Driver Scanning Behavior at Urban and Suburban Intersections: An On-Road Approach

by

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Abstract

The safety of Vulnerable Road Users (VRUs), such as pedestrians and cyclists, is highly jeopardized at intersections, with driver inattention being a leading cause. It is not well known (1) where drivers distribute their visual attention at real intersections or how this impacts VRU safety, and (2) how driver attention interacts with different intersection elements from an on-road perspective. This thesis utilizes rich instrumented vehicle data from 26 experienced drivers (13 cyclists and 13 non-cyclists) to quantify drivers gaze distributions at signalized right turns. Key findings include that drivers spent the most time glancing at relevant pedestrians, irrespective of signal status, and that driver attention was heavily skewed toward leftward traffic during red lights. Additionally, this thesis outlines an instrumented study which will examine the effects of Guelph's suburban road infrastructure on driver scanning behaviour. Reported findings can benefit broad road safety perspectives from urban planning, collision forensics, and more.

Acknowledgments

There were many people I've met and interacted with that have that led me to this point. I wish I could list them all. First, a special thank you to my supervisor Professor Birsen Donmez: Thank you for always being fair, kind and strong in your leadership. You embody scientific integrity and show your students how to do the same. It was a real honour working with and learning from you. Speaking of wonderful supervisors, thank you to Professor Jay Pratt for welcoming me into your lab and for always finding the time to participate and provide invaluable feedback during the different stages of my research. Thank you to our Guelph partners Liraz Fridman, Benita van Miltenburg and Lauren Short for their incredible engagement and profound knowledge of road safety. This unique partnership has been a meaningful contribution to my time at U of T and will surely lead to impactful results. Thank you to Professor Paul Hess for sharing your expertise regarding road design and infrastructure which has pushed me to think outside of the box as I address the safety of vulnerable road users.

Next, I would like to thank Mattea Powell and Margaux Roncière for the many, many hours you volunteered to help me with my video analysis. I must have told you this a million times, but I really do appreciate you. I would also like to thank Mattea for her ongoing support and active contributions to my thesis. Her initiative, creativity and Illustrator skills have undoubtedly saved the day, and I am sure that she will find great success in taking over this research. To my dear lab mates: it was a pleasure getting to know you and being on this journey together. Each one of you has gone out of your way to help me in some way or another. You will go on to do great things. A special thank you to Brady Hansma and Dengbo He. Brady, your passion for statistics is infectious and so is your kindness. You were always ready to pick up the phone and help even years after you graduated and I'm glad to have a dorky friend like you. Dengbo, thank you for always making yourself available to answer my thousand questions about equipment and procedures. It's hard to imagine HFASt without you, but I know you will excel in your new chapter of life. I would also like to thank my dear friend Omar Chehab for being the best Python consultant ever. You're an exceptional engineer and your kindness will not be forgotten. Last but certainly not least, my best friend, anchor, and number one fan, Dale. When life gets really hard, you bring me all that is good. When I felt like I had nothing left, you persistently reminded me that there was "80% more". We made it!

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Introduction to Document

This thesis aims to improve the scientific understanding of driver visual attention allocation and how it can vary based on driver-specific and context-related factors. The instrumented vehicle research outlined in this document can benefit broad road safety perspectives from public health, urban planning, collision forensics, and more. For example, from public health perspective, driver misallocation of attention at intersections comes at a high cost to the safety of Vulnerable Road Users (VRUs) and research is needed to understand how to further support drivers in detecting hazards while making turns. From an urban planning perspective, active transportation initiatives have been adopted by major cities such Toronto and Guelph to improve VRU safety through various approaches, including infrastructure modifications and public education campaigns. However, these policy-makers often do not have the capacity to study driver behavior at the micro level (i.e., within the vehicle).

Two major projects are outlined in this document: (1) a detailed on-road experimental plan taking place in (and in partnership with) the City of Guelph and (2) a quantitative analysis of our latest on-road data in downtown Toronto.

In September 2020, HFASt partnered with the City of Guelph Engineering and Transportation Services to design an on-road experiment which examines the effect of the City' road infrastructure and VRU-centered design changes on driver scanning behaviour. With the support of Dr. Donmez, Dr. Jay Pratt, Dr. Hess from UofT, and Dr. Fridman from the City of Guelph, I took leadership in writing grant applications to acquire funding for this project which led us to secure a SSHRC Partnership Engage Grant at the maximum allotted amount of 25K. I also led in the formulation of research questions and experimental design. The details of this experiment presented in Chapter 2.

Although Guelph study plans were finalized in time for data collection this summer, COVID-19 restrictions did not allow for this. So, in addition to the design of this experiment, I have conducted a secondary analysis which quantifies raw eye tracking footage from Kaya et al.'s 2021 instrumented vehicle study. This study offers a detailed summary of drivers' glance distributions and overall visual behaviour while turning right at signalized intersections. It also examines whether the presence of VRUs in safety-critical areas could predict driver checks to those areas through mechanisms of peripheral vision. In Chapter 1, this analysis is detailed in the form of a draft manuscript which will be submitted for publication in a peer-reviewed journal.

Chapter 1

Driver Glance Allocation during Right Turns at Signalized Urban Intersections: An On-Road Approach

Abstract

Background: Motor vehicle maneuvers at urban intersections pose a particularly high risk to Vulnerable Road Users (VRUs), such as cyclists and pedestrians. In the majority of related collision cases, VRUs are identified as having the right of way, which points to driver attention misallocation as a major contributor. Research is critically needed to understand how and where drivers allocate their visual attention at intersections and how this may influence VRU safety. Although a few naturalistic studies have examined driver gaze behaviour at intersections, findings are limited to general gaze directions obtained through video analysis, meaning that the specific objects or agents to which drivers are attending to can only be inferred. **Methods:** This paper analyzed an on-road instrumented vehicle dataset collected in 2019 which offers rich eye-tracking and in-vehicle camera data from 26 experienced drivers (13 cyclists and 13 non-cyclists). In a secondary analysis of this dataset, three trained evaluators jointly examined eye-tracking footage from four right-signalized turns (n = 96) to quantify drivers' glance distribution and whether the presence of VRUs, in particular cyclists, in safety-critical areas could predict driver visual scanning to those areas. **Results:** (1) Relevant pedestrians were the top objects of glance irrespective of signal status, (2) during red lights, driver attention was heavily skewed toward leftward traffic, and (3) no clear association found between cyclist presence and the likelihood of drivers committing a visual scanning failure at a given turn. **Significance:** This analysis provides a novel and thorough report of driver glance distributions toward scene-specific areas (as opposed to general directions) at urban intersections, and discusses how these patterns may influence VRU safety. This is critical to gain a deeper understanding of the human factors challenges of vehicle-VRU collisions so that they can be addressed.

Keywords: glance allocation, vulnerable road users, driver attention, urban intersections, right turns, instrumented vehicle, eye tracking

1 Background

The safety of Vulnerable Road Users (VRUs), such as pedestrians and cyclists, is a global health challenge (World Health Organization, 2021). In Canada, from 2006 to 2017, a yearly average of 74 cyclists were killed and 7,500 were seriously injured in traffic collisions (CAA Club Group, 2021; Statistics Canada, 2019). Of the fatalities, 73% resulted from a collision with a motor vehicle. As for pedestrians, a yearly average of 317 pedestrians were killed from traffic collisions in Canada between 2009 to 2018 (Statistics Canada, 2019), while many more were seriously injured. In Ontario, both cyclist and pedestrian fatalities increased by 64% and 18%, respectively from 2017 to 2018 alone (Ministry of Transportation, 2018). These latest trends suggest that VRU safety is deteriorating.

Intersections pose a particularly high risk for VRUs, given that this context requires multiple road users to cross paths, including motor vehicles (Robertson, 2015). From a driver attentional demand perspective, complex intersections, such as those in busy urban environments with high traffic density, can exacerbate this risk (Cantin et al., 2009). From 2008 to 2012, 54% of pedestrian injuries and fatalities in the City of Toronto, resulted from collisions at an intersection, 72% of which occurred when a driver was conducting a turn as opposed to proceeding straight through an intersection (Bassil et al., 2015). Similarly, in the City of Vancouver, about 51% of cyclist collisions between 2007 and 2012 were at urban intersections, 55% of which took place during a vehicle turning maneuver (Urban Systems, 2015). Simulator studies have found that making a turn significantly increases cognitive workload in comparison to straight driving; this effect is also seen when drivers are simply approaching an intersection (Hancock et al., 1990; Teasdale et al., 2004). As a result of drivers having to divide their attention toward several directions while turning, the demands of intersections may exceed drivers' attentional capabilities, leading to driver attentional misallocation and accidental neglect of VRUs (Easterbrook, 1959; Miura, 1992; Stinchcombe & Gagnon, 2010).

It is widely agreed that driver attention misallocation is a leading cause for vehicle collisions with VRUs (Canadian Council of Motor Transport Administrators (CCMTA), 2013; Hills, 1980; Olson, 1993; Räsänen & Summala, 1998; Romer et al., 2014; Sivak, 1996; Werneke & Vollrath, 2012). In the majority of collision cases, VRUs are identified as having the right of way. For example, in the Toronto collisions with pedestrians reported above, 72% of pedestrians had the right of way when struck. For the Vancouver collisions reported above, cyclists were identified as having the right of way in 73% of collision cases during which vehicles were turning left or right (Urban Systems, 2015).

The question remains: Where are drivers looking (and not looking) at urban intersections as they make turns? Research is needed to understand how and where drivers allocate their visual attention at intersections and how this may influence VRU safety. A variety of methods have been applied to study drivers' glance allocation within intersections (Angell et al., 2015; Gstalter & Fastenmeier, 2010; Räsänen & Summala, 1998; Summala et al., 1996; Werneke & Vollrath, 2012; Wu & Xu, 2017). Räsänen and Summala (1998) conducted a post hoc investigation of 188 bicycle-motor vehicle collisions at various cross- and T-intersections and used accident reports to assess driver visual search patterns. They found that most collisions occurred when drivers were turning right from a local to collector road, while a cyclist approached from the right side (on a cycle track perpendicular to the vehicle). For this type of incident, only 11% of the drivers noticed the cyclist, whereas 68% of the cyclists noticed the vehicle. The authors concluded that drivers' inappropriate allocation of attention toward the left when they do not have right-of-way is the major reason for cyclist collisions. An analysis of the SHRP-2 naturalistic driving study data by Wu and Xu (2017) came to a similar conclusion while assessing driver facing in-vehicle video data during right turns at signalized intersections in non-crash scenarios. In contrast to the previous study, Wu and Xu (2017) could more directly assess driver glance behaviour through video footage. They found that at red lights, drivers made more frequent glances to their left window/mirror (i.e., leftward traffic) to assess whether they had room to merge, compared to when the signal status was green. This suggests that drivers paid less attention toward traffic areas on their right from which relevant pedestrians and cyclists could approach. Interestingly, this leftward bias seemed to improve when a group of pedestrians entered the intersection rather than one or none. Another analysis of naturalistic driving video footage by Angell et al. (2015) reported glance proportions to general directions while drivers made turns at a stop-controlled T-intersection. They found that forward-facing glances did not differ for left and right turns; however, while for left turns drivers distributed their gaze equally to left and right windows, for right turns, glances to the right window were less. For right turns, 50% of glance time was toward the forward path, followed by glances to the left window (16% -26%) and right window (1-9%); again, reflecting drivers' primary concern for the stream of leftward traffic due to a higher inherent threat valuation. While the above findings significantly improve the understanding of driver gaze behaviour at real intersections, findings are limited to general gaze directions obtained through video analysis, meaning that the specific objects or agents to which drivers are attending to can only be inferred. Without an eye tracker, analysts could not determine the specific areas that the drivers glanced at (e.g., it would not be clear from the videos whether a glance toward the left window is directed at a crosswalk, sign or vehicle traffic).

1.1.1 Current Study

Using an existing dataset from a recent on-road experiment which was conducted in downtown Toronto (Kaya et al., 2021), this paper aims to provide a novel and thorough report of (a) driver glance distributions toward scene-specific areas (as opposed to general directions) at urban intersections, and (b) how these patterns impact VRU safety. The dataset offers rich eye-tracking and in-vehicle camera data from 26 experienced drivers (13 cyclists and 13 non-cyclists) who completed 18 different turns in an instrumented vehicle. Kaya et al. (2021) assessed the rate of driver visual scanning failures toward areas where conflicting VRUs could approach, and examined whether there is an influence of cycling experience. However, visual scanning failures (the dependent variable reported) were coded on a failure/non-failure dichotomy which leaves this unique eye tracking dataset largely unutilized. The current analysis aims to quantify the areas and objects to which drivers attend in order to gain a deeper understanding of the human factors challenges that lead to driver attention misallocation at urban intersections.

Previously discussed research highlights that right turns yield high rates of attention misallocation especially when drivers do not have right-of-way (Angell et al., 2015; Gstalter & Fastenmeier, 2010; Räsänen & Summala, 1998; Summala et al., 1996; Werneke & Vollrath, 2012; Wu & Xu, 2017). Kaya et al. (2021) also found that visual scanning failures were more common at right turns in comparison to left turns. Moreover, they report that the difference between cyclist and non-cyclist drivers was particularly large at right signalized turns: the rate of failures was 20% higher for non-cyclist drivers than cyclist drivers at signalized right turns, 13% at unsignalized right turns, 7% at unsignalized left turns, and 2% at signalized left turns. For these reasons, this current analysis examines driver glance behaviour at four right signalized turns to further examine driver visual attention allocation at this challenging turn scenario and how it varies based on cycling experience.

As a secondary objective, this paper investigates the method that Kaya et al. (2021) used to capture visual scanning failures and whether it may be confounded by context specific attention-capture. Kaya et al. (2021) labeled a turn to have a visual scanning failure if the driver's gaze did not fall on one or more pre-determined areas of importance (AOIs) where potential conflicting VRUs could approach (e.g. right mirror, pedestrian crosswalk), irrespective of the absence or presence of VRUs in those areas. While Kaya et al. (2021) did not claim that gaze position is synonymous for visual attention, there is a strong relationship between the two constructs. On the other hand, vision science research has demonstrated that attention is not required for perception (Blanchette, 2006; Royden et al., 2001; Subra et al., 2017; Williams et al., 2006; Wolfe, Seppelt, et al., 2020), and that serial, overt gaze is not necessary to detect VRUs. It is possible that Kaya et al.'s (2021) methodology over-emphasised the importance of foveal vision while under-valuing the role that peripheral information can have in drivers' awareness of the road environment.

Previous works support that peripheral vision - among other capabilities - is critical for acquiring global information about the road environment (i.e., scene gist) which allows for hazard perception (Greene & Oliva, 2009; Huestegge & Böckler, 2016; Navon, 1977; Wolfe, Sawyer, et al., 2020; Wolfe, Seppelt, et al., 2020). According to Information Acquisition Theory posited by Wolfe et al. (2020), much of the visual input that drivers receive at any moment is peripheral, thus, both global (periphery and scene gist) and local (overt attention and gaze shifts) scales are critical for understanding how drivers acquire —and subsequently act on— information from the surrounding traffic environment (Wolfe, Sawyer, et al., 2020). Pertinent to visual scanning failure coding, if there is no peripheral information to guide a driver's attention to an AOI (e.g., cyclist in the cycle lane), there may be no need to shift their gaze to the lane (i.e., to identify a cyclist who is not there). Through a post-hoc analysis, this paper explores whether the presence of cyclists in safety-critical areas is a significant factor as to whether drivers check those areas. If yes, then we expect that less visual scanning failures (as identified by Kaya et al., 2021) will be observed, at turns with at least one cyclist present, while more failures will be observed when there is no cyclist present in the road scene. Although this research concerns both cyclist and pedestrian VRUs, coding pedestrian presence on a binary scale would not be sensitive enough or meaningful because a number of pedestrians was present for nearly all turns. Thus, we chose to focus on cyclist presence.

1.2 Methodology

This paper presents secondary analysis of an instrumented vehicle study originally reported in Kaya et al. (2021), conducted in the spring of 2019 in downtown Toronto with 26 participants, half of whom were cyclists and the other half non-cyclists. Data collection took place on the weekends and in good weather. During data collection, three people were present in the vehicle: (1) the participant, (2) the primary experimenter, who provided turn-by-turn directions, and (3) another experimenter, who monitored the data collection computer from a rear seat. The study was approved by the University of Toronto Research Ethics Board (Protocol ID 36440). In the sections below, we provide the relevant methodological details for this experiment, further details can be found in Kaya et al. (2021).

For the current analysis, three trained evaluators jointly examined eye-tracking and camera footage from four signalized right turns completed by these 26 participants to identify (a) drivers' glance allocations on a frame-by-frame level and (b) whether the presence of cyclists in safety-critical areas is a significant factor as to whether drivers check those areas. Across the four turns, a total of 96 observations was available (excluding missing data, n = 8). All data analyses for this paper were conducted in R (R Core Team, 2019) and figures were produced using a combination of the R package ggplot2 (Wickham, 2009) and Microsoft Excel version 16.51.

1.2.1 Participants

The instrumented vehicle study offers data from 26 participants (13 male, 13 female) aged 35 to 54 (Mean = 42, Standard Deviation = 4.5). Participants were required to have a full driver's license (G in Ontario) for a minimum of three years and have self-reported normal or corrected-to-normal vision. On average, participants were fully licensed for 21 years (Min = 5, Max = 32), with 65% (n = 17) of participants indicating that they drove "every day/almost every day". Regarding the frequency of driving in any downtown area, 35% (n=9) of the participants indicated that they did so "every day or almost every day", while 65% (n = 17) indicated they did so "a few days a week" or less. Overall, all participants reported having no vehicle crashes within the past five years. Respondents who self-reported that they cycled for transportation purposes at least "a few days a month (excluding winter)" were recruited under the cyclist-driver group (7 males and 6 females), while those who selected that they cycled less than "a few days a year (excluding winter)" were recruited under the non-cyclist driver group (6 males and 7 females). As presented in Kaya et al. (2021), these categories also overlapped with cycling for recreational purposes in that drivers who identified as not regularly cycling for commuting purposes also identified as not regularly cycling for recreational purposes.

1.2.2 Apparatus

The instrumented vehicle was a 2014 Toyota RAV4 vehicle with an automatic transmission. Two fixed, windshield-mounted cameras were used: one facing the road scene to capture visual information pertaining to the roadway, and the other facing the driver's seat to capture participants' facial expressions and head movements (Figure 1A). Most pertinently to the current analysis, eye movements were recorded using a pair of lightweight (52g) head-mounted eye tracking glasses (Dikablis Eye Tracking Glasses 3 by Ergoneers; Figure 1B). These eye tracking glasses detected pupils and corneal reflections using two cameras pointed toward the eyes at a tracking frequency of 60 Hz and with a resolution of 648 x 488 pixels (pupil tracking accuracy = 0.05^{o}, gaze direction accuracy = 0.1 to 0.3^{o} visual angle). The calculated gaze position was then overlaid onto the video captured by the front-facing camera (i.e., scene camera) of the eye tracker (Figure 2). The eye tracker's scene camera visual angles are 92^{o} horizontal FoV and 67^{o} vertical FoV. All camera data was collected through the D-Lab software version 3.50.8786.0. Post-processing calibration was conducted in D-Lab to ensure that participant pupils were precisely captured for every frame. The current analysis was conducted in D-Lab version 3.55.9166.0.

