threshold value of 1.5 seconds is a reasonable time-based index of hazard. To develop the Surrogate Safety Assessment Model (SSAM) for deriving surrogate safety measures for traffic facilities from data output by traffic simulation models, Gettman et al. (1998) stated that “conflicts with TTC values larger than 1.5 seconds are not generally considered in the safety community to be “severe” enough events for recording in a traditional field conflict study”. Again, Sayed et al. (1999) calculated traffic conflict frequency and severity standards for signalized and unsignalized intersections using the data collected from 94 conflict surveys, in which the standards showed the relative comparison of the conflict risk at various intersections. They presented a ROC (risk of collision) score, which was defined as “a subjective measure of the seriousness of the observed conflict and is dependent on the perceived control that the driver has over the conflict situation, the severity of the evasive maneuver and the presence of other road users or constricting factors which limit the driver’s response options”. Table 7-4 presents a relationship between the TTC (s) value and ROC score present by Sayed et al. (1999) and cited in Saunier (2013).

Table 7-4: TTC and ROC score (Sayed et al., 1999)

TTC and ROC scores	Time to collision (TTC) (sec)	Risk of collision (ROC)
1	1.6-2.0	Low Risk
2	1.0-1.5	Moderate Risk
3	0.0-0.9	High Risk

7.5.1 Traffic Conflicts and TTC for RH Crash Scenarios

Near-crashes or traffic conflicts between a right-turning motorist and through-moving bicyclist where calculated where a collision was imminent if the trajectories remained unchanged. The majority of the RH crashes occurred when a bicyclist was approaching from behind and to the right in the motorist’s blind spot. Therefore, the traffic conflicts for the typical intersection scenarios, where the bicyclist was approaching from behind the motorist were investigated to further assess out the risk of collisions through TTC.

Adopting the variable terms and associated calculations for TTC described in Figure 7-2 and Figure 7-3, a simple form of the TTC calculation for a RH crash scenario was developed in Figure 7-4, where the bicyclist was approaching from behind the motorist.

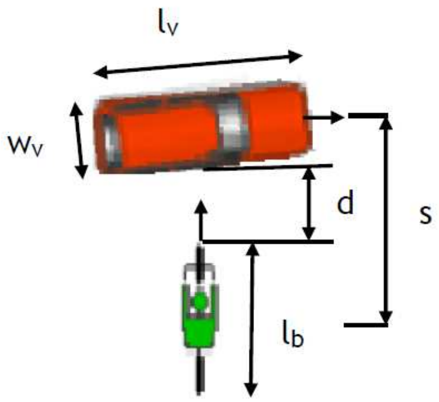


Figure 7-4: TTC Calculation for a RH Crash Scenario

Since, the location of the vehicle and bicycle centroids was recorded in the driving simulator, distances between the vehicle and the bicyclist were calculated from their centroids. Therefore,

$= p -$ ….. Equation 7-6

$= \; - p - \; - p -$ …. Equation 7-7

where,

w_v = width of vehicle (i.e. car)

l_b and l_v = length of bicycle and car respectively

v_b and v_v = velocity of bicycle and car respectively

d = distance from middle point of the side of the car and front of the bicycle

s = center to center distance between bicycle and car

7.5.2 Data Analysis and Result

Using Equation 7-6 and Equation 7-7, the TTC was calculated for eight typical intersections where the bicyclist was approaching from behind the motorist. The calculated TTCs were classified according to Table 7-4. Table 7-5 displays the number of traffic conflicts, and corresponding TTC values, for eight typical intersections, where the bicyclist was approaching from behind the motorist and the motorist was exposed to other experimental factors present in that driving scenarios.

There were a total 159 conflict events among 408 (51*8) right-turns. However, according to the 1.5 second TTC threshold value and the ROC score (Brown, 1994, Gettman et al, 1998, Sayed et al. (1999), only 26 incidents could be considered having high (0-0.9 seconds) (n=8) or moderate risk (1.0-1.5 seconds) (n=18).

Table 7-5: Number of Traffic Conflicts and TTC (s)

Relative position of bicyclist	Oncoming traffic Volume	Bicyclist Speed (mph)	Crossing ped	TTC (sec)				Total
				0-0.9	1.0-1.5	1.6-2.0	2.0+	
1 bicyclist behind	None	16	None	2 (7%)	5 (17%)	9 (31%)	13 (45%)	29
1 bicyclist behind	None	12	None	2(6%)	4 (11%)	4 (11%)	26 (72%)	36
1 bicyclist behind	None	16	1 ped	0 (0%)	0 (0%)	0 (0%)	23 (100%)	23
1 bicyclist behind	3 veh	16	None	3 (14%)	3 (14%)	8 (36%)	8 (36%)	22
1 bicyclist behind	3 veh	16	1 ped	1 (10%)	1 (10%)	2 (20%)	6 (60%)	10
1 bicyclist behind	3 veh	12	None	0 (0%)	4 (14%)	1 (3%)	24 (83%)	29
1 bicyclist behind	None	16	1 ped	0 (0%)	0 (0%)	0 (0%)	4 (100%)	4
1 bicyclist behind	3 veh	12	1 ped	0 (0%)	1 (17%)	0 (0%)	5 (83%)	6
Total				8 (5%)	18 (11%)	24 (15%)	109 (69%)	159

The frequency and cumulative frequency distribution were plotted for the above intersections. Figure 7-5 demonstrates the frequency distribution and cumulative frequency distribution for one of the right-turning intersections (one bicyclist approaching at 16 mph from behind, 3 oncoming vehicles, and no pedestrian). It can be seen that 27 percent of the traffic conflicts had TTCs equal to or less than 1.5 seconds. Similar plots for traffic conflicts at the other seven intersections have been provided in Appendix G.

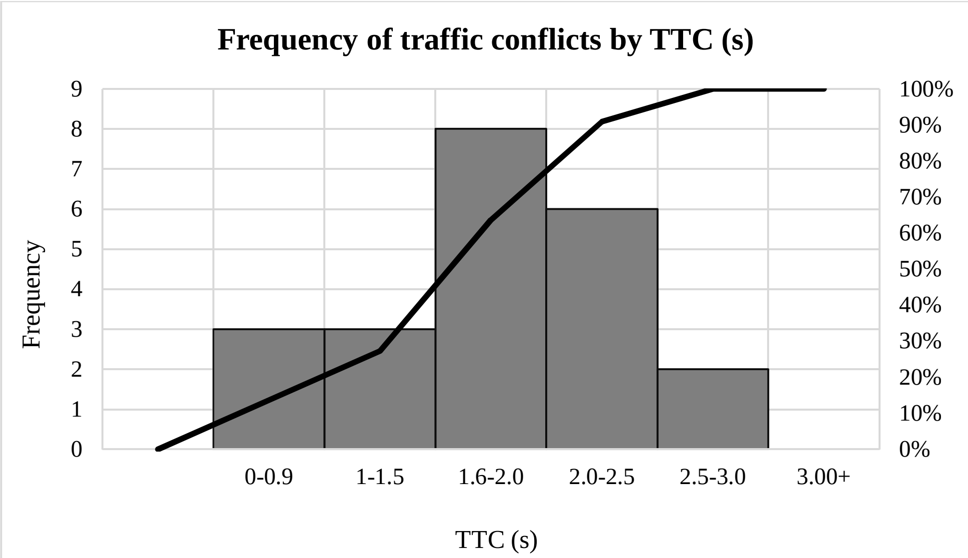


Figure 7-5: Frequency and Cumulative Frequency Distribution Curve For the Intersections with a Bicyclist (16 mph) Behind, 3 Oncoming Vehs, And No Ped

Table 7-6 describes the motorist related causal factors of the 26 severe near-crash scenarios. It was found that the eight high risk traffic conflicts (TTC ≤ 0.9 sec) were contributed by seven participants, i.e. one participant was involved in two near-crash incidents. For the moderate risk traffic conflict (TTC = 1.0-1.5 sec), 14 participants were involved in 16 traffic conflicts. Also, one participant had both high risk (TTC ≤ 0.9 sec) and moderate risk (TTC = 1.0-1.5 sec) traffic conflicts in two different intersections. In summary, it was found that 20 participants were involved in a total of 26 severe near-crashes.

Table 7-6: Motorist Related Causal Factors for Near-Crash Incidents

Category	**Level**	**TTC (sec)**		
		0-0.9 (n=7)	**1-1.5 (n=14)**	**Total (n=20)**
Gender	Male	71%	64%	70%
	Female	29%	36%	30%
Experience (year)	1-5	29%	50%	40%
	6-10	14%	21%	20%
	11-20	14%	14%	15%
	20+	43%	14%	25%
Education	High School	0%	7%	5%
	Some College	29%	57%	40%
	Associates Degree	14%	0%	5%
	4 year degree	43%	7%	20%
	Master's Degree	14%	21%	20%
	PhD Degree	0%	7%	5%
Age (year)	18-24	43%	64%	55%
	25-34	14%	21%	20%
	35-44	14%	7%	10%
	45-54	0%	0%	0%
	55-64	14%	7%	10%
	65+	14%	0%	5%
Cause	Fails to look (Improper Lookout)	78%	47%	58%
	Look but did not see (Improper Lookout)	22%	24%	23%
	Poor Projection	0%	29%	19%

As found from Table 7-6, males were more involved in near-crash incidents than females. More participants involved in near-crashes had 1-5 years of driving experience, went to some college, and were between the ages of 18-24 years. Motorist’s glance data revealed that in most cases, in particular for high risk conflicts, 78% of the time motorists did not check their mirrors before turning right and as a result failed to detect bicyclist in their blind spot. In 23% of the conflicts, participants glanced at a mirror once or twice when the bicyclist was visible, but the motorist failed to yield the right-of-way. This glance type was considered to be a “look but did not see” failure often referred to as an inadequate surveillance error. In some cases, motorists checked the mirror more than twice and fixated on the bicyclist, but still failed to yield the right-of-way. This type of error was considered as “poor projection”, which accounted for 19% of the near-crash causes.

Another interesting point of the near-crash analysis revealed that 11 (54%) of the 20 participants involved in a near-crash experienced a crash in one of the intersections in the complete experiment.

7.6 Discussion

The performance of a right-turning motorist was assessed through the global performance measure of crash avoidance. The crash avoidance behavior observed in this experiment indicated motorist’s ability to detect a bicyclist in a timely manner and make appropriate decision to avoid a crash with that bicyclist while turning right at a signalized intersection.

Among 51 participants completing total of 1,071 right turns, 23 participants could not avoid a crash with a bicyclist in 26 RH crash scenarios. Relative position of a bicyclist, bicyclist’s speed, and the presence of oncoming left-turning vehicle were found to have significant effect on crashes. This finding is consistent with the finding from Chapter 5 and Chapter 6, that when motorists’ dynamic working memory is overloaded due to the presence of adjacent traffic on the roadway, they focus their attention to the immediate hazard in their forward visual field, i.e. the oncoming traffic and did not shift their attention to the rear and side-view mirrors to check for the presence of a bicyclist in their blind spot. Also, higher speed of bicyclists was found to be a significant crash contributing factor as reported by the survey respondents in Chapter 2.

Male participants were involved in more RH crashes than female participants, with statistical significance (p-value = 0.02). A binary logistic regression conducted to assess the probability of a RH crash occurrence given the demographics of participants in this experiment also revealed that gender was a significant predictor of crash involvement.

Motorist's inadequate surveillance was found to be the major cause of observed RH crashes, where the motorist did not check for the bicyclist in the mirror before turning in most cases (66%) or looked but did not see (inattention blindness) in some cases (15%). Some RH crashes (19%) were caused due to motorist's poor projection where he detected the conflicting bicyclist, but did not yield the right-of-way.

Collision Diagrams were created to visualize the observed RH crashes with vehicle and bicycle trajectories, their speed and crash locations.

Investigation of near- crash incidents revealed that among 51 participants completing total of 408 right-turns, 20 were involved in 26 severe near-crash incidents having TTC value less than or equal to 1.5 seconds. Inadequate surveillance was found to be the cause of most near-crash incidents. Eleven of these 20 participants were also found to ultimately have a crash in the experiment suggesting their susceptibility to RH crash scenarios.

Chapter 8 Conclusion

Motivated by a desire to improve bicyclist safety, this research investigated the causal factors of RH crashes leveraging the OSU Driving Simulator. A comprehensive review of more than 150 scientific and technical articles revealed that although RH crashes have received significant attention, no robust experimental evidence exists proving the factors contributing to RH crashes. This research effort filled that gap by exploring the causal factors of RH crashes. The online survey contributed to a better understanding of the motorist and bicyclist behavior while interaction at a signalized intersection, whereas the driving simulator experiment provided valuable insight on the motorist and driving environment related casual factors of RH crashes during the latter portion of the green phase at signalized intersections. The significance of this research is that it presents an expanded understanding of RH crash causal factors by combining the disciplines of traffic engineering and human factors.

8.1 Online Survey Findings

The survey analyzed the behavior of motorists and bicyclists between the ages of 18-75 years at intersections. From the self-reported responses of 246 motorists, 209 of whom regularly ride bicycles, the survey results found that:

- Men (71%) were more likely to ride bicycles than women (29%). Most bicyclists were between the ages of 26 to 35 and 71% of bicyclists were White or Caucasian. These findings were consistent with a previous study by Moudon et al.

