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Driver Response Time to Cyclist Path Intrusions

Ryan Toxopeus University of Guelph

Shady Attalla and Sam Kodsi Kodsi Engineering

Michele Oliver University of Guelph

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Abstract

Motor vehicle crashes with cyclists are on the rise, with a six percent increase in fatal crashes from 2006 to 2015 in the USA. Although some research exists on the response time of drivers to some types of path intrusions, data on the perception-response of through drivers to cyclists who fail to stop at a stop sign, and ride into the path of the vehicle has not been researched. The purpose of this study was to quantify the Driver Response Time (DRT) to a cyclist that intrudes perpendicularly in front of a through vehicle at an intersection where the driver has the right-of-way. The DRT was measured from when the cyclist is positioned at the stop sign until the driver reacts, whether by touching the brake pedal, swerving (steering wheel angle change of at least 2 degrees), accelerating, or a combination of those responses.

26 (N_{Female} = 13; N_{Male} = 13) university aged licensed volunteer drivers participated in the study conducted at the University of Guelph Driving Research in Virtual Environments (DRiVE) lab using an Oktal complete vehicle driving simulator. After a brief practice drive to acclimatize to the virtual environment, participants completed the approximately 10 minute experiment drive during which the cyclist hazard was presented. About one quarter of drivers crashed into the cyclist, with a mean time-to-impact of 3.26 seconds. There were no gender differences in terms of DRT or collision rates.

Introduction

Vehicle crashes with cyclists are on the rise, with 818 cyclists killed in 2015 in the USA [1]. This may be in part due to the fact that the number of cyclists on the road has increased from 51 million in 2012 to 66 million in 2017 [2]. Since a cyclist has a smaller profile than a typical passenger vehicle, it might make it more difficult to detect, thus leading to higher collision rates. Indeed, pedestrians, who have an even smaller profile, are killed at even higher rates, with 5376 killed in 2015 [1].

Accident reconstructionists and collision investigators are often asked to reconstruct a collision with respect to vehicle and cyclist speeds and dynamics. In addition, they are also asked to determine if the collision involving the cyclist was avoidable by the driver. Often the biggest challenge in this collision avoidance analysis is determining a reasonable perception-response time (i.e., the time required for the through driver to detect, perceive, and begin an evasive maneuver in response to the pedestrian) given the circumstances involved in the incident.

Please note that there are many terms (i.e., perception-response time, brake-response time, perception-reaction time, etc.) used in the literature that interchangeably refer to the different phases of DRT, thus requiring the reconstructionist and collision investigator to interpret and apply literature values carefully. In the current study the term "Driver Response Time" (DRT) is used to refer to all the different response choices including braking, swerving, accelerator release, or combinations of these reaction types. The DRT data from this study are further separated into later defined categories depending on the specific participant response choice.

To determine a reasonable DRT or range of DRTs, the investigator relies on the most applicable literature. They must then interpret how the research methodology influenced the observed DRT values and then make comparisons to the circumstances encountered by the incident driver.

While studies have been conducted that quantify DRTs to path intrusions such as pedestrians and vehicles [3], DRTs for normal speed profiles associated with a cyclist travelling through an intersection have not been studied. Therefore, the purpose of this study was to examine DRTs of through drivers when a cyclist travels through an intersection, and across the path of the through vehicle at a constant speed. Depending on the situation, this research can provide DRT values that are applicable to accident reconstructionists and collision investigators when determining the avoidance potential for a cyclist collision. The research can also be considered by roadway designers to ensure that there is sufficient visibility for drivers to perceive potential hazards such as cyclists.