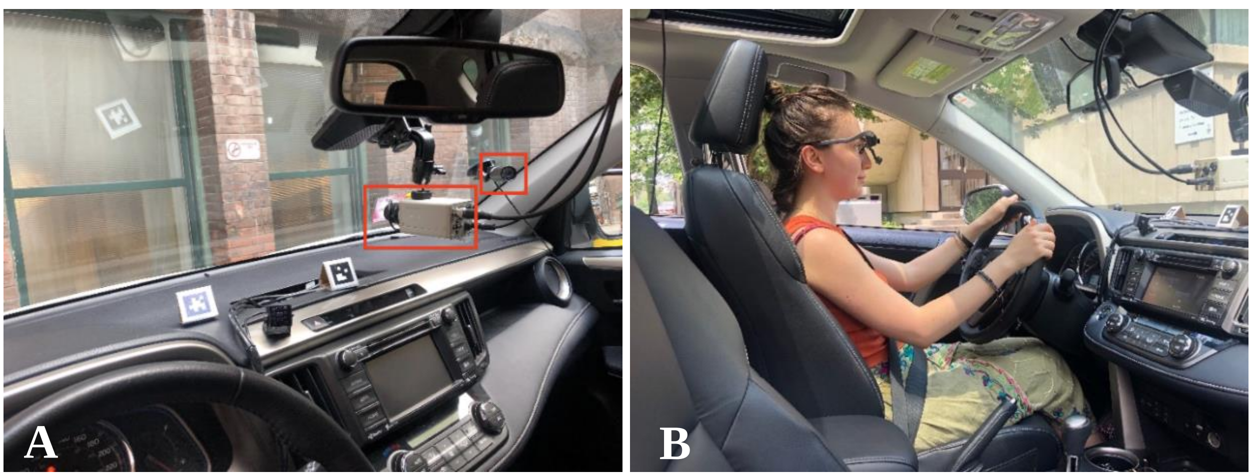
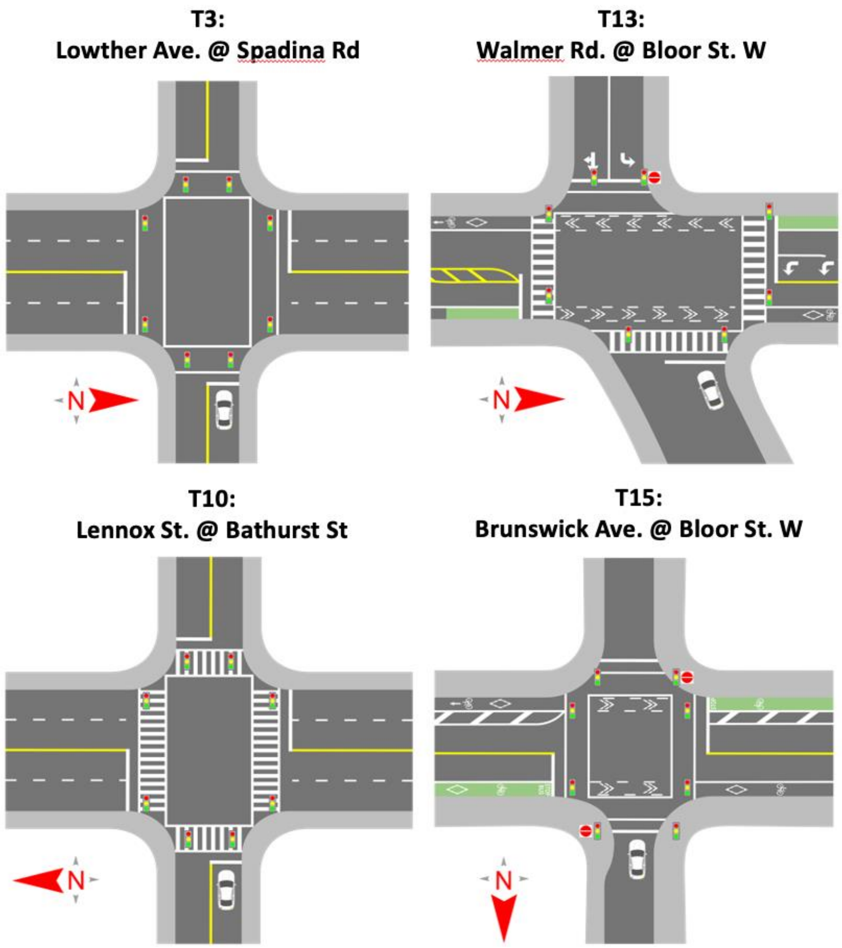


Figure 1. Instrumented vehicle: (A) one camera facing the front scene and the other facing the driver seat, (B) driver outfitted with the eye tracker.

Figure 2. Image from the head-mounted eye tracker video, as a participant prepares to make a right turn at a red light. Following calibration, the eye tracking software superimposed the red crosshair (i.e., gaze position indicator) onto its scene camera view so that researchers could visualize the location of participants' gaze in real time during data collection and later in data processing. Note that the crosshair corresponds to about 4 ^{o} visual angle, which approximates foveal vision.

1.2.3 Analyzed Intersections

Although data was available for a wide range of turns, signalized right turns were selected for reasons explained earlier. There were seven signalized right turns across Kaya et al.'s (2021) experimental routes. Four of those turns had very similar context whereas three were more distinctive or stand-alone. The most similar intersections were chosen for this analysis to ensure some control over context (less variability). This approach also enabled the aggregation of turn observations across different intersections which increased sample size and accounted for the fact that the order of turns was not fully counterbalanced. Figure 3 presents relevant intersection details including diagrams, while a step-by-step selection rationale is available in Appendix A.



Turn Code	Bike lanes on T.R.	# Vehicle Lanes on O.R.	# Vehicle Lanes on T.R.	Size	Land Use
T3	None	2	4	Small	Mixed (majority residential)
T10	None	2	4	Small	Mixed
T13	Painted	2	2	Medium	Mixed
T15	Painted	1	2	Small	Mixed (majority commercial)

Figure 3. Detailed summary of the intersections analyzed. Turn code is from Kaya et al. (2021). All four intersections were cross junctions and had no bike lane on the origin road (O.R.; road from which the driver begins their turn), while two of four had existing cycling infrastructure on the target road (T.R.) in the form of a painted bike lane. Also, all were made from a local road to major arterial.

1.2.4 Coding of Driver Glances

Three trained evaluators watched frame-by-frame eye tracking video footage and jointly categorized the specific area/object onto which each driver glance fell at each intersection. All raters were blind to participant characteristics and had a valid driver's license which enabled them to apply their driving knowledge in making coding decisions. Rarely, the gaze indicator fell equally onto two overlapping objects/areas which led to some frames being double-coded to maintain objectivity. There were 22 categories which are summarized in Table 1. Cases where the gaze indicator (i.e., crosshair) fell on an object/area for shorter than 100 ms were excluded from the statistical analysis. This cut-off is informed by the fact that saccades are typically less than 100 ms (Leigh & Zee, 2015), and that this is the minimum time required to extract visual information from the environment during visual search (Manor & Gordon, 2003); albeit a variety of definitions still exist depending on the research domain and task (Hessels et al., 2018).

Table 1. A description of all driver glance categories/areas used in coding.

Area	Description
Vehicle Ahead	Any vehicle in front of participant vehicle (leading, or perpendicular vehicles going in either direction of traffic within the intersection). Includes vehicles on other side of intersection with the exception of Cross Turning Vehicles.
Road Ahead (Clear)	Unoccupied roadway in front of the ego vehicle (i.e., no road users or vehicles). Includes the roadway on other side of the intersection. Crosswalks and bicycle lanes not included.
Leftward Traffic	Area (and vehicles coming from) left of intersection, on destination road. Includes cyclists who are far away and blending with vehicle traffic.
Vehicle in Target Lane	Vehicle in the target lane(s) where the driver can turn right.
Target Lane (Clear)	Unoccupied target lane(s) where the driver can turn right.
Opposite Target Road	Lane on target road where vehicles go in leftward direction (i.e., opposite direction of target lanes).
Signal or Sign	Driving-related signal/signs, incl. pedestrian signals, traffic lights, and construction signage.
Cross Turning Vehicle	Vehicle turning left from the opposite direction into participant's target lane (or waiting to turn left).
Right Mirror	Glances directly on the right mirror or within four visual degrees around it.
Shoulder Check	Area out the right passenger and rear windows (accompanied by head turn).
Relevant Pedestrian Area (Clear)	Crosswalk/sidewalk areas where pedestrian presence could impact turn-related decisions.[1]
Relevant Pedestrian(s)	Pedestrians located in a Relevant Pedestrian Area. [1]
Irrelevant Pedestrian Area (Clear)	Crosswalk/sidewalk areas where pedestrians would not cross paths with vehicle.
Irrelevant Pedestrian(s)	Pedestrians located in a Irrelevant Pedestrian Area.
Relevant Cyclist Area (Clear)	Cyclist areas on the right shoulder of origin or target roads[2] which could impact turn-related decisions.[1]
Relevant Cyclist(s)	Cyclists located in a Relevant Cyclist Area.
Irrelevant Cyclist Area (Clear)	Cyclist areas[2] where cyclists would not cross paths with vehicle.
Irrelevant Cyclist(s)	Cyclists located in an Irrelevant Cyclist Area.

Rear Traffic	Traffic behind vehicle on origin road. Can be checked through rear view mirror, left side mirror, or diagonal head/eye movement.[3]
Parked Vehicles	Any vehicle which is parked and not part of actively moving traffic.
Origin Road Left	Area left of driver on the origin road.
Other	Non-traffic related object in scene (e.g., building, tree, etc.). Includes in-vehicle objects such as the dashboard.

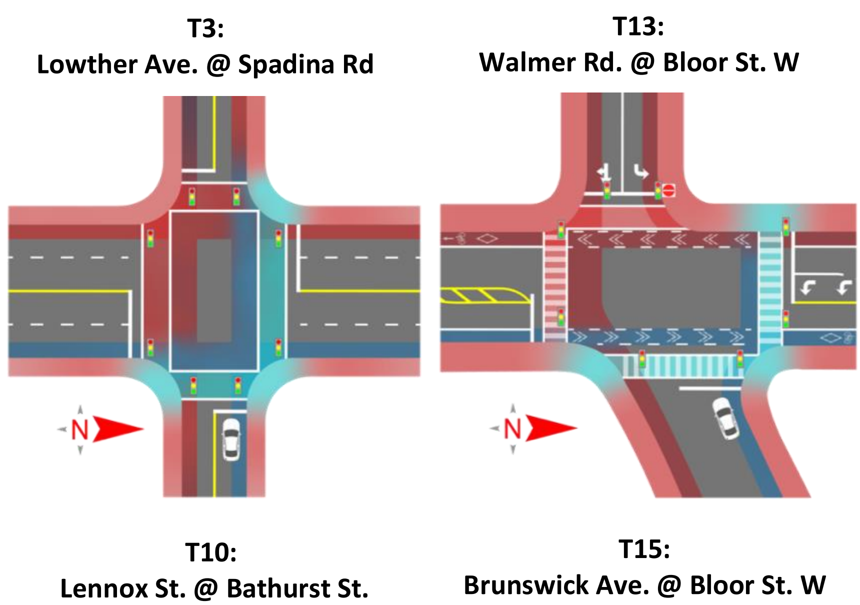
1. VRU locations considered safety critical for the turn
2. The right shoulder of a road was considered a cyclist area with or without the presence of a dedicated/painted bicycle lane. The only dedicated/painted bicycle lanes were on the target road of turns T13 and T15. For the remaining two (T3 and T10), a cyclist area refers to the right-most real estate of the target road. For all turns, the origin road did not have a painted/dedicated bicycle lane, and thus, the cyclist area refers to the right-most real estate of the origin road.
3. Although rear traffic is visible from the right mirror, glances to this area were identified as Right Mirror and not Rear Traffic.

The window of time in which raters categorized driver glances is referred to here as a "turn-analysis interval". A turn-analysis interval always included the "turn phase" but could also include a "pre-turn phase", depending on whether the driver needed to stop at an intersection, or whether they proceeded through smoothly. The beginning of a turn phase is marked by the ego vehicle's arrival at the intersection (i.e., turn start), and ends when the turn is complete. A pre-turn phase captures the approach to an intersection and is defined as the 10 seconds prior to arriving at the intersection. A turn-analysis interval included the pre-turn phase if a driver turned at a green light without stopping, but not if the driver stopped and waited at a red light before making their turn. There were two main scenarios which required drivers to stop: if the traffic signal was red, or if they were waiting for pedestrians to cross during a green light. In these cases, the pre-turn was not included in the turn-analysis interval, meaning that the interval started when at the beginning of the turn phase. Further details and justification of these phases can be found in Kaya et al. (2021).

Pedestrian and cyclist areas were classified as either 'relevant' or 'irrelevant' based on their location or proximity to the vehicle. This distinction will be described using turn T15 from Figure 5 as an example. Relevant areas are marked by shades of blue (dark blue for cyclist areas and light blue for pedestrian areas). Irrelevant areas are marked by shades of red (dark red for cyclist areas and light red for pedestrian areas). Relevancy was defined by factors such as location and proximity to the ego vehicle, but also in reference to the turn maneuver itself. VRU areas were deemed relevant if potentially conflicting VRUs could approach from those areas. For example, it would be dangerous, if, before proceeding to turn, a driver did not check for pedestrians crossing in front of the vehicle. Contrastingly, VRU areas were deemed irrelevant if they were far enough that they did not pose any immediate danger to the driver and vice versa. A pedestrian entering the road from the top-left (red) corner of the intersection is not a critical piece of information for drivers who were looking to turn right. However, because the state of moving VRUs was highly dynamic, judgments about relevancy were made on a glance-by-glance basis. Using the previous example, if the same pedestrian got close enough into the blue zone on the driver's left, they might be considered relevant, as they could suddenly change their direction of travel and start crossing in front of the vehicle. Given the judgement required, the multi-rater approach used in this analysis was essential.

If VRUs were located within less clear-cut areas (e.g., the gradient areas in Figure 4), this meant that some discussion among raters was needed to define their relevance through the systematic consideration of contextual factors such as velocity or direction of travel. For instance, if a group of pedestrians have just completed crossing using the relevant crossway in front of the vehicle, they were deemed relevant until they exited the blue sidewalk corner. Alternatively, if pedestrians were walking on the sidewalk toward a relevant pedestrian corner and crossway, they were deemed relevant from a greater distance due to the direction of their travel. Notably, approaching cyclists or runners were deemed relevant from a farther distance in comparison to pedestrians because they moved at a faster rate.

The three raters made all efforts to reach consensus and glance locations were coded with a minimum consensus of two out of three raters. In the rare chance that the relevance of a VRU was ambiguous, it was conservatively classified as a relevant area which assumed that a driver allocated their attention to an area for a safety-relevant reason. For additional information, highly detailed explanations of each glance category can be found in Appendix B.



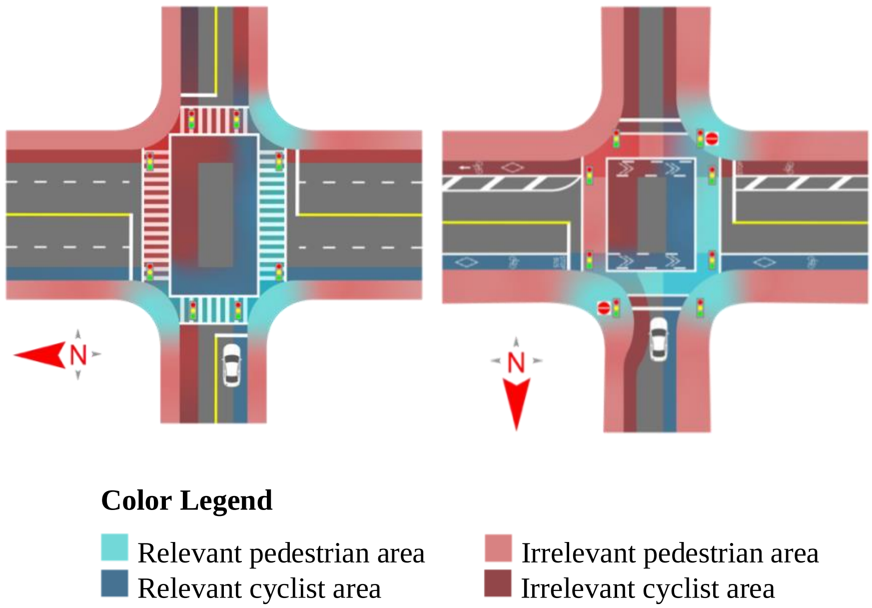


Figure 4. Relevant (blue) and irrelevant (red) pedestrian and cyclist areas for all four signalized right turns. The use of gradients demonstrate the absence of clear-cut transition points from one category to the other. The same spatial classification was applied at all four intersections.

Although 96 turn observations with eye tracking were available (excluding missing video data from 8 turns), 27 were excluded from the coding of glance categories due to unreliable gaze indication, resulting in a sample size of 69 turns. The excluded videos exhibited: (a) improper mapping of the pupils and frame-by-frame jitter which could not be corrected using post-process calibration techniques, and/or (b) distortion of extreme horizontal glances. Because the current analysis aimed to pinpoint glances to exact objects/locations across consecutive frames, it required a high level of scrutiny. Attempts to include these less reliable videos would reduce the accuracy of the reported % Time Looking measure and could even result in a systematic bias in quantitative glance proportions at left and right areas. In contrast, these errors did not affect the original visual scanning failure analysis reported in Kaya et al. (2021) because the same level of granularity was not required in determining whether drivers looked at an AOI before turning. Specifically, Kaya et al.'s (2021) high-level method could tolerate small variations in gaze mapping by considering spatially proximal (but not exact) glances as a sufficient check to account for some peripheral information acquisition. Also, the pre-determined AOIs were not located at extreme horizontal areas. Thus, these errors were out of scope. Please see the original study for a full description of their coding approach.

Signal Status

Since traffic signal status is a key contextual factor at intersections, it was recorded for each turn-analysis interval. Data was grouped as green vs. red signal status. The majority of turns started and ended on green (n = 30) or red (n = 27). There were three green-to-yellow cases (i.e., turn started at green and ended at yellow) which were recoded as Green because the driver still had the right of way. In some cases (n = 8), the turn-phase started on a red but the driver could not safely turn until the light turned green. A decision was made to split these turn observations. Specifically, driver glances while waiting at the red-light portion were recoded as Red, and driver glances while waiting at the green-light portion were recoded as Green. In the end, the total number of turn segments for driver glances was 78, with 42 Green + 36 Red (see Appendix C for a detailed decision-making process and special cases).

% Time Looking

Because real world turn maneuvers naturally vary in duration, we report a standardized % Time Looking in lieu of glance duration. % Time Looking reflects the proportion of time drivers spent looking at the different intersection areas listed in Table 2. It is derived by dividing the amount of time (in ms) each driver spent looking at an area, by the total duration of coded glances (in ms) for that turn observation or segment. It is worth noting that the denominator used was always less than the total length of raw turn videos, because saccades, eye blinks, and large head or eye shifts within each turn could not be coded (see Appendix B for a description of excluded frames). % Time Looking was calculated for each turn segment (i.e., *turn i*; Figure 5, Step 1) and then averaged across the total number of segments to produce a single percent value per participant for every area category (Figure 5, Step 2). Most drivers could have a maximum of four values for each area, one for each intersection/turn observation. However, because 27 observations were excluded for this analysis, some participants could have missing data in that their % Time Looking value is based on scores from less than four turns. For the eight different participants who had one of their turns split into red and green light segments, their average score for one area had a denominator of five % Time Looking values (assuming no missing observations for that participant). % Time Looking(individual) values were then aggregated across drivers to provide descriptive statistics.

Step 1:

$$\%\,Time\ Looking_{\text{turn i}} = \frac{\sum duration\ of\ driver's\ glances\ to\ an\ area}{\sum duration\ of\ coded\ glances\ \ for\ all\ areas},\ i = 1\ to\ n$$

Step 2:

$$\%\,Time\ Looking_{\text{individual}} = \frac{\sum_{i=1}^{n} \%\,Time\ Looking_{\text{turn i}}}{n}$$

Figure 5. Calculation of % Time Looking for any given glance category. n = total number of turn segments (i.e., % number of Time Looking $_{\text{turn i}}$ values) available for a given individual which is affected by missing data or additional signal status splits.

For the 69 turns included in this analysis, the average length of turn-analysis intervals was approximately 19.8 s, with a minimum of 4.7 s, and a maximum length of 80 s. After all turns were coded and some split by signal status, there became 78 observations which ranged from 2.98 and 49.90 s, and had a median duration of 14.03 s. Average glance duration was 502.7 ms, with a minimum glance time of 103 ms and a maximum of 9.3 s.

1.2.5 Coding of Cyclist Presence

As a secondary question, we aimed to investigates the method that Kaya et al. (2021) used to capture "visual scanning failures". Since visual scanning failure outcomes were reported for the four turns in Kaya et al. (2021), those scores were used in this analysis (see Table 2). This section provides details of the method we used to identify cyclist presence for each turn as well as an overview of Kaya et al.'s (2021) failure outcomes for the four turns in this analysis.

Coding of cyclist presence was carried out by the same three raters who coded driver glances, as described in the previous section. They independently watched the video footage from the head-mounted scene camera and recorded relevant and irrelevant cyclist presence during all turn and pre-turn phases. All available video data (n = 96) was included for this analysis because eye tracking information was not required. For this task, raters were asked to score cyclist presence on a Yes/No scale for the following four categories: Turn Phase: Relevant Area, Turn Phase: Irrelevant

Area, Pre-turn Phase: Relevant Area, Pre-turn Phase: Irrelevant Area. The method of classifying relevance is consistent with the one described previously in section 1.2.4. Interrater reliability was calculated for all turns and relevant pre-turns. Since this was a fairly objective task, it was found that the three raters had Almost Perfect Agreement overall (91.6%, fixed marginal kappa = 0.86; (Landis & Koch, 1977).

Although visual scanning failures are explained in great length in Kaya et al. (2021), pertinent details of this outcome variable are provided here. Visual scanning failures were coded conservatively on a failure/non-failure dichotomy for each turn. Specifically, a turn was identified to have a visual scanning failure if the driver did not look at one or more Areas of Importance (AOIs) where potential conflicting VRUs could approach (e.g. relevant crosswalk, sidewalk or cycle lane). AOIs were defined beforehand for each intersection which took into consideration the intersection infrastructure, direction of the turn, and signal status at the time of the turn. Three trained evaluators, who were blind to participant characteristics, independently watched frame-by-frame eye tracking video footage and labelled each turn as a visual scanning failure or not. The three raters had a substantial level of agreement overall (fixed marginal kappa = 0.63), and any uncertainty due to subjectivity and outstanding disagreements between the three raters were discussed and brought to a consensus. Lastly, the window of time which raters evaluated driver scanning is similar to the turn-analysis interval used in our primary analysis. All four intersections had the following pre-determined AOIs: (1) Right side mirror or shoulder check and (2) Relevant pedestrian crossway. In addition to these areas, T13 and T15 required drivers to check the oncoming cycle lane on left side, but only if the signal status was red meaning that leftward cyclist traffic had right of way. Table 2 presents visual scanning failures results for the four intersections of focus and the number of drivers who exhibited them.