(2005) who found increased rates of bicycling for white, middle-aged, male respondents.

- Almost one-fourth (22%) of bicyclists reported that they would *not* yield the right-of-way to vehicles before making through movement at an intersection, as they assumed vehicles would yield the right-of-way. Such behavior may increase the vulnerability of bicyclists to RH crashes at intersections.
- Most bicyclists (78%) were unaware of their stopping position with respect to stopped vehicles queued at an intersection in response to a red indication.
- While 84% of motorists (n=225) said they would *always* look for the traffic signal status, 76% would *always* look for crossing pedestrians, and 68% would *always* look for oncoming vehicular traffic, only 56% reported that they would *always* look for bicyclists at their right before turning right at an intersection. This indicates that motorists may search less frequently for bicyclist to their right than other targets before turning right at an intersection. This could contribute to the occurrence of RH crashes.
- A statistically significant difference was found in motorists' self-reported turning behavior at an intersection with respect to bicyclist's relative position in the adjacent bicycle lane. Only 1% of motorists reported that they would *not* yield to a bicyclist that was riding ahead and would accelerate to pass the bicyclist before turning at an intersection. However, 19% of motorists reported that they would *not* yield to the adjacent bicyclist approaching from the behind, whom the motorist detected in the rear- or side-view mirror and would turn right at the

intersection assuming the bicyclist would yield. Motorist’s *not* yielding the right-of-way to bicyclists contribute to the occurrence of a RH crash.

- Bicyclist speed and the absence of a bike lane were found to be the most significant RH crash contributing factors, as self-reported by the survey respondents (71%). However, the effect of the absence of bike lanes on RH crashes was outside the scope of this research – the following driving simulator experiments were conducted on intersection approaches with bike lanes.

8.2 Driving Simulator Experiment Findings

The driving simulator experiment investigated the motorist and driving environment related causal factors of RH crashes using three different motorist performance measures: i) visual attention, ii) SA and iii) crash avoidance behavior. As such, the driving simulator experiment was divided into three components to address specific sets of research questions associated with each performance measure. All performance measures were assessed during right-turn maneuvers which occurred during latter portion of the green phase at signalized intersections. This section summarizes the findings from each component of the driving simulator experiment.

8.2.1 Visual Attention

Motorist’s visual attention was investigated during 20 right-turning scenarios with bicycle traffic using the eye-tracking technology. The objective of this study was to investigate if motorists actively search for bicyclist before turning right and to examine the influence of various adjacent traffic configurations, such as a pedestrian in the conflicting crosswalk and oncoming vehicles on motorist’s visual attention. The ATFD within a prescribed AOI was used to measure motorist’s visual attention on different targets. Findings related to each research question on motorist’s visual attention are summarized below.

Research Question 1 (RQ_1): Is the visual attention of a right-turning motorist influenced by the relative position of the adjacent bicyclist?

Findings: A statistically significant difference (p-value < 0.001) was found in the ATFDs on adjacent bicyclist between when a bicyclist was approaching from behind and when a bicyclist was riding ahead of the motorist. This finding is consistent with the finding of Falzetta (2004), where it was found that participants detected forward events more successfully than rear events, and the location effect was consistent with an attention allocation strategy that gave higher priority to the road ahead. A statistically significant difference (p-value < 0.001) was observed between the frequencies of motorist fixations on the bicyclist when the bicyclist was approaching from behind (44%) vs. when bicyclist was riding ahead (87%). Such scanning behavior places bicyclists approaching from behind in a more vulnerable situation where they are not detected by a motorist at an intersection, contributing to the occurrence of RH crashes.

A statistically significant difference was also observed for the ATFDs on conflicting pedestrian (p-value = 0.039) and oncoming vehicles (p-value = 0.002) with respect to bicyclist's position. This finding suggests that in the absence of the bicyclist in the focal vision, i.e. when the bicyclist was approaching from the behind, motorists spent more time fixating on other traffic elements immediately relevant to safe operation of the vehicle.

A statistically significant finding (p-value = 0.049) was observed in the ATFDs on the right-side mirror when the bicyclist was approaching from behind compared to when there was no bicyclist. This suggests that when a bicyclist approaching from behind was detected in the right side mirror, the motorist spent more time fixating on the right-side mirror while waiting for the bicyclist to pass at the intersection as compared to when there was no bicyclist present.

Research Question 2 (RQ_2): Is the visual attention of a right-turning motorist influenced by bicyclist's approach speed at a signalized intersection?
Findings: Bicyclist's speed had a statistically significant effect on the ATFDs directed at the RV mirror (p-value = 0.03), indicating that the total fixation duration on the RV mirror in search of bicyclist was higher when the bicyclist traveled at a lower speed.

Research Question 3 (RQ_3): Is the visual attention of a right-turning motorist influenced by the presence of oncoming left-turning traffic at the intersection?
Findings: Statistically significant differences in the ATFDs were found for crossing pedestrians (p-value < 0.001), side traffic signal (p-value = 0.02) and bicyclist riding ahead of the motorist (p-value = 0.01) between all intersections with the presence of oncoming vehicular traffic vs. no oncoming vehicular traffic.

Results suggest that in the presence of oncoming vehicular traffic, motorists spent the majority of their visual attention looking at the most significant hazards in their forward vision, i.e. oncoming left-turning traffic. These findings are consistent with previous findings of Hurwitz et al. (2013), Knodler et al. (2005), and Summala et al. (1996).

Research Question 4 (RQ_4): Is the visual attention of a right-turning motorist influenced by the presence of a pedestrian in the conflicting crosswalk?

Findings: The presence of pedestrian had statistically significant effect on the ATFDs of a bicyclist approaching from behind the motorist (p-value <0.001). Results suggest that the presence of a conflicting pedestrian in the motorist's focal vision motorists spent more time fixating on the pedestrian and failed to fixate on the bicyclist that was approaching from behind in the blind spot.

8.2.2 Situation Awareness (SA)

Motorist's three levels of SA, i.e. Level 1 SA (perception), Level 2 SA (comprehension), Level 3 SA (projection) and the overall SA was measured immediately after six right-turning scenarios. The objective was to investigate if right-turning motorists had the knowledge needed for the driving subtask of monitoring and hazard avoidance, i.e. the knowledge of the traffic around them in order to successfully complete a safe right-turn maneuver at a signalized intersection during the latter portion of the green phase. Findings of each research question on this performance measure are listed below.

Research Question 5 (RQ_5): Does the relative position of a through-moving bicyclist in the adjacent bicycle lane influence right-turning motorists' SA during the latter portion of green phase at an intersection?

Findings: The relative position of an adjacent bicyclist significantly influenced right-turning motorist's overall SA (p-value = 0.002) and Level 2 SA (p-value = 0.016). Participant's overall SA scores and Level 2 SA scores were lower when bicyclists were approaching from behind compared to when bicyclists were riding ahead of the motorist indicating that motorists were less aware of the presence of bicyclists when the bicyclist was approaching from behind in motorist's blind spot. This finding reinforces the findings of Gugerty (1997), Falzetta (2004) and Crundall et al. (1999), who summarized that motorists focus majority of their attention on nearby cars and cars in front of them that were perceived most likely to pose a hazard and focused less attention on cars in the blind spot or in peripheral vision. Also it demands greater working memory load to track an object in the blind spot (Gugerty, 1997).

Research Question 6 (RQ_6): Does the presence of oncoming left-turning traffic influence right-turning motorists' SA during the latter portion of green phase at an intersection?

Findings: There was no significant effect of the presence of the oncoming left-turning traffic on right-turning motorist's overall SA (p-value>0.05).

Research Question 7 (RQ_7): Does the combination of the presence of oncoming left-turning traffic and the relative position of bicyclist influence right-turning motorists' SA during the latter portion of green phase at an intersection?

Findings: Motorist's Level 1 SA (perception) of the surrounding traffic significantly degraded when oncoming vehicles were present and the bicyclist was approaching from behind (p-value = 0.025). This observation could be explained by the cue utilization study, which evaluated the extent to which participants' behavior is constrained by environmental cues (Brunswick, 1956; Hursch et al., 1964). In this experimental scenario, motorist's focal hazard-perception tasks competed for limited cognitive resources and eventually decreased the frequency of detecting peripheral visual events, i.e. the bicyclist approaching from behind leading to poor Level 1 SA – a finding consistent with that of Crundall et al. (1999).

However motorist's projection (Level 3 SA) of the driving environment significantly degraded when the bicyclist was riding ahead of the motorist and oncoming vehicles were present (p-value < 0.001). This can be explained by the limitation of motorist's attentional capacity. With excessive demands on attention due to multiple environmental stimuli (e.g., presence of a bicycle and oncoming cars) motorist's task performance declined as evidenced by reduced SA.

Research Question 8 (RQ8): Is there any correlation between the number of correct responses and the crash avoidance behavior of right-turning motorists?

Findings: Since perception and detection of the hazard is an important criterion of crash avoidance, a Point biserial correlation analysis was conducted between participant's Level 1 SA score and crash occurrence. A significant negative linear association was found between the Level 1 SA score and crash occurrence (r_{pbi}= -0.3, p-value=0.043), indicating that as a whole motorist having lower Level 1 SA scores were more likely to be involved in a crash. This finding suggests that a common cause of observed crashes was failure to detect the presence of an adjacent bicyclist before turning right during the latter portion of green phase at intersections.

8.2.3 Crash Avoidance

The objective of this study was to assess if motorists can detect the potential hazard, i.e. the bicyclist in the adjacent bicycle lane in a timely manner and avoid a crash with the bicyclist while performing a right-turn during the latter portion of the green phase. Motorist's crash avoidance was measured as the number of motorists who could not avoid crashes with a through-moving bicyclist while turning right at 21 simulated signalized intersections. Findings of each research question on this performance measure are listed below.

Research Question 9 (RQ_9): What are the driving environment causal factors leading to the occurrence of a RH crash during the latter portion of a green phase?

Findings: Among 51 participants completing total of 1,071 right turns, 23 participants could not avoid a crash with a bicyclist in 26 RH crash scenarios. Relative position of a bicyclist, bicyclist's speed, and the presence of an oncoming vehicle were found to have a statistically significant effect on crashes.

Twenty-four crashes occurred with the bicyclist approaching from behind in the motorist's blind spot and 21 of those crashes occurred in the presence of oncoming left-turning traffic. This finding is consistent with the finding of motorist's visual attention in Chapter 5 and SA in Chapter 6, which stated that when motorists' dynamic working memory is overloaded due to the presence of adjacent traffic on the roadway, they focus their attention on the most immediate hazard in their forward visual field, i.e. the oncoming traffic and did not shift their attention to the rear and side-view mirrors to check for the presence of a bicyclist in their blind zone. Again, in 23 observed crashes, bicyclists were approaching the intersection at higher speed, i.e. at 16 mph. This finding is also consistent with the findings of online survey in Chapter 2, where higher speed of bicyclists was found to be a significant factor contributing to crashes as reported by the survey respondents.

Research Question 10 (RQ_{10}): What are the motorist related factors that contribute to the occurrence of a RH crash during the latter portion of a green phase?

Findings: Male participants were involved in more RH crashes than female participants (p-value=0.02). A binary logistic regression was conducted to assess the probability of a RH crash occurrence given the demographics of participants in this experiment also revealed that gender was a significant predictor of crash involvement.

Motorist's inadequate surveillance was found to be the major cause of observed RH crashes, where the motorist did not check for the bicyclist in the mirror before turning in most cases (66%) or looked but did not see (inattention blindness) in some cases (15%). Some RH crashes (19%) were caused due to motorist's poor projection where the conflicting bicyclist was detected, but the motorist did not yield the right-of-way. This finding reinforces the finding from motorist’s SA in Chapter 6, which suggested that a common cause of the observed crashes was due to the failure of detecting the adjacent bicyclist before turning right at the latter portion of green phase at intersections.

This study also investigated near-crash events where a collision between the right-turning motorist and through-moving bicyclist was imminent if their trajectories remained unchanged. The near-crash events were measured using a TTC threshold value of 1.5 seconds. Investigation of near- crash incidents revealed that among 51 participants completing total 408 right turns, 20 were involved in 26 severe near-crash events having TTC value less than or equal to 1.5 seconds. Inadequate surveillance was found to be the cause of most near-crash incidents. Eleven of these 20 participants were also found to ultimately have a crash in the experiment.

8.2.4 Summary

In summary, the findings from each of the three performance measures of this experiment indicate that motorists detected a bicyclist riding in their forward field of view more successfully than a bicyclist approaching from behind in the motorist’s blind spot.

Therefore, the bicyclist approaching from behind the motorist is the most vulnerable to a right-turning motorist and failure to detect this bicyclist may lead to a RH crash. In the presence of oncoming vehicular traffic, motorists spent the majority of their visual attention looking at the oncoming traffic that posed immediate hazard to them and failed to detect a bicyclist approaching from behind in their peripheral vision due to the limitation of motorist's attentional capacity. As such, the presence of oncoming vehicular traffic is likely to increase the risk of RH crash. Results also indicated that higher speed bicyclists are likely to contribute to the risk of RH crash. Inadequate surveillance was found to be the leading cause of the observed RH crashes. Therefore, the author concludes that this research contributes to the gap in the body of knowledge by presenting a better understanding of the causal factors of RH crashes during the latter portion of the green phase. Table 8-1 presents a complete summary of the research questions and the corresponding findings of this experiment.