Methods

Simulator

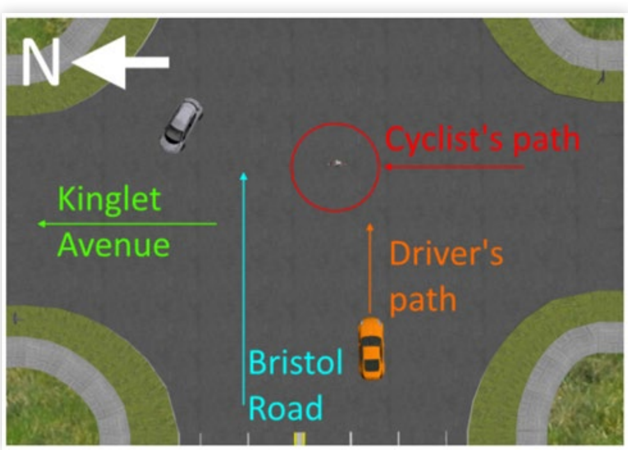
The study was conducted at the University of Guelph using acomplete car Pontiac G6 convertible driving simulator (Oktal, Paris, France). The vehicle, as seen in Figure 1, is surrounded by 300 degrees of wrap-around screens using HD projectors to give the driver an immersive experience. The steering wheel has force feedback, and vibrations are created in the car body through subwoofer speakers and two ButtKicker mini LFE units mounted to the vehicle frame. The simulator collected data on all the variables of interest including brake pedal pressure, accelerator pedal pressure, and steering wheel angle. Collisions were analyzed through looking at birds-eye view recordings captured by the simulator.

Virtual Environment

The environment the drivers navigated was based on roadways found in Mississauga, Ontario, Canada. The specific roadway that was modeled was at Bristol Road West and Kinglet Avenue (BK), as seen in Figure 2. Bristol Road West had two through lanes in each direction, with a fifth merge lane in the middle that transitioned into a left turn lane. Additionally, there were bicycle lanes on both sides of the road. The traffic lanes were 3.5 meters wide and the bicycle lanes were 1.5 meters wide.

FIGURE 1 University of Guelph Driving Research in Virtual Environments (DRiVE) Lab full car Oktal driving simulator.

FIGURE 2 Intersection with hazard cyclist (circled in red) in front of participant driver (orange).



The median between east- and westbound traffic was 0.5 meters wide. Kinglet Avenue is a 14 meter wide side road with no painted markings, and one lane of traffic in each direction. Parking was available on both sides of the street. This was a 2-way stop intersection controlled by stop signs on Kinglet Avenue. The stop sign was 10.79 meters from the south curb of Bristol Road West. The speed limit used for this study was 60 km/h.

Ambient traffic and pedestrians were added to the scenario to give drivers a rich visual experience. The lighting and visibility were consistent with daytime clear weather conditions.

Hazardous Scenarios

The hazardous situation created was the same for all participants, and there were no vehicles obstructing the view the drivers had of the intersection or hazard cyclist.

The hazard cyclist was initially occluded by a building that was 9.38 meters from the curb. The cyclist was travelling northbound (from right to left with respect to the participants) at a constant speed of 20 km/h [4]. The cyclist reached the plane of the stop sign 0.77 seconds (with the through driver travelling at 70 km/h) to 0.98 seconds (with the through driver travelling at 60 km/h) after coming into view, depending on the speed of the driver. The time to impact for all participants was 3.26 seconds. The timing began when the cyclist's front tire first crossed the plane of the stop sign. In other words, if the driver made no response to avoid the collision, the vehicle would have collided with the cyclist 3.26 seconds after the cyclist crossed the plane of the stop sign.

The participants were all travelling in the passing lane at/near the posted speed limit of 60 km/h, with some travelling close to 70 km/h. The eccentricity or the angle between the through driver and the cyclist when the front of the cyclist was positioned in line with the stop sign was measured to be approximately 16 to 19 degrees.

This work was part of a larger study where four different hazard types were presented. The hazards were counterbalanced such that the cyclist hazard could have appeared in any one of the four positions. A univariate analysis found that the DRT was significantly different between the first and second hazard presentations of the cyclist ($p < 0.01$). This indicated that participants learned to watch out for hazards after the

FIGURE 3 Cyclist crossing in front of vehicle at the Bristol Road West and Kinglet Avenue intersection.

first hazard presentation. Thus, only the first hazard was included in the analysis.

