

**UNALERTED PERCEPTION-REACTION TIME AND EMERGENCY STOPPING SIGHT  
DISTANCE FOR PEOPLE RIDING BICYCLES**

by

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UNALERTED PERCEPTION-REACTION TIME AND EMERGENCY STOPPING SIGHT  
DISTANCE FOR PEOPLE RIDING BICYCLES

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submitted by Stephen Michael Martin in partial fulfilment of the requirements for

the degree of Master of Applied Science

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## **Abstract**

Motivated by climate change and increasing emissions from the transportation sector, government initiatives aim to shift travel away from automobiles to other modes such as bicycling. Despite broad agreement that high-quality infrastructure is critical to attracting and safely accommodating active travel, current design procedures for bicycle facilities lack evidence-based grounding of fundamental design parameters that are critical for user safety, such as perception-reaction time (PRT) and deceleration rate in stopping sight distance calculations. This research aims to measure the perception-reaction time and deceleration rate for bicyclists reacting to a fixed object in unexpected braking scenarios.

Bicyclist PRT and braking behaviours were measured across two samples: (1) an unexpected response trial (n=52), and (2) an expected response trial (n=250). In the unexpected trial, participants rode around a course on an instrumented bicycle, and their braking response to an unexpected hazard was measured using a strategically placed video camera. In the expected trials, participants rode toward a manually-controlled traffic signal, and were told to “come to a full stop as quickly as possible, safely” once the light changed from green to red. Regression models were estimated to determine predictors of PRT, deceleration rate, and overall stopping distance.

We found that the 85<sup>th</sup> percentile unexpected PRT was 0.84 seconds, substantially lower than previously observed in motor vehicle studies, possibly due to heightened vigilance when riding a bicycle. Based on these results, the current design guidance of 2.5 seconds appears to be conservative for use in bicycle facility design. However, the 85<sup>th</sup> percentile deceleration rate was found to be 0.20 g, suggesting that current design guidance of 0.25 g may not be conservative. Age and gender were not significant predictors of PRT or deceleration rate, whereas self-identified bicycling confidence was significant in predicting both variables. Speed was also found to be a significant predictor of PRT. This study is the first to measure on-road bicyclist perception-reaction time and braking in unalerted conditions, and provides valuable evidence to inform design guidance for bicycle facilities.

## **Lay Summary**

In response to climate change, governments are creating more bicycle paths to encourage bicycling over driving a car. However, these paths are designed based on data measured for motor vehicle drivers, due to a lack of studies on bicyclists. This study measured reaction times and braking of bicyclists responding to an unexpected obstacle appearing in their path, which has not been studied before. Expected reactions were also measured for a larger, more representative sample, with the goal of inferring unexpected values for the population. The results showed that the reaction times of bicyclists were faster than previous studies on car drivers, maybe because bicyclists are more alert when riding. While current design methods are safe for bicyclist reaction times, observed braking deceleration rates were lower than what is currently assumed, suggesting revised design guidance is needed.

## **Preface**

This research was conducted under the supervision of Dr. Alex Bigazzi at the University of British Columbia as thesis supervisor and principal investigator. The author of this thesis, Stephen Martin, was responsible for the literature review, research question formulation, experimental design and instrumentation procurement, planning, managing, and administration of the survey, data processing, model preparation, and analysis. The principal investigator provided invaluable feedback and guidance throughout the duration of this research, particularly in refining research questions, study design, and data analysis. Together, their collaborative efforts have contributed to advancing knowledge in the field.

The research was conducted in compliance with the UBC Behavioral Research Ethics Board (BREB) requirements, under the project titled “Evidence-based design of off-street paths and cycleways: fundamental traffic engineering parameters for bicycles and micromobility devices”, UBC BREB number H23-01234, approved on July 14<sup>th</sup>, 2023.

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## List of Abbreviations

Avg	Average
AAA	All Ages and Abilities
BREB	Behavioral Research Ethics Board
CDF	Cumulative Distribution Function
PRT	Perception-Reaction Time
SBC	Single-Bicycle Crash
SSD	Stopping Sight Distance
UBC	University of British Columbia

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## **Chapter 1: Introduction**

This thesis targets the overarching objective of providing evidence-based grounding for design parameters used in facility design for active transportation. Specifically, a study was developed to investigate perception-reaction time and deceleration rate of bicyclists, for use in the stopping sight distance calculations of bicycle facility design.

### **1.1 Context and Motivation**

Motivated by climate change and increasing emissions from the transportation sector (Government of Canada, 2022), recent government policy and initiatives have aimed to shift travel away from automobiles towards more sustainable and physically active modes such as bicycling and other forms of micromobility. One example comes from the City of Vancouver's transportation plan, which aims for two-thirds of all trips in the city to be made by foot, bicycling, or transit by 2040 (City of Vancouver, 2012). The City's Climate Emergency Action Plan (2020) accelerated this target, now aiming to achieve the two-thirds goal by 2030. These governmental priorities and investments have resulted in an increased uptake in travel by active modes, with bicyclist mode share in Vancouver increasing from 4% to 9% from 2013 to 2019 (R.A. Malatest & Associates Ltd. and Associated Engineering Ltd., 2023). These mode shift targets align with other goals in the realms of affordability, equity, and health, with one complimentary goal relating to traffic safety through reduced road fatalities for bicyclists.

A primary means of attracting new users to active travel is through investment in attractive, protected bicycling networks. These networks must consider the varying needs of their users, leading to the adoption of an "All Ages and Abilities" (AAA) mindset for design purposes. The AAA philosophy encourages the design of facilities that are safe, comfortable, and equitable (National Association of City Transportation Officials, 2017), such that all users, but specifically vulnerable groups like children, seniors, and people with disabilities, are encouraged to consider bicycling as a mode of transport. Despite broad agreement that high-quality infrastructure is critical to attracting and safely accommodating active travel, the current transportation engineering design procedures for off-street bicycle facilities lack evidence-based grounding of fundamental design parameters such as perception-reaction time and deceleration rate. This lack of evidence for bicycle facility design is not a recent concept. Nearly 25 years ago, Taylor and Davis (1999)

compiled a comprehensive overview of bicycle facility design research; however, the basic design principles identified back then as needing further verification are still being used today without empirical studies confirming their validity.

The most important factor in geometric design of transportation facilities is Stopping Sight Distance (SSD): the advance distance required for a road user to perceive a roadway hazard, react to it, and safely decelerate to a stop (Transportation Association of Canada, 2017). As shown in Equation 1 (Transportation Association of Canada, 2017), the first component of SSD represents the distance travelled while the road user detects a hazard, recognizes an action is required, and initiates a response. This component is determined by the user's initial speed ( $V_0$ ) and perception-reaction time ( $t$ ). The second component represents the distance travelled while braking to a full stop and is a function of the user's initial speed ( $V_0$ ), deceleration rate ( $a$ ), and grade ( $G$ ). This formula is unit-specific and takes speed in km/hr, perception-reaction time in s, deceleration in  $m/s^2$ , grade in m/m, and provides SSD in m.

*Equation 1 - SSD Formula*

$$SSD = 0.278 * V_0 * t + \frac{V_0^2}{254 * (\frac{a}{9.81} + G)} \quad (1)$$

Another parameter that governs stopping sight distance that does not explicitly appear in Equation 1 is user eye height, which is used to calculate sight distances on vertical and horizontal curves; it is taken as 1.08 m for motor vehicles and 1.37 m for bicycles (Transportation Association of Canada, 2017). European design guidance (Highways England, 2020) recommends a range of 0.8 to 2.2 m, to account for the diversity in eye heights of different micromobility devices.

Traffic engineering design guidance often recommends 85<sup>th</sup> to 95<sup>th</sup> percentile thresholds as conservative estimates that cover a wide range of users. For instance, higher initial speeds, longer perception-reaction times, or lower deceleration rates all require greater distances to achieve a complete stop. Additionally, a shorter eye height governs, as users with shorter eye heights have less visibility over vertical curvature.

Current design guidance for stopping sight distance uses a value of PRT determined from motor vehicle studies without any research validating the transferability to non-auto modes on off-street paths, potentially leading to unsafe or inefficient designs. Bicycles have different mechanics of

power, guidance, and control than automobiles, and their performance is more heterogeneous and rider dependent (Parkin, 2018). Additionally, the stopping maneuver for bicycles is more complex than their automobile counterpart, with considerations for independent front and rear braking force control, lateral and longitudinal weight shifting, personal safety through additional crash modes, and different maneuverability options for response such as swerving all playing a potential role in bicycle braking scenarios. The action of balancing the front and rear brakes is known as the ‘brake force ratio’. Unlike motor vehicle drivers who apply pressure to one brake pedal, the brake force ratio is a manual procedure for bicyclists, resulting in a more complex braking response. Another difference in the braking maneuver between these two modes is the physical mechanism of applying the brakes. In a motor vehicle, this requires shifting the foot from the accelerator to the brake pedal, whereas braking on a bicycle involves moving from the user’s preferred riding hand position onto the brake levers. The introduction of the leaning (roll) axis requiring balance when turning and cornering (Wang et al., 2019) further complicates the stopping behaviour. It is well known that a more complex response results in an increase in reaction time (Maslovat et al., 2019), thus the same could be expected for perception-reaction time.

One offsetting factor towards the effect of complexity on perception-reaction time is user vigilance, or alertness. Vigilance is a term with various definitions (Oken et al., 2006); in the context of this research, it is defined as the state of being physiologically and psychologically ready to react to a stimulus (Mackworth, 1948). The idea of vigilance in bicyclists has been discussed in relation to bicyclist stress responses (Bigazzi et al., 2022). Although vigilance has not been explicitly measured in the context of reactions for bicyclists, a positive correlation has been found between vigilance and simple reaction times (Surwillo and Quilter, 1964; Appelle and Oswald, 1974). Bicyclists who maintain vigilance while riding could react more favourably in higher complexity stopping maneuvers, compared to those who ride more complacently.

User considerations of personal safety may also influence the complexity of a braking maneuver on a bicycle due to additional crash modes exacerbated by a lack of physical protection for the user. Beyond the traditional automobile failure mode of locked-wheel sliding, additional crash typologies are present for bicycles resulting from additional degrees of freedom. These bicycle crash typologies include over-the-handlebar falls as a result of a sudden stopping, and sideways ‘slide-out’ falls due to steering maneuvers in corners or for collision avoidance (Niska and Wenall,

2019; Schepers and Wolt, 2012). Over-the-handlebar falls can lead to particularly severe injuries, as these types of falls are associated with more forceful head impacts (Niska and Wenall, 2019). While bicycle collisions with motor vehicles generate the majority of fatalities to bicyclists (Statistics Canada, 2019), single-bicycle crashes (SBCs) are also a key concern. SBCs are crashes or falls that do not involve direct contact with another road user, often reported through hospital admittance records. On average, SBCs cause 17% of cyclist fatalities, and between 60-95% of hospital admissions depending on the country (Schepers, Agerholm, Amoros et al., 2015). A study of hospital admissions in Vancouver and Toronto showed that 60% of cyclist injuries were a result of SBCs (Teschke et al., 2014). In situations where a bicyclist must suddenly apply their brakes to avoid an unexpected obstacle, the possibility of falling off the bicycle and sustaining an injury may be considered in the cyclist's decision-making process, thus creating a more complex stopping scenario which may influence the user's perception-reaction time.

The presence of car, bus, and truck traffic is a key deterrent for choosing to bicycle, which is consistent across bicyclists of all abilities (Winters et al., 2011; Broach et al., 2012); consequently, fully separated, protected facilities have been proven to be critical in attracting bicyclists to use these bike networks (Winters and Teschke, 2010; Buehler & Dill, 2016). With the increasing implementation of separated facilities to incentivize new bicyclists, it becomes important to study the interactions occurring on these pathways, specifically focusing on the interactions between bicyclists and fixed objects or avoidance maneuvers leading to SBCs. This examination is crucial to ensure the safety and effectiveness of cycling infrastructure.

Prioritizing the safety of the growing population of bicyclists within transportation networks necessitates a design foundation of evidence-based research. The infrastructure investments emerging from government initiatives to address climate change and promote bicycling must be designed to accommodate users of all ages and abilities, incorporating methodologies that consider the diverse needs of the actual users.

## **1.2 Literature Review**

This section is divided into two parts. First, the current body of knowledge on perception-reaction time for stopping sight distance application is discussed, followed by an examination of the literature on bicyclist deceleration rates. Finally, the research gaps that this thesis aims to address are identified.

### 1.2.1 Perception-Reaction Time

Perception-reaction time is the time it takes for a road user to detect a stimulus, identify it, recognize an action is required, and initiate a response (Transportation Association of Canada, 2017). It is composed of four stages:

1. **Detection:** when the object enters the user's field of view until the user becomes consciously aware of the object;
2. **Identification:** the user collects information on the object to inform the decision-making process;
3. **Decision:** the user decides which action, if any, is required; and
4. **Response:** the user initiates the action.

The current accepted design value for perception-reaction time in SSD applications is 2.5 s (Transportation Association of Canada, 2017) for both motor vehicle and bicycle facility design, and 2 s in European guidance (CROW, 2017; Highways England, 2020). While previous studies have shown that the measured 85<sup>th</sup> or 95<sup>th</sup> percentile perception-reaction times are less than 2.5 s (Fambro et al., 1997; Lerner, 1993; Olson and Sivak, 1986), the 2.5 s threshold is often recommended as a more conservative value to account for the variety across user abilities, but also the link between reaction times and distractions (Dozza, 2013; Bellinger et al., 2009; Hancock et al., 2003), or factors like fatigue (Guo et al., 2016) and alcohol or drug use (Moskowitz and Fiorentino, 2000; Christoforou et al., 2013; Berghaus et al., 1995).

In general, perception-reaction times are measured through studies that test the reactions of road users in response to a stimulus. These are broken up into two key categories of PRT: expected and unexpected reactions. Expected studies measure the simplest driver reaction resulting in the shortest perception-reaction times. In these studies, participants are informed that they are to apply the brakes in response to a stimulus, which is most commonly a light (Fambro et al., 1997; Davoodi et al., 2011), but other stimuli have been used such as a foam object (Olson and Sivak, 1986), a rotating stop sign (Landis et al., 2004), or an audible cue from a horn (Johansson and Rumar, 1971). Due to the unrealistic alerted condition of the participant, expected PRTs provide more of a baseline reaction and are not used to inform design guidance.

In comparison, unexpected PRT studies provide a better representation of real-world perception-reaction times since travelers are not normally anticipating an emergency stopping reaction.