Table 2. All visual scanning failures reported for the four turns of focus. Percentages are rounded to the nearest whole. Failure to scan the right-side mirror or an over-the-shoulder check towards the right was the only observed error for all right turns. Some turns had missing data (i.e., n < 26) due to equipment failure.

Turn code (sample size)	% (and number) of drivers exhibiting a visual scanning failure
T3 (n = 26)	27% (n = 7)
T10 (n = 24)	29% (n = 6)
T13 (n = 23)	33% (n = 9)

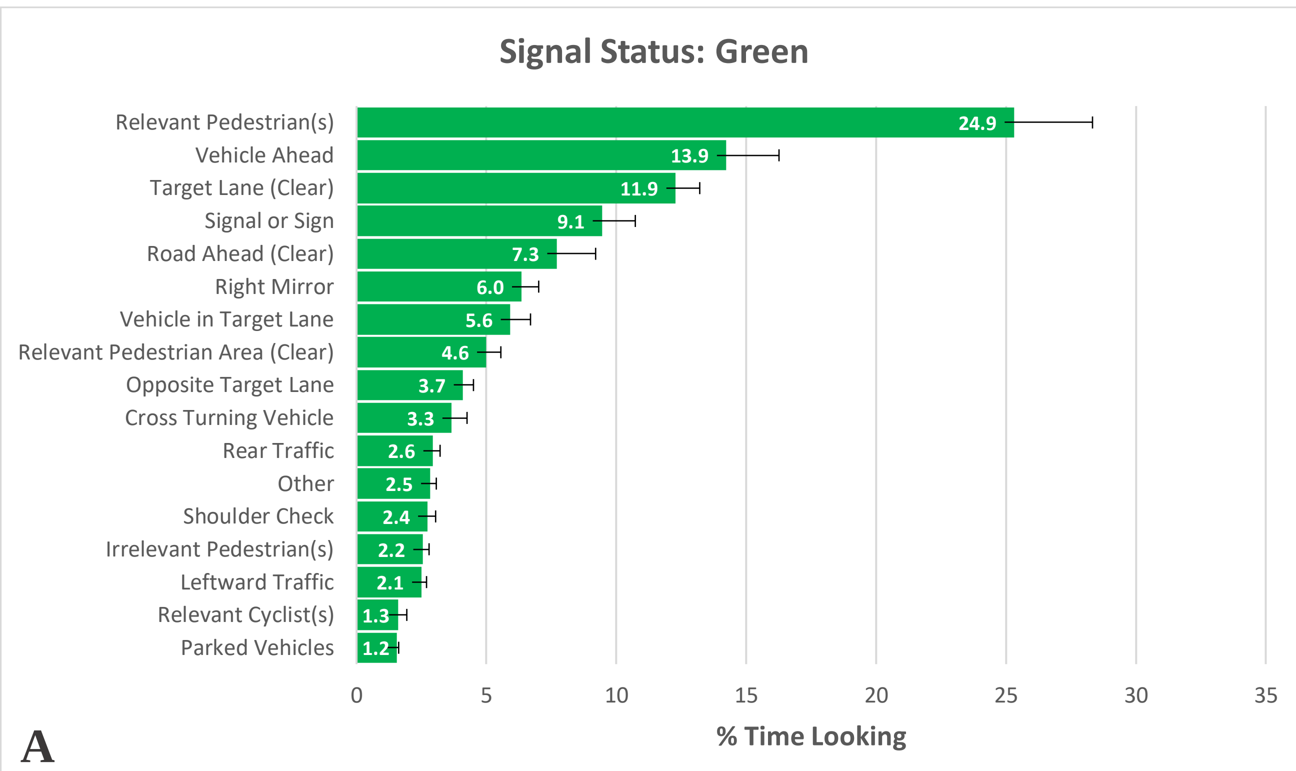
T15 (n = 23)	48% (n = 11)

1.3 Results

This section contains a descriptive analysis of driver glance distribution while turning right at signalized intersections. Trends are then broken down by signal light contexts and cycling experience. A linear mixed effects model was used to investigate the effects of some of the observed trends. Lastly, through descriptive statistics, we investigate and report the relationship between presence of cyclists in safety-critical areas and whether drivers fail to scan those areas.

1.3.1 Trends: % Time Looking Overall

Figure 6 shows % Time Looking toward the different intersection areas while drivers executed or prepared to execute a right turn; mean glance times less than 1% are excluded from the graph. The top three areas of focus at green lights were relevant pedestrian(s), vehicle ahead, and clear target lane. The top three areas of focus at red lights were relevant pedestrian(s), leftward traffic, and clear target lane.



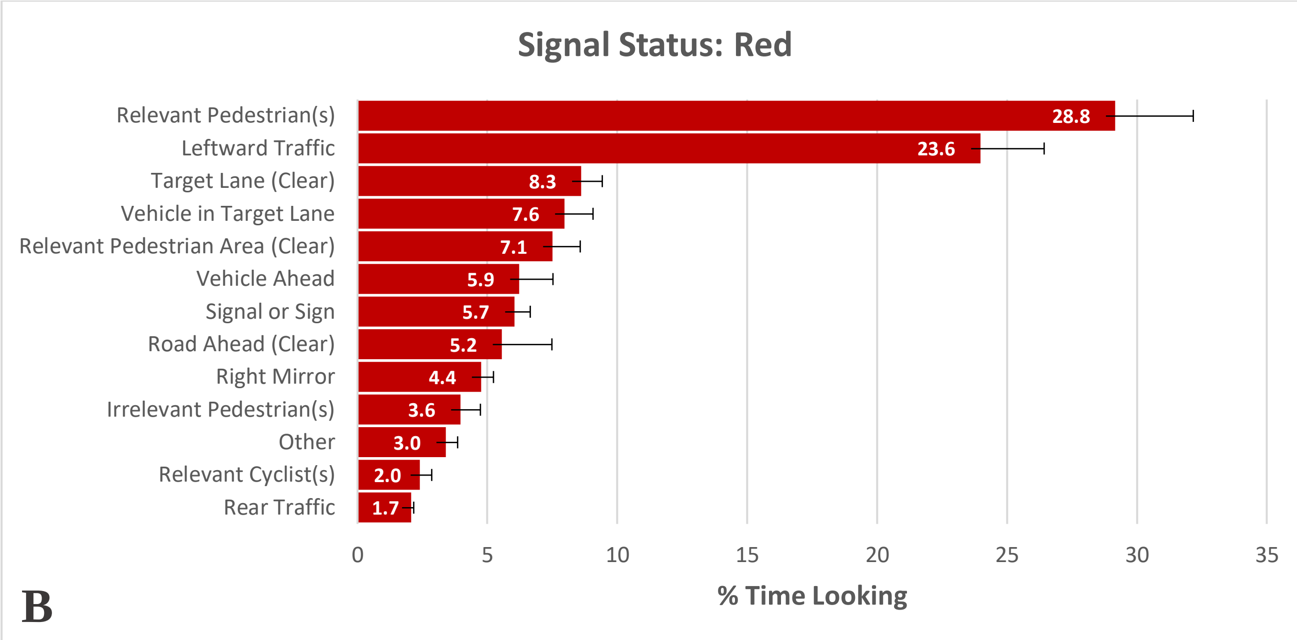


Figure 6. Where drivers spent most of their time looking while turning at (A) green and (B) red lights. Categories with a mean % Time Looking < 1 were excluded for each to improve interpretability. Black bars represent standard errors for each area.

1.3.2 Trends: % Time Looking by Cycling Experience

Glance proportions at green and red lights were broken down by cyclist group. Figures 7A and 7B summarize the glance allocations of non-cyclist and cyclist drivers, respectively. Areas were ordered by most to least attended. Again, areas or points were excluded if % Time Looking was <1%. The top area for both groups was relevant pedestrians followed by leftward traffic. A side-by side examination of these graphs shows that, across signal status, cyclist drivers tended to spend more time looking at cyclist-related areas such as the right mirror (ranked 7 vs. 8), over-the-shoulder areas (ranked 13 vs. 16), and relevant cyclists (ranked 13 vs. >16). On the other hand, non-cyclist drivers tended to spend more time checking for clear but relevant pedestrians areas (ranked 9 for cyclists vs. 6 for non-cyclists).

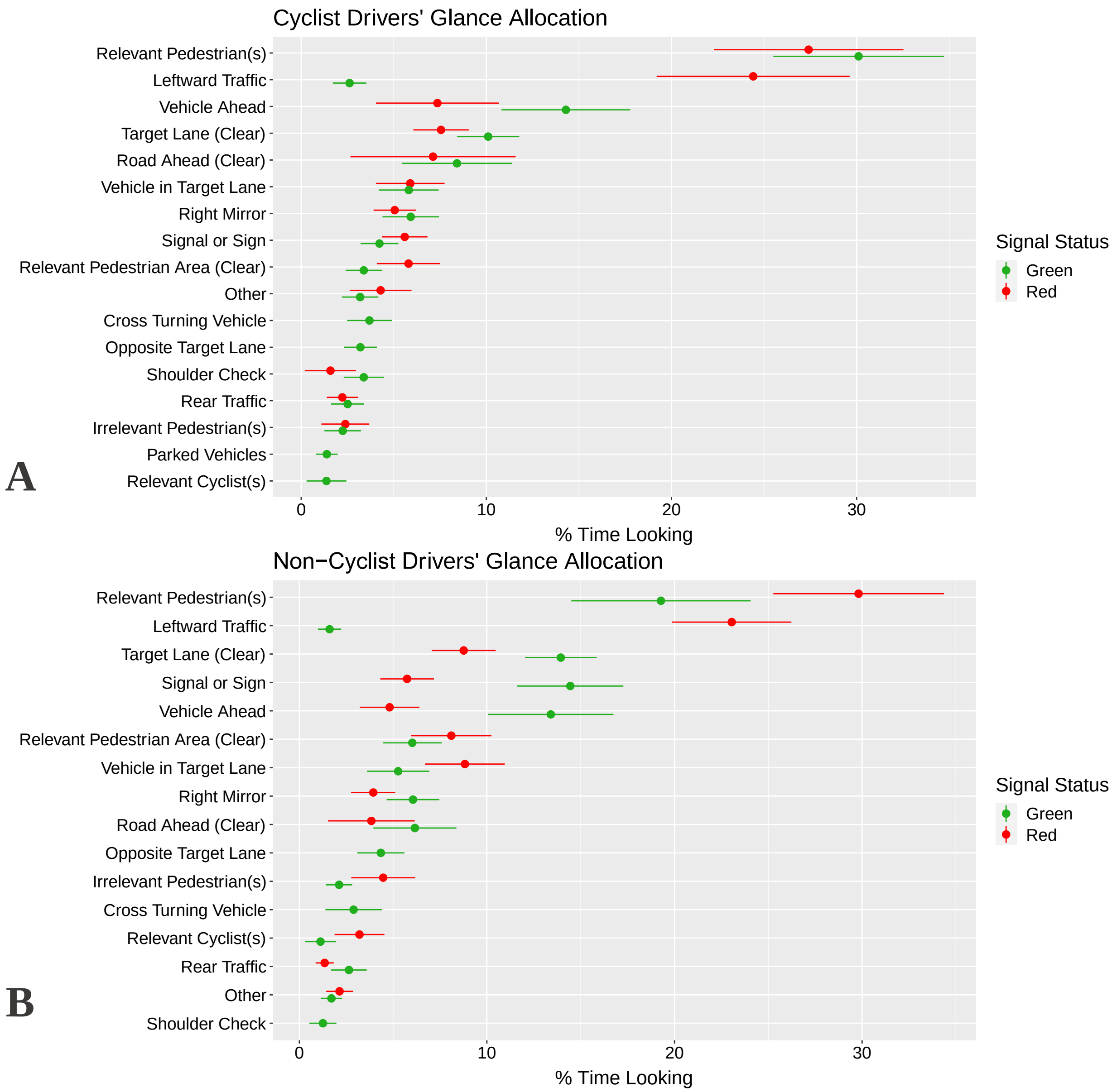


Figure 7. (A) Where cyclist drivers and (B) non-cyclist drivers spent most of their time looking while turning at green and red lights. Each data point represents mean % Time Looking, with horizontal bars to reflect standard errors. Data points with less than 1% Time Looking are excluded.

1.3.3 Glance Allocation toward right-side AOIs

The relationship between drivers' cycling experience and visual scanning failures was examined in depth in Kaya et al. (2021). Overall out of 443 turn observations, they found that non-cyclist drivers had 12% higher failure rate than drivers who did have cycling experience. This trend holds true for the subset of intersections used in the current analysis. Specifically, among the 69 original turn observations, non-cyclist drivers exhibited 13 visual scanning failures while cyclist drivers exhibited

3. This is a 23% increase for non-cyclist drivers. Figure 8 plots the percentage of failures and non-failures by cycling experience.

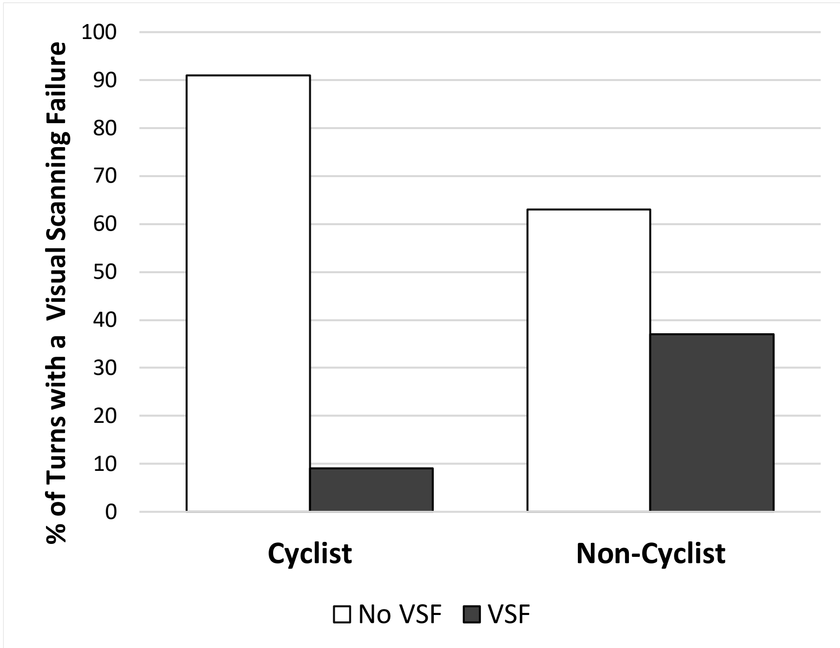


Figure 8. Percentage of turns with visual scanning failures (VSF) by cycling experience.

To understand the nature of visual scanning failures reported from the original analysis, we examined the effect of cycling experience and signal status on % Time Looking at the Right Mirror or Over-the-Shoulder areas (i.e. reported by Kaya et al. (2021) as the most unchecked Areas of Importance, or *AOIs* for all right turns). A plot of this relationship is presented in Figure 9. Cyclist drivers spent approximately 3.3-4.6% of their total glance time looking at these two areas, with the lower percent values representing red signal status. As for non-cyclist drivers, approximately 2.2-3.7% of their glances were directed toward these two areas. Across driver groups, % Time Looking at the Right Mirror or Over-the-Shoulder areas was higher while turning at green lights. Across signal status, cyclist drivers spent slightly more time (1%) on average checking their Right Mirror or Over-the-Shoulder areas.

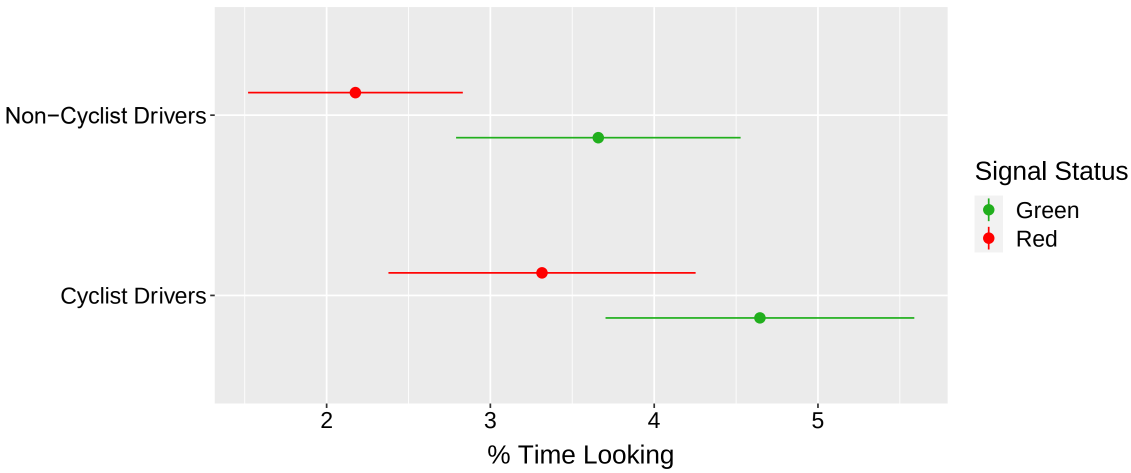


Figure 9. Mean % time looking at Right Mirror or Over-the-Shoulder areas by signal status and cycling experience. Horizontal bars reflect standard errors. Data points with less than 1% Time Looking are excluded.

These trends (Figure 9) were investigated in a mixed-effects linear model. The dependent variable was % time looking at the two AOIs; signal status and cycling experience were fixed factors and participant was modeled as a random factor. Results are presented in Table 3. No significant main effects or interactions were found. Signal status was not significant, $\chi^2 = 2.27$, $p > .05$, nor was cycling experience, $\chi^2 = 0.39$, $p > .05$. The interaction is not reported here.

Table 3. Mixed-effects linear model examining the effect of signal status and cycling experience on % time looking at Right Mirror or Over-the-Shoulder areas.

	Estimate	**Std. error**	**χ^2**	**p**	**95% CI**
Intercept	4.35	0.85	41.39	<0.001	2.70, 6.01
Signal status [green vs. red]	-1.26	0.87	2.27	> 0.5	-2.96, 0.43
Cycling experience [cyclist vs. non-cyclist]	-0.67	1.07	0.39	> 0.5	-2.85, 1.52

Table 4 presents the frequency of total checks to by cycling experience and number of checks towards these two AOIs. This table indicates that glances to the right mirror glances are more abundant than over-the-shoulder glances, and that cyclist drivers checked more frequently.

Table 4. Chi-square contingency table for number of checks to Right Mirror and Over-the-Shoulder Area by cycling experience.

	AOI		
Cycling Experience	Right Mirror	Over-the-Shoulder Area	**Total checks**
Cyclist	75	20	**95**
Non-Cyclist	59	11	**70**

To further examine the effect of cycling experience on number of checks to Right Mirror and Over-the-Shoulder areas, a negative binomial regression was conducted. The dependent variable was number of checks for each turn segment (n = 78). Total duration of glances was used as the offset variable to account for the varying lengths of turn segments. Results presented in Table 5 indicate that there were no significant main effects of signal status, B = -0.38, $p > 0.05$, or cycling experience, B = -0.27, $p > 0.05$, on the number of checks to Right Mirror or Over-the-Shoulder areas. Also, no interaction was found.

Table 5. Negative binomial model examining the effect of signal status and cycling experience on number of checks to Right Mirror or Over-the-Shoulder areas. Offset = total duration of glances.

	Estimate	Std. error	z	p	exp(B)	95% CI
Intercept	-8.38	0.18	-46.14	<0.001	0.00	-8.73, -8.01
Signal status [green vs. red]	-0.38	0.23	-1.65	>0.05	0.68	-0.84, 0.08
Cycling experience [cyclist vs. non-cyclist]	-0.27	0.23	-1.17	>0.05	0.76	-0.72, 0.18

1.3.4 Relationship between Cyclist Presence and Visual Scanning Failures

As described in Methods section 1.2.4., each of the 96 turn observations were broken down by turn phase and cyclist relevance leading to four subcategories: Turn Phase: Relevant Area, Turn Phase: Irrelevant Area, Pre-turn Phase: Relevant Area, Pre-turn Phase: Irrelevant Area. Figure 10 shows that at least one relevant cyclist was present 27% of the time and 20% of the time during the observed turn and pre-turn phases, respectively. As for cyclists in irrelevant areas, they were present 39% of the time during the turn phase, and 24% of the time during the pre-turn phase.