Table 8-1: Research Questions and Findings

Research Objective RO. 1	**Investigation of motorists' *visual attention* to assess if right-turning motorists actively search for bicyclists at a signalized intersection to avoid the occurrence of RH crash**		
Research Question - Visual Attention		*Yes/No*	*Significant Effect on ATFDs on:*
RQ1. Is the visual attention of a right-turning motorist influenced by the relative position of the adjacent bicyclist?		Yes	i) Bicyclist, ii) Crossing Pedestrian, iii) Oncoming Traffic, iv) Right-side mirror
RQ2. Is the visual attention of a right-turning motorist influenced by bicyclist's approaching speeds at a signalized intersection?		Yes	i) Rear-view mirror
RQ3. Is the visual attention of a right-turning motorist influenced by the presence of oncoming traffic at the intersection?		Yes	i) Crossing Pedestrians, ii) Side traffic signal, iii) Bicyclist riding ahead
RQ4. Is the visual search pattern of a right-turning motorist influenced by the presence of conflicting pedestrian crossing the intersection?		Yes	i) Bicyclist approaching from behind
Research Objective RO. 2	**Assessment of motorists' *SA* in the driving environment to determine if right-turning motorists had the knowledge needed for the driving subtask of monitoring and hazard avoidance to avoid the occurrence of RH crash**		
Research Question - SA		*Yes/No*	*Motorist SA*
RQ5. Does the relative position of an adjacent bicyclist influence right-turning motorists' SA at a signalized intersection?		Yes	Overall SA
RQ6. Does the presence of oncoming traffic influence right-turning motorists' SA at a signalized intersection?		No	N/A
RQ7. Do the combination of the presence of oncoming traffic and bicyclist relative position influence right-turning motorists' SA at a signalized intersection?		Yes	Level 1 and Level 3 SA
RQ8. Is there any correlation between the number of correct responses and crash avoidance behavior of right-turning motorist in a driving simulator environment?		Yes	Level 1 SA and crash
Research Objective RO. 3	**Assessment of motorists' *crash avoidance behavior* to determine if timely detection of bicyclists and appropriate decision making can avoid the occurrence of a RH crash**		
Research Question)- Crash Avoidance		*Factors*	
RQ8. What are the driving environment causal factors leading to the occurrence of a RH crash at the latter portion of a green phase observed in the simulated intersections?		i) Relative position of a bicyclist, ii) bicyclist's speed, iii) the presence of an oncoming vehicle	
RQ9. Does motorists' SA deteriorate due to higher volume of adjacent traffic (possibly contributing to right-hook crashes)		i) Gender, ii) Inadequate Surveillance, iii) Poor projection	

8.3 Future Work

This research provides valuable insights on the causal factors of RH crashes during the latter portion of the green phase. Additional work is recommended to address the limitations of this study and potential RH crashes mitigation strategies are proposed as guided by the findings from this research.

- One of the fundamental limitation of within-subject design is fatigue effects that can cause participant’s performance to decline as the experiment goes on. There is the possibility that participants might get tired or bored as the experiment progressed. Also, repeated right-turning maneuvers pose the threat of inducing simulator sickness more frequently than through movements in simulated driving. Therefore, to reduce the risk of fatigue effect and simulator sickness, the experiment could be conducted in two trials on two different days.
- Although many studies found the effect of driving experience on motorist’s visual attention in the driving simulator experiment (Underwood et al., 2005; Pradhan et al., 2005), this study did not find any significant difference on motorist’s performance with respect to driving experience. A larger and more diverse sample may indicate some significance of on motorist’s visual attention and crash avoidance.
- Additional variables could be included in the experiment to determine their effects on the occurrence of RH crashes, for example the conspicuity of bicyclist, and time of the day.
- To reinforce the causal factors found in this study, motorist’s behavior exhibited during the simulator experiment should be validated through field-based

observational study at RH crash prone intersections or through a naturalistic driving study.

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Appendix A: Online Survey Questionnaire

The aim of this survey is to gain insight on the behaviors of drivers and bicyclists at intersections in Oregon. Findings from this survey will contribute to improved intersection safety at intersections in Oregon.

The survey will take approximately 10 minutes to complete. Your participation in this survey is completely voluntary.

Your responses will be strictly confidential and data from this survey will be reported only in the aggregate. Your information will be coded and will remain confidential. However, the security and confidentiality of information collected from you online cannot be guaranteed. Confidentiality will be kept to the extent permitted by the technology being used. Information collected online can be intercepted, corrupted, lost, destroyed, arrive late or incomplete, or contain viruses.

There are no foreseeable risks to participating in this survey. There is no direct benefit, but the results from this survey will help to gain insight on the behaviors of drivers and bicyclists at intersections.

If you have any questions about this research project, please contact David S. Hurwitz, Assistant Professor, School of Civil and Construction Engineering at (541) 737-9242 or by email at david.hurwitz@oregonstate.edu.

If you have questions about your rights or welfare as a participant, please contact the Oregon State University Institutional Review Board (IRB) Office, at (541) 737-8008 or by email at IRB@oregonstate.edu.

Thank you for your participation.

Please answer the following questions.

Do you have a current:

	Yes	No
Driver's license	○	○
Transit pass	○	○
Carshare Membership	○	○

What is your gender?

○ Male
○ Female

How old are you (years)?

[ ]

Do you consider yourself (select all that apply):

- American Indian or Alaska Native
- Asian
- Black or African American
- Hispanic or Latino
- White or Caucasian
- Other

How many working motor vehicles does your household own or lease (Do not include motorhomes)?

How many working bicycles does your household own?

How many years of school have you completed?

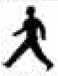
- Some high school or less
- High school diploma or GED
- Some College
- Trade/Vocational School
- Associate Degree
- Four-year college degree or more
- Other, please specify:

Where do you live?

What percent of your total weekly travel involves the following transportation types (please slide the bar)?

	0					50					100	
	0	10	20	30	40	50	60	70	80	90	100	
Car/motor vehicle/truck (including carpool)												0
Public transportation (bus, street car, etc.)												0
Bicycle												0
Walk												0
Motorcycle												0
Other, please specify												0
Total:												**0**

Please indicate if you agree or disagree with the following statements:

	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree
 Most drivers follow the rules of the road	○	○	○	○	○
Most drivers are predictable	○	○	○	○	○
 Most bicyclists follow the rules of the road	○	○	○	○	○
Most bicyclists are predictable	○	○	○	○	○
 Most pedestrians follow the rules of the road	○	○	○	○	○
Most pedestrians are predictable	○	○	○	○	○

Have you ridden a bicycle in the past year?

○ Yes

○ No

Regardless of whether you currently bicycle in all of the following situations, please consider how comfortable you would be riding a bicycle in each place:

	Very uncomfortable	Somewhat Uncomfortable	Neutral	Somewhat Comfortable	Very comfortable
 (A) On a path or trail separate from the street					
 (B) On a commercial Street with two lanes of traffic in each direction, with traffic speeds of 35 miles per hour, on-street car parking, and no bikeway					
 (C) On a similar street to (B), but with a striped bikeway added					
 (D) On a similar street to (B),with a painted buffer and parked cars					
 (E)....With a 2-3 foot buffer and plastic flexposts					
 (F) . . .With planters separating the bikeway					
 (G). . . With a raised concrete curb					
 (E)....With Bike box with bike lane extension					

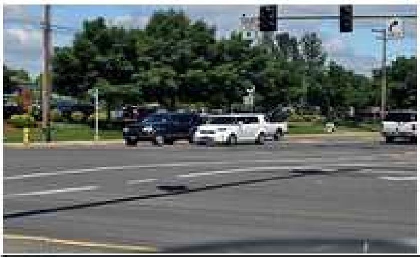
While riding a bicycle, suppose you approach an intersection and you want to go straight crossing the intersection. What would you do if you are presented with a traffic signal showing a green light at the intersection (check one):

- Always scan left, right and left again, and pass when it is safe
- Scan occasionally, but never yield for vehicle assuming it will yield
- Without scanning, quickly ride your bicycle assuming vehicles will yield
- Do not know
- Other, please describe briefly:

While riding a bicycle, suppose you are approaching a traffic signal and a car is going to turn right immediately from your left (figure below). **If you want to proceed through the intersection , you would:**

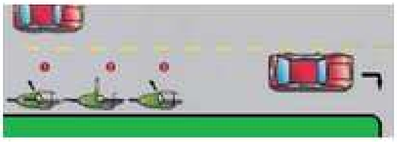
- Maintain your speed and try to pass the vehicle assuming the driver will yield
- Accelerate to pass the vehicle before it turns
- Slow down and yield for the vehicle to turn
- Do not know
- Other, please specify:

While riding bicycle in a bike lane, assume you need to stop in response to a red traffic light at an intersection with a line of stopped vehicles, as shown in the figure. **Where would you stop (check one)?**



- (a) Behind the first stopped vehicle
- (b) In front of the first stopped vehicle
- (c) Anywhere in bike lane
- (d) Just right to the first stopped car
- (e) a+b
- (f) Other, please specify:

While riding a bicycle, **what would you do if you want to pass a right-turning vehicle at an intersection**, as shown in the figure (check one).



- (a) Pass the vehicle on the right at intersection
- (b) Pass the vehicle on the left at intersection
- (c) Stay behind the vehicle to let it turn
- (d) b+c
- (e) Do not know
- (f) Other, please specify:

Have you driven a car in the past year?

- Yes
- No

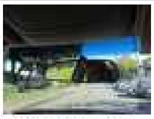
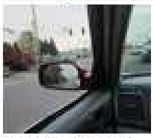
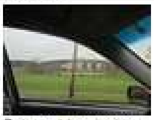
While driving a car, when you make a right turn on a green light at an intersection (Figure below), please tell us how frequent you perform the following steps:

	Never	Sometimes	Often	Always
Look for the oncoming vehicular traffic before making the turn	○	○	○	○
Look for the pedestrian crossing the street before making the turn	○	○	○	○
Look for the bicyclist(s) to your right before making the turn	○	○	○	○
Look for the traffic signal status before making the turn	○	○	○	○
Other, please specify:	○	○	○	○

Before turning right at an intersection (in the previous figure), which of the following you think is/are important (check all that apply):

- Use your right turn signal
- Check for the bicyclist(s) in the blind spot on your right
- Check for the bicyclist(s) in the blind spot to your left
- Be alert for bicyclist(s) who may ride up on the right side of your vehicle
- All of the above
- None of the above

When you make a right turn at an intersection, how frequently do you check the following spots in order to detect ***the presence of bicyclists***?

	Never	Rarely	Sometimes	Often	All the time
 Rear view mirror	○	○	○	○	○
 Passenger side mirror	○	○	○	○	○
 Driver side mirror	○	○	○	○	○
 Front Passenger side window	○	○	○	○	○
 Driver side window	○	○	○	○	○
 Rear passenger side window	○	○	○	○	○
 Looking over shoulder	○	○	○	○	○
Other, please specify	○	○	○	○	○

Suppose you detect a bicyclist in the passenger side mirror just before turning right during a green light at an intersection as shown in the figure. **What would you do in such condition (check one)?**

- Yield and let the bicyclist pass
- Accelerate and make turn before the bicyclists reach the intersection
- Make your turn at your current speed assuming the bicyclist would yield to you
- Other, please specify:

While approaching an intersection you see a bicyclist riding ahead to the right of your vehicle as shown in the figure. **In order to turn right, you would** (check one):

- Accelerate past the bicyclist and turn right
- Slow down and let the bicyclist pass before you turn
- Stop and let the bicyclist pass
- None of the above
- Other, please specify:

Have you ever been involved in any crash or near-crash with other people or objects on the road?

**Near-crash: a conflict situation requiring a rapid, severe, evasive maneuver to avoid a crash (NHTSA, 2006).*

- Yes, a crash
- Yes, a near-crash
- No, neither
- Both

Please briefly describe those crash/ near crash:

	You were	Occur at:	How many?	Were reported to police?	Fatal/ non-fatal
			#		
Crash					
Near crash					

Please provide a brief description of those crash(es) you were involved in while riding a bicycle or driving a car.

Have you ever heard the phrase, "right-hook crash"?

- Yes
- No

A right-hook crash describes a type of bicycle-motor vehicle crash at intersection that occurs between (check one):

- A left-turning vehicle and a through moving bicyclist
- A right-turning vehicle and a through moving bicyclist
- A left-turning vehicle and a right-turning bicyclist
- Do not know

Have you ever been involved in a right-hook crash while driving a vehicle or riding a bicycle?

*Right-hook crash: between a right-turning vehicle and through moving bicyclist at intersection

- Yes
- No

Were you driving a car or riding a bicycle when the right hook crash occurred?

- Riding bicycle
- Driving car

What type of intersection did the right-hook crash occur at?