Unexpected PRT studies have involved either an auditory cue (Johansson and Rumar, 1971) or a visual hazard such as a light (Normann, 1953; Sivak et al., 1982), a foam obstacle (Olson and Sivak, 1986), a large barrel (Lerner, 1993; Fambro et al., 1997), or a barrier stretching across the roadway (Fambro et al., 1997; Davoodi et al., 2012). In unexpected PRT studies, there is minimal margin for error, as each participant has only one attempt before becoming aware of the true purpose of the study.

Davoodi et al. (2012) measured unexpected perception-reaction time of motorcyclists and found an 85<sup>th</sup> percentile of 2.12 s, illustrating a higher PRT than previously measured values for unalerted motor vehicle drivers (85<sup>th</sup>: 1.9 s – Lerner et al., 1993; 95<sup>th</sup>: 1.6 s – Olson and Sivak, 1986; 95<sup>th</sup>: 2.0 s – Fambro et al., 1997). Similar to riding a bicycle, operating a motorcycle requires considerations of balance, brake force ratio, and weight shifting when performing a braking action, which could be an explaining factor for the increased PRT observed by Davoodi as a result of a more complex stopping procedure.

There has been extensive research on perception-reaction times for motor vehicle drivers; however, research involving bicyclists and micromobility users' perception-reaction times is lacking. One of the only studies investigating PRT for various micromobility devices comes from Landis et al. (2004), which investigated multiple design parameters including stopping sight distance for modes such as bicycles, kick scooters, and Segway devices. The 85<sup>th</sup> percentile expected perception-reaction time for bicycles was measured at 1.3 s and varied between 1.0 and 2.3 s for the other modes.

Another study (Strohaecker et al., 2022) investigated the difference in reaction time for 72 e-bicyclists receiving acoustic, vibro-tactile, and no warnings in staged conflicts with other bicyclists on a test-track. This study captured video footage using a first-person camera mounted to the participants' chest, and utilized a computer algorithm to estimate the start and end of the reaction time. While this methodology differs from the standard procedure for measuring PRT in SSD applications, the mean PRT was observed to be 1.65 s for the baseline group receiving no conflict-specific warnings, despite being told to expect conflict situations throughout the course. This average PRT is notably high compared to the average reaction times found in other studies, which may demonstrate the complexity of the braking task on a bicycle.

No research has investigated unexpected perception-reaction times for bicyclists, a knowledge gap exacerbated by the fact that “most of the total stopping distance [for bicycles is] due to the human reaction time”, because of the typically low speeds of bicycles resulting in low physical braking distances (p. 322, Wilson and Schmidt, 2020). A summary of previous *in situ* studies measuring perception-reaction time for various modes in both expected and unexpected conditions are provided in Table 1.

While this list is not exhaustive for motor vehicle studies, it is for bicycle studies to the best of our knowledge. The absence of research regarding the fundamental safety parameter of unexpected perception-reaction time, which is integral to the safe design of bicycle facilities across North America, is concerning. Inadequate sight distances along horizontal and vertical curves expose bicyclists to potential conflicts with fixed objects and other road users, which increases the risk of serious injury. Although substantial research has been conducted to establish the design values used in stopping sight distance calculations for motor vehicle roadways, further investigation is necessary to validate the design procedures for bicycle facilities.

Table 1 - Summary of Previous In Situ PRT Research

Study	Mode	n <sup>1</sup>	Expectation	Stimulus	Mean PRT [s]	Upper Percentile [s]
Normann (1953)	Motor Vehicle	53	Expected	Roadside Light	0.73	0.9 (95th)
Johansson and Rumar (1971)	Motor Vehicle	321	Expected	Auditory - Airhorn Blast	0.54	-
		5	Unexpected	Auditory - Airhorn Blast	0.73	1.5 (90th)
Olson and Sivak (1986)	Motor Vehicle	64	Expected	Yellow Foam	0.72	~1.3 <sup>2</sup> (95th)
		49	Unexpected	Yellow Foam	1.1	1.6 (95th)
Lerner (1993)	Motor Vehicle	116	Unexpected	Large Barrel	1.5	1.9 (85th)
Fambro et al. (1997)	Motor Vehicle	26	Unexpected	Fabric Barricade	0.82	
		12	Unexpected	Fabric Barricade	1.08	2.0 (95th)
		11	Unexpected	Large Barrel	1.10	
Davoodi et al. (2012)	Motorcycle	89	Expected	Roadside Light	0.68	1.01 (85th)
		16	Unexpected	Fabric Barricade	1.29	2.12 (85th)
Landis et al. (2004)	Bicycle	130	Expected	Handheld Stop Sign	0.9	1.3 (85th)
Strohaecker et al. (2022)	E-Bicycle	51 <sup>3</sup>	Expected	Staged Road User Conflicts	1.65	N/A
Zak et al. (2023)	Bicycle	55	Expected	Manually-controlled Traffic Signal	0.348 <sup>4</sup>	N/A
Dozza et al. (2023)	Bicycle	34	Expected	Auditory - Stop Command	~0.5 <sup>5</sup>	N/A

<sup>1</sup> Number of observations

<sup>2</sup> Estimated from scatterplot

<sup>3</sup> Baseline Group (no pre-conflict warning)

<sup>4</sup> Median

<sup>5</sup> Estimated from boxplot (median)

### 1.2.2 Deceleration Rate

In transportation engineering, the deceleration rate refers to the rate at which a vehicle decreases its speed when applying the brakes. For design purposes, a lower deceleration rate serves as a conservative estimate to account for the majority of users, requiring a longer stopping distance. The currently accepted design value for deceleration rate in geometric design of roadways for motor vehicles is  $3.4 \text{ m/s}^2$  (Transportation Association of Canada, 2017), which was found to be the threshold at which 90% of drivers chose greater decelerations (Fambro et al., 1997). These braking maneuvers were performed on wet surfaces and were evaluated based on the driver's ability to "stay within their lane and maintain steering control during braking maneuvers" (p.74, Fambro et al., 1997). Prior to the 1997 study, design decelerations varied from  $1.64 \text{ m/s}^2$  to  $5.88 \text{ m/s}^2$ , depending on the type of deceleration and whether the design condition assumes wet pavement (Fambro et al., 1997; AASHTO, 1994).

Current guidance on the deceleration rate portion of the SSD formula for bicycles represents the deceleration rate as a coefficient of friction, which assumes the bicycle wheels are locked during braking. While current recommended values can vary based on speed, surface type and condition, tire type and condition, and pavement wetness (AASHTO, 2012), some typical values for this coefficient of friction are 0.25 (Ministry of Transportation and Infrastructure, 2019), 0.16 in wet and 0.32 in dry conditions (AASHTO, 2012), 0.15 (CROW, 2017) and 0.25 (Highways England, 2020). The use of a coefficient of friction has been criticized in literature, mentioning that the use of this coefficient implies a theoretical maximum stopping power that a cyclist can achieve, which may not accurately reflect a user's actual braking behaviour for fear of falling over the handlebars (Wilson and Schmidt, 2020).

For braking on bicycles,  $0.25 \text{ g}$  ("g" is gravitational acceleration of  $9.81 \text{ m/s}^2$ ; in this case equivalent to  $2.45 \text{ m/s}^2$ ) is classified as comfortable braking, whereas a value of  $0.365 \text{ g}$  ( $3.58 \text{ m/s}^2$ ) is used for emergency braking (Parkin, 2018). A deceleration rate of  $0.5 \text{ g}$  ( $4.91 \text{ m/s}^2$ ) is "almost the maximum" a bicyclist can apply before going over the handlebars (p.333, Wilson and Schmidt, 2020). Deceleration rate for bicycles has been measured through GPS (Luo, 2014; Strauss et al., 2017), accelerometers (Huertas-Leyva et al., 2018, Famiglietti et al., 2020; Dozza et al., 2023), and video coding (Beck, 2004; Twaddle and Grigoropoulos, 2016; Joganich, 2018). One study investigated micromobility deceleration rates using an inertial measurement unit (IMU)

and a light detection and ranging sensor (LiDAR) under different braking scenarios for 34 participants, and found bicycle averages of  $1.50 \text{ m/s}^2$  for ‘comfort’,  $3.00 \text{ m/s}^2$  for ‘harsh planned’, and  $3.60 \text{ m/s}^2$  for ‘unexpected’ braking (Dozza et al., 2023). A study of eight mountain bike riders using radar and video footage found that the deceleration rate ranges on dry pavement, when prompted to lock up the wheels as fast as possible, were 0.25-0.33 g, 0.29-0.47 g, and 0.35-0.52 g for rear only, front only, and both brakes, respectively (Beck, 2004), illustrating the noticeable increase in braking power through application of the front brakes. Similar to perception-reaction time, there is a lack of research on the deceleration rate of bicycles under unexpected conditions.

Various studies have discussed the potential of a relationship between perception-reaction time and deceleration rate. The concept suggests that a road user will compensate for a slower reaction time (requiring a longer stopping distance) with a more abrupt braking behaviour, resulting in a higher deceleration rate (requiring a shorter stopping distance), which could mitigate the increased stopping distance resulting from a longer reaction time. Hancock et al. (2003) explored the impact of mobile phone distractions on drivers completing a stopping maneuver. Results showed that distractions slowed response time; however, to compensate for that slowed response, “drivers subsequently brake more intensely” (p.1, Hancock et al., 2003). Similarly, Wood and Zhang (2017) investigated relationships between perception-reaction and deceleration rate using naturalistic driving data and found that in near crash events, longer perception-reaction times were associated with larger deceleration rates.

Current research lacks empirical grounding of operational bicycle characteristics determined under unexpected conditions. To effectively guide the design of real-world bicycle facilities and prioritize user safety, it is essential to conduct evidence-based research to establish these values.

### **1.3 Research Questions**

Bicyclist perception-reaction time and deceleration rate have not been previously measured under unexpected conditions. This research aims to measure the perception-reaction time for use in the design of bicycle facilities by investigating unexpected reaction times of bicyclists in response to a fixed object. We hypothesize that the perception-reaction time for bicyclists will be longer than previously measured values of PRT for motor vehicle drivers, due to the maneuvering complexities and user considerations of safety making for a more complex response.

Additionally, this study will determine the deceleration rate of bicycles in unexpected braking scenarios and the resulting unexpected stopping sight distance. Further, the relationship between perception-reaction time and deceleration rate for bicyclists will be explored. We hypothesize a positive correlation between these variables due to a heightened sense of urgency (and thus greater deceleration rate) resulting from a slower reaction time.

As the number of individuals using bicycle infrastructure continues to grow worldwide, designers must prioritize the safety of these users through evidence-based design procedures for bicycle facilities. This study will provide the empirical evidence that is desperately needed by measuring these design values from bicyclists, instead of relying on assumptions of values determined from motor vehicle studies.

## **Chapter 2: Methodology**

The methodology of this research study comprises three main steps: data collection, data processing, and data analysis with model estimation. Data collection involved crafting and executing a methodology to obtain raw data for perception-reaction time, deceleration rate, and approach speeds from two samples of participants. Data processing involved taking the raw data (including video footage, data files, and survey responses) from the data collection phase and then cleaning, filtering, and extracting the data to prepare it for analysis in the final step, where trends and relationships were investigated.

All study methods were reviewed and approved by the University of British Columbia Behavioral Research Ethics Board (BREB), project number H23-01234, approved on July 14<sup>th</sup>, 2023.

### **2.1 Data Collection**

The data collection for this research was undertaken in two parts: the *Unexpected Trials* and the *Expected Trials*. In the unexpected trials, unalerted perception-reaction times and deceleration rates were measured for a sample (n=52) on the University of British Columbia Vancouver campus using deception. In the expected trials, alerted perception-reaction time was measured for both the UBC campus sample (n=52) and a larger, more representative Vancouver sample (n=250). The rationale for conducting two separate trials was to mitigate potential risks for participants during the unexpected trials, while also being able to collect data from a larger, more representative sample from Vancouver. The aim was to examine the relationship between expected and unexpected perception-reaction times within the smaller UBC campus sample, then apply the determined relationship to the expected responses of the larger sample to get unexpected response estimates for the cycling population. This correction factor methodology is based on a similar procedure from a 1971 study (Johansson and Rumar, 1971). The following sections describe the data collection methodology for both trials in detail.

#### **2.1.1 Unexpected Trials**

##### **Purpose**

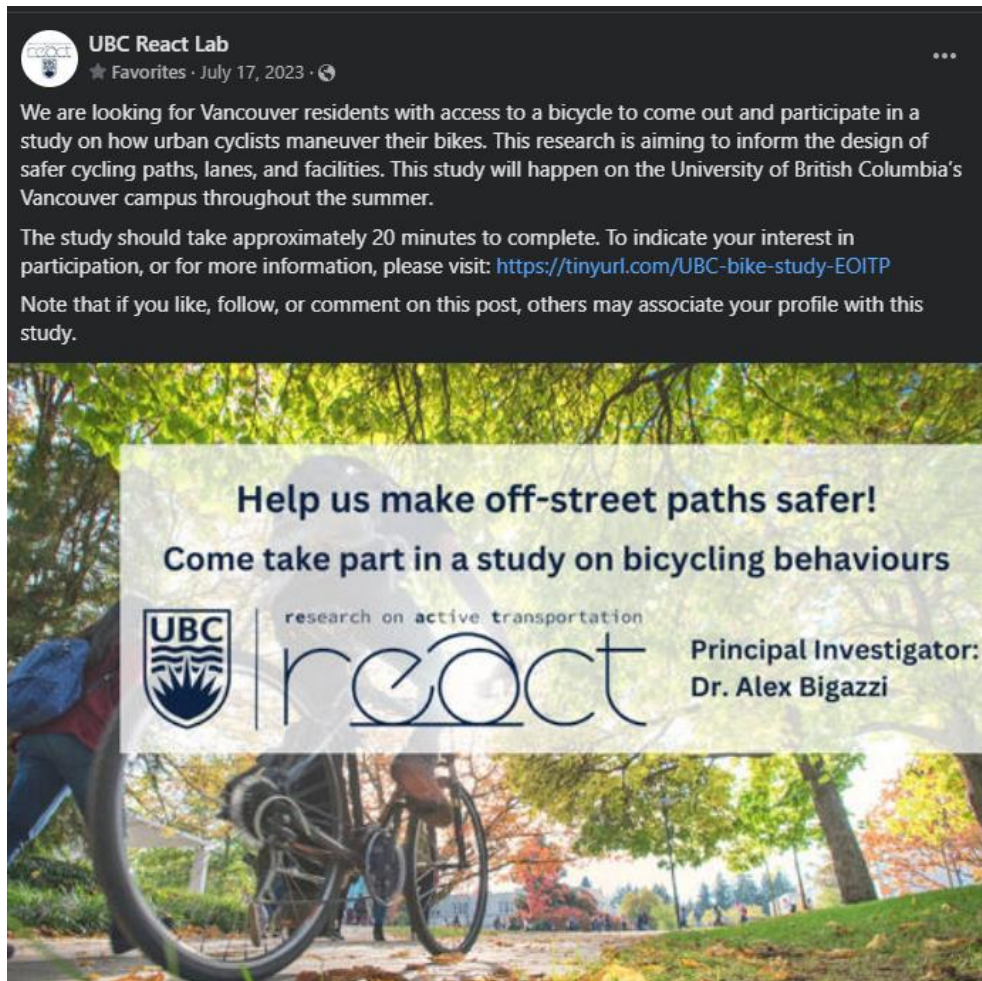
The purpose of the unexpected trials was to measure unexpected perception-reaction time and deceleration rate in an emergency response to a fixed object. In this experiment, participants were informed that the purpose of the study was to evaluate bicycle speed and acceleration in different

operating environments by completing four laps of a marked course. This was a deception prompt, and on the second lap of the course, a vinyl banner obstacle was inserted around a test corner and the participant's perception-reaction time was measured using video data.