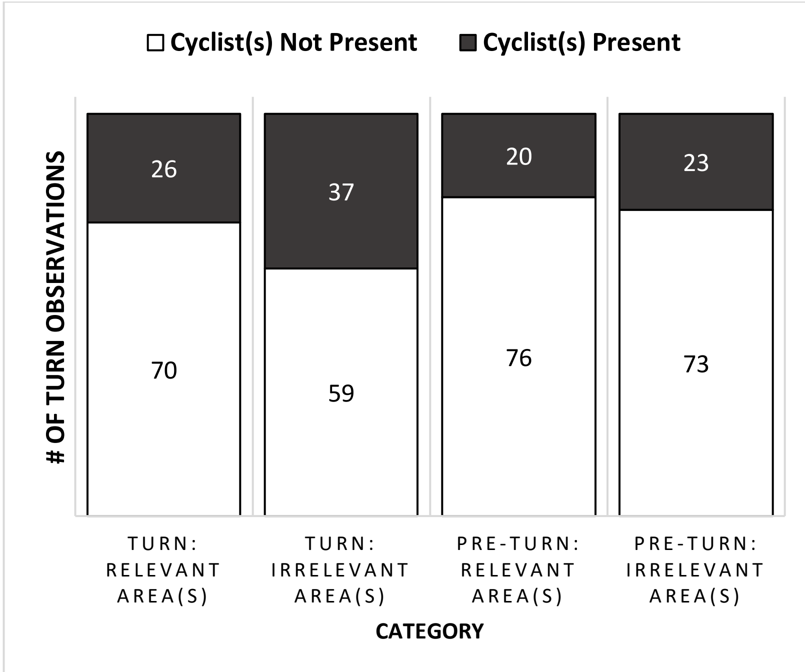


Figure 10. Number of turns with a cyclist present (either in a relevant or irrelevant area) at each turn phase (either pre-turn or turn). N = 96 for each category.

To examine the relationship between cyclist presence and visual scanning failures, the data was further broken down by failure outcome. Trends are presented in Figure 11. Bar height in all four graphs shows that turns without a visual scanning failure were more prevalent than turns with a failure and that this was irrespective of whether cyclists are present. In fact, the majority of cases (64 out of 96) where drivers did sufficiently check AOIs had no relevant cyclists present. Furthermore, the proportions of cyclist presence varied within each category and trends did not appear to be directional. For example, 23% of turn cases with no visual scanning failure had a cyclist present while, for the remaining 77% of no failure cases, a cyclists was not present (left bar in top right graph). Moreover, failure cases show similar proportions of cyclists present (right bar in top right graph). Cyclists were present in only 34% of cases, and not for the majority 66%. The remaining graphs are similar in pattern, suggesting that there is no strong association between visual scanning failures and the presence of cyclists, regardless of relevance and turn phase.

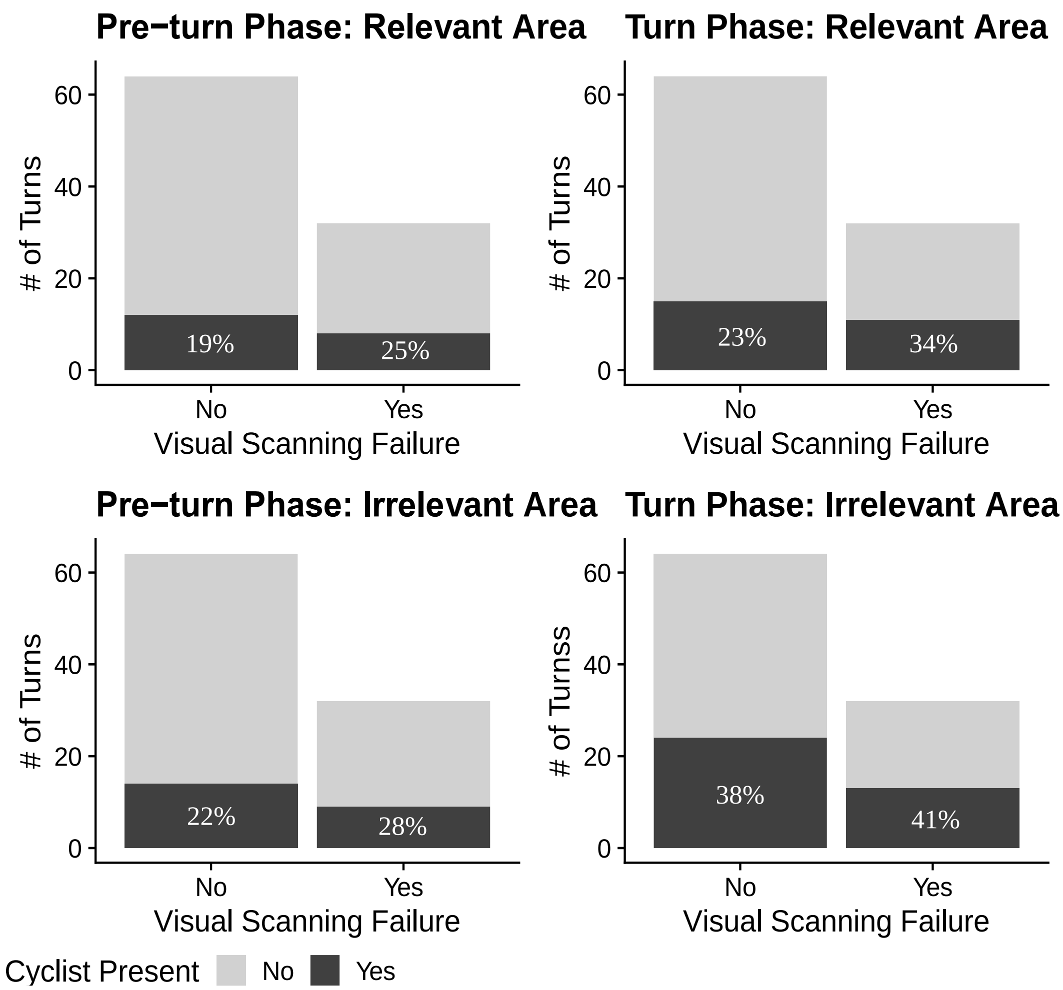


Figure 11. Plots of the relationship between cyclist presence and visual scanning failures for the four turn phase/cyclist relevance categories. Percentages are reported for cases with cyclists present, and are rounded to the nearest whole.

A mixed-effects logistic regression model was used to investigate the above trends (Figure 11). The dependent variable was whether a turn was labelled as a visual scanning failure or not; the fixed factors indicated presence of cyclists for the four turn phase/relevance categories. Saying this, the predictors were binary within-subject variables will levels “No” (there was no cyclist present) and “Yes” (there was at least one cyclist present). Again, participant ID was modeled as a random factor. The model intercept was significant suggesting that for any given turn, the odds that drivers did not check all AOIs is 0.33 (B = -1.11, p = 0.01, 95% CI = 2.12, -0.36). There was no significant effect, $p > 0.05$, of cyclist presence on driver visual scanning towards AOIs while turning right, as all confidence intervals crossed zero.

1.4 Discussion

1.4.1 Trends: % Time Looking Overall

Average glance distributions were examined across all drivers for both red and green signal status contexts. While executing or waiting to execute a right turn, drivers spent most of their time (26.9%) looking at pedestrians who were in safety-relevant areas of the intersection such as close by crosswalks and sidewalk corners. This was the top glance area irrespective of signal status. The second prominent trend is that drivers' attention was heavily skewed toward leftward traffic while waiting to turn right on red (23.6% Time Looking). This tendency to focus on left oncoming vehicles is confirmed by previous glance allocation studies (Angell et al., 2015; Räsänen & Summala, 1998; Werneke & Vollrath, 2012; Wu & Xu, 2017). It is generally agreed that drivers primarily focus their attention towards leftward traffic to identify a gap for merging. From an information value perspective, the most task-relevant information arises from the left side because oncoming vehicles pose the biggest threat to drivers' safety (Wickens et al., 2001; Wu & Xu, 2017).

The finding that relevant pedestrians were most attended seems unexpected considering previous driver glance results that disproportionate focus to left oncoming traffic during right turns on red leads to underattended pedestrian areas on the right. However, because the category Relevant Pedestrian(s) was not specific to a certain glance direction (e.g. left or right), it is difficult to compare this result in the same terms. In some earlier studies, overly attending to the left is framed to be a contradiction against glances/driver attention toward pedestrians. This is seen in studies such as Werneke and Vollrath (2012) which operationalized driver attention toward pedestrians through right side glances only. However, safety-relevant pedestrian information can of course be gathered from the driver's left as well. Saying this, it is worth clarifying the following from glance allocation findings: pedestrians on the driver's right side are more at risk of injury or collision due to attention misallocation. This does not mean that all pedestrian areas are equally overlooked, per se.

Our finding that drivers spent the majority of their time looking at pedestrians does not challenge that the right side is the less attended side. In fact, since Leftward Traffic is the second most common glance location for red lights, there is a good possibility that drivers did spend more time looking at the left area, although this cannot be confirmed here. This is, however, supported by Wickens (1993) who demonstrated that human scanning patterns are innately optimized to circumvent long or repetitive movements such as head rotations or long saccade amplitudes. This means that, following a glance toward leftward traffic, a driver's gaze is more likely to fall on adjacent objects or areas (e.g., pedestrian or cyclist areas on left side) before large movements are made (e.g., to right side VRU areas requiring a head movement; (Kvålseth, 1978; Sheridan, 1970). The same assumption about pedestrian glance direction cannot be made for green light status, as none of the top attended areas are direction specific.

The observed focus on relevant pedestrian areas supports the theory of Safety in Numbers. The Safety in Numbers posits that higher presence of walking or cycling decreases the risk of motor vehicle drivers' chances of colliding with VRUs (Elvik, 2009; Jacobsen, 2003; Johnson et al., 2014). As mentioned in Methods section 1.2.4, pedestrians are often abundant at downtown Toronto intersections and this was the case for the intersections included in this analysis. Thus, drivers could have paid the most attention to relevant pedestrians because they can be quite salient in the road scene, especially in groups. In line with this, a driving simulator study found that the leftward bias seemed to improve when pedestrians were present on the right (Werneke & Vollrath, 2012). Other studies also highlight that increased presence of pedestrians at an intersection leads to more cautious acceleration behaviour (Wu & Xu, 2017), and even may decrease the risk of vehicle-VRU collisions (Brüde & Larsson, 1993).

1.4.2 Trends: % Time Looking by Cycling Experience

There were some notable differences in glance distribution between cyclist drivers (who rode a bicycle for transportation purposes at least a few days a month) and non-cyclist drivers. In general, cyclist drivers tended to allocate greater glance time to cycling-related areas such as relevant cyclists, over-the-shoulder areas, and the right mirror. This is reflected by the higher ranking positions of these areas on the graph, out of 22 categories. Specifically, across signal status, cyclist drivers tended to spend more time looking at cyclist-related areas such as the right mirror (ranked 7 vs. 8), over-the-shoulder areas (ranked 13 vs. 16), and relevant cyclists (ranked 13 vs. >16). There was no noticeable moderating effect of signal status. Checking the right side, whether it be through a right mirror or over-the-shoulder check is critical for a driver to safely turning right at an intersection (Kaya et al., 2021). Note that this is only under the assumption that a driver had to stop. Otherwise, a scan as drivers approached a green light would also be considered sufficient. Saying this, we examined the influence of cycling experience and signal status on % Time Looking to these two right-side Areas of Importance (AOIs). While trends indicated that cyclists spent slightly more time (1%) looking at these AOIs, no significant main effects were found. It is important to note that all drivers from our analysis were relatively experienced drivers or non-novice at the least (reported driving frequently and had a full G driving license or equivalent for at least three years). Additionally, drivers were between 35-54 years old, representing the lowest relative probability of at-fault collisions in comparison to all other cohorts (Cooper, 1990; McGwin & Brown, 1999). Thus, the effect of cross modal experience on drivers' scanning to cyclist-related areas may be more concerning and should be explored for higher risk driving populations such as younger or more novice drivers (Bates et al., 2014; Martínez-Ruiz et al., 2014; Underwood et al., 2002, 2005), or older (Angell et al., 2015; Bao & Boyle, 2009; Romoser & Fisher, 2009) adults.

An overall summary of counts suggested that, although drivers spent a similar amount of time looking at the right mirror or over-the-shoulder areas, cyclist drivers checked these areas more times in total, than their counterparts did. This would suggest that cyclist drivers made shorter glances more often. However, a further examination of this trend using a negative binomial model find no significant effect on number of checks per turn. This is a surprising result considering previous research which has reported beneficial effects of cycling experience on driving tasks related to VRU safety such as detection speed and effective visual scanning (Beanland & Hansen, 2017; Kaya et al., 2021; Rogé et al., 2017). It is possible that the data did not have enough power to identify significant differences between groups. Specifically, a negative binomial regression was used in place of a Poisson model due to observed overdispersion in the data which the former can account for. However, negative binomial models can provide biased estimates at small sample sizes. From these findings we conclude that cycling experience does not predict the amount of time drivers spend looking at VRU-related areas nor does it predict the number of checks to those areas. Potentially, due to limitations of sample size, further data is needed to examine the effect of cycling experience on the number or frequency of driver checks.

1.4.3 Relationship between Cyclist Presence and Visual Scanning Failures

The relationship between the presence of one or more cyclists in cyclist AOIs and visual scans to those areas was also assessed. Trends show that, at baseline, relevant cyclists were present only a quarter of the time. Additionally, turns without a visual scanning failure were more prevalent than turns with a failure. In other words, most turns with a visual scanning failure had no cyclists present for the four turn phase/cyclist relevance categories. Irrelevant areas during the turn phase seems to have the highest relative rate of cyclists (37%), irrespective of visual scanning failure outcome. This could be due to more cyclist infrastructure on the target arterial roads (i.e., Bloor St , Spadina Rd and Bathurst St).

The link of cyclist presence and visual scanning failures was tested in a logistic mixed effects model which found no significant relationship at any of the turn phase/cyclist relevance categories on likelihood of committing a visual scanning failure. Thus, our results do not support that drivers base their AOI checks on peripheral cues (bottom-up attention capture mechanisms). Instead, evidence suggests that observed glances to these VRU areas tended to be top-down-guided actions influenced by drivers' knowledge, expectations, and experiences. This explains the significant differences found in Kaya et al. (2021) in that, in comparison to drivers with cycling experience, the odds of committing visual scanning failures towards VRUs during a turning maneuver were greater by 2.01 odds for drivers without cycling experience. However, it is important to acknowledge that glance behaviour is not a completely endogenous, stereotyped process. It may be influenced by various other scene driven factors, such as stimulus salience and threat valuations, which are difficult to quantify in a natural driving setting.

While peripheral information acquisition is critical for hazard detection and situation awareness and more; it can degrade under various conditions including environmental complexity, task difficulty, age, stimulus salience, and stimulus eccentricity (Ball et al., 1998; Lamble et al., 1999; Lord et al., 1998; Park & Reed, 2010). While we agree that "visual attention" is not synonymous with foveal vision, pupil tracking in an instrumented vehicle provides a sufficient method of analyzing where drivers attend in general. For a cyclist to capture a driver's explicit attention during a turning task in a busy urban environment, that cyclist would need to be salient enough. However, cyclists and cyclist areas tend to take up very little real estate at an intersection (in comparison to motor vehicles and pedestrians) which may increase their chance of going undetected by drivers. In a crowded intersection environment, cyclists tend to be overlooked for the sake of attending to oncoming motor vehicle traffic or a pedestrian (Hurwitz et al., 2015). On top of this, in comparison to pedestrians, cyclists require a longer stopping distance and are less agile in their movement (Wachtel & Lewiston, 1994). Relying on global scene detection may not be sufficient in these types of contexts. It could be argued that a cyclist approaching in the right mirror is small enough that it may not be captured at a glance until they become dangerously close to the driver's vehicle. While this conclusion cannot be made with the results at hand, future hazard detection research may clarify the influence of VRU characteristics on driver glance behaviour and perception.

In addition, even if hazards can be detected from the periphery, they may not be timely enough for collision avoidance. Instead, accurate mental models can foster voluntary, proactive checks to AOIs which will increase drivers' ability to promptly detect and avoid a collision. Previous research has demonstrated that drivers who have cross modal cycling experience (i.e., cyclist drivers) are (a) faster at identifying changes in driving-related objects on the road such as VRUs and road signs (Beanland & Hansen, 2017) and (b) able to identify cyclist incursions from a greater distance (> 11.1 meters; Rogé et al., 2017). In conjunction with previous works, results of this analysis suggest that road users have different visual scanning patterns and goals when navigating the roadway, and having cross modal experiences or knowledge impact drivers' visual attention to consider individuals who use these modes of transportation. While driver scanning behaviour is examined at a group level, it can also be moderated by individual differences (e.g. working memory capacity) and this should be taken into account when interpreting these results.

1.4.4 Limitations & Future Research

Hawthorne Effect

Our glance distribution analysis utilizes data from an instrumented vehicle study which required that two researchers be present in the vehicle. The knowledge of being observed (i.e., Hawthorne effect; Hansson & Wigbald, 2006) likely biased participant drivers' behaviour and visual attention allocation to an unknown extent. The reported glance distributions may hold true only when drivers are optimally attentive to the roadway, as they were for the duration of the experiment. In reality (and as seen by naturalistic driving videos), drivers may allocate more attention to non-traffic related objects or distractors such as their vehicle dashboard and personal items (Dingus et al., 2016; Victor et al., 2014). Although the analysis included glances to an "Other" category, its prevalence is likely underreported. Despite this, glance allocation differences were still found between driver groups.

Sample Size

A subset of the original instrumented vehicle dataset was used due to resource and time limitations. Theoretically, selecting four turns, each one completed by 26 participants, leads to 104 observations. However, 35 observations were excluded during the analysis due to missing data or calibration errors. The dependent variable % Time Looking requires aggregation of observations within and across participants. The sample size did not allow for between-intersection comparisons which may have shed some light on gaze behavior as it relates to different VRU infrastructures (e.g. no cycling lane vs. cycling lane present). It would be worthwhile to explore such differences in a larger study of drivers' on-road glance distributions.

Lack of control to examine peripheral cues

Conducting a driving study under real world contexts does not come without its tradeoffs. In this case, certain aspects within and across intersections such as surrounding infrastructure and road user densities could not be controlled. The relationship between the presence of cyclists in VRU areas and visual scanning toward those areas was examined. As results showed, baseline samples were not equivalent (i.e., most turn observations did not have a visual scanning failure and did not have a cyclist present). Although this analysis offered valuable insights about the link at hand, the ideal way to assess driver checking to cyclist areas may be through a controlled driving simulation which could manipulate conditions empirically (keeping in mind that realism is the tradeoff).

Chapter 2

2 Background

This study, which is funded by the SSHRC Partnership Engage Grant, supports a new partnership between the City of Guelph's Engineering and Transportation Services Department, and the University of Toronto. The City of Guelph prioritizes vulnerable road user (VRU) safety through initiatives such as the Community Road Safety Strategy (CRSS), which tackles unsafe road environments for pedestrians and cyclists through various approaches, including infrastructure modifications and public education campaigns (City of Guelph, 2020a). Studies have demonstrated that traditional citizen request-based approaches utilized by municipalities such as Guelph have led to socioeconomic inequities in roadway features that enhance VRU safety (Rothman et al., 2019, 2020). As such, the City outlines the importance of collaborating on research studies to help narrow this equity gap in future policy making and road safety program distribution. Currently, Guelph has a need for on-road evaluation of their current VRU infrastructures from a driver behavior and attention perspective. This partnership aims to directly address this need, in addition to making significant contributions to the existing literature (below). It will also generate novel and actionable results which will help the City of Guelph meet their road safety goals. This study is timely and relevant, not only for Guelph, but on a global scale, as the world is embracing Vision Zero initiatives, which recognize road safety as a societal priority, and aim to eliminate all preventable traffic-related deaths (Vision Zero Network, 2020).

Vulnerable road user (VRU) safety is a major societal concern. Pedestrian fatalities represented 17.3% of all Canadian road user fatalities in 2018, while cyclist fatalities were at 2.3% (Government of Canada, 2020). Intersections are of particular concern when it comes to VRUs (Robertson, 2015), as they account for a high ratio of fatalities. This is likely because intersections bring VRUs and motor vehicle drivers within close proximity to each other, thus providing opportunities for conflict. Suburban intersections can be particularly dangerous for VRUs due to higher speeds, wider intersections (i.e., longer crossing times) and lower exposure to cyclists. In the City of Guelph, about one pedestrian collision happens every 10 days. According to the City of Guelph's 2015-2019 Collision Report, all reported cyclist and pedestrian collisions resulted in an injury, with 8.1% of these collisions resulting in a major or fatal injury outcome (City of Guelph, 2020b). Over this time period, 381 cyclists and pedestrians were involved in a collision.