	Number of crashes	Time of day
	#	
Intersection with a traffic signal		
Intersection with a STOP sign		
Driveway		
Parking lot		
Do Not know		

What type of bicycle treatment was present at the site of crash?

A commercial street with on-street car parking, and ***NO* bike lane**

A commercial street with **a striped bike lane**

A commercial street with a **physically separated bike lane**

A commercial street with **a painted buffer and parked cars**

Other, please specify

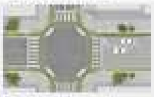
Which of the following factors you think, **increase the risk of a crash** between a through moving bicyclist and right-turning motor vehicle (check all that apply):

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
Volume of oncoming vehicular traffic	○	○	○	○	○
Absence of bike lane	○	○	○	○	○
Presence of pedestrian(s)	○	○	○	○	○
Volume of bicyclist in adjacent lane	○	○	○	○	○
High Speed of bicyclists	○	○	○	○	○
Downhill grade	○	○	○	○	○
Other, please specify	○	○	○	○	○

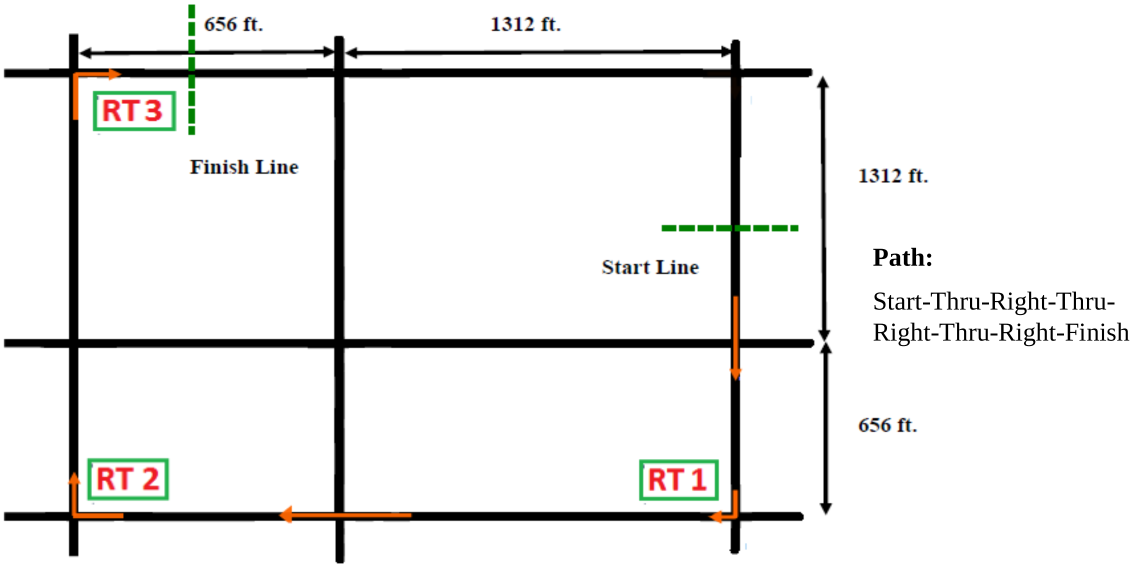
What do you think a *motorist* should do when presented with the following signal (circled in red) at an intersection:

If presented with the signal **(circled in red)** at an intersection in the previous figure, **what do you think a *bicyclist* should do** :

Please share your opinions about the following intersection treatment you think will ***be effective to reduce right-hook crashes at an intersection***?

	Very Ineffective	Ineffective	No opinion	Effective	Very Effective
 Green pavement conflict marking					
 Bike box with bike lane extension					
 Specific bicycle signal head					
 Shared lane					
 Combined bicycle lane/turn lane					
 Dutch Intersection Design with Cycle Tracks * In this design, the					

Appendix B: Grid Layouts



Layout A3-Grid 6

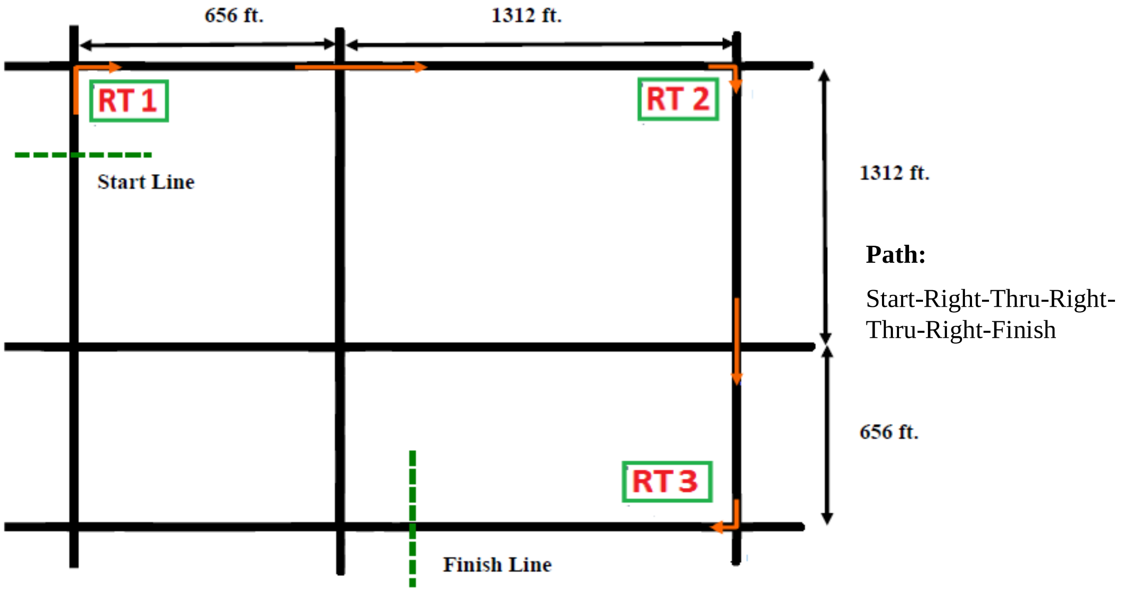


Figure: Different Grid Layout of Three Right-turning Intersections – different Start and Finish Point

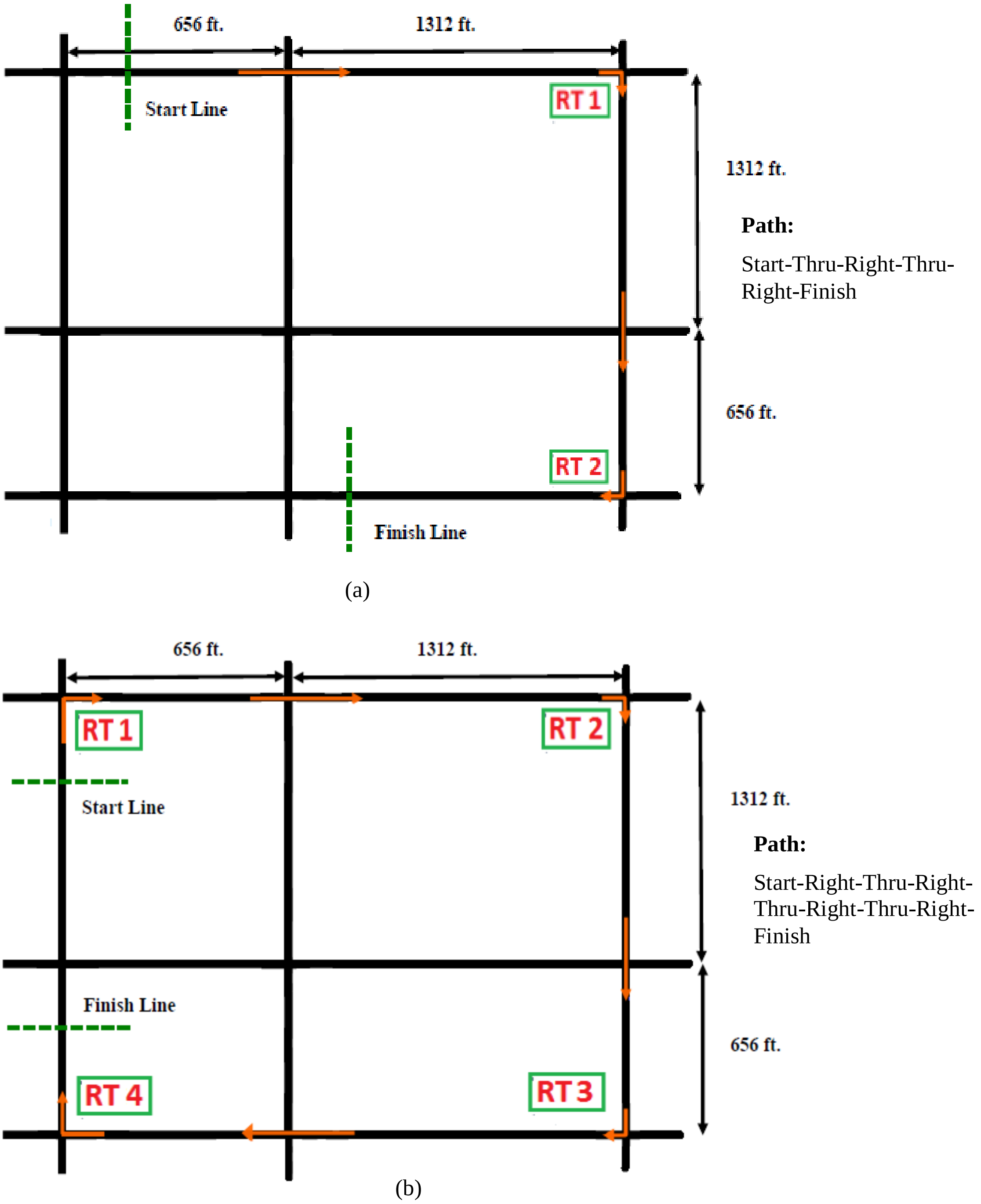
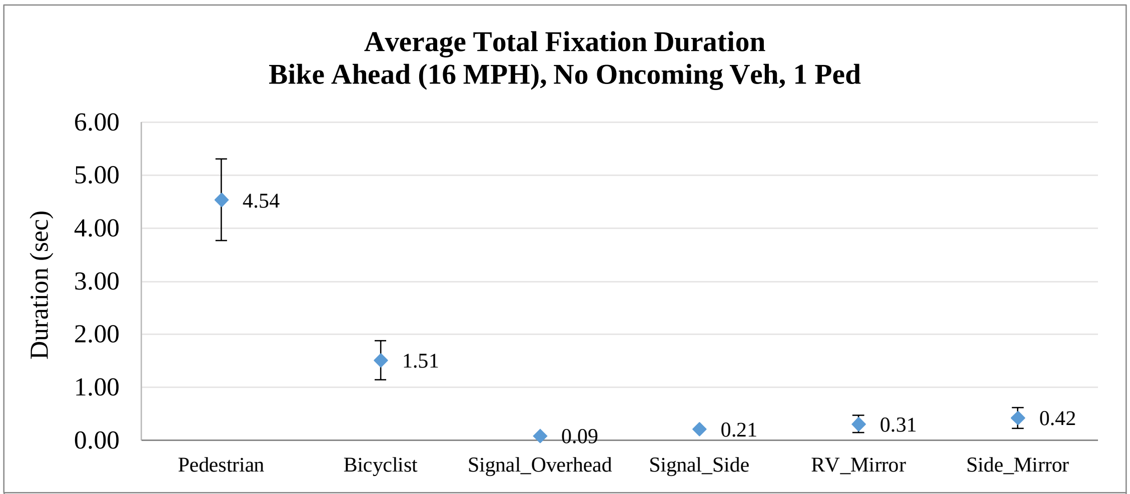
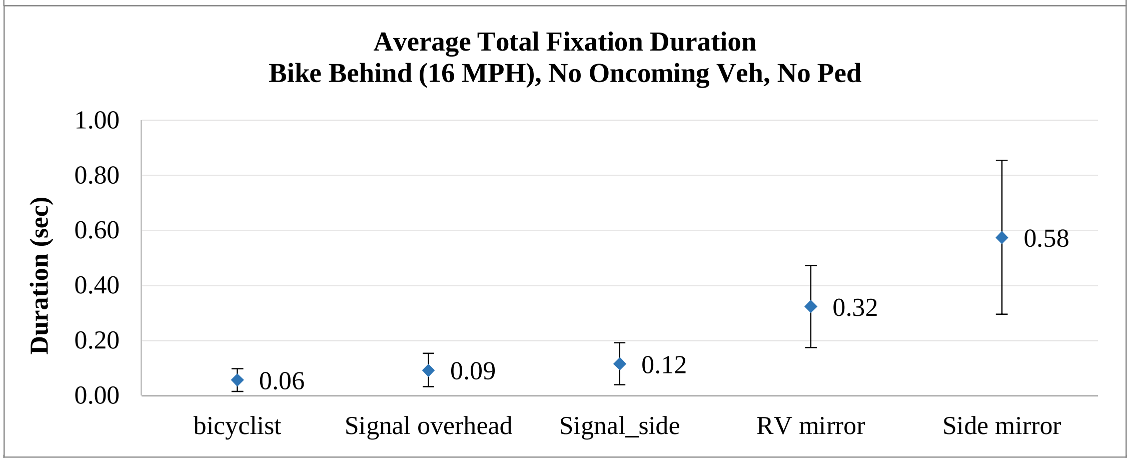
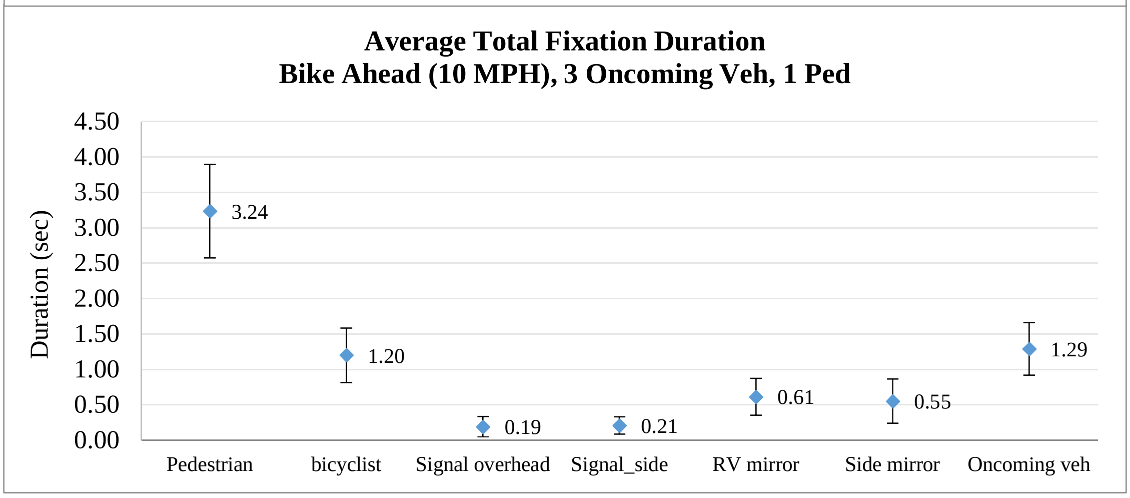