## **Recruitment**

For recruitment, an online targeted advertisement was run through UBC REACT Lab's Facebook profile to generate a preliminary pool of participants, which is shown in Figure 1. The ad included a link to a screening survey (implemented in the Qualtrics survey platform) that provided information about the study, including the study team, location, purpose, procedures, and potential risks and benefits of the study. Individuals who expressed interest in participating in the study provided their email addresses to schedule a date and time for their involvement in the trials. The advertisement ran at \$30 per week for 2 weeks to an audience of age 18 to over 65 in the City of Vancouver, and received a reach of 4600, with 245 link clicks.

In addition to online recruitment, on-site recruitment during data collection days was undertaken. Bicyclists passing a recruitment booth set-up on UBC Campus were flagged down and invited to participate in the study; no individuals were forcibly stopped. One \$5 gift card incentive was given to each participant of the unexpected trials after completion of the experiment. To be eligible to participate in the study, participants must have been able to ride a bicycle, been at least 14 years of age, and been able and willing to transport their bicycle to UBC campus for testing. Any bicycle, including shared bikes or electric-assist bikes, were permitted to take part in the experiment; however, e-bike users were asked to disengage the e-assist for participation in the trials. The age restriction was put in place due to the use of deception in the study, resulting in higher than minimal risk to participants. The unexpected trial consent form is provided in Appendix A.



*Figure 1 - Online Advertisement*

## **Location**

The unexpected trials took place on the University of British Columbia Vancouver campus on July 31 and August 1, 3, 4, 5, 7, 8, 10, 11, and 18, 2023 during clear, dry weather. The route is shown in Figure 2 and includes various mixed-traffic on-street sections, a simulated protected bicycle path along Engineering Road, and a short multi-use section along Main Mall. The length of the path was selected to give the study team sufficient time to set up the banner hazard between lap one and two of the trial.

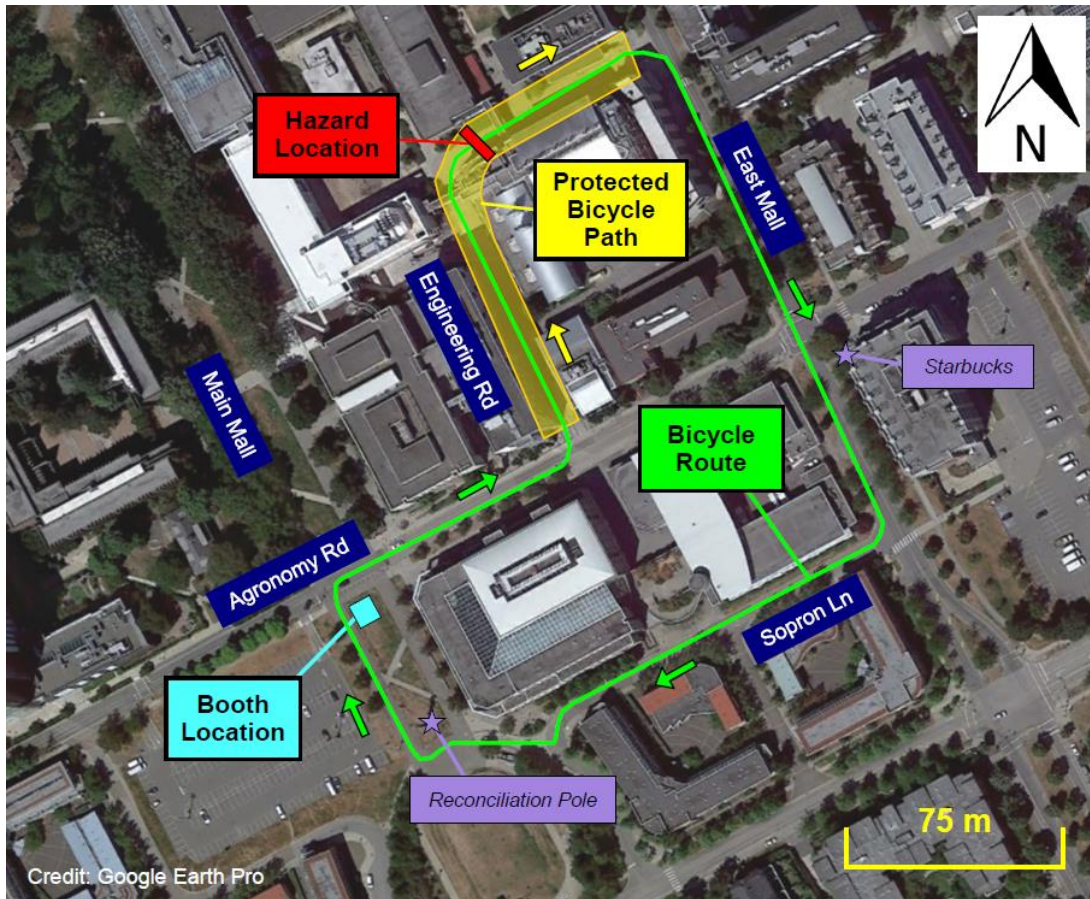


Figure 2 - Unexpected Trial Route (Google Earth, 2024a)

## Equipment

The equipment for the unexpected trial included a participant-owned bicycle (per BREB requirement to decrease the risk of using a bicycle with which the participant was not familiar), a Garmin Edge 530 GPS for location and speed data, a 3-Space Data Logger for acceleration data, an Overade Oxibrake pressure-sensor brake light, two GoPro HERO5 video cameras (one for taking bicycle photos and one for recording video of the trial at 720-pixel resolution with 60 frames per second), a set of silicone straps, cones and delineators, traffic signage, and a vinyl stop banner hazard used as the unexpected stimulus (see Figure 3).



*Figure 3 - Vinyl Stop Banner Hazard*

## **Procedure**

Upon arrival to the booth located on Main Mall, participants were informed of the ‘purpose’ of the study, which was to “evaluate typical bicycling behaviours and operational parameters that are used in design such as speed and acceleration, in different road environments by completing four (4) laps of the marked course”. This was a deception prompt to ensure the participant did not foresee a braking scenario. If interested in participating, the participant then filled out an online consent form using their own device or the provided Samsung Tablet. Participants that were recruited online were only able to view the consent form prior to arriving on-site. All participants had to sign the consent form before participating. Concurrently, the participant’s bicycle was instrumented with the brake light and pressure-sensor, the Garmin GPS, and the data logger, which is illustrated in Figure 4. The data logger was set up at a recording interval of 10 Hz, which collects ten data points per second. The Garmin GPS was set up to record at the fastest possible interval using “Every Second” mode, which collects a single data point every second.



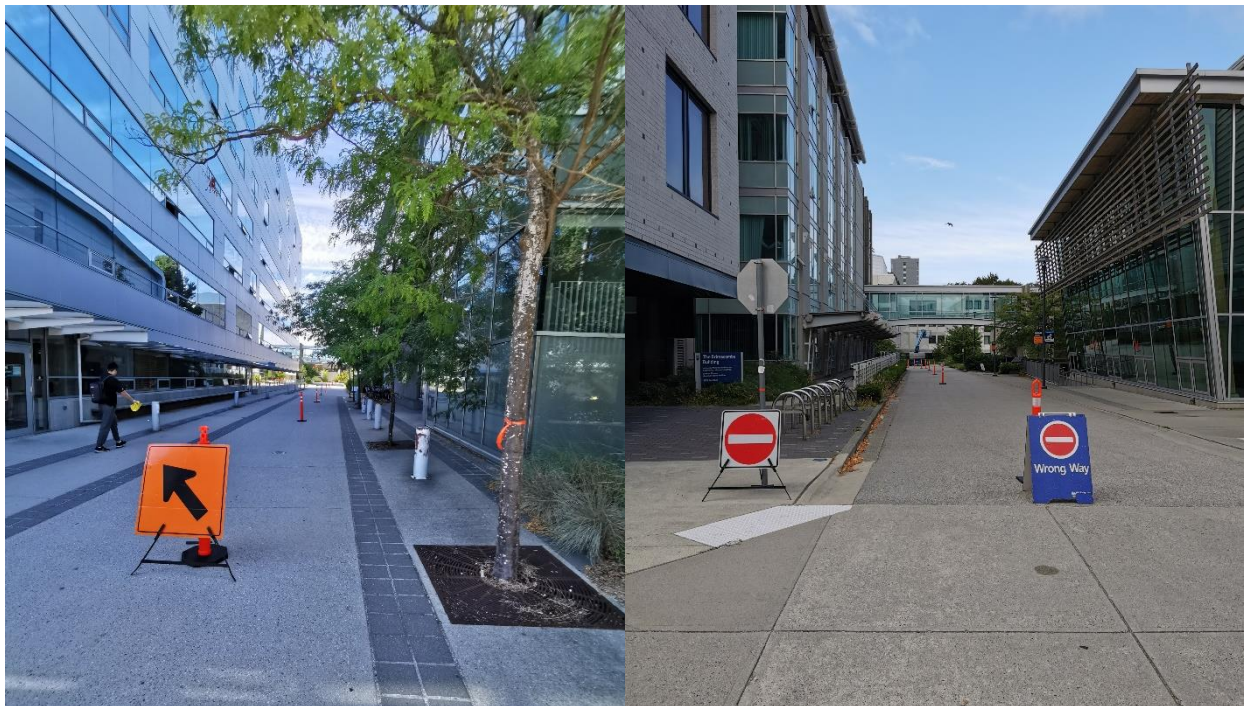
*Figure 4 - Instrumented Bicycle*

Socio-demographic information (age, gender) and bicycling habits (self-identified bicycling confidence, bicycling frequency) were collected after the participant agreed to the online consent form. Self-identified bicycling confidence was evaluated by asking the participant “*Which description best describes your confidence as a bicyclist?*” between Strong and Fearless: will ride regardless of roadway conditions, Enthused and Confident: prefer biking on separated facilities, Interested but Concerned: hesitant to bike and require their own facilities, and No Way No How: will not ride a bicycle (Dill and McNeil, 2013). The method of asking the participant to self-identify their confidence is preferred over inferring confidence from other questions (Hosford et al., 2020). Bicycling frequency was evaluated through the question “*How many days per week do you typically ride a bicycle in the summer months?*”, which was selected to avoid confusion around weather conditions and other considerations for seasonal riders. The full demographic survey is provided in Appendix A. Once the online consent form and demographic information was completed, the participant was assigned an ID number to use for data synchronization.

Prior to beginning the trial, photographs of the bicycle were taken using a GoPro camera for classification in the data processing step. Participants were then asked to sit on the bicycle seat,

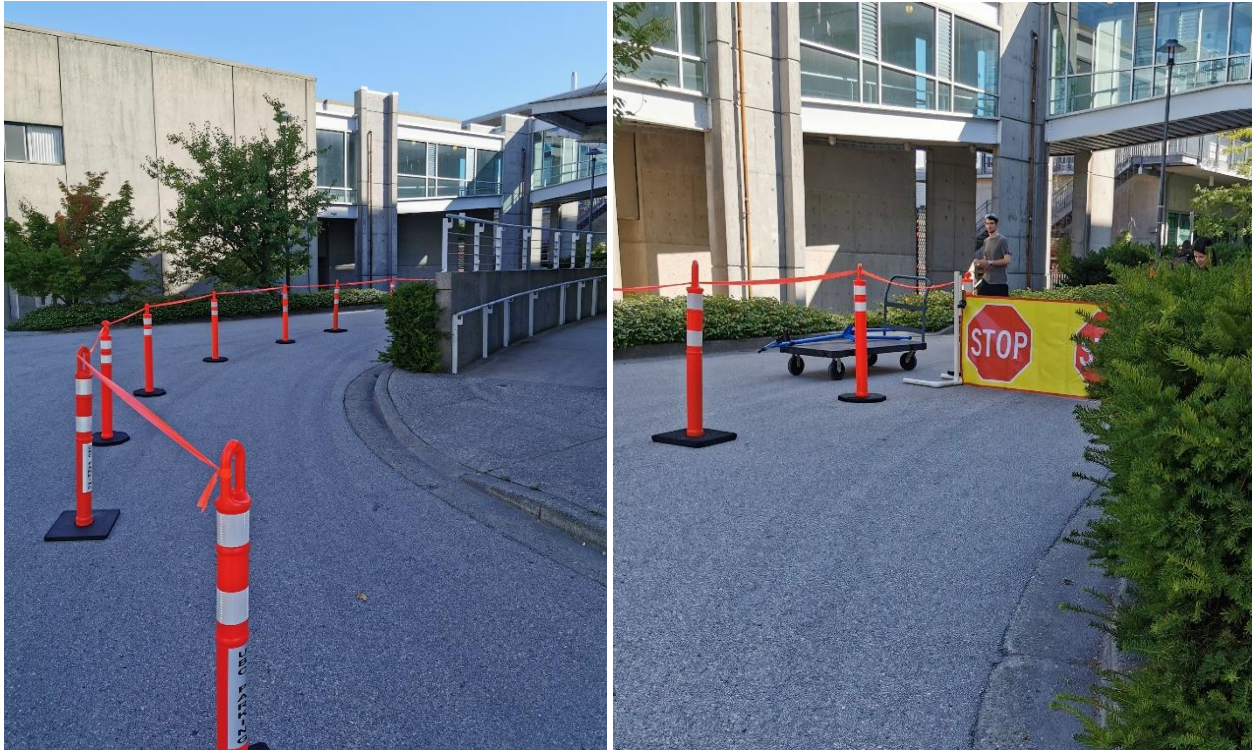
place their hands on the handlebars, and position themselves in their typical riding orientation. One member of the data collection team assisted with balancing the participant, while the other used a tape measure to determine the user eye height. This eye height was recorded in an Excel spreadsheet on a laptop computer.