Driver inattention is a leading cause for collisions with VRUs. Numbers show that, in the majority of collision cases, VRUs are identified as having the right of way. In 2016, 50% of all pedestrian injuries in Ontario occurred while pedestrians were crossing an intersection with right of way, as opposed to 16% when the pedestrian crossed without right of way (Ministry of Transportation, 2016). Canadian police-reports list "failing to yield the right-of-way" and "distraction and inattention" as the two most common driver errors leading to pedestrian crashes (CCMTA, 2013). An in-depth analysis conducted in Finland on cyclist-car crashes found that only 11% of drivers noticed the cyclist before impact, whereas 68% of the cyclists noticed the driver, with the majority expecting that the driver would give way as required by law (Räsänen & Summala, 1998). The drivers were identified to be misallocating their attention mostly because they were focused on motor vehicle traffic.

It is well established that drivers experience increased demands while navigating intersections (Cantin et al., 2009; Hancock et al., 1990; Teasdale et al., 2004), as intersections require drivers to divide their attention in several directions and toward a variety of traffic agents (e.g., other drivers, pedestrians, cyclists) and control devices (e.g., road signs, traffic signals; Romer et al., 2014). These demands can be mitigated with better infrastructure designs - a topic that is of major importance to municipalities such as the City of Guelph. For example, a recent meta-analysis found that, out of fifteen broad cycling infrastructure solutions, cycle tracks (physically separated cycling lanes) are the most effective solution for preventing cyclist injuries (DiGioia et al., 2017). Although the road safety literature supports the effectiveness of some infrastructure solutions, relevant studies look at conflicts or crash events but do not capture their root causes: most notably, how driver attention interacts with different intersection elements (e.g., cycle tracks vs. painted multi-use paths), and which design elements are best in supporting drivers to detect VRUs. Saying this, rigorous on-road research is still needed to quantify the impact of various measures on VRU safety (DiGioia et al., 2017).

Despite the City of Guelph's great interest and dedication to protecting VRUs (as is reflected by its various detailed road safety reports), it currently lacks the resources to implement and evaluate pilot programs of different intersection designs, and is unable to study driver behavior at the road level (i.e., within the vehicle). Identifying and understanding the on-the-ground predictors of driver behavior in high-collision-rate areas is critical to developing effective road safety plans and countermeasures. With this, the **overall aim** of this partnership is to understand how drivers interact with vulnerable road users within different road infrastructures implemented in the City of Guelph.

2.1.1 Research Objectives

Specific research objectives are as follows:

1. Examine whether the quality of driver scanning toward VRU areas is inherently worse at intersections with high collision injury risk (based on crash or near miss data), in comparison to lower risk counterparts.

2. Determine whether drivers exhibit safer scanning toward VRU areas at intersections with novel, VRU-centered design interventions, in comparison to traditionally designed counterparts.

3. Evaluate whether drivers exhibit safer scanning toward VRU areas at locations with more developed VRU infrastructure (e.g. cycle track, buffered lane), as opposed to traditional narrow painted bike lanes. Also, does driver scanning differ between intersections with different VRU infrastructure?

2.2 Methodology

This section describes the details of an on-road, instrumented vehicle case study designed in collaboration with the City of Guelph Engineering and Transportation Services. Between April to September 2022, 50 non-novice drivers (half of whom frequently cycle as a mode of transportation) will conduct 13 experimental turns at City of Guelph intersections. These turns were selected either based on VRU injury risk, or to examine existing VRU infrastructures for which driver scanning insights were desired. Driver behaviour will be recorded using head-mounted eye tracking glasses along with cameras placed on the vehicle's interior and exterior. Eye tracking videos will be coded to assess whether drivers exhibited visual scanning failures towards areas of importance to VRUs.

2.2.1 Participants

Fifty volunteer drivers (25 females, 25 males) aged 35 to 54 will participate in this study. This age cohort was selected due to its demonstrated low crash risk (Cooper, 1990; McGwin & Brown, 1999) which contributes to greater participant safety. Participants will be recruited through various outreach methods such as Community Newsletters, Recognized Facebook groups, local bike shops, local cycling/active transit advocates, and the City of Guelph's social media channels. During recruitment communications, the compensation rate of $17 per hour for up to 3 hours will be disclosed. Participants are required to have a full driver's license (G in Ontario or equivalent) for a minimum of 5 years who drive frequently and are familiar with the experimental area. Recruitment materials are available in Appendix D. We will require drivers to report that they drive in Guelph "at least a few days a week" whether it be for commuting or residential purposes. Guelph drivers were selected for two reasons: (1) to impose some control over drivers' experience with the experimental area, and (2) they are the target population of Guelph's transportation decisions. Participants need to have self-reported normal or corrected-to-normal vision, hearing and memory for safety purposes. They must also report no restrictions in neck mobility (which would influence over-the-shoulder checks). Participants will also be asked to refrain from wearing eyeglasses and makeup as these are known to interfere with eye tracker accuracy. For participants who require vision correction, contact lenses must be worn.

Each participant will be grouped into "cyclist" or "non-cyclist" driver categories. These categories enable the comparison between drivers who have cross modal cycling experience, and those who do not. The distinction is operationalized based on responses to the following screener question: "Over the year (excluding winter), how often do you ride a bicycle as a transportation tool?". Those who self-report that they cycled for transportation purposes at least "a few days a month" will be recruited under the cyclist-driver group, while those who select that they cycled less than "a few days a year" will be recruited under the non-cyclist driver group. Previous studies looking at cycling experience have used similar criteria (e.g. Beanland & Hansen, 2017; Johnson et al., 2014; Kaya et al., 2021; Robbins & Chapman, 2018; Rogé et al., 2017). Independent t-tests and Wilcoxon rank-sum tests will be used on pre-drive survey responses to ensure that no additional demographic differences exist between the two groups. Respondents who currently hold a motorcycle license or have previously participated in an on-road study will be excluded to prevent potential confounds related to cycling experience.

2.2.2 Apparatus

For data collection, this experiment utilizes the same apparatus as that outlined in Chapter 1. One difference is that, in addition to road-facing and driver-facing cameras, two cameras will be installed to the vehicle exterior's left and right sides to capture lateral objects in the road scene such as cyclists. All camera data is to be collected and processed through the latest D-Lab software, v3.55.9166.0. Eye trackers may require post-processing calibration and corrections. This will be conducted in D-Lab to ensure that participant pupils were precisely captured for every frame. Before participant recruitment, a pilot test will be conducted to ensure equipment is in optimal order. This includes evaluating eye tracker precision and calibration quality and that all vehicle cameras are synced to each other. Any concerns raised by the pilot test will be troubleshooted before data collection.

2.2.3 Intersection/Site Selection

Intersection/turn selection was done collaboratively with representatives from the City of Guelph Engineering and Transportation Services and led by practical considerations. Site and route details were decided using Guelph maps, Google Maps, and various meetings with the City's road safety experts. Intersections of Interest (IOIs) are grouped into three types: high risk IOIs, pilot IOIs, and exploratory intersections. An overview of all study intersections is presented in Table 6. Intersections from the first two groups are paired with a counterpart which serves as a control. The following segments describe these selections in detail.

Table 6. Summary of all study intersections.

Intersection of Interest	Type	Counterpart
Gordon St at Surrey St (plaza)	High Risk IOI	Gordon St at Kortright Rd (plaza)
Clair Rd W at Gordon St		Gordon St at Kortright Rd
Gordon St at Wellington St		Wyndham St S at Wellington St E
Gordon St at Stone Rd	Pilot IOI	Gordon St at College Ave
Paisley Rd at Alma St N		Victoria Rd N at Cassino Ave
Stone W at Chancellors Way	Exploratory Intersection	None
Stone Rd E at South Ring Rd E		None
Elizabeth St at Arthur St		None

High Risk IOIs

Objective 1: Examine whether the quality of driver scanning toward VRU areas is inherently worse at intersections with high collision injury risk (based on crash or near miss data), in comparison to lower risk counterparts.

The majority of IOIs were chosen for their appraisal as "dangerous" or "problematic" intersections where traffic collision injury rates, or near-miss interactions were high. In 2020, the City of Guelph published a collision report which detailed collision rates and problem areas for VRU safety between 2015 and 2019 (City of Guelph, 2020b). Particularly, the City reported the Top 10 Intersection Locations with Highest Percentage of Injury Collisions. The first IOI in Table 1, Gordon Street at Surrey Street, is number one on the list, with 29 total collisions of which 51.7% resulted in an injury. Similarly, Clair Road West at Gordon Street had a 23.4% injury collision rate out of 77 total collisions and was ranked number five on the list. This list was not VRU-specific, however, the severity of vehicle collisions is not independent of VRU safety. For instance, Gordon Street at Surrey Street (the highest % injury location for all road users), had 9 total vehicle-cyclist collisions, where cyclists were seriously injured 100% of the time. Notably, this turn is not onto Surrey Street (local road) but rather into a plaza entrance adjacent to the local road. It is the only IOI which turns into a plaza instead of a road (see Figure 13 for visual representation). Also relating to risk, one near-miss location was included based on information from two sources: BikeMaps crowdsourced data (bikemaps.org) and confidential incident reports directed to Guelph. Here, a near miss is defined as a narrowly avoided collision which did not result in injury but had significant potential to do so. According to bikemaps.org, there were five reported near misses directly at the intersection of Gordon Street at Wellington Street and many others close to the intersection. While crowdsourcing data has limitations such as sampling bias, it provides valuable information about risk exposure and a framework for interpreting crash data (Ferster et al., 2021). These three IOIs, which will be referred to hereafter as 'high risk IOIs', were also chosen to contain similar painted bike lanes on at least one of the roads. They are also all signalized. This enables some exploration of whether painted bike lanes - the most commonly used and cost-effective bicycle corridor treatment - are similarly effective under different implementations or contexts.

Pilot IOIs

Objective 2: Determine whether drivers exhibit safer scanning toward VRU areas at intersections with novel, VRU-centered design interventions, in comparison to traditionally designed counterparts.

Pilot IOIs are intersections which have experienced a recent infrastructure change that serves as a safety countermeasure. These changes are a part of Guelph's Community Road Safety Strategy (City of Guelph, 2020a). Since it is too early to rely on collision data, examining driver scanning behavior at these locations is a proactive method of shedding light on VRU exposure and risk.

In 2018, the intersection of Gordon Street and Stone Road was redesigned due to concerns for pedestrian and cyclist safety. Because this location is nearby the University of Guelph campus, many students cycle and walk through this intersection. Additionally, Gordon Street and Stone Road are both large arterials with heavy motor vehicle traffic density. It also ranked as the ninth Intersection Location with Highest Percentage of Injury Collisions before its redesign. These reasons led the City of Guelph to implement a user-centered protected green cross ride design which allows cyclists to maneuver through the intersection more easily without needing to dismount their bicycle or use the pedestrian crosswalk (see Figure 12 for illustration). The pedestrian crosswalk was also freshly painted to produce a more salient thick striped design.

Figure 12. Images of new protected cross ride redesign at Gordon Street and Stone Road, Guelph, Ontario.

The second pilot IOI is Paisley Road at Alma Street. Unlike Gordon Street and Stone Road, this IOI does not have any obvious infrastructural element; however, it has a newly implemented Leading Pedestrian Interval (LPI). This provides pedestrians with a head-start of five seconds to begin crossing, before cars are given a green signal. In 2020, Paisley Road at Alma Street was selected to as an LPI pilot location for a variety of reasons. In addition to high vehicle volume and high volume of VRU populations such as school children, seniors and persons with disabilities, it housed increasing collision reports of turning vehicles.

Counterpart selection

Each of the 5 IOIs was matched with a counterpart to provide a baseline control for driver visual scanning behavior. For high risk IOIs, this enables some exploration of whether the quality of driver scanning toward VRU areas is inherently worse at intersections with high collision injury risk, in comparison to lower risk counterparts. “Lower risk” counterparts are defined as those with no immediate concern based on collision history (e.g. not identified in Guelph’s Top 10 Collision Report). For pilot IOIs, this allows a kind of Before-After comparison of visual scanning behavior to assess whether pilot changes contribute to safer results, in comparison to a similar but traditionally designed intersection.

Ideally, counterparts are exactly identical to IOIs with the exception of collision history or pilot changes (depending on IOI category). However, this is not a realistic expectation when conducting research in a geographically-bound naturalistic road setting. Saying this, counterpart selection was prioritized based on the features that were Necessary to Match, and those which were Nice to Match (but not critical) to the driving context. The first column in Table 7 reflects specific attributes to infrastructure which can strongly affect the driver experience and workload on the roadway. For example, it is necessary for pedestrian and cyclist infrastructure to be the same for an IOI and its counterpart since driver scanning toward these areas will be evaluated. On the other hand, if a potential counterpart intersection checked all the Necessary to Match criteria, but had one extra lane on the destination road, it would still be considered a match (assuming no better match is available in Guelph). Naturally, drivers must turn in the same direction at counterpart locations; this is discussed in the following section. Illustrations of all five IOI-counterpart pairings are presented in Figure 13. While an overview of similarities and differences are highlighted for each, further details can be found in Appendix E.

Table 6. Criteria for selecting comparable counterparts.

Necessary to Match	Nice to Match
Pedestrian and cyclist infrastructure	Number of lanes
Intersection shape/type	Road sloping
Signalization	Intersection size
Dedicated turning lanes	Road messaging (e.g. non-essential signage)
Road types/classifications	Other (e.g. lane width, freshness of paint)
General land use context	

IOI: Gordon St at Surrey Street (plaza)

Counterpart: Gordon St at Kortright Rd (plaza)

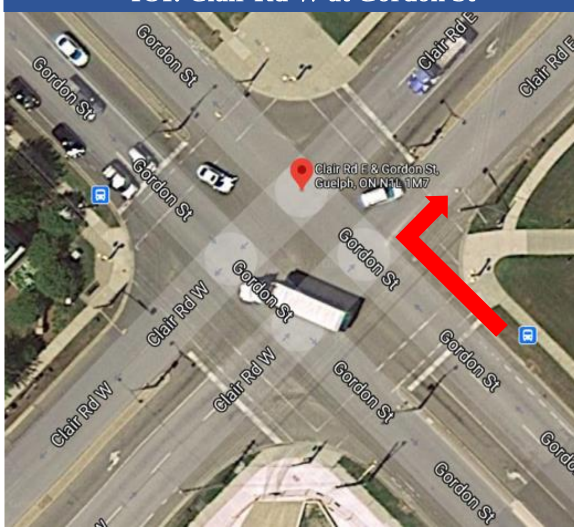
Similarities

- Pedestrian infrastructure: paved sidewalk before driveway
- Bike infrastructure Painted lane, downhill travel
- Uncontrolled
- No dedicated left turn lane
- Large arterial
- Transit stops in similar location/nearby (may indicate increased VRU exposure)
- Commercial area
- Close proximity to major intersection

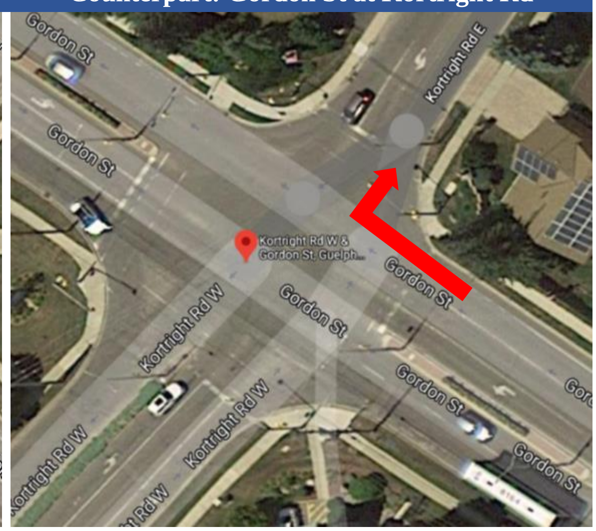
Differences

- “Do not Block Bike Lane” sign at IOI

IOI: Clair Rd W at Gordon St



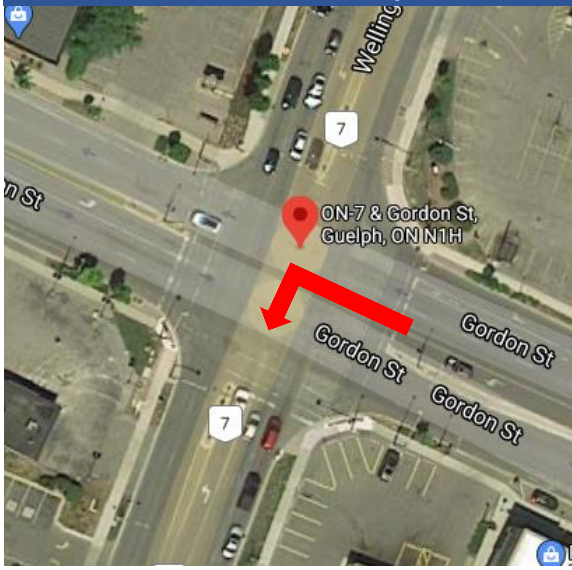
Counterpart: Gordon St at Kortright Rd



Similarities

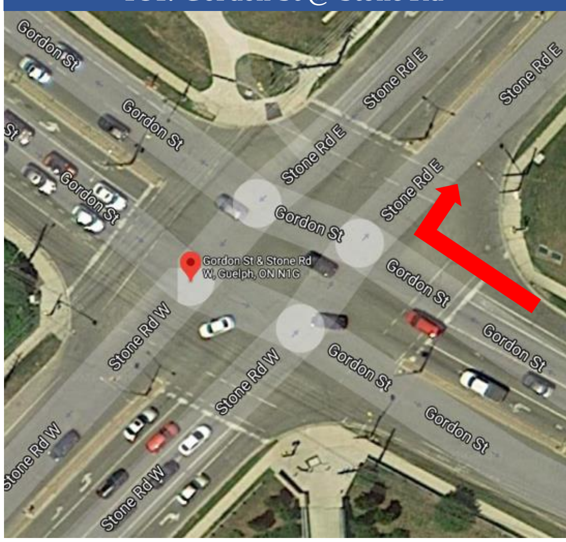
- Pedestrian infrastructure: Crosswalk with simple painted lines
- Bike infrastructure: Painted bike lanes
- 4-way signalized cross of arterials
- No dedicated right turn lane
- Majority commercial (counterpart has more residential buildings)

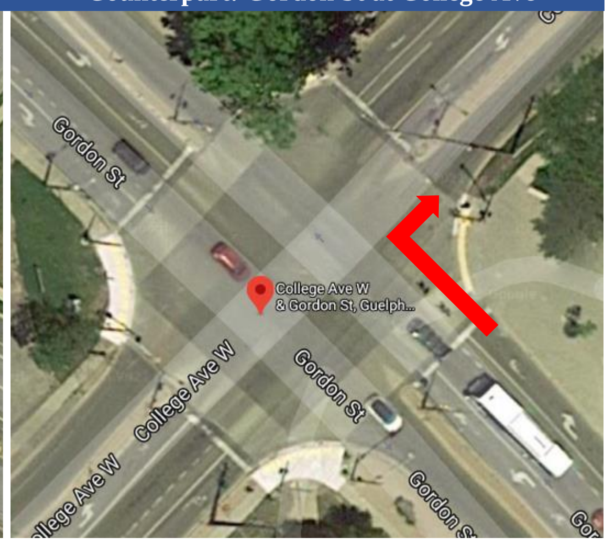
IOI: Gordon St at Wellington St	Counterpart: Wyndham St S at Wellington St E



Similarities
- Pedestrian infrastructure: Thick striped crosswalk
- Bike infrastructure: Painted bike lanes
- 4-way signalized cross of arterials
- Dedicated left turn lanes
- Majority commercial

IOI: Gordon St @ Stone Rd	Counterpart: Gordon St at College Ave





Similarities
- 4-way signalized cross of arterials
- Signalized
- University/campus area
- Dedicated right turn lanes

Differences
- Pedestrian infrastructures
- Bike infrastructures
- IOI has wider roads and noticeably newer (green cross ride) design

Similarities
- Pedestrian infrastructure: crosswalk with simple painted lines
- Bike infrastructure: None
- Cross intersection between arterial and local roads
- Signalized
- Residential land use
- No dedicated turn lanes

Differences
- Leading Pedestrian Interval (LPI) installed at IOI
- Arterial is 2 lanes (smaller arterial) at IOI

Figure 13. All five IOI/Counterpart pairings. *Note: Some satellite images are not up to date. Also, the bird's eye view images below are best for illustrating the overall structure and context of an intersection; however, particular road elements/updates can be seen from Street View only.*

Additional Exploratory Intersections

Objective 3: Evaluate whether drivers exhibit safer scanning toward VRU areas at locations with more developed VRU infrastructure (e.g. cycle track, buffered lane), as opposed to traditional narrow painted bike lanes. Also, does driver scanning differ between intersections with different VRU infrastructure?

Three "exploratory" intersections were added to the route due to their more unique VRU infrastructure/designs. These locations possess more separated VRU infrastructures such as a cycle track, buffered bike lane, or multi-use path instead of the classic painted lane found in the high risk or pilot IOIs. The inclusion of these locations is more exploratory or probative. These intersections were not assigned counterparts due to our priority to keep the driving routes at a reasonable length to limit driver fatigue. However, eye tracking data from these locations can provide some insight into how driver scanning behavior may vary based on road design elements in hopes to guide future research. These exploratory intersections are listed in Table 8 and their designs illustrated in Figure 14.