Participants

26 participants (13 male [*Mean Age* 23.8 years, *SD* = 2.3], 13 female [*Mean age* = 22.1 years, *SD* = 2.9]) completed the study. All participants held at least a G2 Ontario driver's license (learner's permit that allows the driver to drive without an experienced passenger).

Measures

For the purpose of this study, the term "Driver Response Time" (DRT) is used in the general sense to refer to all different response choices. The data, however, are presented in two different categories, as follows:

Brake-response time (BRT): defined as the time period from when the cyclist's front tire was positioned at the stop sign, until the driver reacts by touching the brake pedal.

Swerve-response time (SRT): defined as the time period from when the cyclist's front tire was positioned at the stop sign, until the driver turned the steering wheel 2 degrees.

The vehicle mechanical brake lag was not considered in this study. The plane of the stop sign was chosen as the onset of DRT because this is the earliest point at which a cyclist would be expected to stop. In other words, the cyclist would not have been expected to stop south of this area.

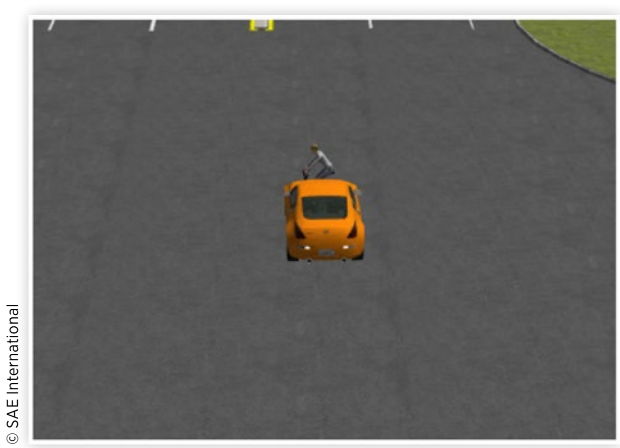
Collisions were detected visually through recorded video data, since the simulator's crash detection variable was unreliable (Figure 4).

Statistical Analyses

Analyses were conducted using SPSS (IBM SPSS Statistics for Windows, Version 24.0. Armonk, NY). First, frequencies were calculated to find the means and standard deviations of DRT, along with 15th, 50th, and 85th percentile scores.

The DRT values (dependent variable) and collision rate (dependent variable) were compared between males and females (fixed factor) using analysis of variance procedures ($p \leq 0.05$).

FIGURE 4 Participant driver crashing into the cyclist.



Results

Figure 5 shows the combined DRT results for drivers responding to the cyclist hazard (*M* = 1.93 s, *SD* = 0.47, 15th percentile = 1.32 s, 50th percentile = 2.03 s, 85th percentile = 2.37 s, with a S.E. Mean = 0.092). The mean collision rate was 0.31, meaning almost one third of drivers collided with the cyclist.

The test drivers' response choices to the cyclist hazard are shown in Figure 6 which showed that 80% of drivers applied the brake pedal and 20% swerved.

Figure 7 looks deeper into the response choices and collisions illustrating that 15% of drivers who chose to brake and 100% of those who swerved resulted in a crash.

It is important to note that there were 5 participants that chose a combined braking and swerving maneuver (*M* = 1.95 s, *SD* = 0.47). The braking and swerving inputs were almost simultaneous. However, out of these 5 participants, 4 began their swerve maneuver first, while 1 began the brake maneuver first. The DRT for these 5 participants were combined accordingly with the swerve only response time, and brake only response time. The overall data are presented in Table 1 and Figure 8 below.

FIGURE 5 Driver Response Time (DRT) of drivers reacting to the cyclist hazard. Error bars indicate the 95% confidence interval for the mean.