The participant was reminded to “operate the bicycle how they normally would bike around campus, but to stay within the cones where they are provided”. No instructions were provided for a specific hand position (i.e., having hands on the brakes). After being provided time to get used to the instrumented bicycle, participants set off on the marked course. As shown in Figure 5, the course was marked in certain locations with orange flagging tape, and delineators were set up to create a coned bicycle path along Engineering Road.



*Figure 5 - Coned Bicycle Path and Flagging Tape*

After passing the test corner on the first lap, the vinyl banner hazard was set up in the test corner on Engineering Road and the GoPro video camera, located on the outer edge of the stop banner, began recording (see Figure 6). A staging area with all the test equipment adjacent to the testing location was used to hide the equipment from the participant on the first lap.



*Figure 6 - Test Corner and Stop Banner Setup*

As the participant came around the test corner on the second lap, they encountered the vinyl stop banner blocking the path and completed an unexpected stopping maneuver. During the study, one participant requested to record their trial using a bicycle-mounted video camera, which was not initially planned in the study design. Subsequently, permission was successfully obtained after the trial to utilize the video footage, demonstrating the first-person participant perspective of the trial. The video can be accessed [here](#) (Cycl'n Vancouver, 2023). A plan view diagram of the test setup is provided in Figure 7.

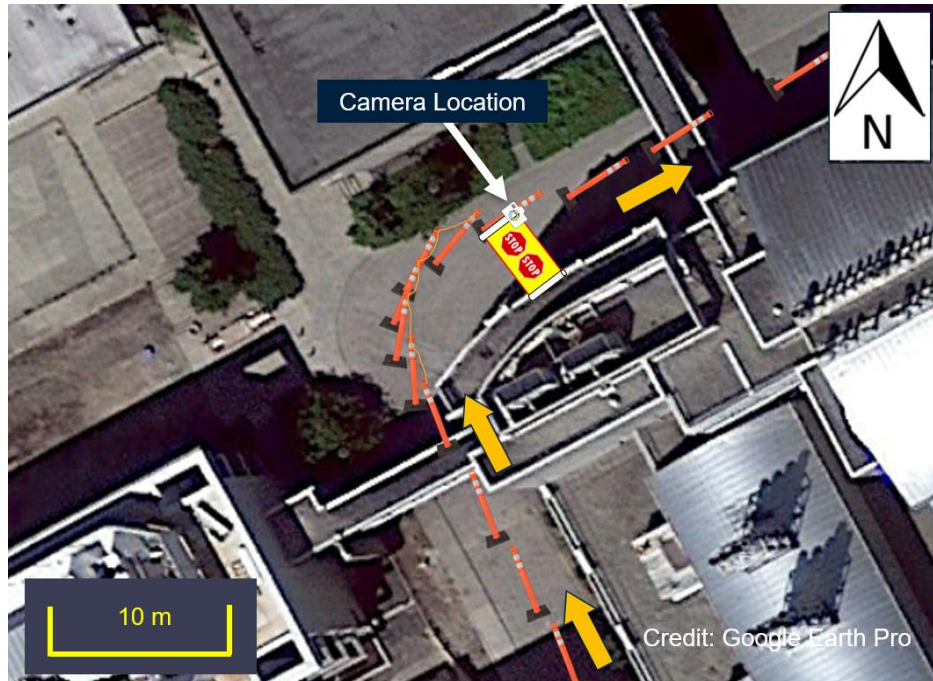


Figure 7 - Plan View Diagram of Test Corner (Google Earth, 2024a)

The perception-reaction time and braking time were measured using video footage and the brake light, approach speed using the Garmin GPS, and deceleration rate using the data logger; all measurement procedures are described in Section 2.2. In the unexpected trial, the GoPro was mounted in front of the participant on the vinyl stop banner, and the brake light was mounted to the front of the bicycle, such that the participant's first moment of seeing the hazard and the brake light would be captured on the same video to avoid challenges with the synchronization of multiple video sources.

Once the participants completed the unexpected trial and came to a full stop in front of the banner hazard, they were then debriefed on the true purpose of the study: "to measure unexpected perception-reaction time of bicyclists in response to a fixed object, which is why a deception prompt was necessary to obtain a meaningful estimate for this critical design value". Verbal consent to continue was obtained, and the participant was asked to complete the data collection procedure for the expected reaction trials, which is outlined in the following section. The full debrief script is provided in Appendix A. If consent was withdrawn at any time during the trials, the participant's data were immediately discarded. Fortunately, there were no instances of consent being withdrawn from a study participant.

## **2.1.2 Expected Trials**

### **Purpose**

The purpose of the expected trials was to measure expected perception-reaction time and deceleration rate in response to a stimulus. This step was added into the study design to collect data from a larger, more representative sample within the City of Vancouver. In this part of the experiment, participants were asked to ride at a normal speed towards a red-green, manually-controlled traffic signal, and to “come to a full stop as quickly as possible, safely” when the light changed from green to red. The term “safely” was added in order to avoid participants falling over the handlebars when performing the braking maneuver.

### **Recruitment**

No online advertisements were run for expected trials recruitment. A booth was set up at each testing location and individuals passing by were flagged down and invited to participate in the study; no individuals were forcibly stopped. Recruitment signage, illustrated in Figure 8, was deployed on each approach to the test site to notify individuals of the ongoing study. Participants were able to provide an email address to enter a draw for a chance to win 1 of 4 \$25 gift cards as an incentive for participating. To participate in the study, participants must have been able to ride a bicycle and been at least 14 years of age. In the expected trials, due to the minimal risk, individuals without a bicycle were permitted to participate by using a bicycle provided by the REACT Lab, which is shown in Figure 8. Any bicycle, including shared bikes or electric-assist bikes, were permitted to take part in the experiment; however, e-bike users were asked to disengage the e-assist for participation in the trials. The age restriction was kept in place for this part of the study for consistency with the unexpected trials. The expected trial consent form is provided in Appendix A.



*Figure 8 - Recruitment Signage and REACT Lab Bicycle*

## **Location**

The expected trials took place at three locations 1) the University of British Columbia Vancouver campus during the same dates specified in the previous section, 2) Ontario Street at the Seawall on August 21, 22, 23, 25, 28, 30, and September 5, 8, 2023, and 3) Ontario Street at Riley Park on September 28, 29, and October 5, 2023. All data collection days occurred on clear, dry days. The geographic location for each of these locations is provided in Figure 9, and the location setup is provided in Figure 10. The testing locations were chosen based on criteria such as having a flat, paved surface, being adjacent to a bicyclist path or route to maximize potential participant numbers, and for representativeness of the cyclist population.



Figure 9 - Expected Trial Study Locations in Vancouver (Google, 2024b)



Figure 10 - Expected Locations (Left to Right: UBC, Seawall, Riley Park)

## Equipment

The equipment needed for the expected trial portion of this study included a bicycle (either participant-owned or provided by REACT Lab), a Garmin Edge 530 GPS for location and speed

data, a 3-Space Data Logger for acceleration data, an Overade Oxibrake pressure-sensor brake light, two GoPro Hero 5 video cameras (one for taking bicycle photos and one for recording video of the trial at 720-pixel resolution with 60 frames per second), a set of silicone straps, cones and delineators, a portable battery, and a red-green traffic signal to be used as the expected reaction stimulus. The expected trials set-up on UBC campus is provided in Figure 11.



*Figure 11 - UBC Expected Trials Set-up*

## **Procedure**

For Locations #2 and #3 within the City of Vancouver, upon arrival to the booth located adjacent to the testing site, participants were informed of the study's objective, which was to evaluate expected perception-reaction time in response to a light changing from green to red. At Location #1, participants would participate in the expected trials immediately after the completion of the unexpected trial. Participants at Location #1 would re-consent before proceeding, and consequently would only complete the procedural steps related to measuring their reaction to the red-green traffic signal.

If interested in participating, the participant would fill out the online consent form using their own device or the provided Samsung Tablet. Concurrently, the trial bicycle, either participant-owned or REACT Lab provided, was instrumented with the brake light and pressure-sensor, the Garmin

GPS, and the data logger. The data logger was set up at a recording interval of 10 Hz, which collects ten data points per second. The Garmin GPS was set up to record at the fastest possible interval using “Every Second” mode, which collects a single data point every second.

Socio-demographic information (age, gender) and bicycling habits (self-identified bicycling confidence, bicycling frequency) were collected after the participant agreed to the online consent form. The same fields and descriptions were provided in the expected trials as in the unexpected trials discussed in Section 2.1.1. The full demographic survey is provided in Appendix A. Once the online consent form and demographic information was completed, the participant was assigned an ID number to use for data synchronization.

Prior to beginning the trial, photographs of the bicycle were taken using a GoPro camera for classification in the data processing step. Participants were then asked to sit on the bicycle seat, place their hands on the handlebars, and position themselves in their typical riding orientation. One member of the data collection team assisted with balancing the participant, while the other used a tape measure to determine the user eye height. This eye height was recorded in an Excel spreadsheet on the field laptop.

The participants were informed that they could bike towards the light at any speed, but to apply the brakes as quickly as possible (safely) and come to a full stop once the green light turned to red. Once again, no instructions were provided for a specific hand position (i.e., having hands on the brakes). Figure 12 illustrates a diagram of the expected trial procedure and each of the measured study variables.

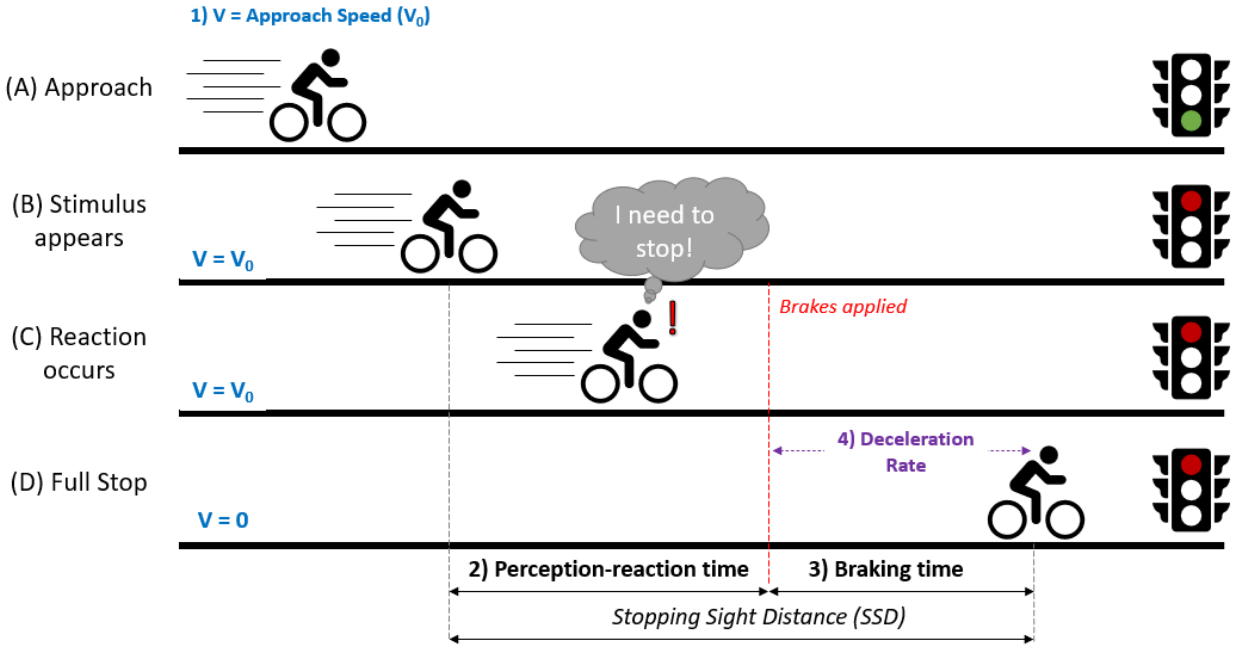


Figure 12 - Expected Trial Procedure and Measured Variables

The approach speed (1) was measured using the Garmin GPS, the perception-reaction time (2) and braking time (3) were measured using video footage and the brake light, and deceleration rate (4) using the data logger; all measurement procedures are described in Section 2.2. In the expected trial, the GoPro was mounted behind the participant such that the bicycle-mounted brake light and the red-green traffic signal would be captured on the same video to avoid challenges with the synchronization of multiple video sources. If consent was withdrawn at any time during the trials, the participant's data were immediately discarded.

The expected trial was repeated three times in the Vancouver sample, and two times as the follow-up to the unexpected trials for the UBC campus sample, for a total of three observations per participant. The difference in the number of expected trials was selected due to the longer time involvement for participants of the unexpected trial.

### 2.1.3 Data storage and download

After each trial was complete, the video cameras, Garmin GPS, and 3-space Data Logger were removed from the participant's bicycle and returned to the booth. A member of the research team then transferred the files from each device to a folder named after the previously disclosed participant ID on the field laptop. The file folders were named after the location and the day of

data collection; for example, a participant with ID number 91 undertaking the study on Day 3 at the Seawall location would have their data stored in "...\Expected\_Seawall\Day 3\091". In addition to the participant eye height recorded in the Excel spreadsheet, each participant would have four files saved in their respective file folder in the Vancouver trials, and seven files for UBC Campus participants, which are highlighted in Table 2 below.

*Table 2 - Summary and Format of Collected Data*

<b>Device</b>	<b>Data Transfer Mechanism</b>	<b>Vancouver (Expected)</b>	<b>UBC Campus (Unexpected)</b>
Garmin GPS	USB Cable	1x .fit file	2x .fit files
3-Space Data Logger	USB Cable	1x .txt file	2x .txt files
GoPro Video Camera	MicroSD card + Adapter	1x .MP4 file 1x .JPG	2x .MP4 files 1x .JPG

In the event that multiple participants were lined up back-to-back without a break for the data download, multiple data files were stored on the respective devices before downloading to the field laptop. In this case, time stamps were used to classify each of the files into the correct participant ID folder. The default naming convention for the GPS and data logger files included a timestamp, which was used to assist with data synchronization. The "Date/Time Created" file management field was used for video footage and photos. The data were deleted from each of the devices after being transferred to the field laptop.

At the end of each data collection day, the research team packed up all the equipment and returned to the team lab space for storage of all equipment. Data were then uploaded from the field laptop to a secure server at UBC, and subsequently downloaded to be stored on a password-protected computer kept in a locked area. Once this upload and download process was successful, all data were deleted from the field laptop.