Table 7. Summary of exploratory intersections with unique infrastructures in Guelph.

IOI	*Infrastructure*
Stone Rd W at Chancellors Way	Cycle Track
Stone Rd E at South Ring Rd E	Buffered Bike Lane
Elizabeth St at Arthur St	Multi-use Path

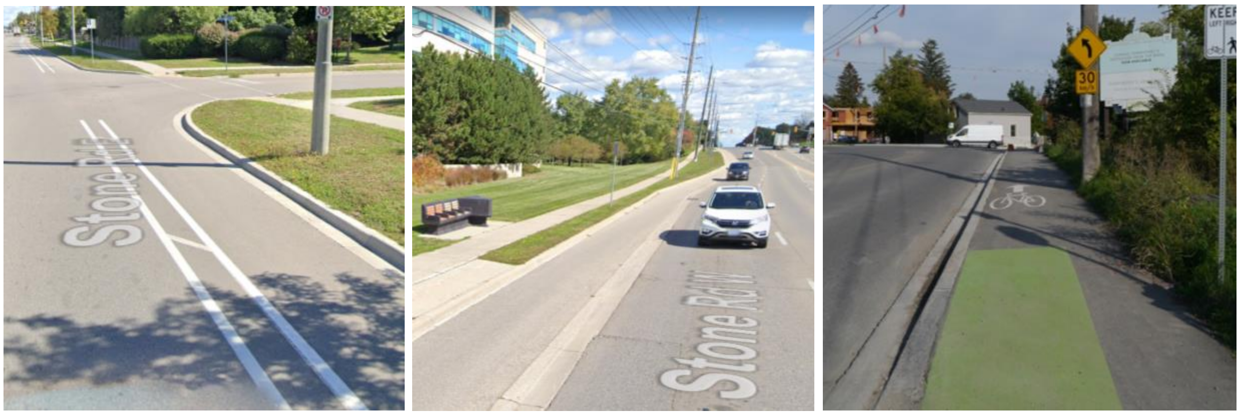


Figure 14. Exploratory intersections with more separated VRU designs. Left: Buffered bike lane located on Stone Road East, Middle: Paved cycle track on Stone Road West, Right: Multi-use path on Elizabeth Street. While the first two infrastructures are used by cyclists only, the multi-use path design encompasses multiple VRUs, such as pedestrians and cyclists, by offering a two-meter wide asphalt path for travel both ways.

2.2.4 Driving Route

All intersections listed in Table 6 were broken up into two driving routes. Route A includes all IOIs as well as the buffered bike lane location (6 turns in total), while Route B includes all counterpart locations as well as cycle lane and multi-use path locations (7 turns in total). Google Maps estimates suggest that these routes are very similar in length; Route A = 29 minutes, Route B = 27 minutes). To partially account for learning and fatigue effects, the order of routes will be counterbalanced.

Turning movements (as opposed to driving straight or changing lanes) were selected for two reasons. First, research shows that most collisions with VRUs take place as vehicles are turning (Bassil et al., 2015; Urban Systems, 2015). Secondly, this pattern is supported in Guelph, where turning movements were the most common impact type at Guelph signalized intersections (27%), following rear end collisions (City of Guelph, 2020b). The direction of turns (either left or right) was informed by a confidential report of 2015 to 2019 collision data provided by Guelph. The goal was to mimic the problematic maneuvers which have occurred at the chosen IOIs. For each intersection included in this study, the report provided information regarding the number of vehicle and vehicle-VRU collisions as well as the types of vehicle movements upon impact (e.g. proceeding straight, turning left). Based on this data, Guelph's traffic safety specialists also annotated this report with suggestions regarding turn direction. For example, at Gordon Street and Stone Road, most motor vehicle collisions with pedestrians or cyclists took place while turning right onto Stone Road. Thus, a right turn maneuver was selected for this intersection. As mentioned previously, counterparts were assigned the same direction as IOIs. Using the previous example of Gordon Street and Stone Road, participants would also be asked to make a right turn at its counterpart, Gordon Street at College Avenue. Table 9 provides route details including turn direction and order of turns. Detailed route maps can be found in Appendix F. Routes were mainly devised based on an IOI and counterpart distinction. However, to set up the correct orientation or approach-direction for an experimental turn, drivers will sometimes be required to make additional turns. These turns will not be analyzed for this study. Notably, all roads in this study are major arterials with the exception of some target roads: Alma Street, Cassino Avenue (its counterpart), and the target roads for the exploratory intersections. These are local roads.

The main experimenter in the front passenger seat will provide standardized turn-by-turn instructions which will be given at the same point of drive for all participants. The timing of turn directions will be done using pre-determined geographical landmarks along the route. This is to circumvent timing challenges which would arise in such a naturalistic driving setting (i.e. "10 seconds prior to intersection" is not a helpful point of reference, since a driver's speed is dependent on dynamic vehicles or traffic elements ahead). To add an element of familiarity, the phrasing of instructions will approximate that of popular GPS systems. This means concise phrasing and standardized wording across turns to keep driver's working memory load at a minimum (see Appendix G for route scripts).

Table 8. All study intersections listed in order of turn. The order of Routes A and B will be counterbalanced across participants.

	Turn number	Maneuver	Turn direction
ROUTE A	1	Clair Rd W onto Gordon St	Right
	2	Gordon St onto Stone Rd	Right
	3	Stone Rd E onto South Ring Rd E	Left
	4	Gordon St onto Wellington St	Left
	5	Gordon St into Surrey St (plaza)	Right
	6	Paisley Rd onto Alma St N	Right
ROUTE B	1	Gordon St onto Kortright Rd (plaza)	Right
	2	Gordon St onto Kortright Rd	Right
	3	Stone W onto Chancellors Way	Left
	4	Gordon St onto College Ave	Right
	5	Wyndham St S onto Wellington St E	Right
	6	Elizabeth St onto Arthur St	Right
	7	Victoria Rd N onto Cassino Ave	Left

Each route has a start and end point. The location at which participants meet for set up and conduct a practice drive is dependent on which route they are assigned first (see following section 1.2.5. Procedure for set up details). For example, if a participant is assigned order B-A, then they will be instructed to meet experimenters at a location near the start point of Route B. These points are mapped in Appendix F. After completing the first route, participants will receive a 5-minute break. Experimenters will then transport the vehicle to the starting point of the second route. This will be about a 10-minute drive where talking will be kept to a minimum to ensure a standardized experience for all participants. After completion of the second route, participants will receive another 5-minute break, then the experimenter will take over and drive vehicle back to original start/meeting point where the experiment will end.

All data collection will take place during daylight, on weekends, and in good weather conditions (i.e., Saturdays and Sundays from April to September 2022). This decision was informed by a thorough evaluation of vehicle and VRU density patterns obtained through Guelph traffic count data. More specifically, counts were calculated using a Miovision in-situ video system which was installed exclusively at one of the IOIs, Gordon Street and Wellington Street. Traffic density was visualized across a fourteen day period from Saturday March 6 to Sunday March 14, 2021. It was found that weekends offered a more consistent traffic volume whereas weekdays exhibited various peaks of traffic throughout the day which were not ideal for standardization purposes. On weekends, traffic volume was consistent from 11:00 PM until 5:00 PM. Therefore, a data-driven decision was made to conduct experiments at either 11:00 AM or 2:00 PM, when traffic data fluctuated the least. Although these counts are specific to one location in the route, they provided some indication of density across the route. Weekends are also ideal because (a) most construction work is active on weekdays only and (b) large commercial vehicles are at a minimum. If weekend construction projects are to take place that will affect the experimental route, Guelph will notify researchers and data collection will be avoided for these days.

2.2.5 Procedure

Eligibility will be assessed via a screening/demographic questionnaire which participants will complete online (see Appendix H). This questionnaire asks about respondent's age, gender, licensure status, general health (e.g., hearing, vision), as well as the frequencies in which they drive, walk, and cycle. Eligible participants will then be contacted via email with information about the driving task (including a detailed consent form) and asked to sign up for one of four weekend time slots. Participants will be instructed to arrive at a designated meeting place in a quiet Guelph neighborhood (see start and end points in Appendix F) with their driver's license. There, a small table and chair will be set up, with opaque desk dividers on both sides of the table to provide privacy while participants read and fill out confidential information such as the consent form (consent form can be found in Appendix I). The consent form discloses to participants that, "this study aims to understand driver behavior in urban settings". No additional information about the study's aim will be given away.

Following consent, participants will complete a pre-drive questionnaire which collects new information about participants' demographic backgrounds and driving records. It also asks some similar questions to those in the screening questionnaire (to ensure answers have not changed). Answers will be reviewed to confirm eligibility before the drive begins. If the status of eligibility has changed or cannot be confirmed (e.g. participant forgot corrective contact lenses, or driver's license), participants will kindly be sent home and compensated for the time elapsed. The pre-drive questionnaire also collects new information about participants' demographic backgrounds and driving records (see Appendix J for pre-drive questionnaire). Before the drive, participants will receive orientation and training about the instrumented vehicle and the driving procedure. Lastly, participants will be told to keep talking to a minimum, that they should exhibit natural driving behavior including following the rules of the road (e.g., giving right of way to emergency vehicles, no cell phone use) and that aberrant driving will result in immediate termination of the experiment (see Appendix K for Emergency Vehicle Reminder Sheet).

Participants will then complete a 5 to 10-minute familiarization drive in the neighborhood during which they can ask questions about the experimental procedure and the vehicle. Here, they will also be given examples of turn-by-turn instructions so they know what to expect (e.g., “At the next traffic signal, turn right”). Following the familiarization drive, participants will be equipped with the eye tracking glasses and will undergo a calibration process. Without moving their heads, participants will be asked to gaze directly at 6 points located outside of the vehicle. Four of the points will correspond to the experimenter’s fingertip who will stand outside of the vehicle and point in the shape of a rectangle, capturing four quadrants. Two additional points will be added to capture the driver’s extreme left and right gazes. To ensure that calibration is successful, participants will fixate their eyes towards various locations in the environment while a second experimenter, using the monitor positioned in the back seat, verifies that the participant’s gaze indeed falls on the locations indicated by the gaze position indicator.

Upon calibration, participants will complete the two experimental routes described in section 2.2.4. The eye tracker will be recalibrated before the start of each route. Three people will be present in the vehicle at all times during the drive(s): (1) the participant, (2) the primary experimenter, who will provide all instruction including turn-by-turn directions, and (3) a supporting experimenter, who will monitor the data computer from a rear seat. Following the completion of both (all) routes, the eye tracker will be removed from participants, and the experimenter will take over to drive the vehicle back to original start/meeting point where participants may have left their vehicle or taken transit. Lastly, participants will complete a five-question post-drive survey where they will provide rating regarding how natural and cautious they felt their driving to be during the experiment (Appendix L).

Procedures will take a maximum of 2.5 – 3 hours to complete. This study is in the process of approval by the University of Toronto Research Ethics Board. However, previous studies using a similar approach in downtown Toronto have been approved and conducted (Ponnambalam, 2018; Kaya et al., 2018; Kaya et al., 2021).

2.26 Driver Video Analysis

Three trained evaluators, who are blind to participant characteristics, will independently watch frame-by-frame eye tracking video footage to identify whether each turn reflects a visual scanning failure or not. This is the same coding process which is summarized in Chapter 1 Section 1.2.4, and explained in great detail in (Kaya et al., 2021). Rates will then be compared to address the research questions outlines for this study and to also assess the effect of cycling experience on scanning behaviour toward VRUs.

COVID-19 disclaimer: This study is planned to run in Spring of 2022. However, this will depend on the status of the COVID-19 pandemic and social distancing rules in effect at that time. If data collection is approved for this time, then all the necessary health and safety precautions will be taken, as outlined by Health Canada and the University of Toronto.

Chapter 3

3 Conclusions and Future Work

Chapter 1 of this thesis provides a novel and thorough report of driver glance distributions toward scene-specific areas at urban intersections, and describes how these patterns implicate VRU safety. To aid safer deployment of visual attention resources, sources of driver attention misallocation first need to be identified. While previous naturalistic and accident-investigation studies have provided insight into drivers' glance allocation within intersections, these findings were limited to general gaze directions obtained through video analysis, meaning that the specific objects or agents to which drivers are attending to could only be inferred. This gap was addressed by utilizing an on-road dataset collected by our lab in 2019 which offers rich eye-tracking *and* in-vehicle video data from 26 experienced drivers (13 cyclists and 13 non-cyclists) who completed four right signalized turns in downtown Toronto. Among various trends, this analysis of existing data showed that drivers spent the most time glancing at relevant pedestrians, irrespective of signal status, and driver attention was heavily skewed toward leftward traffic during red lights. The pedestrian finding was somewhat surprising but supports the safety in numbers effect (Elvik, 2009; Jacobsen, 2003; Johnson et al., 2014). While trends were seen, this analysis could not provide statistical support for glance allocation differences between cyclist and non-cyclist drivers and how that may interact with turn context such as signal status. Specifically, there were no significant differences in the amount of time spent looking at VRU-related areas or number of checks to these areas. This is a surprising result considering previous research which has reported beneficial effects of cycling experience on driving tasks related to VRU safety such as detection speed and effective visual scanning (Beanland & Hansen, 2017; Kaya et al., 2021; Rogé et al., 2017). Since patterns were visually noticeable, the results reported could be due to limitations of sample size, and further data is needed to examine the effect of cycling experience number or frequency of checks per turn.

As a secondary aim, this thesis examined **whether the presence of vulnerable road users (VRUs) in safety-critical areas was associated with drivers' visual scanning** to those areas. This exploration meant to challenge the current assumption that pupil tracking in an instrumented vehicle provides a sufficient method of evaluating the safety of drivers' visual scanning by asking: *What do driver actually need in the scene vs. what we think they need?* However, results did not find support for the relationship between cyclist presence and the likelihood of drivers committing a visual scanning failure at a given turn. This indicates that drivers did not mainly base their AOI checks on peripheral cues (bottom-up attention capture mechanisms) although VRUs can still capture a driver's attention to aid in collision avoidance. These results help inform future decisions to use driver gaze tracking. However, since this was a post hoc analysis, baseline samples were not equivalent (i.e., most turn observations did not have a visual scanning failure and did not have a cyclist present). Although this analysis offered valuable insights about the link at hand, the ideal way to assess driver checking to cyclist areas may be through a controlled driving simulation which could manipulate conditions empirically and make causal inferences, keeping in mind the rigour-realism tradeoff. We acknowledge that glance behaviour is not a completely endogenous, stereotyped process. Glance behaviour may be influenced by various other scene driven factors, such as stimulus salience and threat valuations, which are difficult to quantify in a natural driving setting. A valuable future study would be one which could parse out the effect of driver experience from scene-specific variability in assessing eye movements.

In Chapter 2, an instrumented vehicle study was outlined which is set to run on April of 2022 (since data collection requires good weather conditions). Although the road safety literature supports the effectiveness of some infrastructure solutions, relevant studies look at conflicts or crash events but do not capture their root causes: most notably, how driver attention interacts with different intersection elements (e.g., cycle tracks vs. painted multi-use paths), and which design elements are best in supporting drivers to detect VRUs. Primary research findings from this project will allow the City of Guelph to examine its current VRU infrastructures in an unprecedented level of detail. This highly collaborative approach can amplify government resources to address key policy gaps and questions. The instrumented vehicle methodology will observe drivers as they navigate through real intersections and will provide insights beyond what can be gained from collision/conflict data. Moreover, the City will be equipped with personalized, evidence-informed insights and recommendations that aim to benefit VRU road safety goals through infrastructure design.

This collaboration will also foster more equitable and proactive road policy practices for the City of Guelph. Currently, the locations for road safety intervention are selected and prioritized based on the frequency of reported residential concerns. However, these reports typically originate from residential areas with higher socioeconomic status. The City of Guelph aims to make more proactive decisions by prioritizing and understanding intersections which have the highest percentage of injury collisions. This reform can have significant benefits for all road user types, and especially those from lower income areas.

The study is not without limitations. With any behavioral study, the Hawthorne effect may bias the way participants behave while being observed by experimenters in the vehicle (Hansson & Wigbald, 2006). More specifically, it is likely that participants put extra effort and attention into the driving task, despite the fact that interaction with experimenters is kept to a minimum and participants are told to exhibit natural driving behavior. A limitation specific to this study is the fact that intersection selection is limited to real Guelph intersections and accompanying road geography. For example, if an ideal counterpart intersection was too far away from the rest of the route (e.g. 20 minutes away from previous and next locations), a practical decision to exclude this location is made to persevere a reasonable route duration. Although practical considerations played a big role in experimental design, the fact that these are real intersections is also a strength from a generalizability standpoint.

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Appendices

CH 1

Appendix A: Selection of Analyzed Intersections

The instrumented vehicle data set by Kaya et al. (2021) offers data from seven right signalized turns. Due to the scope of the current analysis, it was not feasible to examine all seven turns on a frame-by-frame level. Instead, four turns/intersections were chosen because they had very similar context whereas three were more distinctive or stand-alone. “Similarity” was defined as having the similar intersection size, infrastructure, and land use context. Table 1 below presents these relevant details for all seven right signalized intersections from the experiment. Table 1 shows that the majority of turns are maneuvers from local to major roads at small-to-medium sized junctions. Size was defined by 2 intersection variables: physical width of intersection as well as number of lanes, since one variable alone was not telling. For example, the target road (i.e., T.R.; road which drivers turned onto) at T3 was four lanes wide which is usually indicative of a larger intersection; however the lanes were narrow and the size of the intersection centre was similar to other two-laned intersections. T4 and T11 stood out from the rest in that they were both large, major intersections that had highly commercial land use. This differed from the others which had a more mixed context. Due to these reasons, they were excluded first. The remaining five turns were all of similar size and land use context, but T1 had a pre-turn approach with prominent bicycle parking and bike share facilities which may have had a priming effect on drivers. Although this would be interesting to explore, the current analysis was not set up to control for or examine these effects empirically. Thus, this turn was excluded, leaving T3 from Route A, and T10, T13 and T15 from Route B as the final four. These four were also balanced in terms of existing bicycle infrastructure in that half of them had a painted bike lane on the T.R., while the other half did not.

The table lists shows all right signalized turns from Kaya et al. (2021). The focus of the following sections will be on T3, T10, T13, and T15 which are highlighted in grey. Intersection type was not included because all were cross junctions. All intersections had no bike lane on the origin road (i.e., O.R.; road from which the driver begins their turn).