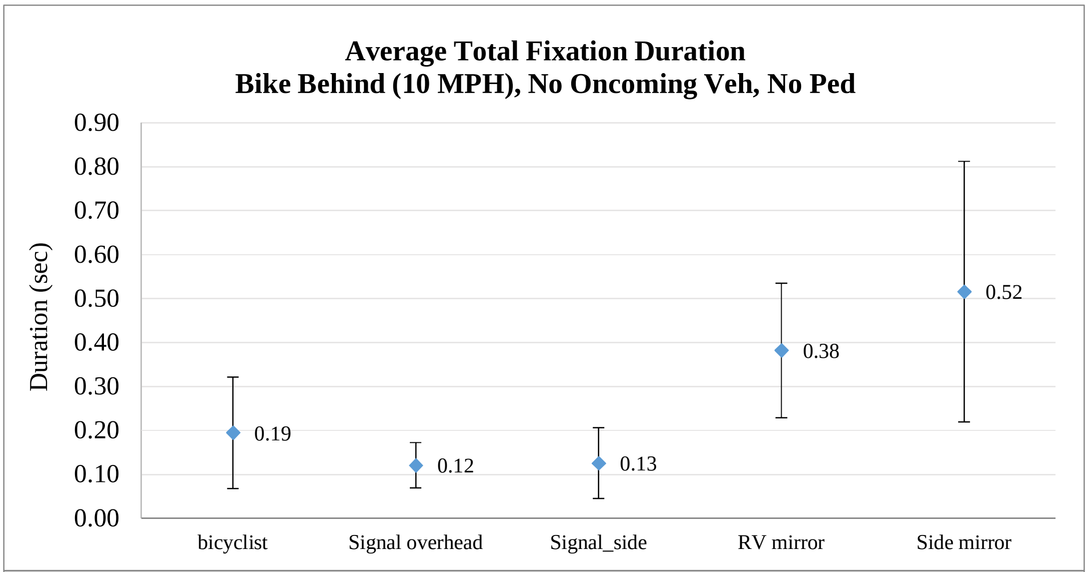
Figure: Grid Layout of (a) Two Right-turning Intersections – Grid 5 and (b) Four Right-turning Intersections – Grid 3

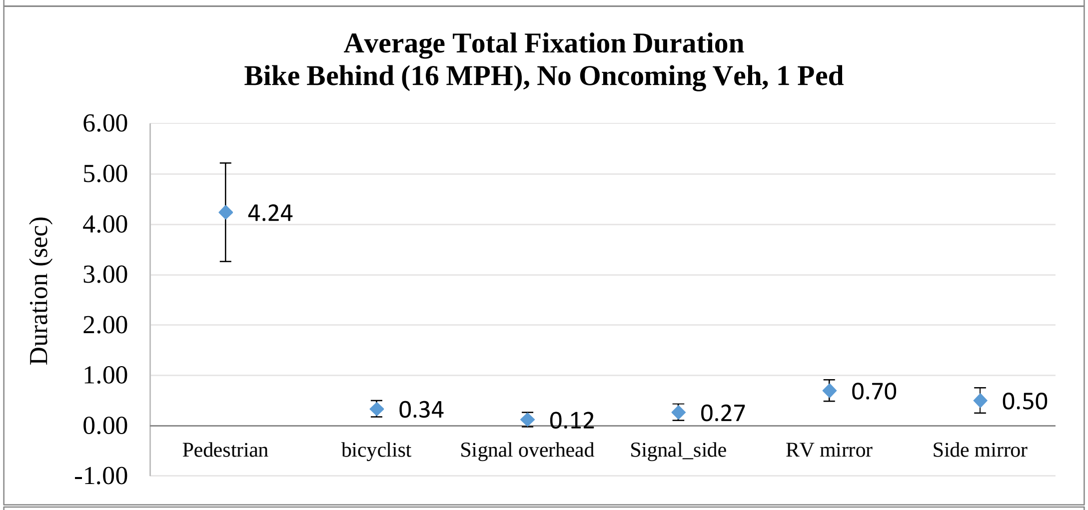
Appendix C: Average Total Fixation Duration (ATFD) with 95% CI for all intersections

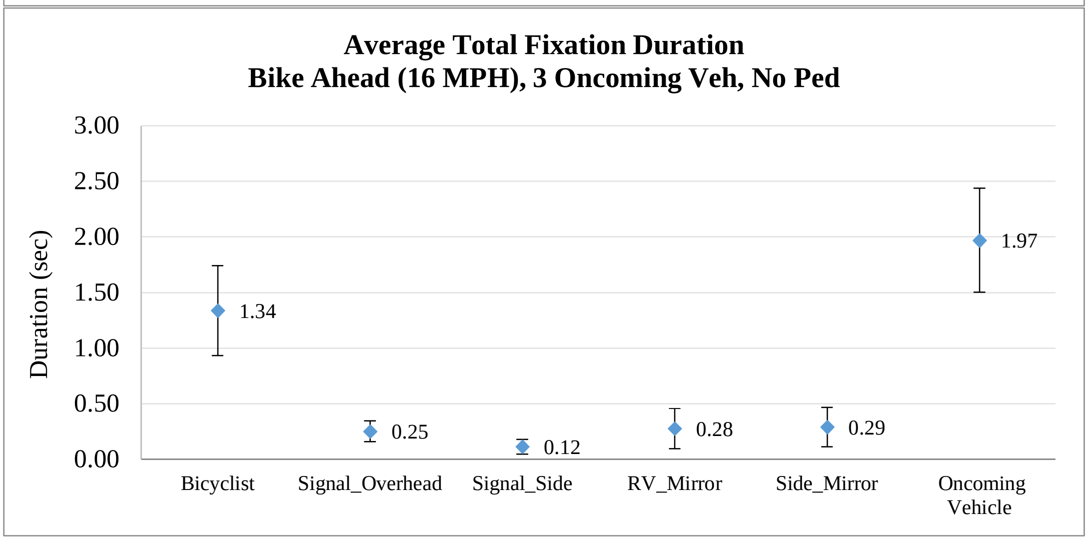


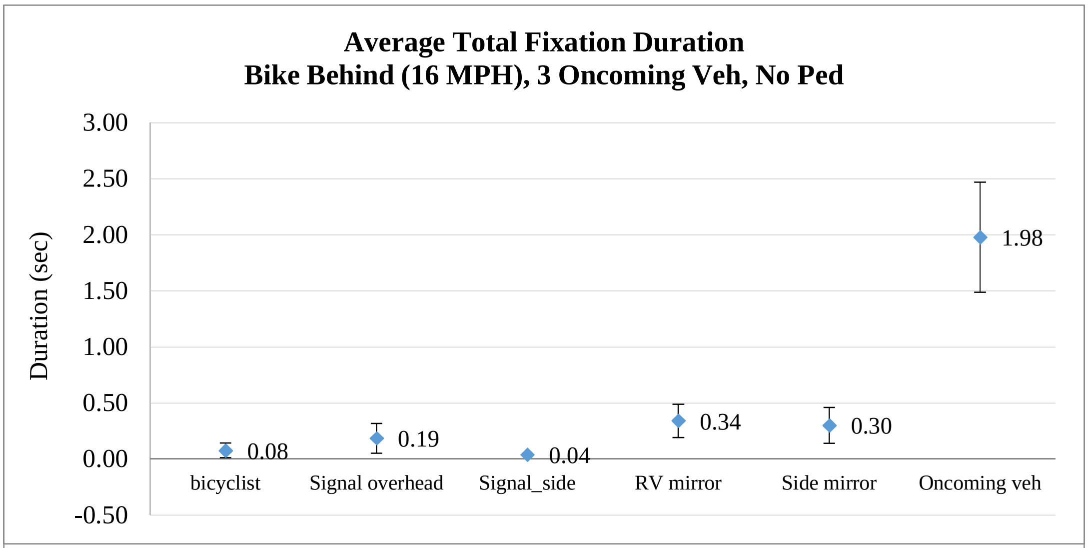


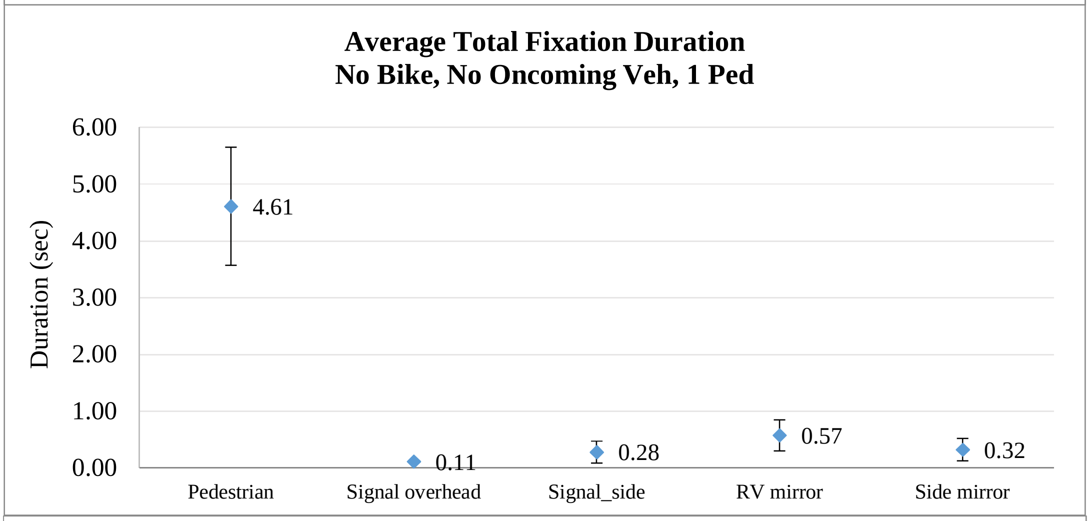


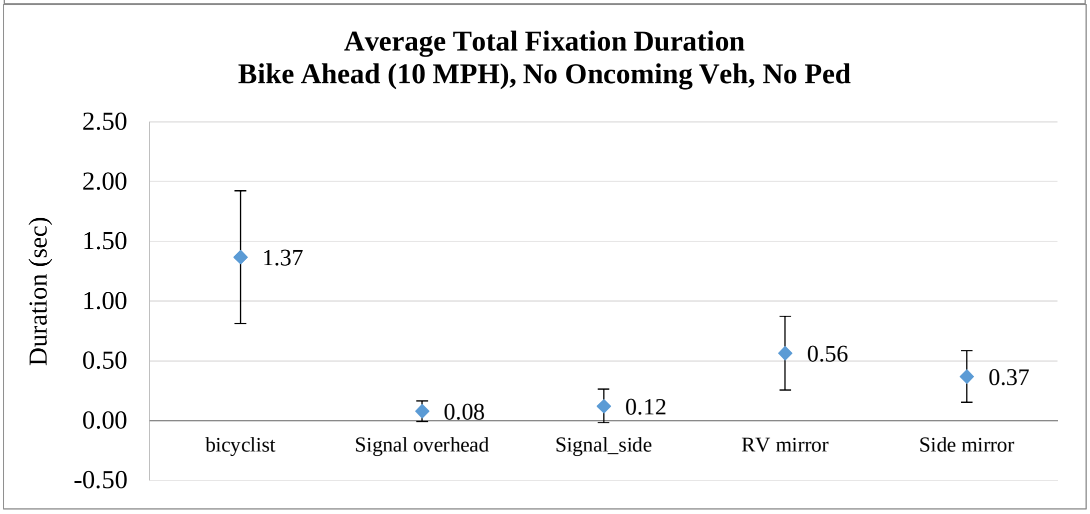

Average Total Fixation Duration
Bike Behind (10 MPH), No Oncoming Veh, No Ped
Duration (sec)
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.19
0.12
0.13
0.38
0.52
bicyclist
Signal overhead
Signal_side
RV mirror
Side mirror