## **2.2 Data Processing**

There were three primary sources of data for each trial: video footage for measuring participant perception-reaction time and braking time, a Garmin Edge 530 cycling computer for measuring the approach speed prior to braking, and a 3-space data logger for recording the bicycle

deceleration rate. The following sections outline the data processing stage, including all classification procedures and data filtering necessary to prepare for the subsequent data analysis stage.

### 2.2.1 Bicycle Characteristics

#### Bicycle Type

Using the bicycle photographs taken for each participant, a classification procedure was used to categorize each bicycle as “Hybrid”, “Road”, or “Mountain”, consistent with previous literature (Tengattini et al., 2018). This process included noting handlebar orientation (drops vs. flat or other) and tire width (narrow-medium vs. wide tires), which is illustrated in Figure 13.

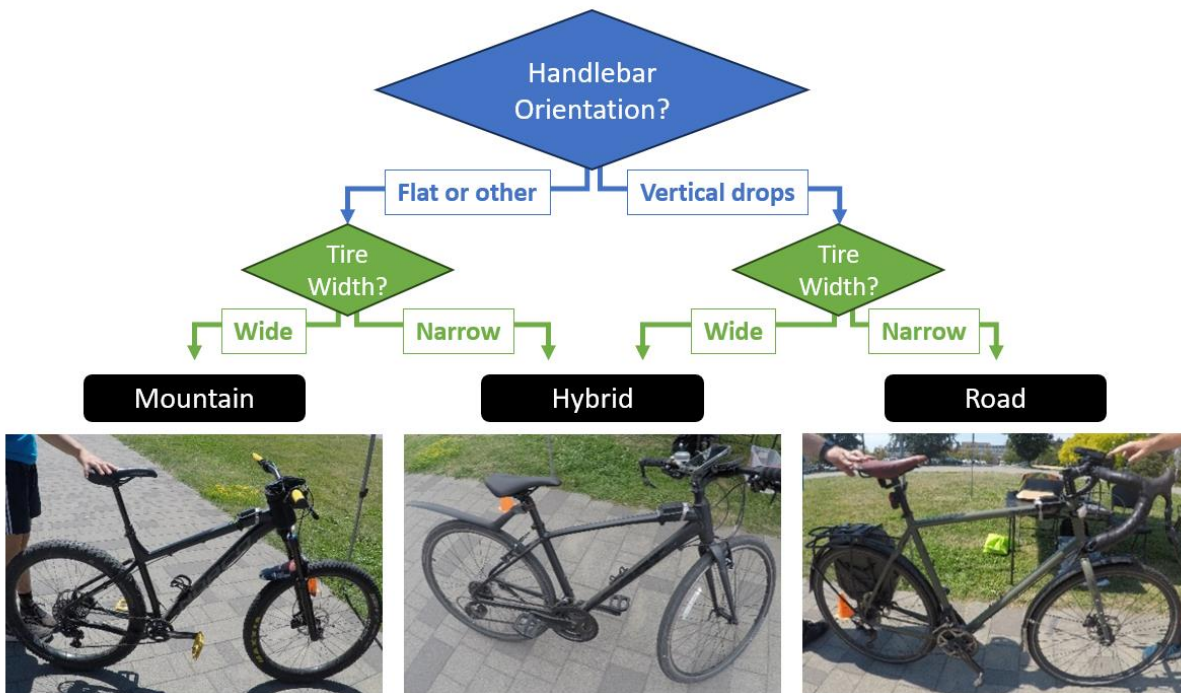


Figure 13 - Bicycle Classification Methodology

#### Brake Type

Using the bicycle photographs taken for each participant, brake types were noted as either “Disc”, “Rim”, or “Drum”. This step was performed to investigate the impact of different brake types on participant’s deceleration rate. An example of each brake type is provided in Figure 14.



Figure 14 - Brake Classification Types (Disc, Rim, Drum)

### 2.2.2 Perception-Reaction Time

Each participant's perception-reaction time was calculated using the video footage extracted from the GoPro video camera recording 720-pixel resolution at 60 frames per second. Video footage was analyzed using Adobe Premiere Pro, which provided the ability to playback the footage in slow motion and displayed the playback time in mm:ss:frames.

Timestamps were extracted for each unexpected and expected trial to determine the first moment the stimulus could be perceived ( $t_1$  and  $t_2$ ). The moment of response, when the PRT action terminates, is when the brakes are applied ( $t_3$ ), which was calculated based on the brake light activation ( $t_4$ ) and the average brake light actuation delay ( $t_A$ ). Finally, the moment the participant came to a full stop ( $t_5$ ) was also defined, to calculate the braking time. Table 3 contains a breakdown of the timestamps recorded for each trial.

Table 3 - PRT Timestamps

	Timestamp	Description	Unexpected Trial	Expected Trial
Perception- Reaction Time	$t_1$	<i>Presence of Stimulus</i>	First eye appears around test corner	Green light off
	$t_2$			Red light on
	$t_3$	<i>Time of Brake Activation</i>	Moment the brakes are applied - equivalent to $t_4$ minus the brake actuation delay ( $t_A$ )	
Braking Time	$t_4$	<i>Time of Brake Light Illumination</i>	Moment the brake light activates	
	$t_5$	<i>Moment of Full Stop</i>	Moment bicycle comes to a full stop	

For consistency with the definition provided in current design guidance (Transportation Association of Canada, 2017), the perception-reaction time in this study is defined as the duration from the moment the participant could first detect the stimulus (“detection”) until the moment that they first apply the brakes (“response”).

In the expected trials, the red-green traffic signal setup had a slight delay between the green light deactivating and the red light activating (between 2 and 8 frames; 0.03 to 0.13 s). To account for this light delay, the mid-way point between the green off and red on was used as the presence of stimulus timestamp.

The actuation delay between the participants’ physical application of the brake lever ( $t_3$  - the end point of the perception-reaction time) and the brake light turning on ( $t_4$ ) was determined from a mix of laboratory tests and participant samples. The participant samples used for this delay calculation came from the unexpected trials and contained a physical braking movement noticeable enough to determine the moment of reaction without use of the brake light. The time between the physical movement to apply the brakes and the illumination of the brake light was recorded for each test trial. The average brake light actuation delay ( $t_A$ ) across these samples, found to be 0.15 s (9 frames), was then subtracted from the brake light activation ( $t_4$ ) to determine the moment the brakes were physically applied ( $t_3$ ), which is the end of the PRT phase, shown in Equation 2. The unexpected and expected PRT formulas are provided in Equation 3 and Equation 4.

*Equation 2 - Time of Brake Activation (Moment of Response)*

$$\mathbf{Time\ of\ Brake\ Activation\ (t_3) = t_4 - t_A} \quad (2)$$

*Equation 3 - Unexpected PRT*

$$\mathbf{Unexpected\ PRT = t_3 - t_1} \quad (3)$$

*Equation 4 - Expected PRT*

$$\mathbf{Expected\ PRT = t_3 - \left(\frac{t_1 + t_2}{2}\right)} \quad (4)$$

The braking time, or the time from brake application until the time of full stop, was calculated using Equation 5. Any trial where the brake light did not activate ( $t_4$ ) or the participant did not come to a full stop ( $t_5$ ) were excluded from subsequent analysis.

*Equation 5 - Braking Time*

$$\mathbf{Braking\ Time = } t_5 - t_3 \quad (5)$$

A visual example of certain timestamps collected for the unexpected and expected trials are illustrated in Figure 15 and Figure 16, respectively.



*Figure 15 - Presence of Unexpected Stimulus,  $t_1$  (left), Time of Brake Light Illumination,  $t_4$  (middle), and Moment of Full Stop,  $t_5$  (right)*



*Figure 16 - Participant Riding Towards Green Light (left), Presence of Expected Stimulus,  $t_2$  – Red Light On (middle) and Time of Brake Light Illumination,  $t_4$  (right)*

### **2.2.3 Deceleration Rate**

Each participant's deceleration rate during the braking maneuver was determined from three-dimensional accelerometer data collected from the 3-Space Data Logger. The initial stage of acceleration data processing involved applying a Savitzky-Golay smoothing filter to address the

substantial noise caused by bicycle vibration (Lépine et al., 2014; Xie et al., 2019; Murgano et al., 2021). A Savitzky-Golay filter is a digital signal processing tool that applies a polynomial of a specific degree to a window of data points using the least squares method (Savitzky and Golay, 1964). The key advantages of a Savitzky-Golay filter are the preservation of key signal features such as peaks or valleys, the use of a small window size to assist in capturing variations, and the minimization of phase shift in the filtered signal which helps with interpretation of the data (Schafer, 2011). Through exploration of a range of parameter values aimed at balancing the preservation of peaks and the removal of noise, filter parameters were set at a window size of 11 (representing 1.1 s) and a polynomial order of 1.

Once the X, Y, and Z acceleration fields were smoothed, the orientation of the device on the bicycle had to be determined. For each participant, the data logger was consistently mounted to the top tube on the frame, with the buttons facing upwards. The angle of the top tube on each bicycle varies relative to the ground, and thus the raw 3D acceleration extracted from the data logger needed to be orientation-compensated such that the longitudinal acceleration in the bicycle's direction of travel could be determined. At the start and end of the trial, the bicycle is at rest and gravity is the only force acting on the device. By calculating the resultant magnitude and direction of the Y (upward) and Z (forward) accelerations of the logger during the final 2.5 s of the trial, a correction angle ( $\Phi$ ) was determined between the Y-axis of the data logger and the Y-Z resultant, which represents the Y\* direction of gravity in the earth/bicycle reference (on level ground).

This correction angle was then used to extract the components of the data logger Y and Z accelerations that contribute to the Y\* and the Z\* accelerations in the direction of the bicycle. This method permits the Y and Z accelerations to be transferred into the bicycle reference, assuming the bicycle operates on a flat grade which was the case for all testing locations. Even with bicycle roll, the relative proportions of gravitational force in the Y and Z directions are constant, so the X-axis acceleration was not used in calculation of the correction angle ( $\Phi$ ). Figure 17 below illustrates the methodology used to account for the orientation of the data logger.

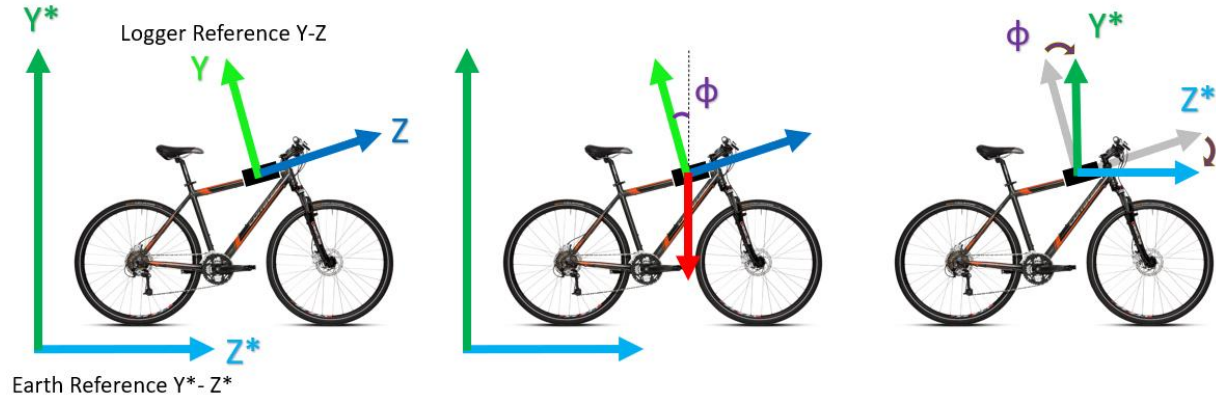


Figure 17 - Adjusting Data Logger Orientation

The longitudinal acceleration of the bicycle can then be calculated using Equation 6 below. Since the orientation of the data logger is tilted upwards from the  $Z^*$  axis, the Y-component contributing to the  $Z^*$  acceleration is negative.

Equation 6 - Longitudinal Acceleration Using Correction Angle

$$Z^* = Z * \cos(\Phi) - Y * \sin(\Phi) \quad (6)$$

A validation test was performed to confirm the correction angle methodology. The  $Y^*$  acceleration, as calculated by Equation 7, along the length of the ride was plotted. Since the orientation of the data logger was tilted upwards from the  $Z^*$  axis, both the Y- and Z-components contribute to the  $Y^*$  acceleration in the same direction. This value of  $Y^*$  is expected to average around 1 g ( $9.81 \text{ m/s}^2$ ), in the downward direction.

Equation 7 - Acceleration Due to Gravity Using Correction Angle

$$Y^* = Z * \sin(\Phi) + Y * \cos(\Phi) \quad (7)$$

The resultant longitudinal acceleration ( $Z^*$ ) was plotted along the duration of the trial for each participant. In the unexpected trials, the braking event was easily identified as the final drop in acceleration (of at least  $-0.09 \text{ g}$ ) prior to the device being turned off. In certain cases, the braking event was not easily identified due to the device not being turned off immediately. In these instances, a combination of video footage analysis and GPS data was utilized to identify the deceleration event by synchronizing time and tracking location. For the expected trials, the data logger recorded all trials consecutively without being turned off. In order to identify the

deceleration events associated with the light change from green to red, vertical lines representing the video-determined gap time between each stopping event were overlaid on the deceleration plot, and the first line was aligned with the initial braking maneuver, which was identified as the first speed drop after the recording started. This allowed the subsequent braking maneuvers to be identified.

The braking time extracted from the video footage, shown in Equation 5 above, was overlaid on the acceleration plots to extract the deceleration profile during the braking event. Due to synchronization error (caused by small imprecision in the device time clock), a heuristic process was used to align the braking event window precisely with the accelerometer data, based on maximizing the net-negative acceleration (or net-positive deceleration). This was done by sliding the brake event window over an interval of +/- 10 s on either side of the brake event identifier in the accelerometer data. The average and maximum deceleration was then extracted for each trial, for use in the data analysis step, and plots of each deceleration profile were generated. Figure 18 below demonstrates the identification of the braking event using the maximum net-negative approach, followed by a zoom-in of the braking event.