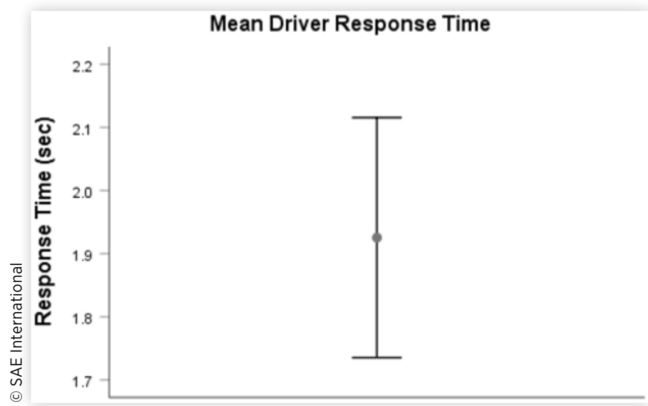


FIGURE 6 Percentage of drivers who responded to the hazard by braking or swerving.

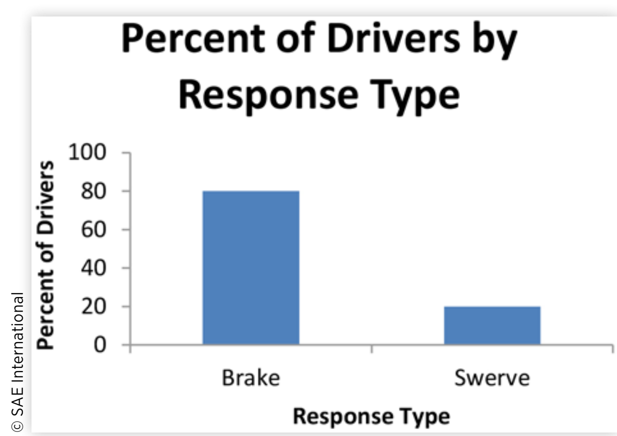


FIGURE 7 Hazard response type by drivers who crashed.

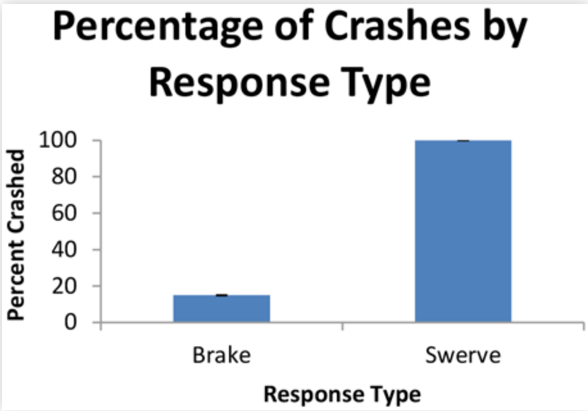


TABLE 1 Driver Response Time (DRT) by response type. Brake Response Time (BRT); Swerve Response Time (SRT).

DRT	*Mean (s)*	*SD*
BRT	1.92	0.48
SRT	1.95	0.47

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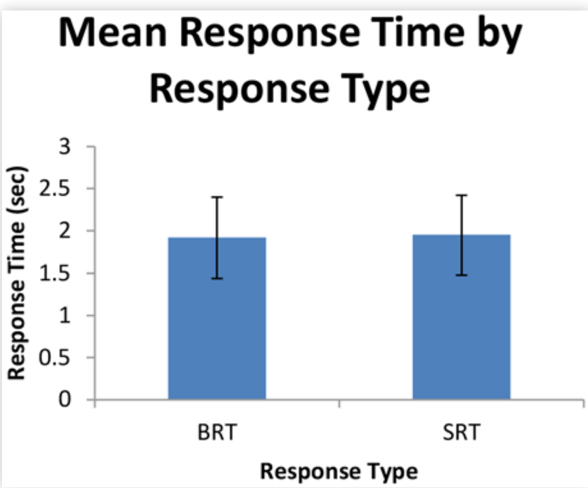
FIGURE 8 Driver Response Time (DRT) by response type. Error bars indicate the standard deviation. Brake Response Time (BRT); Swerve Response Time (SRT).