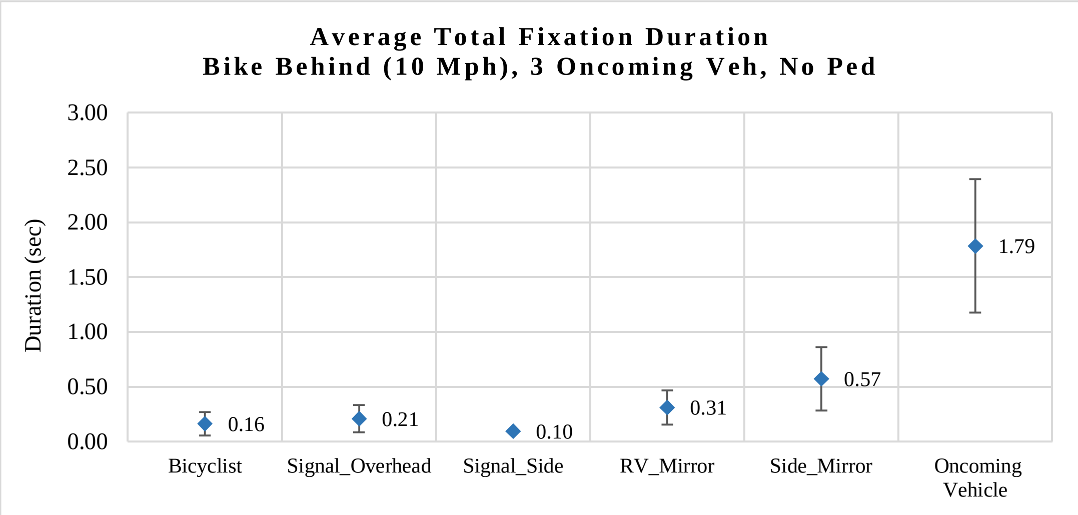

Average Total Fixation Duration
Bike Behind (16 MPH), No Oncoming Veh, 1 Ped
Duration (sec)
6.00
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
4.24
0.34
0.12
0.27
0.70
0.50
Pedestrian
bicyclist
Signal overhead
Signal_side
RV mirror
Side mirror

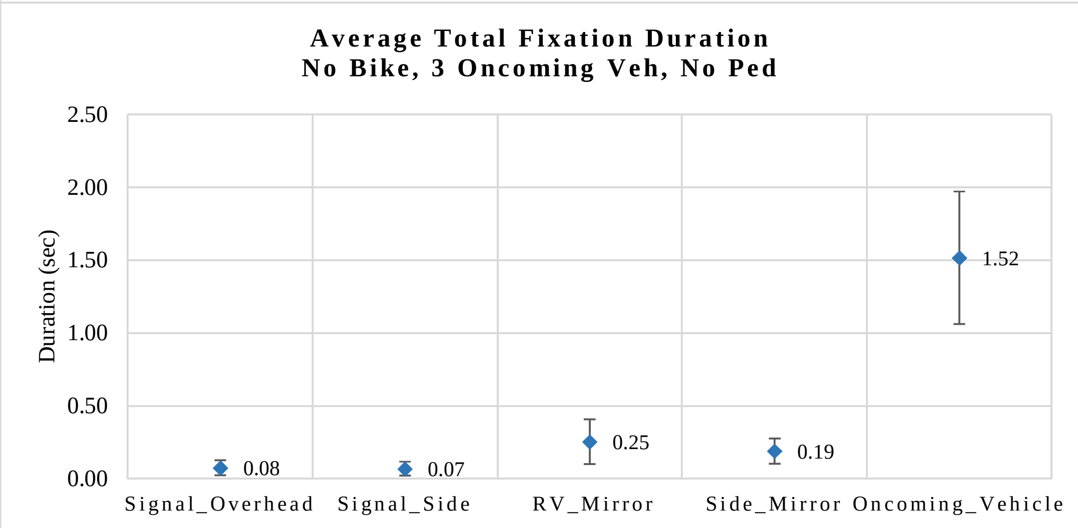

Average Total Fixation Duration
Bike Ahead (16 MPH), 3 Oncoming Veh, No Ped
Duration (sec)
3.00
2.50
2.00
1.50
1.00
0.50
0.00
1.34
0.25
0.12
0.28
0.29
1.97
Bicyclist
Signal_Overhead
Signal_Side
RV_Mirror
Side_Mirror
Oncoming Vehicle

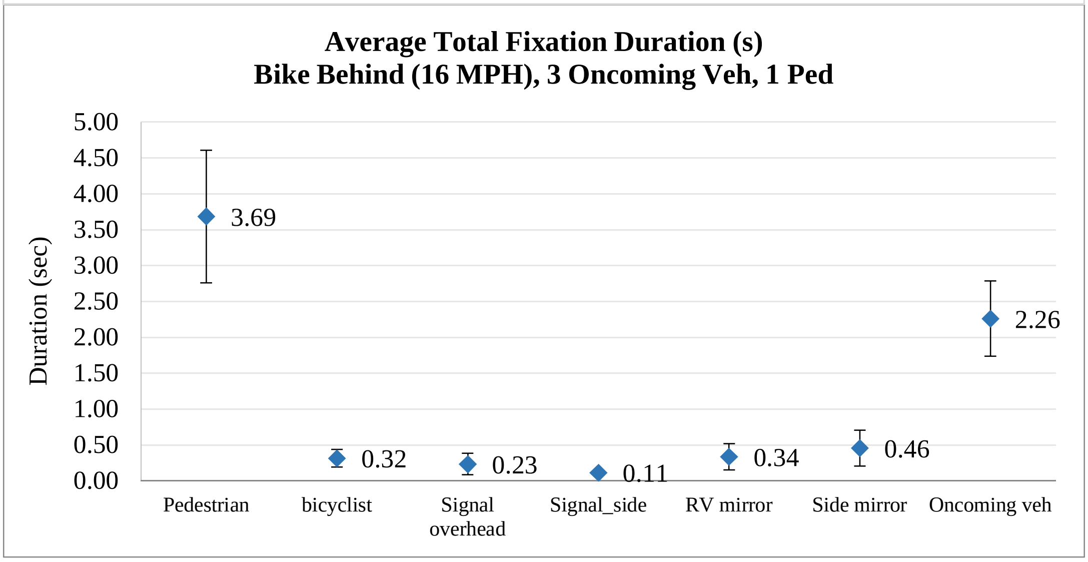

Average Total Fixation Duration
Bike Behind (16 MPH), 3 Oncoming Veh, No Ped
Duration (sec)
3.00
2.50
2.00
1.50
1.00
0.50
0.00
-0.50
0.08
0.19
0.04
0.34
0.30
1.98
bicyclist
Signal overhead
Signal_side
RV mirror
Side mirror
Oncoming veh

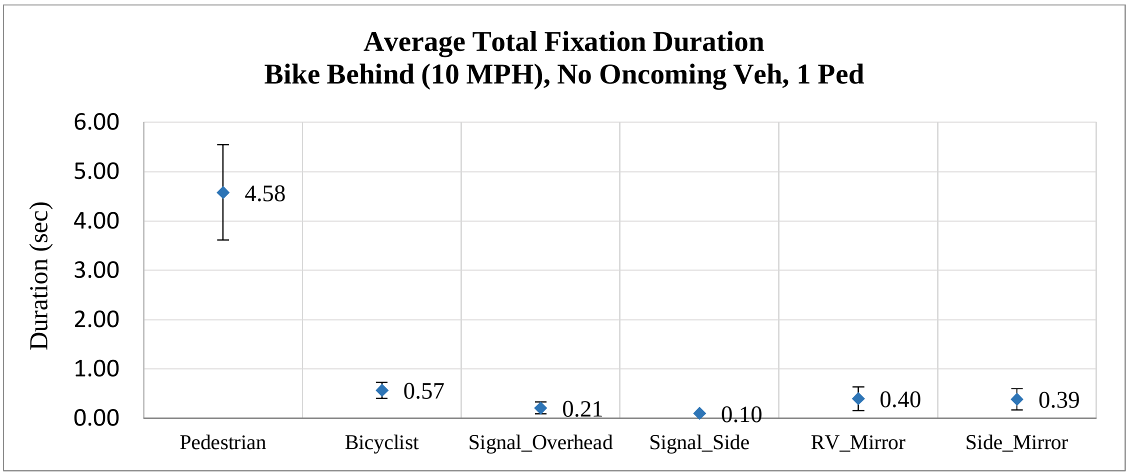

Average Total Fixation Duration
No Bike, No Oncoming Veh, 1 Ped
Duration (sec)
6.00
5.00
4.00
3.00
2.00
1.00
0.00
4.61
0.11
0.28
0.57
0.32
Pedestrian
Signal overhead
Signal_side
RV mirror
Side mirror

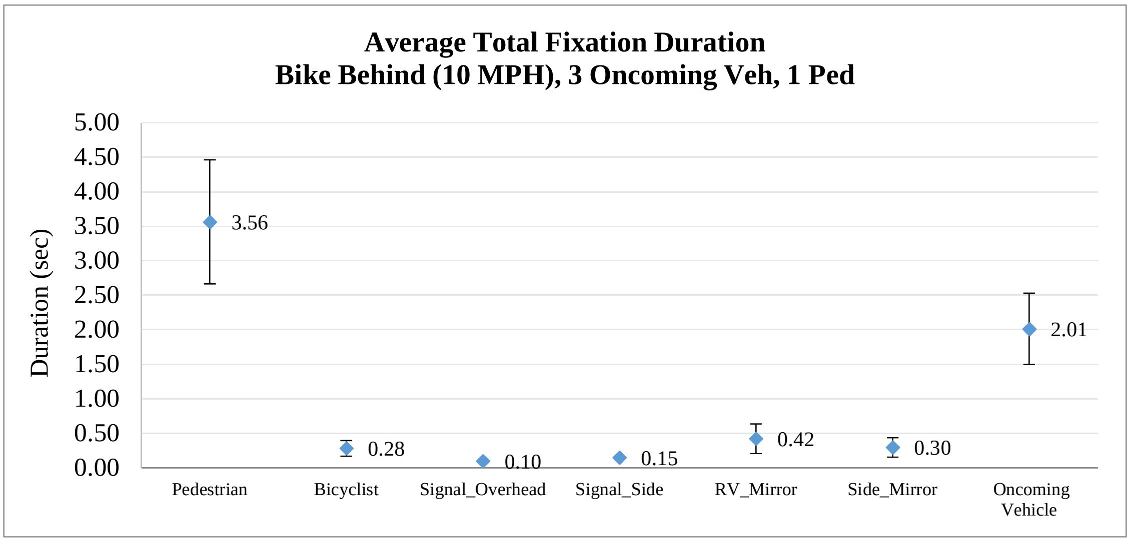

Average Total Fixation Duration
Bike Ahead (10 MPH), No Oncoming Veh, No Ped
Duration (sec)
2.50
2.00
1.50
1.00
0.50
0.00
-0.50
1.37
0.08
0.12
0.56
0.37
bicyclist
Signal overhead
Signal_side
RV mirror
Side mirror

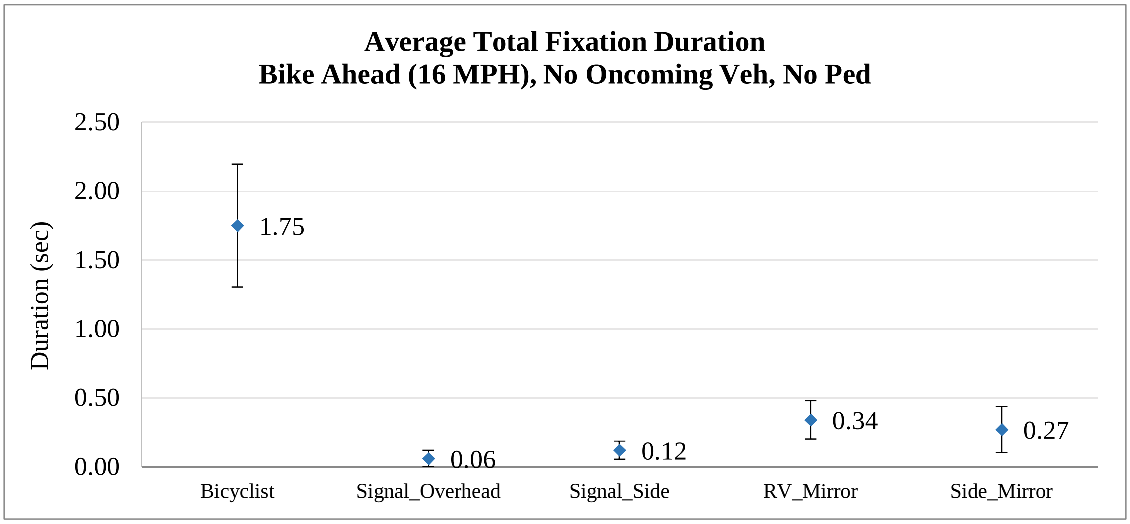

Average Total Fixation Duration
Bike Behind (10 Mph), 3 Oncoming Veh, No Ped
Duration (sec)
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0.16
0.21
0.10
0.31
0.57
1.79
Bicyclist
Signal_Overhead
Signal_Side
RV_Mirror
Side_Mirror
Oncoming Vehicle