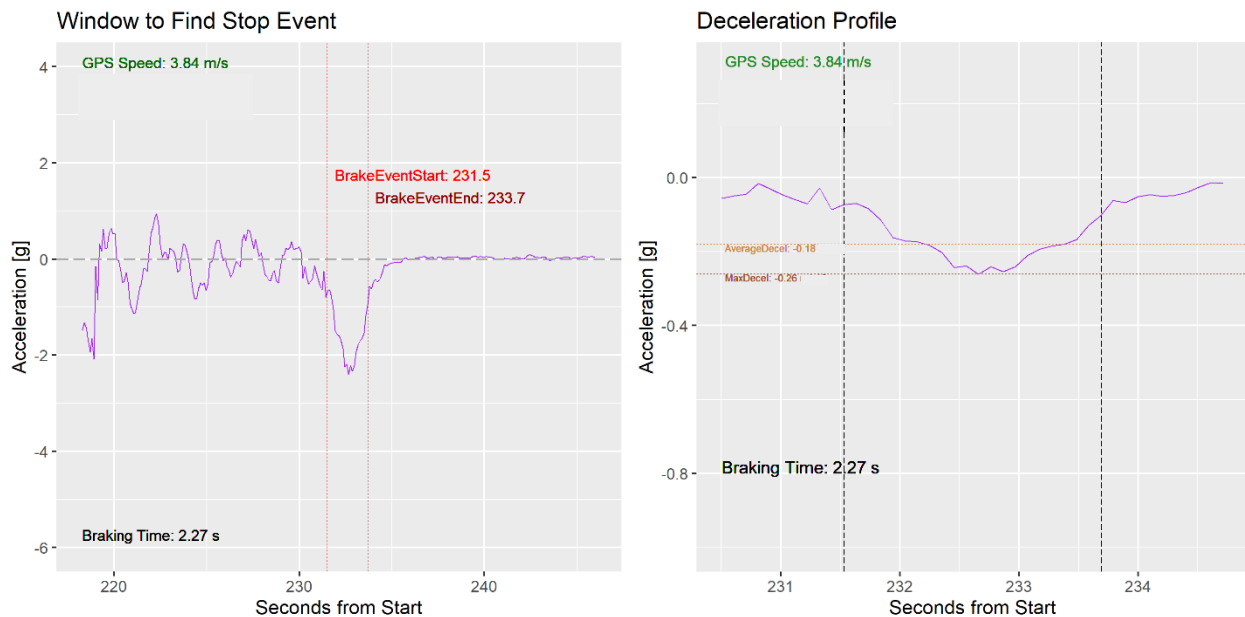


Figure 18 - Brake Event Identification and Deceleration Profile

As a result, three deceleration event plots were prepared for each participant. For UBC Sample participants, this included one unexpected reaction plot and up to two expected plots. For

Vancouver Sample participants, this included up to three expected reaction plots. Since braking time was required to determine the deceleration event window, any trial where the brake light did not activate ( $t_3$ ) or the participant did not come to a full stop ( $t_4$ ) were excluded from the analysis.

#### **2.2.4 Approach Speed**

Each participant's approach speed at the onset of braking ( $V_3$  at  $t_3$  - *Time of Brake Activation*) was determined from GPS data collected from the Garmin Edge 530 cycling computer. This value was assumed to be constant during the perception-reaction time phase, meaning the speed at  $t_1$  and  $t_2$  equals the speed at  $t_3$  ( $V_1=V_2=V_3$ ). Once the data collection was complete, all GPS files in .fit format were converted to .csv files and renamed using a consistent naming convention noting the trial and participant number. An R-script was developed to extract, clean, and analyze the data for each participant. The cleaning process consisted of filtering the Garmin Edge recordings down to data points measured during the ride only, converting the longitude and latitude from semi-circles to degrees, and correcting the time from EPOCH format to Pacific Time.

The "Speed" field [m/s] was then plotted along the full duration of the trial. For the unexpected trial, each participant came around the test corner, came to full stop, and then the Garmin device was shut off. Therefore, the final drop in the speed profile represents the braking maneuver associated with the perception-reaction test. The final speed prior to application of the brakes at  $t_3$  (known as the "approach speed" -  $V_3$ ) was then extracted using an R script.

Given the banner hazard's position around a corner, it was anticipated that participants might have slowed before negotiating the test corner turn, making the preceding maximum speed unreliable as the approach speed ( $V_3$ ). The braking time from the video footage (as determined by Equation 5) was subtracted from the timestamp of the first recording of zero speed to determine the speed just prior to application of the brake ( $V_3$ ). Since the Garmin GPS recorded at a frequency of 1 Hz, the braking time was rounded up to the nearest 1.0 s. For example, with a braking time of 4.4 s, the speed 5 s before the first 0 m/s recording was used for the approach speed. A sample illustration is provided in Figure 19.

Using this methodology to determine approach speed based on braking time, if the brake light did not activate or if the participant did not come to a full stop in any trial, the approach speed could not be calculated.

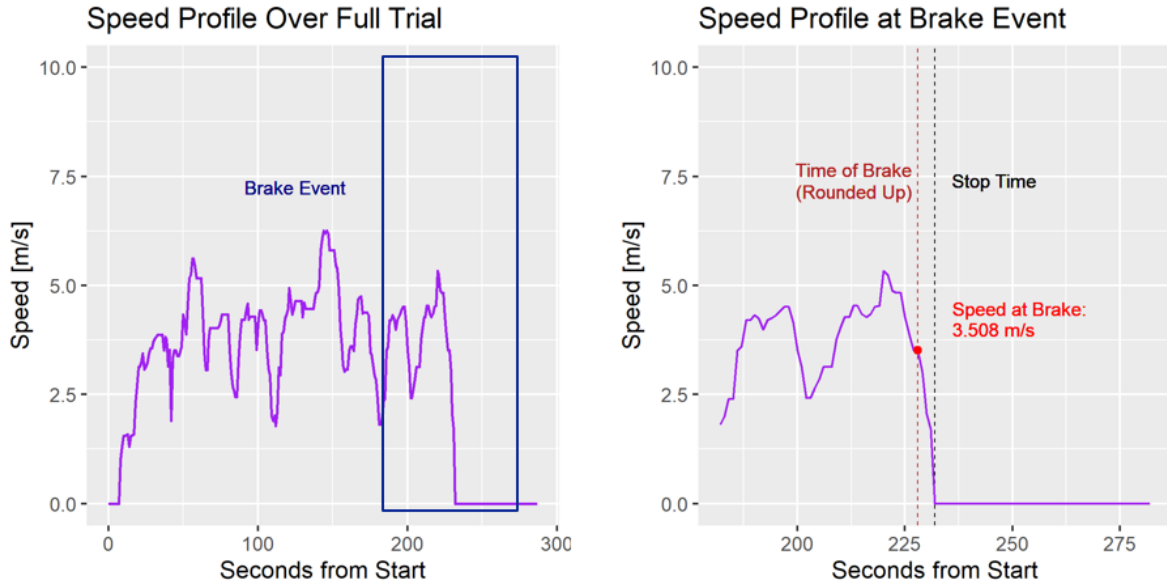


Figure 19 - Unexpected Speed Profile and  $V_3$  Method

In the expected trials, participants would begin at the start line, brake in response to the red-green traffic signal change, then continue around in a loop to the start line again to repeat the test. Therefore, the speed associated with each braking event is not readily identifiable from visual inspection of the graph. In this case, the time interval between each braking event (defined by the moment of brake light activation), as recorded by the GoPro camera, was overlaid on the speed graph and the first braking event was aligned with the initial speed drop. This allowed the subsequent two brake events to be identified among the other speed peaks. The final speed prior to each brake event ( $V_3$ ) was then extracted using the R script. In this case, since the participant is navigating a straight line, the maximum speed prior to braking was taken as  $V_3$ . An example of this process is provided in Figure 20.

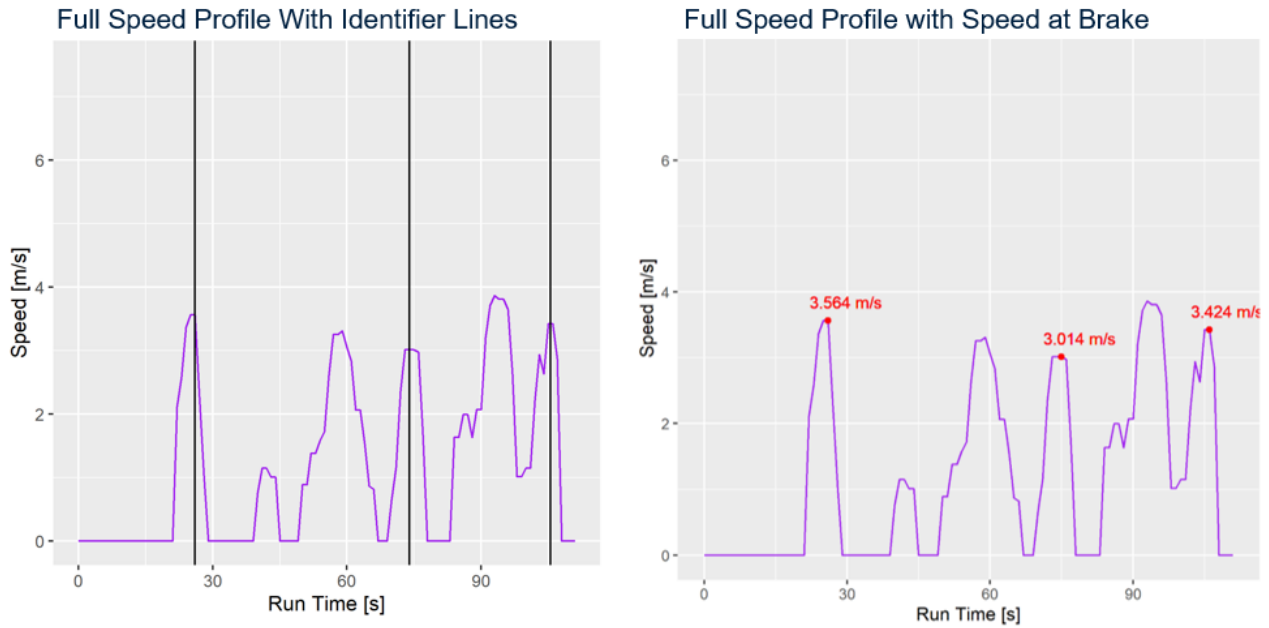


Figure 20 - Expected Speed Profile and  $V_3$  Method

### 2.2.5 Speed Profiles

The GPS data resolution of 1 s was too low of a resolution to be used for generating a deceleration speed profile for each trial. Instead, the following procedure was taken to generate the speed profiles:

1. The approach speed ( $V_3$ ) was extracted from the Garmin GPS at the onset of braking ( $t_3$ ) as described in the previous section;
2. The speed profile between the onset of braking ( $t_3$ ) and the moment of full stop ( $t_5$ ) was determined by integrating the area above the brake event deceleration profile over the video-determined braking time ( $t_5 - t_3$ ), and subtracting the change in speed along each timestep;
3. After the integration over the full braking time, if the final speed ( $V_5$ ) determined from the acceleration data was greater than 1 m/s (or less than -1 m/s), the speed profile was discarded; and
4. All speed profiles passing the 1 m/s test had their final speed fixed at 0 m/s.

This 1 m/s ‘SpeedCheck’ test permitted the comparison of the approach speed ( $V_3$ ) from the GPS to the change in speed associated with integration of the deceleration profile over the braking time window. As described in Step 3, if the difference between the area above the deceleration curve

over the braking time (equal to the total change in speed) and the GPS-determined approach speed was greater than 1 m/s, it was excluded from subsequent analysis based on the inconsistency between measurements of the approach speed from both devices. This speed check procedure was also used to filter out average and maximum deceleration rates extracted for each observation. In instances where the GPS speed compared to the accelerometer total speed change check failed (i.e., was greater than 1 m/s), both the average and maximum deceleration for that observation were excluded from use in the subsequent data analysis and model estimation phase. An illustration of speed profiles passing and failing this check are provided in Figure 21, and the final speed profile with the final speed fixed at 0 m/s is shown in Figure 22.



Figure 21 - Passing and Failing Speed Profiles Determined from Integrating Acceleration Data

### Speed Profile

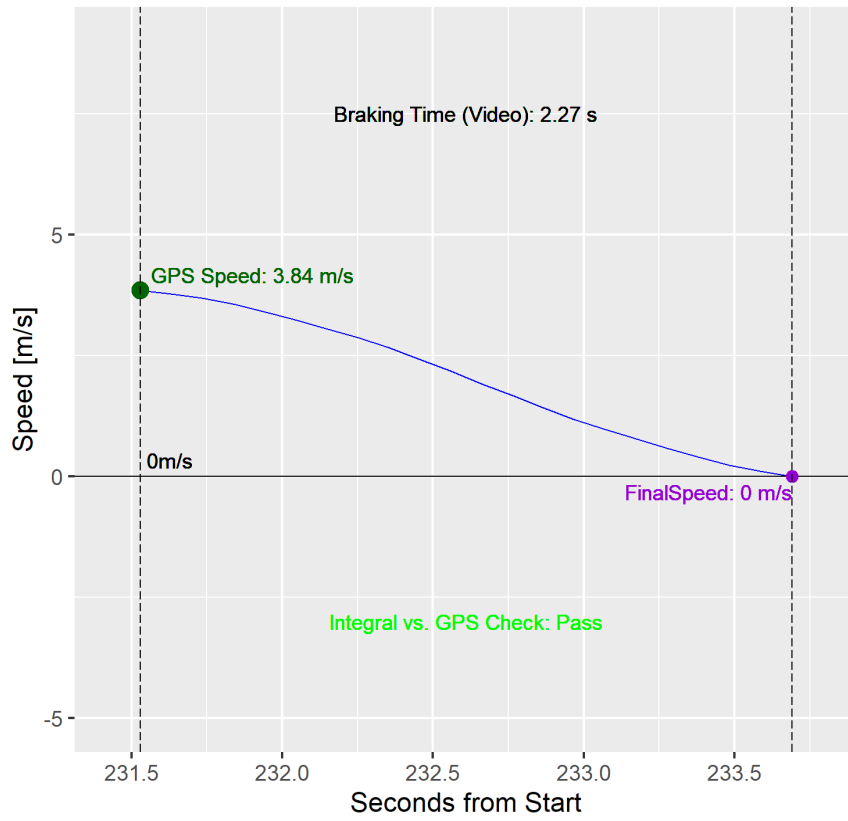


Figure 22 - Adjusted Speed Profile with Final Speed at 0 m/s

## 2.3 Data Analysis and Model Estimation

After processing the data for each trial, the final step in the study methodology was to analyze the trends and relationships among the collected variables. Consistent with the research objectives, the primary focus was to determine the PRT and the deceleration rate of bicyclists in unalerted conditions. Consequently, understanding the relationship between expected and unexpected perception-reaction times was necessary to estimate unexpected PRT for the larger Vancouver sample. Finally, the relationship between perception-reaction time and deceleration rate was of interest to align with the research objectives.