There was no significant gender difference in DRT ($p = 0.46$) or collision rate ($p = 0.49$).

Discussion

Based on our literature review, there is a gap in research when looking at DRT values of drivers responding to cyclists not obeying the stop sign and approaching from the driver's right side. As such, a comparison of the results from this study with other literature is not possible. However, a comparison between the results of this study and output from Interactive Driver Response Research Software (I.D.R.R.) was conducted. I.D.R.R. is a tool comprised of mathematical equations that estimate DRT based upon a meta-analysis of previous research [5, 6]. Assuming an eccentricity of 17.5 degrees (the average between 16 and 19 degrees from the current study), daytime conditions, and with the hazard being presented at an intersection, the I.D.R.R. tool outputted an average DRT (including foot movement time, but excluding any brake lag phase) value of 1.3 seconds (with a 15th to 85th %ile time of 0.8 to 1.8 seconds). This was approximately 0.6 seconds shorter than the 15th to 85th %ile DRT from the current study. Please note, however, that most of the path intrusion situations relied upon in the I.D.R.R. software would have involved hazards that are more similar to a vehicle than a bicycle, at least in size. It is expected that a driver would respond to a relatively larger hazard (i.e., a passenger vehicle) that is intruding into his/her path earlier than he/she would to the smaller, less conspicuous cyclist.

Although most drivers managed to react between 1.32 and 2.37 seconds, overall the hazard presented by the cyclist was not easily avoidable, as almost one third of the participants collided with the cyclist.

It is noteworthy that almost all the drivers who swerved in response to the cyclist (whether by swerving and braking, or by swerving alone) collided with the cyclist. This may not be the case in the real world however. When drivers decide to respond by swerving, they typically swerve away from the direction of approach of the hazard (in this case to the left) in an attempt to increase their opportunity to avoid the collision by increasing the time to impact [7]. In the real world, this increased time may be all that is needed for the cyclist to brake to a stop, or slow down enough to allow the through vehicle to clear their path without an impact. However, in our study, the cyclists were programmed to proceed through the intersection without any evasive maneuver attempts, and hence a collision occurred (in the cases where the vehicle struck the cyclist).

As previously indicated, the brake lag phase of the vehicle is not included in the DRT reported in this study. This is because the driving simulator was not equipped with hydraulic brakes (and hence did not have mechanical lag) and hence the end of the DRT was taken at the moment the participant's foot contacted the brake pedal (i.e., before any significant force was applied). In order for the BRT values to be converted to Perception-Response Time (PRT) values, the investigator would need to add an appropriate brake lag time.

With respect to response choice, our results were consistent with previous findings that drivers are more likely to respond by braking, than any other evasive maneuver [7].

There were no gender differences in terms of DRT or collision rates.

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Contact Information

Michele Oliver
moliver@uoguelph.ca

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Appendix

Raw Data

Legend	
Gender	Male = 1; Female = 2
Reaction Type	Brake =1; Swerve = 2; Brake and Swerve = 3
Driver Response Time (DRT)	Time (s)
Collision	No Collision = 0; Collision = 1

Participant #	Gender	Reaction Type	DRT (s)	Collision
1	2	1	1.58	0
2	2	3	2.18	1
3	2	1	1.80	0
4	2	1	2.28	0
5	2	1	2.30	0
6	2	1	2.28	0
7	2	1	2.00	0
8	2	3	2.37	1
9	2	2	1.65	1
10	2	1	1.32	0
11	2	1	2.31	1
12	2	1	1.98	0
13	2	3	2.30	1
14	1	1	2.42	0
15	1	3	1.28	1
16	1	1	2.37	1
17	1	1	2.70	1
18	1	1	0.97	0
19	1	1	2.05	0
20	1	1	2.18	0
21	1	1	1.40	0
22	1	1	1.05	0
23	1	3	1.64	0
24	1	1	1.42	0
25	1	1	1.88	0
26	1	1	2.35	0

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