	Turn Code	**From**	**To**	**Bike lanes on T.R.**	**# Vehicle Lanes on O.R.**	**# Vehicle Lanes on T.R.**	**Size**	**Land Use**
	T1	Local road	Major arterial	Buffered	1	2	Small	Mixed (majority commercial)
A	T3	Local road	Major arterial	None	2	4	Small	Mixed (majority residential)
	T4	Major arterial	Major arterial	Buffered	5	3	Large	Highly commercial

B	T10	Local road	Major arterial	None	2	4	Small	Mixed
	T11	Major arterial	Major arterial	Painted	4	3	Large	Highly commercial
	T13	Local road	Major arterial	Painted	2	2	Medium	Mixed
	T15	Local road	Major arterial	Painted	1	2	Small	Mixed (majority commercial)

Appendix B: Glance Coding Guidelines

Note: "AOI" = Area of Interest and refers to the raw glance categories in D-Lab

- **Right mirror (3 levels: clear, cyclist present, or pedestrian present)**: Glances to/near the right mirror; "Present" reflects pedestrians and/or cyclists reflected in the mirror
    - Occasionally double-coded with relevant pedestrian/cyclist area or destination road due to ambiguity between looking at or looking beyond the right mirror
    - Levels are not mutually exclusive (e.g. both a pedestrian and a cyclist can be present in the mirror)
- **Shoulder check (2 levels: clear, present)**: Area in the far right and rear window
    - Begins when driver's head is oriented to the right-side window (beyond the right mirror at about halfway through the window), not incl. very rapid eye movements to/from the back right or rearview window unless they are between points of fixation all in the shoulder check area
    - Examples of "present" incl. cyclists or pedestrians
- **Leftward traffic**: Area left of intersection, on destination road
    - Coded as leftward traffic regardless of traffic (vehicle) presence
    - Included all lanes of the road
    - Stop coding as leftward traffic when the car passes the crosswalk lines on the destination road
    - Can include a parked vehicle on the leftward traffic area
- **Cross-turning vehicle**: Vehicle turning left from the opposite direction into destination lane (or waiting to turn left)
    - Indicated by turn signal or other contextual clues, such as vehicles going around the cross-turning vehicle to continue straight through the intersection around it
    - Specific to green and/or amber lights (i.e., area does not include a potentially left-turning vehicle waiting at red)
- **Roadway ahead (2 levels: clear, vehicle present)**: Road in front of the vehicle, including the roadway in the turn intersection and beyond (excepting crosswalks/bicycle lanes). Crosswalk is sometimes captured in those areas.
    - Examples of "clear" incl. gazes to stop lines and open road ahead
        - When the vehicle was completing the actual turn portion, coded as clear ahead regardless of vehicles present in a lane next to them (unless they are looking directly at the vehicle)
        - Clear not referring to the lack of pedestrian/cyclist presence, i.e., refers to vehicle presence specifically
    - Examples of "vehicle" incl. any moving vehicle in either direction of traffic

    - Code as "vehicle" when either looking at a vehicle, or looking near a vehicle, esp. when looking across a large distance ahead
  - T13: expanded for because of unique intersection shape. There is no straight travelling traffic for this turn. Technically opposite lane is on the left of driver, but based on functionality it falls under this category
  - T15: includes the vehicles in the lane directly ahead
- **Destination road (3 levels: clear, vehicle present, vehicle present in opposite lanes)**: Road which the driver intends to turn right into (this roadway area is considered the destination road through the entire duration of the turn, including the pre-turn interval)
  - "Opposite" refers to vehicles in the left side of the road travelling in the direction opposite to the lane the driver intends to turn into
  - Leftward and cross-turning traffic enter the destination road area once they have entered into the relevant pedestrian crosswalk
  - Coded "Clear" at the end of the turn as vehicle entered destination road when there were minimal/no cars in the crosshairs
- **Rear traffic**: Traffic behind vehicle on origin road. Can be checked through rear view mirror, left side mirror, or diagonal head/eye movement. Not a sufficient VRU check and should not be coded as such without the presence of other AOI scans
  - Not incl. glances out the rear window performed with a head turn (this is instead part of shoulder check)
- **Parked vehicles**: Any vehicle which is parked and not part of actively moving traffic, on destination road, leftward traffic, or roadway ahead in either direction of travel. Also includes parked vehicles in parking lots.
- **Relevant pedestrian area (2 levels: clear, present)**: Area of crosswalk/sidewalk where pedestrian presence could impact turn-related decisions; Location considered safety critical for turn
  - Incl. the crosswalks drivers must drive over to complete the right turn and the sidewalks/corners which supply pedestrians to those areas
  - Differentiated from a shoulder check as the area more directly behind the right mirror, rather than the area directly out the right window requiring significant head movement to view
  - Incl. cyclists which dismount their bicycles to walk through pedestrian areas (such as 2002 T13)
  - "Clear" incl. when looking directly at a part of the pedestrian area which has no pedestrians present (even if there are pedestrians located in the entire relevant pedestrian area)
  - Incl. pedestrians walking away from crosswalk, as long as they are **very close** to the corner/road (reminder: focus on the area not so much the VRU)
  - In crosswalks or street corners deemed relevant to turn (diagram)

- **Irrelevant pedestrian area (2 levels: clear, present)**: Area of crosswalk/sidewalk where driver is *not* required to check (i.e., in the scene but not near AOI for given signal status – location not safety critical for turn)
    - Incl. crosswalks/sidewalks to the left of the intersection and on the opposite side of the intersection
    - Considered pedestrians (usually during the pre-turn) which were in pedestrian areas leading up to the intersection to be relevant to turn completion, but those pedestrians which were **significantly far from** the intersection during the pre-turn were considered irrelevant
        - Far enough where they may never cross paths at intersection based on timing (this state is very dynamic and so judgment is made on a glance by glance basis)
    - RE relevant corners: If pedestrian is walking in opposite direction from the intersection, the distance to become irrelevant is very short. Specifically, if they are no longer in the corner = irrelevant

<u>Note on cyclist areas</u>
T3 and T10: There are no designated bike lanes on any of the roads
T13 and T15: designated lanes on destination road

- **If cyclists are close enough or glance can be differentiated from other road areas or agents, then cyclist AOI was used – this was especially the case with roads that did not have a designated bike area (e.g. Could be blended with leftward traffic AOI)**
- If no cyclist AND no designated lane = Destination road, Leftward traffic or Roadway ahead (depending on location of glance)
- Clear lanes will often be double coded with other glance objects (lane AOI is very small in comparison to others)

- **Relevant cyclist area (2 levels: clear, present)**: Area that cyclists travel in, incl. any bike lanes or shoulder of road cyclists use (depends on intersection)
    - "Present" incl. cyclists which travel through pedestrian areas like crosswalks (clarification: those that remain on the bicycle) (updated below for each turn i.e., with or without cyclist lanes)
    - Included cyclists which were ahead of the vehicle (during the pre-turn) as relevant as the vehicle could overtake them by the intersection. If no cyclist, coded as roadway ahead
    - Cyclists walking bike in pedestrian area = pedestrian
    - T3 and T10: Cyclists biking in pedestrian area = Cyclists
    - T13 and T15: Cyclists biking in pedestrian area = Pedestrian because they have a designated cycling lane

- **Irrelevant cyclist or cyclist area (2 levels: clear, present)**: Cyclist areas or unmarked parts of the road (e.g. all roads for T3 and T10, and origin road for T13 and T15) where driver is not required to check (e.g., in bike lane on opposite side of road – location not safety critical for turn)
- **Origin Road Left (or Adjacent)**: for T13, cars pulling up on driver's left due to 2 lane
- **Signal or sign**: Driving-related signal/signs, incl. pedestrian signals, traffic lights, and construction signage
- **Other**: Non-traffic related object in scene (e.g., building, tree, etc.) Includes the inside of the car, such as the dashboard.

Eye Movements

- **Blinks**
  - Did not include the blinks, unless they were within a single fixation
  - Sometimes the pupil is detected, but the glance is removed if it is at the end/beginning of the blink
- **Missing frames**
  - Included if it was a single frame missing within a larger set of frames (about 100ms)
  - Did not include large missing sections unless they could be reasonably assumed and were infrequent in the data
- **Passing glances/eye movements**
  - Single frames (unless the exception case below) and those fixations with durations less than 100ms were excluded from coding
  - If the driver is moving their head from one side to the other, but make multiple fixations in the same area with no other disruptions (I.e. fixations on other AOIs) then we included those as the same glance in that AOI
- **Lens glare (on eye-facing cameras)**

Appendix C: Signal Status Groupings

Original counts

Signal	T3	T10	T13	T15	Total
green	11	9	5	3	**30**
red-green	1	1	2	6	**8**
red	8	9	5	5	**27**
green-yellow	2	0	1	0	**3**
green-red-green	0	0	0	1	**1**
Total	**22**	**19**	**13**	**15**	**69**

The majority of turns started and ended on green (n = 30) or red (n = 27). There were three green-to-yellow cases (i.e., turn started at green and ended at yellow) which were recoded as Green because the driver still had the right of way. In some cases (n = 10), the turn-phase started on a red but the driver could not safely turn until the light turned green. A decision was made to split these turn observations. Specifically, driver glances while waiting at the red light portion were recoded as Red, and driver glances while waiting at the green light portion were recoded as Green. Lastly, there was one special turn case which had a turn-analysis interval of 1 minute and 20 seconds. During this, the light changed from green, to red, and to green again before the driver could complete their turn. In an effort to preserve data, the first green portion was excluded, and a red-green split was made using the same method described above. There were two red portion cases that were made up of only one glance. These were excluded from the analysis to avoid the skewing the data toward 100% Time Looking. In the end, the total number of observations for driver glances at Green was 42, and 36 for Red (see Figure 6).

<u>Grouping method</u>

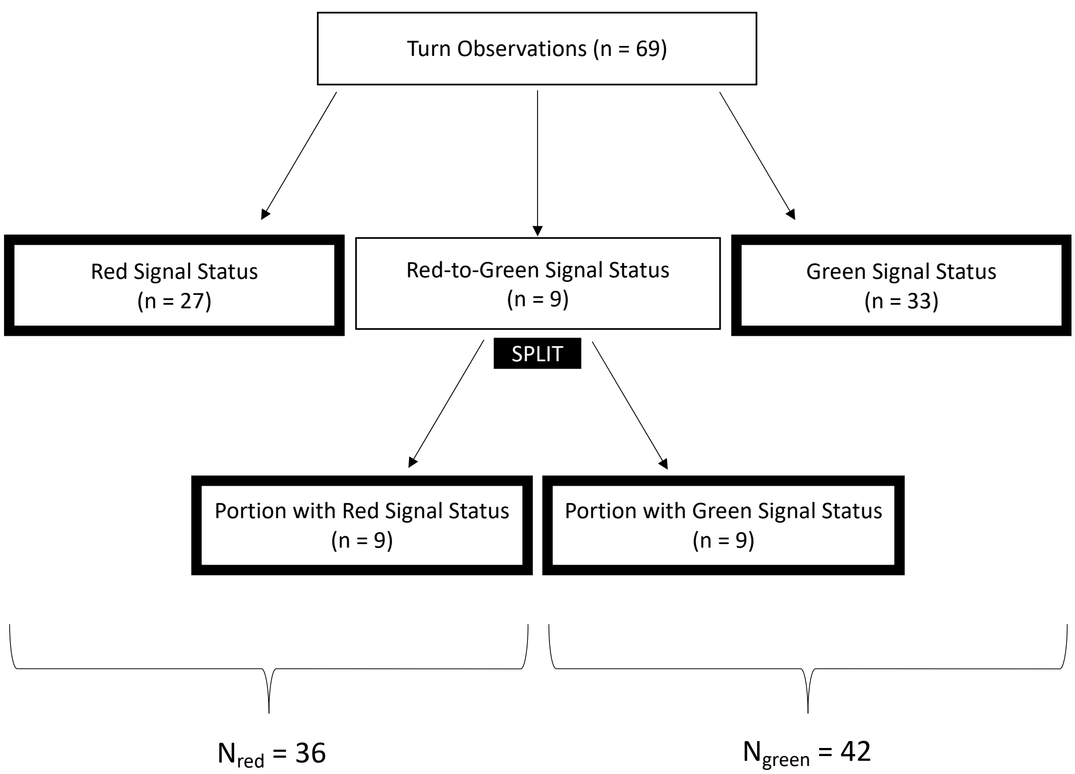


Figure 6. Flowchart illustrating how turn observations were grouped by signal status. Total number of observations (n = 78) includes observations from the boxes outlined in black.

CH 2
Appendix D: Recruitment Materials

D1) Recruitment flyer

D2) Call for participants

Participants Needed
The University of Toronto is looking for participants for an applied driving study.

The study will:

- Take place in Guelph on the weekends
- Take approximately 2.5 – 3 hours
- Provide compensation of $17.00 per hour

If you are between the ages of 35 to 54 and have a valid G license, you may be eligible to participate! Please complete this short survey to find out: [insert survey link]

For questions, please contact [email].

D3) Selection email

Hi [first name],

Thank you for taking the time to fill out our screening survey. We are pleased to inform you that you qualify for our University of Toronto driving study. The study will take place in Guelph on the weekend (Saturday or Sunday) during two time slots, 11 am or 2 pm.

The experiment will take between 2.5 to 3 hours and will require you to answer some surveys before and after the drive. You will be driving in our instrumented vehicle while we collect data from the vehicle and from the eye-tracking glasses that you will be asked to wear. You will be compensated at $17/hr for your time.

The following slots are open:
Saturday XX… _@ 11 AM
Saturday XX… _@ 2 PM
Sunday XX… _@ 11 AM
Sunday XX… _@ 2 PM
--- and subsequent weekends until we have enough participants

If you are still interested in participating, please reply to this email confirming four things:
a) That you are between the ages 35-54
b) That you hold a valid G license issued at least 5 years ago
c) That you can drive legally without wearing glasses (contacts are allowed)
d) Your preferred day and time slot

Also, eye makeup has been shown to interfere with our eye tracker system, so please refrain from wearing any makeup when you come to participate.

The week before your scheduled slot, we will call and confirm your participation, as well as provide further meeting/location details. If you have any questions in the meantime, please don't hesitate to ask.

Thank you!

Appendix E: Guelph Intersection Details

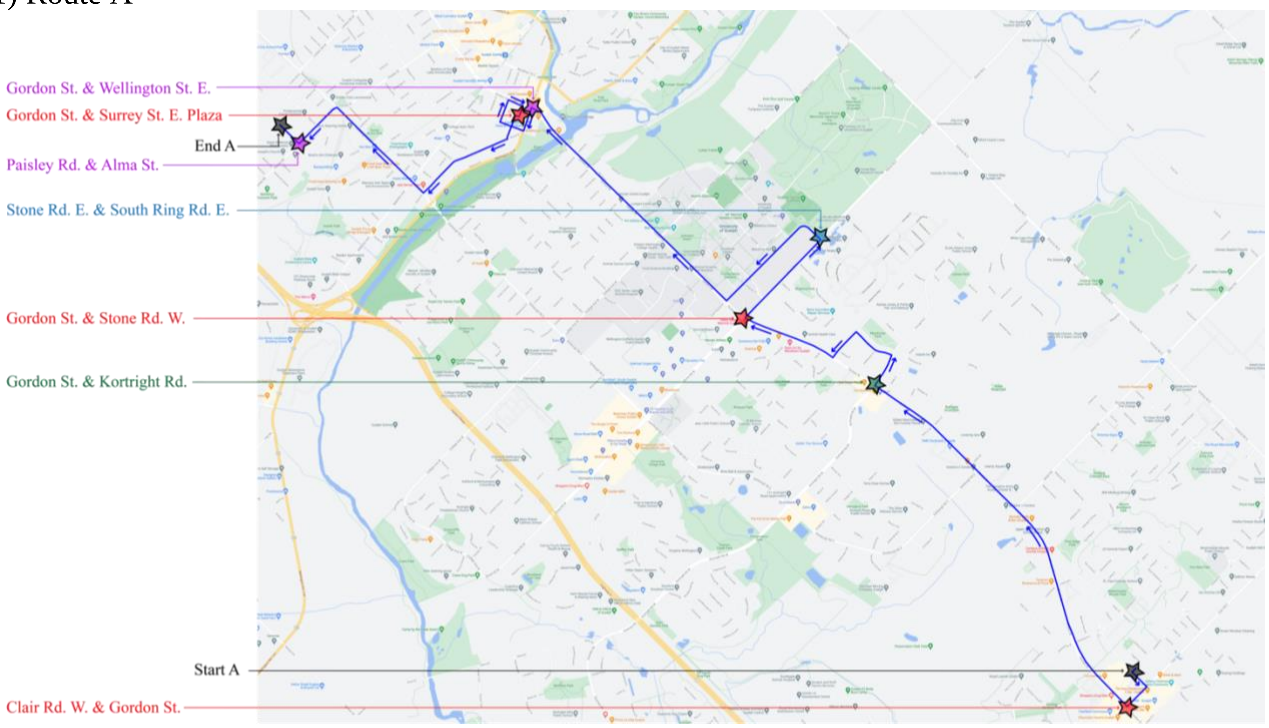
A special layout is required to display this information. To view, please click the following link:
https://1drv.ms/w/s!AmPJczNoDZGNg0fQtO0VlmMy9LyH?e=wK2kh8

Appendix F: Guelph Route Maps

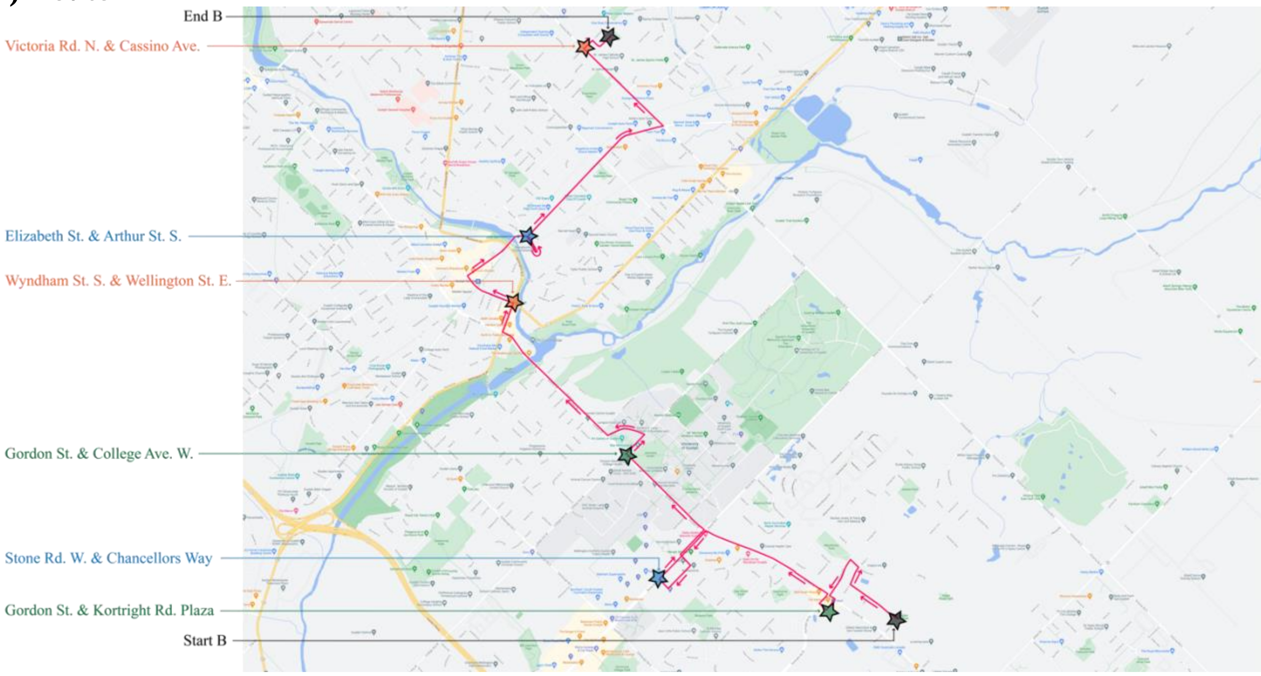
Route Points and Intersections

- High risk IOIs
- High risk IOI counterparts
- Pilot IOIs
- Pilot IOI counterparts
- Design case studies
- Start/End points

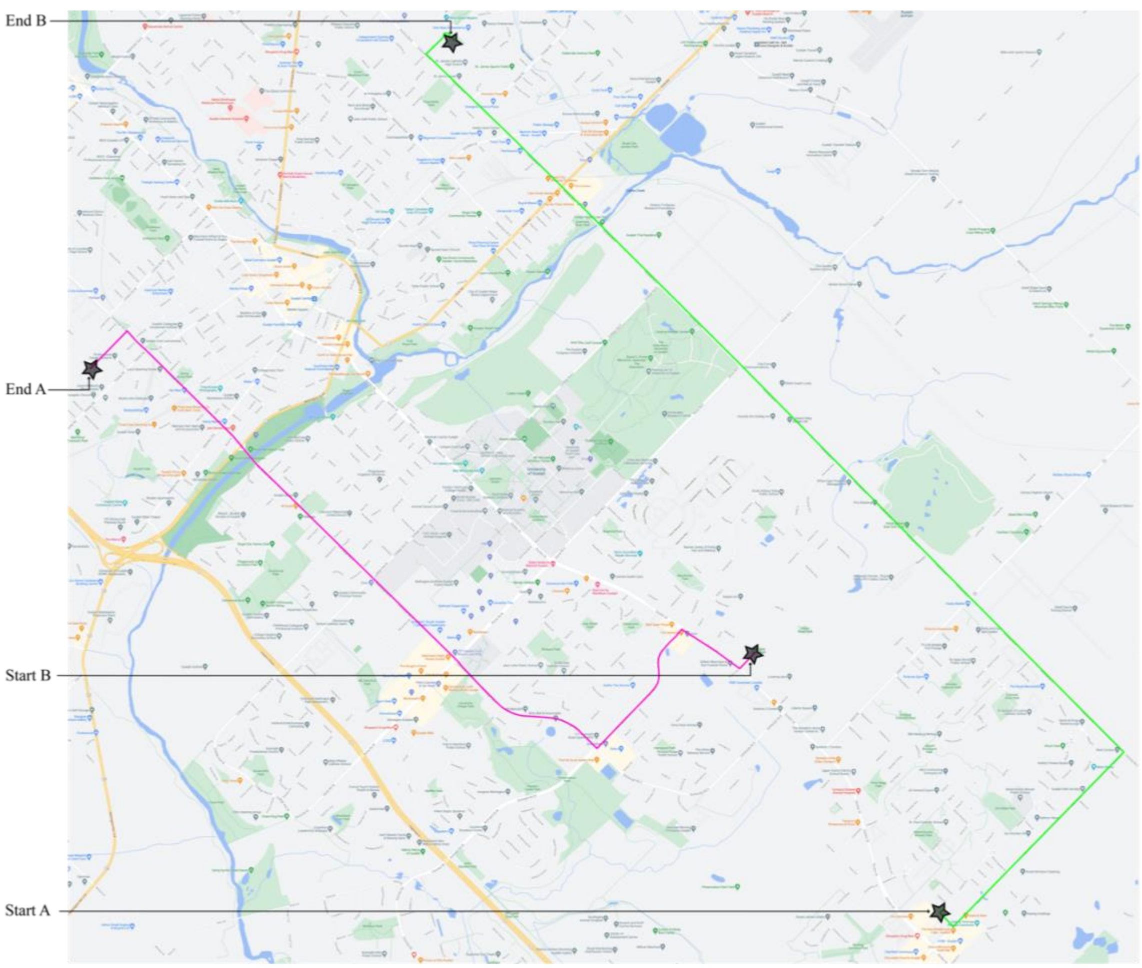
F1) Route A



F2) Route B



F3) Experimenter Routes



Zoom-friendly versions available here:
https://1drv.ms/u/s!AmPJczNoDZGNg0x6GupqhiQZit6c?e=yG1pQu