### 2.3.1 Descriptive Statistics

Once the key variables of perception-reaction time, approach speed, average deceleration, and maximum deceleration rate were extracted for each trial, descriptive and bivariate statistics were calculated, and distributions were plotted to examine relationships among variables. Minimum, maximum, average, and standard deviation were calculated for PRT, speed, average deceleration, maximum deceleration, braking time, calculated stopping sight distance, and eye height in each sample.

### 2.3.2 Sample Weighting

For sample weighting, gender and age of the study sample were compared to regional bicyclists based on data from a 2017 metropolitan Vancouver regional travel survey (TransLink, 2019). Gender identities were collapsed into a binary variable of men versus others for feasibility in statistical analysis. Chi-squared tests were used to examine differences between the study sample and regional cyclist population, and significant differences between the samples and population were corrected by calculating sample weights. The formula used to calculate sample weights is provided in Equation 8.

*Equation 8 - Sample Weight Formula*

$$\text{Sample Weight } (W) = \frac{\text{Proportion in Population}}{\text{Proportion in Sample}} \quad (8)$$

### 2.3.3 Perception-Reaction Time

The relationship between unexpected and expected reaction times was next to be explored in order to determine unexpected PRT estimates from the Vancouver sample. The first step was to investigate the trends between unexpected and expected perception-reaction times to inform a model form. A base model was developed to estimate PRT as a function of whether the trial was expected or unexpected. A series of personal, bicycle, and operational variables were then assessed for potential inclusion in the model through a sequence of model specifications. Finally, significant predictors were retained in the final model.

#### Model Estimation

Estimating a perception-reaction time model first required defining the relationship between unexpected and expected observations, which was done by investigating trends between each UBC sample participant's unexpected reaction and their average expected reaction. This model estimation step consisted of generating two models: first, a model to estimate the offset between unexpected and expected PRT using the UBC sample data. Second, an explanatory model was generated using the full sample dataset to analyze the combined effects of each variable on perception-reaction time.

#### *Offset Model*

A mixed-effect model was generated using the data from the UBC sample only, which contains both expected and unexpected observations. This model estimates perception-reaction time based on whether the observation was an expected or unexpected trial, with random effects to account for error correlation within an individual participant's trials, which is represented by a participant-specific identifier number (*ID*). The base model form is provided in Equation 9.

*Equation 9 - Base PRT Model Form*

$$PRT \sim ExpectedTrial + Random Effect(ID) \quad (9)$$

This model form assumes a fixed offset between unexpected and expected perception-reaction times. Varying magnitude of this offset between unexpected and expected reaction times was further assessed by testing additional variables as moderators of the offset in the model, including personal, bicycle, and operational factors. Where possible, binary specification was preferred due to the limited sample size of the UBC sample. Participant age was grouped into a binary variable

of ‘Aged 60 and over’ or not, to identify senior participants for the purpose of examining the influence of age on perception-reaction time. The self-identified cycling confidence variable was grouped into ‘Interested but Concerned’ or not, to distinguish between low and high confidence participants. No participants identified as ‘No Way, No How’ in the study. A full list of the variables considered is provided in Table 4, and a full list of the excluded variables is provided in Appendix B.

Table 4 - Variables Considered for the PRT Model

Category	Variable	Definition	Specification
Personal	Gender	Participant identified gender	<b>Binary:</b> Man (exclusive) or Not Man-exclusive
Personal	Age	Participant age identified categorically from ‘Less than 15’ to ‘65 and Over’ in 5-year age bins	<b>Binary:</b> Aged 60 and over or not
Personal	Cycling Confidence	Self-identified cycling confidence from survey. 4 categories: No Way No How, Interested but Concerned, Enthused and Confident, Strong and Fearless)	<b>Binary:</b> Interested but Concerned or not
Personal	Eye Height	Participant and bicycle measured eye height from the ground surface	<b>Continuous</b>
Bicycle	Bike Type	Photo-classified bicycle type	<b>Categorical:</b> 3 bins (Road, Hybrid, Mountain) with a reference level of ‘Hybrid’
Bicycle	Brake Type	Photo-classified brake type	<b>Binary:</b> Non-Disc Brakes (Drum and Rim Brakes) or Disc
Operational	Speed	Approach speed prior to braking in each trial, determined via GPS	<b>Continuous</b>

The model also tested whether the bicycle used was an electric-assist (“e-bike”) or a bike share device. The following model specification sequence was used for the variable selection process of the PRT offset model:

1. Generate a base model:  $PRT \sim ExpectedTrial + Random(ID)$ ;
2. Test individual fixed effects to determine variable specifications and significance to PRT in the base model;
3. Combine all fixed effects with  $p < 0.05$  in Step 2;

4. Investigate interaction terms for each test variable with the 'ExpectedTrial' predictor;
5. Combine all interaction terms with  $p < 0.05$  in Step 4 with the fixed effects from Step 3; and
6. Refine the final model by retaining variables with significance of  $p < 0.05$ .

### *Explanatory Model*

An explanatory mixed-effect model was estimated using the dataset from the full, combined sample, unlike the offset model which only used the UBC sample data. The explanatory model simultaneously assessed all fixed effects to investigate the combined effect of the variables on the perception-reaction time of the full sample dataset, retaining the random effects accounting for individual-level variation. The variables tested in this model are consistent with Table 4, and the following model specification sequence was used:

1. Generate a base model:  $PRT \sim ExpectedTrial + Random(ID)$ ;
2. Test all fixed effects simultaneously to determine significant effects on PRT ;
3. Test interaction terms for all test variables with the 'ExpectedTrial' predictor in the model containing all fixed effects together;
4. Remove the least significant interaction term in the model and re-run; and
5. Repeat Step 4 until only significant interaction terms ( $p < 0.05$ ) remain with all fixed effects.

### **PRT Distributions**

The coefficient on the 'ExpectedTrial' variable in the PRT offset model obtained from the UBC sample ( $n=52$ ) served as the offset between expected and unexpected perception-reaction times. This offset was directly added to each expected perception-reaction time (PRT) observation in the Vancouver sample ( $n=250$ ) to derive the unexpected PRT estimates. Subsequently, the resulting weighted distributions of unexpected and expected PRTs in both samples were generated.

#### **2.3.4 Deceleration Rate**

The same model specification procedure used for the perception-reaction time explanatory model was applied to generate the average deceleration rate model. Given that the objective of this model was to investigate the predictors of deceleration rate, rather than determining a correction factor for use elsewhere, the full sample dataset was used.

Average deceleration was estimated by dividing the approach speed measured by the GPS ( $V_3$ ) by the video-determined braking time. This procedure was preferred to using data collected directly

from the accelerometer due to the complexities and assumptions around generating an acceleration curve and extracting an average deceleration rate from each trial. To justify this approach, employing the GPS average deceleration method expanded the available dataset for the model from 439 deceleration rate observations (trials with data logger accelerations that passed the 1 m/s speed check test) to 701 observations (trials with both measured GPS speed and braking time). Further, comparing the average deceleration between the GPS-determined average deceleration rate and the average deceleration rate measured directly from the data logger revealed a small difference of 0.033 g (0.33 m/s<sup>2</sup>).

### **Model Estimation**

The explanatory model simultaneously assessed all fixed effects to investigate the combined effect of the variables on the average deceleration rate of the full sample dataset, retaining the random effects accounting for individual-level variation. For consistency with the PRT model, a mixed-effect model was adopted to investigate the factors influencing the average deceleration rate, starting with a base model testing the effect of whether the trial was expected or not. All variables were simultaneously tested in the model to assess their predictive power, followed by exploring specific interaction terms with the ‘ExpectedTrial’ variable. Consistent with the PRT explanatory model, the following model specification sequence was used:

1. Generate a base model: *Avg Deceleration* ~ *ExpectedTrial* + *Random(ID)*;
2. Test all fixed effects simultaneously to determine significant effects on average deceleration;
3. Test interaction terms for all test variables with the ‘ExpectedTrial’ predictor in the model containing all fixed effects together;
4. Remove the least significant interaction term in the model and re-run; and
5. Repeat Step 4 until only significant interaction terms ( $p < 0.05$ ) remain with all fixed effects.

Personal, bicycle, and operational factors were evaluated for inclusion to the model; where possible, binary specification was again preferred due to the limited sample size. In this case, the average deceleration was determined by the approach speed measured by the GPS, therefore ‘Speed’ could not be tested as a variable in the model. The model also tested whether the bicycle

used was an electric-assist (“e-bike”) or a bike share device. A full list of the variables considered is provided in Table 5, and a full list of the excluded variables is provided in Appendix B.

Table 5 - Variables Considered for the Deceleration Model

Category	Variable	Definition	Specification
Personal	Gender	Participant identified gender	<b>Binary:</b> Man (exclusive) or Not Man-exclusive
Personal	Age	Participant age identified categorically from ‘Less than 15’ to ‘65 and Over’ in 5-year age bins	<b>Binary:</b> Aged 60 and Over or Not
Personal	Cycling Confidence	Self-identified cycling confidence from survey. 4 categories: No way No How, Interested but Concerned, Enthused and Confident, Strong and Fearless)	<b>Binary:</b> Interested but Concerned or Not
Personal	Eye Height	Participant and bicycle measured eye height from the ground surface	<b>Continuous</b>
Bicycle	Bike Type	Photo-classified bicycle type	<b>Categorical:</b> 3 bins (Road, Hybrid, Mountain) with a reference level of ‘Hybrid’
Bicycle	Brake Type	Photo-classified brake type	<b>Binary:</b> Disc Brakes vs Non-Disc (Drum and Rim Brakes)
Operational	PRT	Video-determined perception-reaction time of the participant	<b>Continuous</b>

## Deceleration Rate Distributions

Average and maximum deceleration rate distributions were calculated using sample weights and data from the UBC sample unexpected and expected trials, as well as the Vancouver expected trials. Weighted percentiles were then calculated for each sample.

### 2.3.5 Stopping Sight Distance

The same model specification procedure used for the perception-reaction time model was applied to generate the stopping sight distance (SSD) model. Given that stopping sight distance is the primary design criterion influenced by perception-reaction time and deceleration rate, the aim of this model was to understand other factors that influence stopping distance. SSD was calculated

for each trial by applying the perception-reaction time, the GPS-determined approach speed, and the average deceleration as measured by the accelerometer to Equation 1.

### **Model Estimation**

The explanatory model simultaneously assessed all fixed effects to investigate the combined effect of the variables on the stopping distance of the full sample dataset, retaining the random effects accounting for individual-level variation. For consistency with the PRT and deceleration rate explanatory models, a mixed-effect model was adopted to investigate the factors influencing the stopping distance, starting with a base model testing the effect of whether the trial was expected or not. All variables were simultaneously tested in the model to assess their predictive power, followed by exploring specific interaction terms with the ‘ExpectedTrial’ variable. Consistent with the previous explanatory models, the following model specification sequence was used:

1. Generate a base model: *Stopping Distance* ~ *ExpectedTrial* + *Random(ID)*;
2. Test all fixed effects simultaneously to determine significant effects on stopping distance;
3. Test interaction terms for all test variables with the ‘ExpectedTrial’ predictor in the model containing all fixed effects together;
4. Remove the least significant interaction term in the model and re-run; and
5. Repeat Step 4 until only significant interaction terms ( $p < 0.05$ ) remain with all fixed effects.

Personal and bicycle factors were evaluated for inclusion to the model; where possible, binary specification was again preferred due to the limited sample size. In this case, the stopping distance was calculated using the approach speed measured by the GPS, the perception-reaction time from video footage, and the average deceleration rate from the accelerometer; therefore, ‘Speed’, ‘PRT’, and ‘AvgDecel’ could not be tested as variables in the model. The model also tested whether the bicycle used was an electric-assist (“e-bike”) or a bike share device. A full list of the variables considered is provided in Table 6, and a full list of the excluded variables is provided in Appendix B.

Table 6 - Variables Considered for the Stopping Distance Model

Category	Variable	Definition	Specification
Personal	Gender	Participant identified gender	<b>Binary:</b> Man (exclusive) or Not Man-exclusive
Personal	Age	Participant age identified categorically from 'Less than 15' to '65 and Over' in 5-year age bins	<b>Binary:</b> Aged 60 and Over or Not
Personal	Cycling Confidence	Self-identified cycling confidence from survey. 4 categories: No way No How, Interested but Concerned, Enthused and Confident, Strong and Fearless)	<b>Binary:</b> Interested but Concerned or Not
Personal	Eye Height	Participant and bicycle measured eye height from the ground surface	<b>Continuous</b>
Bicycle	Bike Type	Photo-classified bicycle type	<b>Categorical:</b> 3 bins (Road, Hybrid, Mountain) with a reference level of 'Hybrid'
Bicycle	Brake Type	Photo-classified brake type	<b>Binary:</b> Disc Brakes vs Non-Disc (Drum and Rim Brakes)

### Stopping Distance Distributions

The stopping distance distributions were calculated using sample weights and data from the UBC sample unexpected and expected trials, as well as the Vancouver expected trials. Weighted percentiles were then calculated for each sample. Since the stopping distance calculations rely on the accelerometer's average deceleration rate, stopping distance was not calculated for any trials that failed the 'SpeedCheck' test.

### Chapter 3: Results & Discussion

The UBC sample was comprised of 52 participants who took part in the study, where 56% identified as men and the largest represented age group was 20 to 24 at 19%. A total of 59 individuals expressed interest to participate in the study on UBC campus through the online recruitment form. Of these, 28 responded to the follow-up email to schedule a date and time for participation and 20 participated in the study. The other 32 participants were intercepted on-site.

The Vancouver sample data collection included 250 participants, where 63% identified as men and the largest represented age group was 65 and over at 23%. Both samples demonstrated a larger proportion of medium-to-high confidence cyclists, with around 92% of the combined sample self-identifying as Strong and Fearless or Enthused and Confident. 50% of the full sample indicated that they ride their bike more than 5 days in a typical summer week. A visual representation of the characteristics for each sample is provided in Figure 23 through Figure 26, with a full table provided in Appendix C.