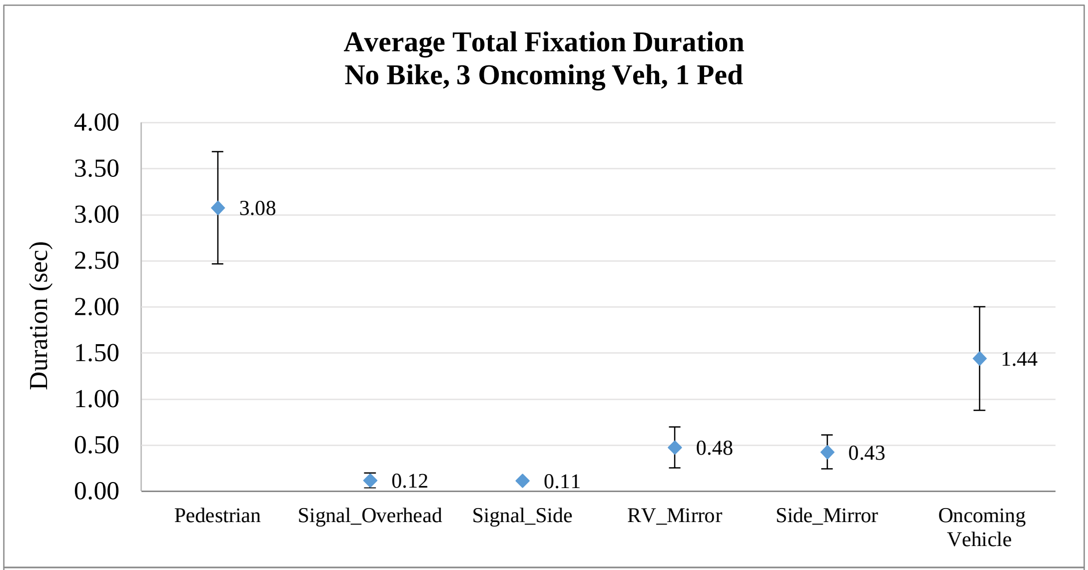

Average Total Fixation Duration
No Bike, 3 Oncoming Veh, No Ped
Duration (sec)
2.50
2.00
1.50
1.00
0.50
0.00
0.08
0.07
0.25
0.19
1.52
Signal_Overhead
Signal_Side
RV_Mirror
Side_Mirror
Oncoming_Vehicle

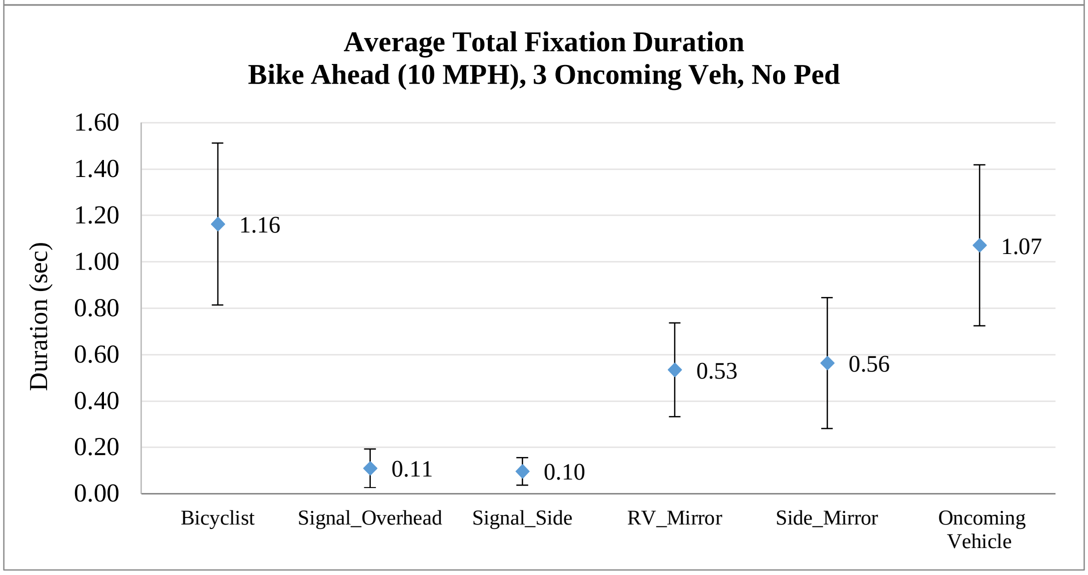

Average Total Fixation Duration (s)
Bike Behind (16 MPH), 3 Oncoming Veh, 1 Ped
Duration (sec)
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
3.69
0.32
0.23
0.11
0.34
0.46
2.26
Pedestrian
bicyclist
Signal overhead
Signal_side
RV mirror
Side mirror
Oncoming veh


Average Total Fixation Duration
Bike Behind (10 MPH), No Oncoming Veh, 1 Ped
Duration (sec)
6.00
5.00
4.00
3.00
2.00
1.00
0.00
4.58
0.57
0.21
0.10
0.40
0.39
Pedestrian
Bicyclist
Signal_Overhead
Signal_Side
RV_Mirror
Side_Mirror


Average Total Fixation Duration
Bike Behind (10 MPH), 3 Oncoming Veh, 1 Ped
Duration (sec)
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
3.56
0.28
0.10
0.15
0.42
0.30
2.01
Pedestrian
Bicyclist
Signal_Overhead
Signal_Side
RV_Mirror
Side_Mirror
Oncoming Vehicle


Average Total Fixation Duration
Bike Ahead (16 MPH), No Oncoming Veh, No Ped
Duration (sec)
2.50
2.00
1.50
1.00
0.50
0.00
1.75
0.06
0.12
0.34
0.27
Bicyclist
Signal_Overhead
Signal_Side
RV_Mirror
Side_Mirror


Average Total Fixation Duration
No Bike, 3 Oncoming Veh, 1 Ped
Duration (sec)
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
3.08
0.12
0.11
0.48
0.43
1.44
Pedestrian
Signal_Overhead
Signal_Side
RV_Mirror
Side_Mirror
Oncoming Vehicle


Average Total Fixation Duration
Bike Ahead (10 MPH), 3 Oncoming Veh, No Ped
Duration (sec)
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
1.16
0.11
0.10
0.53
0.56
1.07
Bicyclist
Signal_Overhead
Signal_Side
RV_Mirror
Side_Mirror
Oncoming Vehicle

Appendix D: SAGAT Questionnaire

SAGAT questionnaire

Subject number?
Q1 How many opposing vehicles turned at the last intersection ahead of you?
❍ No vehicles
❍ One vehicle
❍ Two vehicles
❍ Do Not Know

Q2 How many bicyclists did you pass on or were behind you just before you turned right at the last intersection?
❍ No bicyclists
❍ One bicyclist
❍ Two bicyclists
❍ Do Not Know

Q3 What was the last road sign you saw before you turned right at the last intersection?
❍ Speed limit
❍ Stop sign
❍ Railroad
❍ Bike lane sign
❍ Pedestrian crossing sign
❍ Do Not Know

Q4 Upon arriving at the last intersection, what movement do the vehicles waiting across from you intend to make?
❍ No opposing vehicle
❍ All vehicles would turn right
❍ All vehicles would turn left
❍ All vehicles would go straight
❍ Some would go straight, some would turn left
❍ Some would go straight, some would turn right
❍ Do Not Know

Q5 In what direction is the location your vehicle started this drive from when the simulation stopped?
- To the left
- To the right
- In front of me
- Behind me
- Do Not Know

Q6 How far are you from the last intersection you turned at?
- Less than 100 feet
- 100-150 feet
- 151-250 feet
- 251-350 feet
- More than 350 feet
- Do Not Know

Q7 Suppose that the simulation was not stopped, do you think the pedestrian would finish crossing the intersection by the time you reach the intersection driving at the posted speed limit?
- No pedestrians
- Yes
- No
- Do Not Know

Q8 Suppose that the simulation was not stopped, how long would it take to reach the stop line of the approaching intersection driving at the posted speed limit?
- Less than 10 seconds
- 10 - 30 seconds
- 30 seconds -1 minute
- 1–2 minutes
- 2–3 minutes
- More than 3 minutes
- Do Not Know

Q9 How far would you have to drive to reach the intersection from the point you stopped?
- Less than 100 feet
- 100-150 feet
- 151-250 feet
- 251-350 feet
- More than 350 feet
- Do Not Know

Appendix E: Binary Logistic Regression Output in SPSS

Classification Table

			Predicted		
			Crash		Percentage
	Observed		0	1	Correct
Step 1	Crash	0	25	5	83.3
		1	10	13	56.5
	Overall Percentage				71.7

a. The cut value is .500

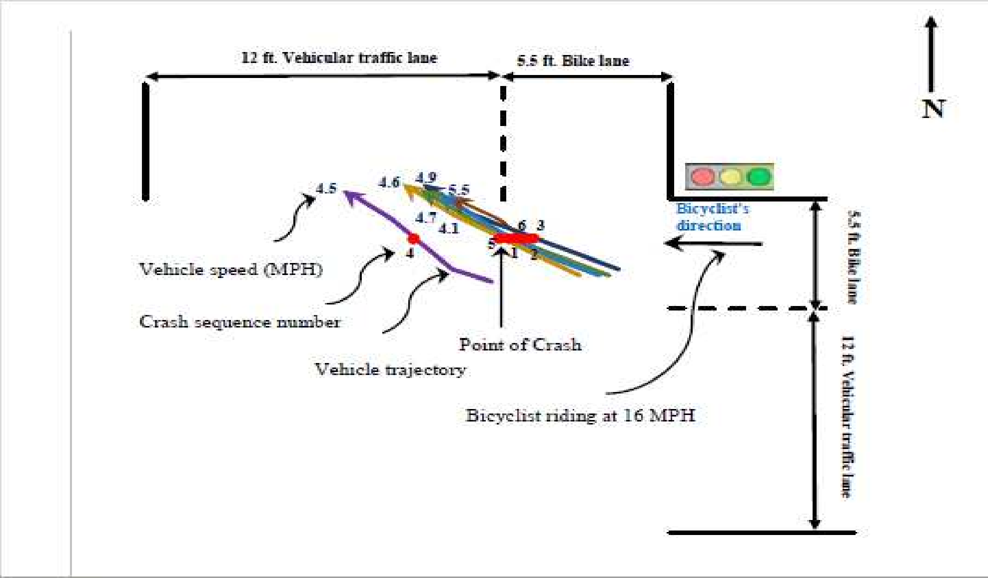
Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	Age	-.017	.041	.166	1	.683	.984
	Gender(1)	1.821	.815	4.989	1	.026	6.180
	Education2			2.217	5	.818	
	Education2(1)	.659	1.604	.169	1	.681	1.933
	Education2(2)	1.320	1.922	.472	1	.492	3.744
	Education2(3)	1.735	1.807	.922	1	.337	5.670
	Education2(4)	.512	2.015	.064	1	.800	1.668
	Education2(5)	21.408	2818.158	.000	1	.999	19091.124
	Experience2			3.988	4	.408	
	Experience2(1)	-1.653	1.111	2.215	1	.137	.191
	Experience2(2)	-1.995	1.558	1.640	1	.200	.136
	Experience2(3)	20.818	2815.455	.000	1	.999	10994.218
	Experience2(4)	.089	1.531	.003	1	.954	1.093
	Constant	-1.481	1.760	.708	1	.400	.228

a. Variable(s) entered on step 1: Age, Gender, Education2, Experience2.