Appendix G: Route Scripts

Script for Route A
(Begins in the parking lot in front of the Guelph Public Library)

1. At the road at the end of the parking lot, turn left
2. At the stop sign, turn left
3. At the next traffic signal, turn right
4. At the next traffic signal, turn right
5. At the next traffic signal, turn right
6. At the next intersection, turn left
7. At the next intersection, turn left
8. At the end of this road, turn right
9. At the next traffic signal, turn right
10. At the traffic signal, turn left (at the University of Guelph entry sign)
11. At the traffic signal, turn right
12. At the next intersection, turn left
13. At the next intersection, turn left
14. At the next intersection, turn left
15. At the next intersection, turn right
16. Take the first right immediately into the plaza (in front of the McDonald's)
17. At the end of the parking lot, turn right (towards the exit)
18. At the road at the end of the parking lot, turn left
19. At the end of the road, turn right

20. At the next stop sign, turn right
21. At the next traffic signal, turn left
22. At the next intersection, turn right
23. At the next intersection, turn right
24. When safe, pull over to the side of the road along a clear, grassy area
25. Park

Script for Route B
(Begin in front of Bathgate Park)

1. At the end of the road, turn right
2. At the next intersection, turn left
3. At the next intersection, turn left
4. At the traffic signal, turn left
5. Take the first right immediately into the plaza (in front of the Shell)
6. At the end of the parking lot, turn right (towards the exit)
7. At the road at the end of the parking lot, turn right
8. At the next traffic signal, turn left
9. At the next intersection, turn left
10. At the end of the road, turn left
11. At the next intersection, turn left
12. At the traffic signal, turn right
13. At the traffic signal, turn left
14. At the next traffic signal, turn right
15. At the next intersection, turn left
16. At the next intersection, turn right

17. At the next traffic signal, turn right
18. At the next traffic signal, turn left
19. At the next traffic signal, turn right
20. At the next intersection, turn right
21. Turn right into the parking lot (Metalworks Condominiums)
22. When safe, turn around to exit the parking lot the way you came in
23. Turn left out of the parking lot
24. At the intersection, turn right
25. At the next traffic signal, turn left
26. At the next traffic signal, turn right
27. At the next intersection, turn right
28. When safe, pull over to the side of the road along Palermo Park
29. Park

Appendix H: Screening/Demographic Questionnaire

Page 1: Description

The University of Toronto
Human Factors and Applied Statistics Lab
Eligibility Questionnaire

You are invited to participate in a driving experiment conducted by the Human Factors and Applied Statistics Lab (Director: Prof. Birsen Donmez) at the University of Toronto. This screening questionnaire will assess your eligibility to participate in this research.

Please note that all information collected will be held in the strictest confidentiality. Personal data will be stored securely in the Human Factors and Applied Statistics Lab's secure password protected Network Attached Storage at the University of Toronto. Under no circumstances will personal data be revealed to any third party, for any purpose. If you do not qualify for this experiment and do not want to be informed about future driving studies conducted by our lab, your information will be deleted.

If you are chosen for the experiment, we will contact you via email to schedule your trial. Bear in mind, driving experiments will take place only on Saturdays or Sundays (Month-Month 202x).

Your participation in this study is voluntary. This questionnaire also asks for personal health information (please be as accurate as possible). You can choose to not participate or withdraw at any time.

If you have any questions or concerns you would like addressed before or after completing this questionnaire, please contact the investigator at [email].

Page 2: Contact Information

1) First Name

____

2) Last Name:

____

3) Email address:

____

4) Phone number:

____

You will be contacted through email; the phone number is asked for emergency cases and reminder text messages.

5) If you would like to be contacted for future research at the Human Factors and Applied Statistics Lab, please indicate below.

- I am interested in participating in your future research; please contact me when opportunities become available.
- I am NOT interested.

Page 3: Demographics and Driving Experience

The following are standard questions that allow researchers to determine how representative the group of participants in a study is of the general population. Remember, completion of this questionnaire is voluntary.

Please fill in the blanks or select the one best response unless otherwise noted.

1) What is your level of fluency in English?

1 ________________________[__]_____________________________ 10
Beginner Intermediate Advanced

2) What is your age?

____

Please note that for confirmation purposes, we will ask to see your driver's license on the day of.

3) What is your gender identity?
- Female
- Male
- Other
- Prefer not to answer

4) Indicate your height (in cm or feet)?

____

5) Please provide the city and province where you mainly reside:
City: ________________
Province: ________________

6) Do you currently hold a valid government issued driver's license?
- Yes
- No

7) What are your current driver's licenses? (Select that all apply)
- Full license (e.g. G license in Ontario)
- Learner's license (e.g. G1 and G2 licenses in Ontario)
- Motorcycle (M, M1 and M2 in Ontario)
- I don't have a driver's license
- Other licenses (e.g. from another country) - Please specify: ________________

*Follow - up question from previous question, if they checked off G license
When did you obtain your FULL G driver's license? (MM / YYYY)

____

8) Please provide the city and province where you drove most often, over the last year:
City: ________________
Province: ________________

9) Over the last year, how often did you drive a car or other motor vehicle?
- Every day or almost every day
- A few days a week
- A few days a month
- A few times a year or less
- Never

10) Over the last year, how often did you drive in a suburban area (e.g. Guelph, Scarborough, Pickering, etc.)? The images below illustrate the type of environment that you should consider when answering this question.

- Every day or almost every day

- A few days a week
- A few days a month
- A few times a year or less
- Never

11) Over the last year, how often did you drive in the city of Guelph (not including downtown Guelph)?
- Every day or almost every day
- A few days a week
- A few days a month
- A few times a year or less
- Never

12) Over the last year, how many kilometers did you drive? (Hint: from Guelph to Montreal one way is about 626 km)
- Under 5,000 km
- Between 5,001 km and 10,000 km
- Between 10,001 km and 20,000 km
- Between 20,001 km and 30,000 km
- Between 30,001 km and 40,000 km
- Over 40,001km
- None
- I don't know

13) In non-winter months, how often did you ride a bike as a transportation tool (i.e., on the road along with motor vehicle traffic)?
- Every day or almost every day
- A few days a week
- A few days a month
- A few times or less during the given period
- Never

*Follow - up question from question above
Which time of day do you most often use a bike for transportation purposes?
- Commuting hours (7-10am and/or 4-7 pm)
- Off-peak hours (other)
- Equally for both

14) In non-winter months, how often did you ride a bike as a recreational tool (i.e., on trails or paths away from motor vehicle traffic)?
- Every day
- A few days a week
- A few days a month
- A few times or less during the given period
- Never

*Follow - up question from question above
Which time of day do you most often use a bike for recreational purposes?
- Commuting hours (7-10am and/or 4-7 pm)
- Off-peak hours (other)
- Equally for both

15) Have you attended any driving related experiment before? *
- No
- Yes - Specify: ________________

<u>Page 4: Health-Related Information</u>

1) Do you ordinarily wear corrective lenses (e.g. glasses, contact lenses) of any kind?
- Yes (Glasses or Lenses)
- No

2) If you do have corrected vision, are you able to wear contact lenses during the experiment?
- Yes
- No

3) Compared with others your age, how would you rate your overall vision? (If you wear glasses or contacts, rate your corrected vision when you are wearing them.)

1 ________________________[__]____________________________ 10
Significantly worse | Average | Significantly Better

4) Compared with others your age, how would you rate your overall hearing?

1 ________________________[__]____________________________ 10
Significantly worse | Average | Significantly Better

5) Compared with others your age, how would you rate your overall memory?
1 ________________________[__]____________________________ 10
Significantly worse | Average | Significantly Better

6) Do you have any restriction in neck movement?
- No
- Yes - Specify:

Page 5: Thank You

Thank you for completing the screening questionnaire and for your interest in our study. Individuals who meet the study requirements will be contacted via email. Ineligible participants, who explicitly consented to being contacted again for further studies, may be contacted in the future for experiments approved by the Office of Research Ethics. All other data provided in this questionnaire for ineligible candidates will be deleted immediately.

If you have any questions or concerns you would like addressed before or after completing this questionnaire, please contact the investigator at [email].

Appendix I: Participant Consent Form

Title of Study: Driver Behavior in Suburban Settings

You are being asked to take part in a research study. Before agreeing to participate in this study, it is important that you read and understand the following explanation of the proposed study procedures. The following information describes the purpose, procedures, benefits, discomforts, risks, and precautions associated with this study. To decide whether you wish to participate or withdraw in this research study, you should understand enough about its risks and benefits to be able to make an informed decision. This is known as the informed consent process. Please ask the investigator to explain any words you don't understand before signing this consent form. Ensure all your questions have been answered to your satisfaction before signing this document.

Purpose

This study aims to understand driver behaviors in suburban settings. You will be asked to:

1. Drive on suburban streets while wearing an eye-tracker and following turn-by-turn directions given by the investigator
2. Fill out two questionnaires: one before and one after the experimental drive

Procedure

There are four parts to this study:

1) **Informed Consent and Pre-drive Survey:** You have been asked to read this consent form. Please feel free to ask the investigator any questions you may have. A photocopy will be made of your driver license for insurance purposes. You will be also asked to provide details about your driving history through some questions in a pre-drive survey.

2) **Familiarization Drive and Initial Setup of Eye-tracker:** First, you will be familiarized with the features of the instrumented vehicle, then you will be guided turn-by-turn through a preset route by the investigator in the passenger seat. We will answer any questions about the system during and after this familiarization drive. You will not be recorded during this drive but will wear the eye-tracker instrumentation to get comfortable with this system.

3) **Experimental Drive:** The experimental drive will take place over two more preset driving routes. Each of the two routes will take around 30 minutes to complete. You will be given a break in the middle. You will again be guided turn-by-turn by the investigator in the passenger seat. The eye-tracker will record your behavior.

4) **Post-drive survey:** After the experimental drive, you will be asked to fill out a 6-question survey related to your driving and behavior.
The experiment is expected to last up to three hours.

Risks
We want to make you aware of two possible risks:

1. The first potential risk is that of a collision. The risk is minimal because all driving for the experiment will be done on streets with speed limits of 50 km/h or less. In case of an emergency, the vehicle is equipped with a secondary brake that can be depressed from the passenger seat. **However, you should not be depending on the experimenter for safe driving.** During the experiment, you will be closely monitored for any signs of discomfort, and you are asked to notify the investigator if you begin to feel uncomfortable driving. The experimenter will stop the experiment if you drive in a dangerous or reckless manner. A first aid kit will always be in the vehicle. In case of collision, you will be covered by University of Toronto insurance. You will not be asked to violate any laws, and you should not. **You will be held responsible for any tickets issued for illegal actions while the vehicle is under your control.**

2. The second risk is associated with the eye-tracking headset which measures where you look while driving the instrumented vehicle. The eye-tracker should not affect your vision or ability to safely operate the vehicle. If you feel discomfort from the eye-tracker while driving, please notify the investigator.

Risks Related to COVID-19
We additionally want to make you aware of the risks related to COVID-19:

This study has been approved by the University of Toronto as Face to Face (F2F) Human Participant Research (#XXXX). All frequently touched areas, including the eye-tracking headset, door handles, and driver's seat, have been sanitized appropriately between participants. The instrumented vehicle's air circulation settings have been adjusted for the prevention of COVID-19 spread. All forms and surveys will be completed outdoors. **To further reduce the risks associated with COVID-19, you are asked to wear your approved face covering and maintain a 6-meter physical distance from others (when possible) for the duration of the study.** The investigator(s) will also follow these same guidelines.

Benefits
There are several benefits to conducting this study. The most important benefit is your contribution to research in traffic safety, which will guide the development of methods to enhance traffic safety in the city of Guelph and beyond. You will also gain experience with academic research and be able to use and test out a state-of-the-art instrumented vehicle.

Compensation
The experiment is expected to last for approximately three hours. You will be receiving payment at the rate of $17/hr. You may withdraw at any time. If a withdrawal should occur, you will be compensated on a pro-rated basis at $17 per hour for your involvement to that point. Compensation will be pro-rated to the next half-hour increment.

Confidentiality

All information obtained during the study will be held in strict confidence. You will be identified with a study number only, and this study number will only be identifiable by researchers working on this project. No names or identifying information will be used in any publication or presentation. No information identifying you will be transferred outside the research facilities in this study. The photocopy of your driver license will be stored separately from your experimental records for the sole purpose of keeping a record for the vehicle's insurance company.
The research study you are participating in may be reviewed for quality assurance to make sure that the required laws and guidelines are followed. If chosen, (a) representative(s) of the Human Research Ethics Program (HREP) may access study-related data and/or consent materials as part of the review. All information accessed by the HREP will be upheld to the same level of confidentiality that has been stated by the research team.

Please be advised that we make video recordings of experimental trials. The recordings will be stored securely in digital format. The videos will only be seen by the investigator, as well as the co-investigator's and faculty supervisor's research assistants and research collaborators. Faces will be blurred in all photographs used in publications. Please indicate below if you give us permission to show videos of your face in in public presentations:
( ) I consent to having my video used for public presentations
( ) I DO NOT consent to having my video used for public presentations

Participation
Your participation is voluntary, and you may refuse to participate, may withdraw at any time, and may decline to answer any question or participate in any parts of the procedures/tasks – all without negative consequences. If you choose to withdraw at any point during the experiment, your data will be deleted, and the experimenter will drive you back to the experiment origin. Only your name will be kept on record for your participation in this experiment. If you choose to participate in this study, the responses you have already given to the screening questionnaire, including your age, gender identity, and driving frequency may be used in data analysis.

Location
The on-road experiment will take place within the city of Guelph.

Questions
You can contact the Office of Research Ethics at ethics.review@utoronto.ca, or 416-946-3273, if you have questions about your rights as a participant. If you have any general questions about this study, please call [investigator] at (XXX) XXX-XXXX or email xxxxxx@mie.utoronto.ca.

Results
To request a copy of the published results of this study, please email xxxxxx@mie.utoronto.ca with subject line "Research Results". A link to the published results of this study will also be made available at https://hfast.mie.utoronto.ca/ under "Publications."

Consent
I have had the opportunity to discuss this study and my questions have been answered to my satisfaction. I consent to take part in the study with the understanding I may withdraw at any time. I have received a signed copy of this consent form. I voluntarily consent to participate in this study.

______________________________ ____________________ ______

Participant’s Name (please print) Signature Date

I confirm that I have explained the nature and purpose of the study to the participant named above. I have answered all questions.

______________________________ ____________________ ______

Investigator’s Name (please print) Signature Date

Appendix J: Pre-Drive Questionnaire

1) Please enter your Participant ID number: *

2) Please enter your birth year: *

3) How safe a driver do you consider yourself?*

Very Unsafe Very Safe

○ 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9 ○ 10

4) In the past five years, how many times have you been stopped by a police officer and received a WARNING (but no citation or ticket) for a moving violation (i.e. speeding, running a red light, running a stop sign, failing to yield, reckless driving, etc.)? *

5) In the past five years, how many times have you been stopped by a police officer and received a CITATION OR TICKET for a moving violation? *

6) In the past five years, how many times have you been in a VEHICLE CRASH where you were the driver of one of the vehicles involved? *

7) **Follow - up question from question #6*

How many of these vehicle crashes involved a:

pedestrian?:

cyclist?:

8) When did you obtain your first driver’s license (after your knowledge test)? (MM / YYYY)*

9) Over the last year, how often did you drive a car or other motor vehicle?*

- Every day or almost every day
- A few days a week
- A few days a month
- A few times a year or less
- Never

10) For how long do you typically drive a car or other motor vehicle per day (in terms of hours)?*

11) Please indicate your current vehicle's make, model, and year:

12) Over the last year, how many kilometers did you drive? (Hint: from Guelph to Montreal one way is about 626 km)*

- Under 5,000 km
- Between 5,001 km and 10,000 km
- Between 10,001 km and 20,000 km
- Between 20,001 km and 30,000 km
- Between 30,001 km and 40,000 km
- Over 40,0001 km
- None
- I don't know

13) Over the last year, how often did you drive in a suburban area (e.g. non-downtown Guelph, Scarborough, Pickering, etc.)? The images below illustrate the type of environment that you should consider when answering this question.*

- Every day or almost every day
- A few days a week
- A few days a month
- A few times a year or less
- Never



14) Over the last year, how often did you drive in the City of Guelph (not including downtown Guelph)?*

- Every day or almost every day
- A few days a week
- A few days a month
- A few times a year or less
- Never

15) Do you drive a motorcycle?*

- Yes
- No

16) In non-winter months, how often did you ride a bike as a transportation tool (i.e., on the road along with motor vehicle traffic) ?*

- Every day or almost every day (Specify):: ________ *
- A few days a week (Specify):: ________ *
- A few days a month (Specify):: ________ *
- A few times or less during the given period (Specify):: ________ *
- Never

17) **Follow - up question from question #16*

Which time of day do you most often use a bike for transportation purposes?

- Commuting hours (7-10am and/or 4-7 pm)
- Off-peak hours (other)
- Equally for both

18) In non-winter months, how often did you ride a bike as a recreational tool (i.e., on trails or paths away from motor vehicle traffic)? *

- Every day or almost every day (Specify):: ________ *
- A few days a week (Specify):: ________ *
- A few days a month (Specify):: ________ *
- A few times or less during the given period (Specify):: ________ *
- Never

19) **Follow - up question from question #18*
Which time of day do you most often use a bike for recreation purposes?

- Commuting hours (7-10am and/or 4-7 pm)
- Off-peak hours (other)
- Equally for both

20) Do you have a family member or close relative who rides a bike frequently?*

- Yes - Specify:: ________ *
- No

21) Do you have a close friend who rides a bike frequently?*

- Yes - Specify:: ________ *
- No

22) Over the last year, how often did you ride a bike in the City of Guelph (<u>not including</u> downtown Guelph)?*

- Every day or almost every day
- A few days a week
- A few days a month
- A few times a year or less
- Never

23) Over the last year, how often did you walk in the City of Guelph (<u>not including</u> downtown Guelph)?*

- Every day or almost every day
- A few days a week
- A few days a month
- A few times a year or less
- Never

24) Please describe the highest level of formal education you have completed:*

- Some high school or less
- High school graduate
- Some college
- College graduate
- Some graduate education
- Completed graduate or professional degree (e.g. Masters, LCSW, JD, Ph.D., MD, etc.)

25) Are you: (Please select all that apply)*

- ☐ A full time student
- ☐ A part time student
- ☐ Unemployed
- ☐ Retired
- ☐ Employed full time
- ☐ Employed part time
- ☐ A full time caregiver (e.g. children or elder)
- ☐ A part time caregiver (e.g. children or elder)
- ☐ None of the above

26) Are you right-handed?*
- ☐ Yes
- ☐ No
- ☐ Ambidextrous (both)

27) How often do you play computer games?*
- ☐ Every day or almost every day
- ☐ A few days a week
- ☐ A few days a month
- ☐ A few times a year or less
- ☐ Never

Appendix K: Emergency Vehicle Information Sheet

<u>Emergency Vehicles</u>
Emergency vehicles (police, fire, ambulance and public-utility emergency vehicles) are easily identified when responding to an emergency through their use of flashing red lights (police may also use red and blue flashing lights), a siren or bell, or alternating flashes of white light from their headlamp high beams.When an emergency vehicle is approaching your vehicle from any direction with its flashing red or red and blue lights, or siren or bell sounding, you are required to bring your vehicle to an immediate stop. When bringing your vehicle to a stop, you are required to bring your vehicle as near as is practical to the righthand curb or edge of the roadway.

If you are in an intersection and preparing to make a turn when an emergency vehicle is approaching, you should abandon the turn and clear the intersection by proceeding straight when safe to do so, then pull to the right and stop. This will clear the intersection and minimize the possibility of a collision with the emergency vehicle should it be passing you on the side you intended to turn towards.

Appendix L: Post-Drive Questionnaire

1) Please enter your Participant ID number: *

____

2) How close to your natural way of driving do you think your driving was in this experiment?*
1 _________________________[__]______________________________ 10

3) Do you think that you were driving more cautiously than you normally would due to being observed?*

1 _________________________[__]______________________________ 10

4) Do you think that you were driving more cautiously than you normally would due to being in an unfamiliar vehicle?*

1 _________________________[__]______________________________ 10

5) How cautious do you think you were towards pedestrians on the road during this driving experiment?*

1 _________________________[__]______________________________ 10

6) How cautious do you think you were towards cyclists on the road during this driving experiment?*

1 _________________________[__]______________________________ 10