Appendix F: Collision Diagram

Collision Diagram: Intersection with 1 bicyclist behind (16 MPH), Three oncoming vehicle, No pedestrian



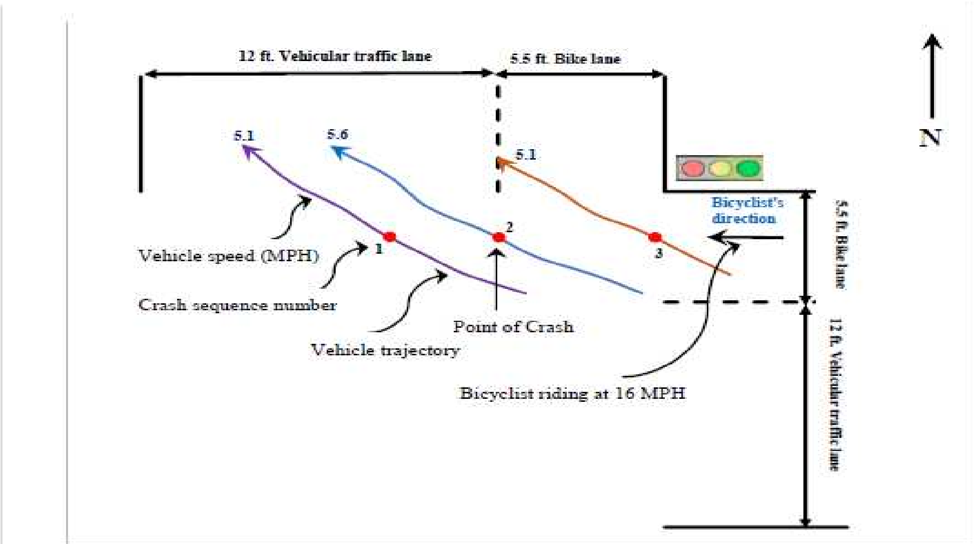
Legends:

- Point of crash between vehicle and bicycle

4.5, … , 5.5: Blue numerical texts indicate vehicle speed during the crash in MPH

1, …, 3: Black numerical texts indicate crash sequence number

Collision Diagram: Intersection with 1 bicyclist behind (16 MPH), No oncoming vehicle, No pedestrian



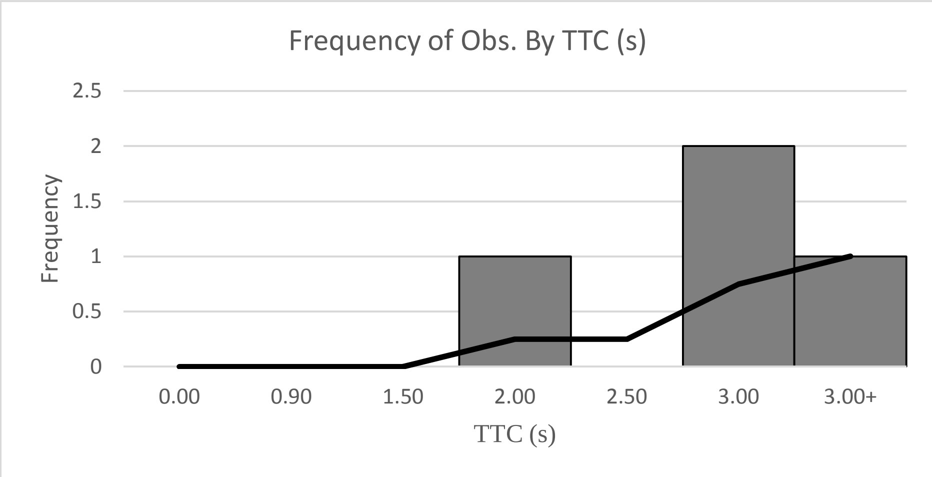
Legends:

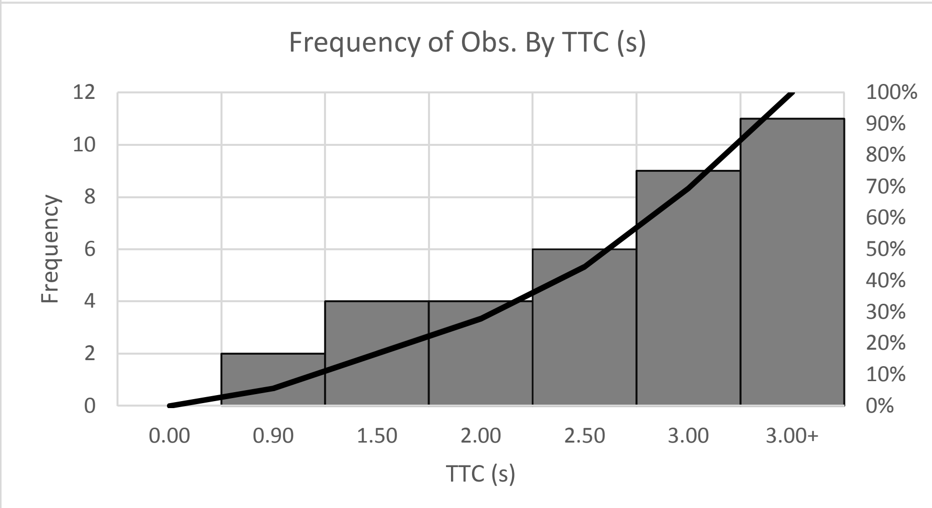
- Point of crash between vehicle and bicycle

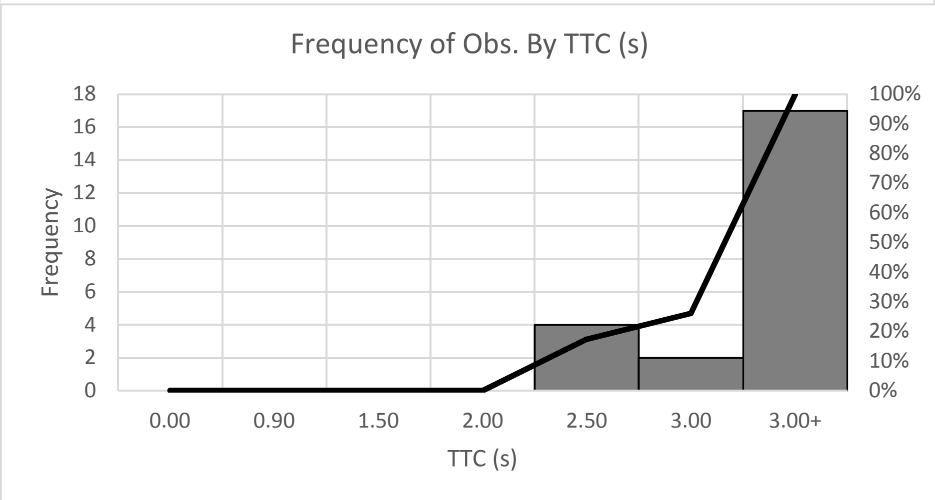
5.6, … , 5.1: Blue numerical texts indicate vehicle speed during the crash in MPH

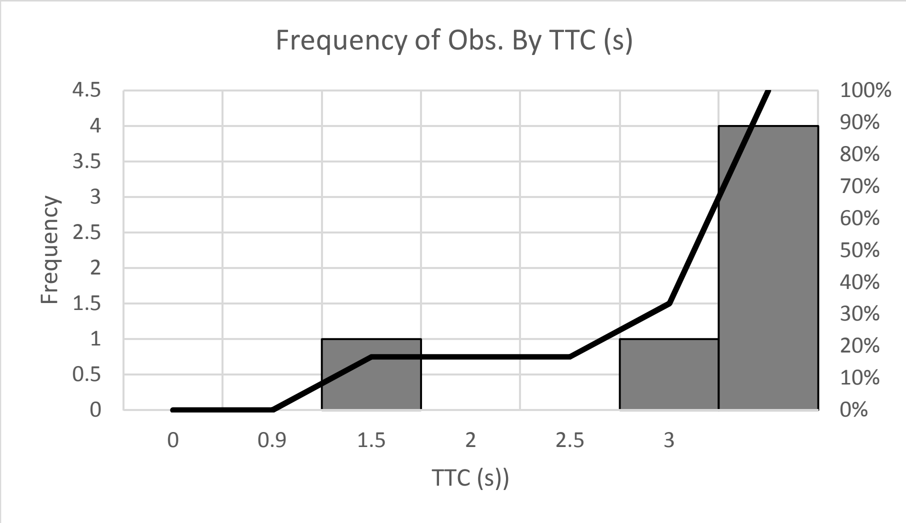
1, …, 3: Black numerical texts indicate crash sequence number

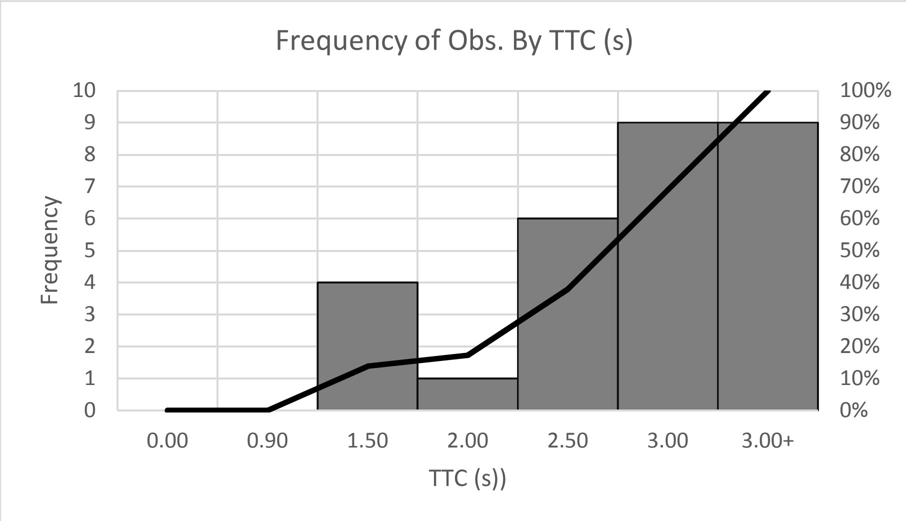
Appendix G: Frequency and cumulative frequency distribution curve for traffic conflict incidents

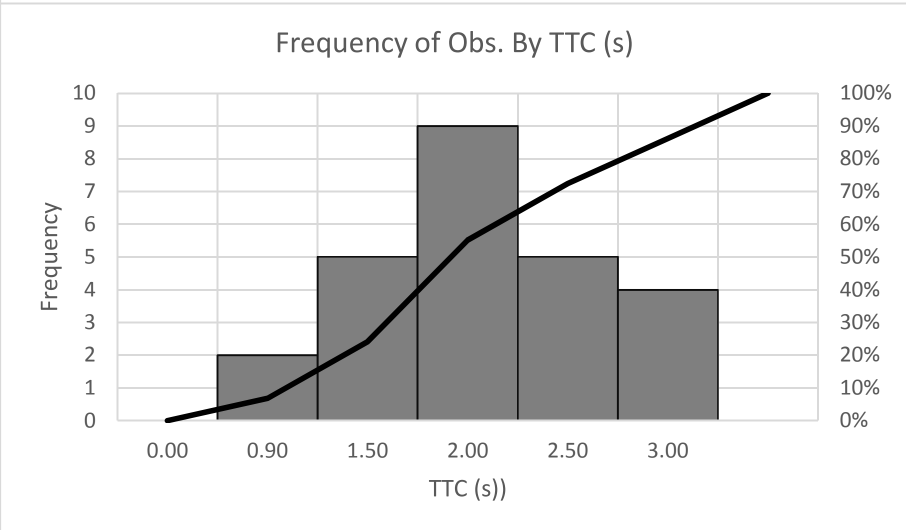


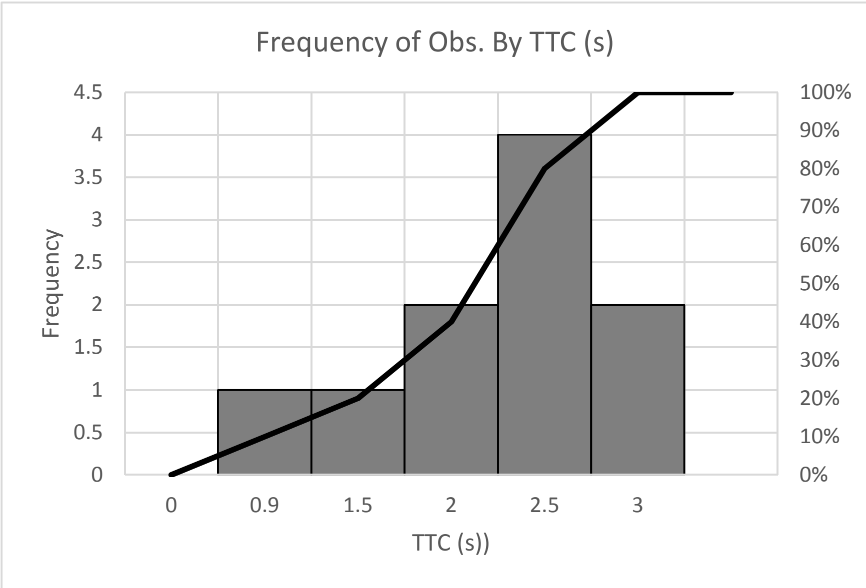





Frequency of Obs. By TTC (s)
Frequency
TTC (s))
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.9
1.5
2
2.5
3


Frequency of Obs. By TTC (s)
Frequency
TTC (s))
10
9
8
7
6
5
4
3
2
1
0
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0.00
0.90
1.50
2.00
2.50
3.00
3.00+


Frequency of Obs. By TTC (s)
Frequency
TTC (s))
10
9
8
7
6
5
4
3
2
1
0
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0.00
0.90
1.50
2.00
2.50
3.00


Frequency of Obs. By TTC (s)
Frequency
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.9
1.5
2
2.5
3
TTC (s))