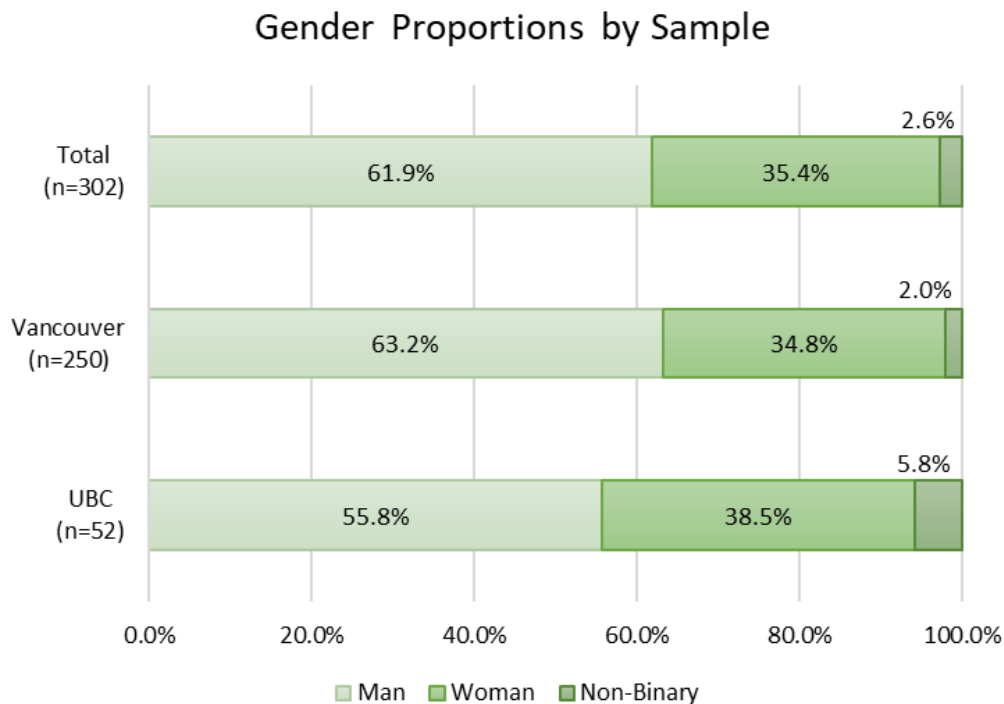


Figure 23 - Gender Proportions by Sample

### Age Proportions by Sample

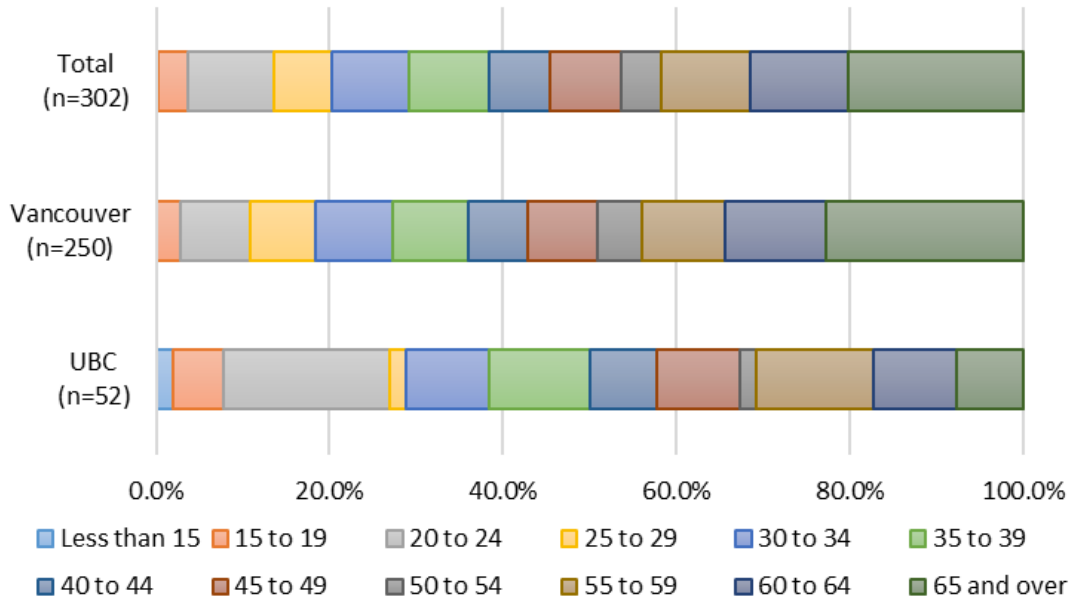


Figure 24 - Age Proportions by Sample

### Self-Identified Cycling Confidence Proportions by Sample

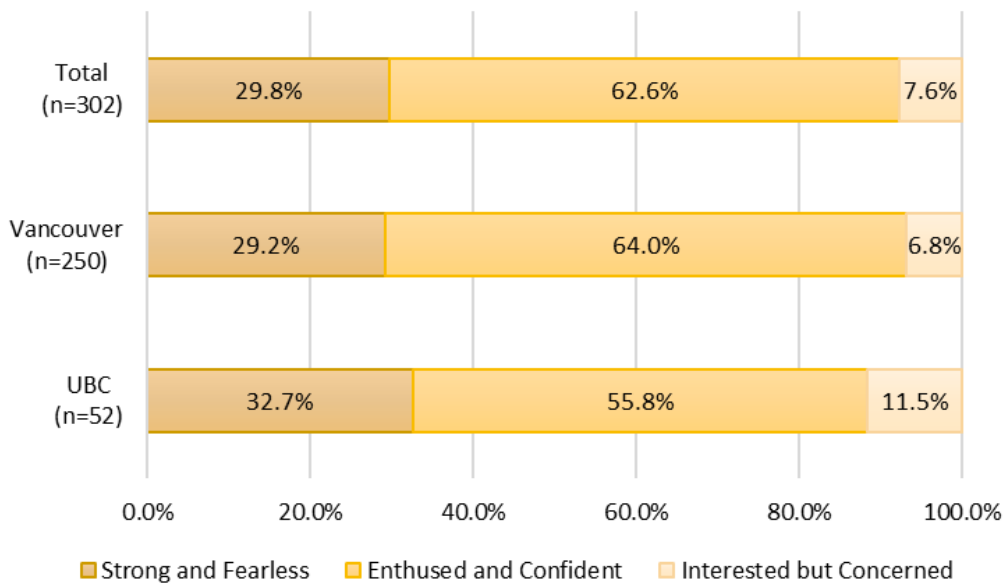
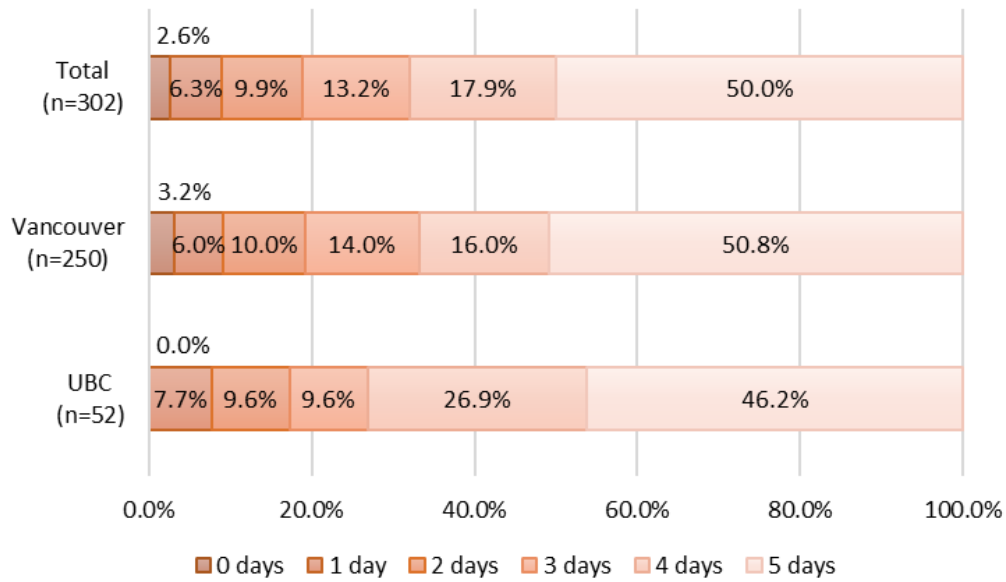


Figure 25 - Self-Identified Cycling Confidence Proportions by Sample

## Weekly Cycling Frequency Proportions by Sample



*Figure 26 - Weekly Cycling Frequency Proportions by Sample*

As discussed in Section 2.3.2, sample weighting was implemented for each sample, with weights determined based on proportions relative to the regional cyclist population data sourced from the 2017 TransLink Trip Diary (TransLink, 2019). The chi-squared analysis revealed that the proportions of gender did not show a significant difference in any of the samples compared to the regional cyclist population, whereas the variations were significant when looking at age. A p-value of less than 0.05 in this case demonstrates strong evidence against the null hypothesis, indicating that there is a significant difference between the proportions of the sample compared to the proportions of the population. Pearson’s chi-squared test results are provided in Table 7.

The gender proportions for each sample are provided in Table 8, with age proportions and the resulting weights provided in Table 9. The raw demographic and bicycle data are provided in Appendix D.

Table 7 - Chi-Squared Test Results

	Age		Gender	
	UBC	Vancouver	UBC	Vancouver
<b>Statistic</b>	67.6	131.8	1.56	0.28
<b>Degrees of Freedom (df)</b>	7	7	1	1
<b>P-Value</b>	<b>&lt;0.01</b>	<b>&lt;0.01</b>	<b>0.21</b>	<b>0.28</b>

Table 8 - Sample vs Population Gender Proportions

Gender	% in UBC Sample	% in VAN Sample	% in Total Sample	% in Cyclist Population
<b>Man</b>	55.8%	63.2%	61.9%	66.5%
<b>Not Man</b>	44.2%	36.8%	38.1%	33.5%

Table 9 - Sample vs Population Age Proportions and Weights

Age Category	% in UBC Sample	% in VAN Sample	% in Total Sample	% in Cyclist Population	UBC Weight	VAN Weight	Total Sample Weight
<b>Less than 19</b>	7.7%	2.8%	3.6%	17.1%	2.22	6.09	4.69
<b>19 to 24</b>	19.2%	8.0%	9.9%	2.4%	0.12	0.30	0.24
<b>25 to 34</b>	11.5%	16.4%	15.6%	19.8%	1.71	1.20	1.27
<b>35 to 44</b>	19.2%	15.6%	16.2%	18.0%	0.94	1.15	1.11
<b>45 to 54</b>	11.5%	13.2%	12.9%	17.6%	1.52	1.33	1.36
<b>55 to 64</b>	23.1%	21.2%	21.5%	16.9%	0.73	0.80	0.78
<b>65 and over</b>	7.7%	22.8%	20.2%	8.3%	1.08	0.36	0.41

Table 10 presents the age-weighted mean and standard deviation for key variables determined in this study, including perception-reaction time, average and maximum deceleration rate, speed, calculated stopping distance, and braking time. The key highlights indicate that the unexpected trials demonstrated longer PRTs, higher speeds, less abrupt deceleration rates, longer braking times and longer stopping distances. Results from the expected trials were generally consistent, apart from a lower average approach speed observed in the Vancouver sample.

*Table 10 - Weighted Sample Results Summary*

Characteristic	UBC Unexpected		UBC Expected		Vancouver Expected		Full Sample	
	Mean	$\sigma$	Mean	$\sigma$	Mean	$\sigma$	Mean	$\sigma$
Perception- Reaction Time [s]	0.75	(0.16)	0.37	(0.18)	0.31	(0.16)	0.34	(0.19)
Average Deceleration Rate [g]	-0.20	(0.08)	-0.31	(0.08)	-0.31	(0.09)	-0.30	(0.09)
Maximum Deceleration Rate [g]	-0.31	(0.11)	-0.42	(0.10)	-0.42	(0.10)	-0.41	(0.11)
Approach Speed [m/s]	4.49	(1.34)	4.33	(0.96)	3.85	(0.80)	3.92	(0.89)
Calculated SSD [m]	5.60	(2.18)	2.79	(1.19)	2.21	(0.86)	2.50	(1.33)
Braking Time [s]	2.69	(1.09)	1.43	(0.43)	1.27	(0.41)	1.38	(0.57)

The raw operational data containing key variables from each observation are provided in Appendix E. A full breakdown of each sample with additional statistics is provided in Appendix F. Percentiles are provided in the following sections.

### 3.1 Bicycle & User Characteristics

#### 3.1.1 Eye Height

As described in Section 2.1, eye height was measured for each participant in the experiment. Over 302 observations, the 15<sup>th</sup> percentile of participant eye height was determined to be 151 cm (see Figure 27), indicating a conservative estimate for use in design. This value aligns with the current typical bicyclist eye height provided by BC’s Active Transportation Design Guide (Ministry of Transportation and Infrastructure, 2019) which is 150 cm; however, this observed eye height is slightly greater than the current guidance of 137 cm for eye height in SSD applications on multi-use paths. The current guidance may consider different forms of micromobility, or younger bicyclists under the age of 14, who were unable to participate in this study.

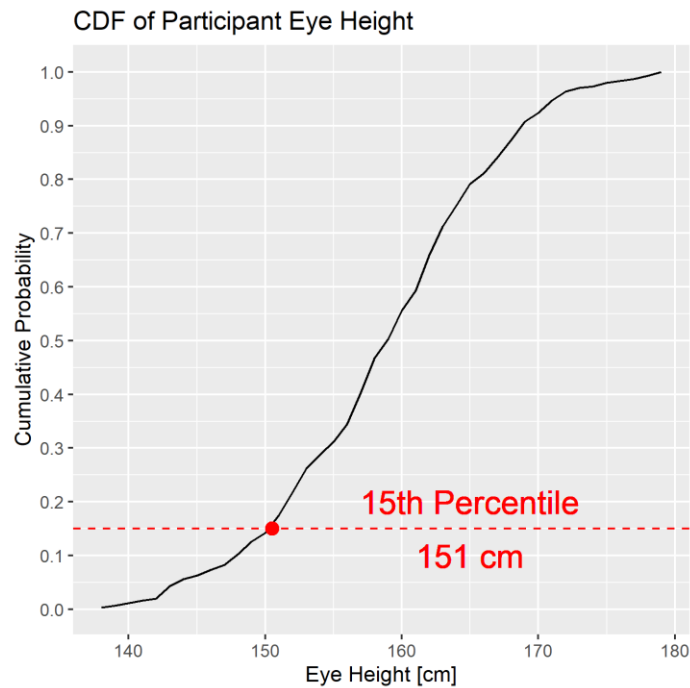


Figure 27 - CDF of Participant Eye Height

A breakdown of the descriptive statistics (average, minimum, maximum, standard deviation) for the participant eye height of each sample is provided in Appendix F.

### 3.1.2 Bicycle Type

Hybrid bicycles were the most common type of bicycle observed in this study at 67%. This result may be attributed to the diverse range of options in the hybrid category, which can include cruiser-style or compact foldable bicycles. Unlike bicycles designed to endure mountainous terrain or for optimal performance, hybrids may be favoured for recreational and commuter purposes. Figure 28 illustrates a breakdown of the bicycle types observed in this study.

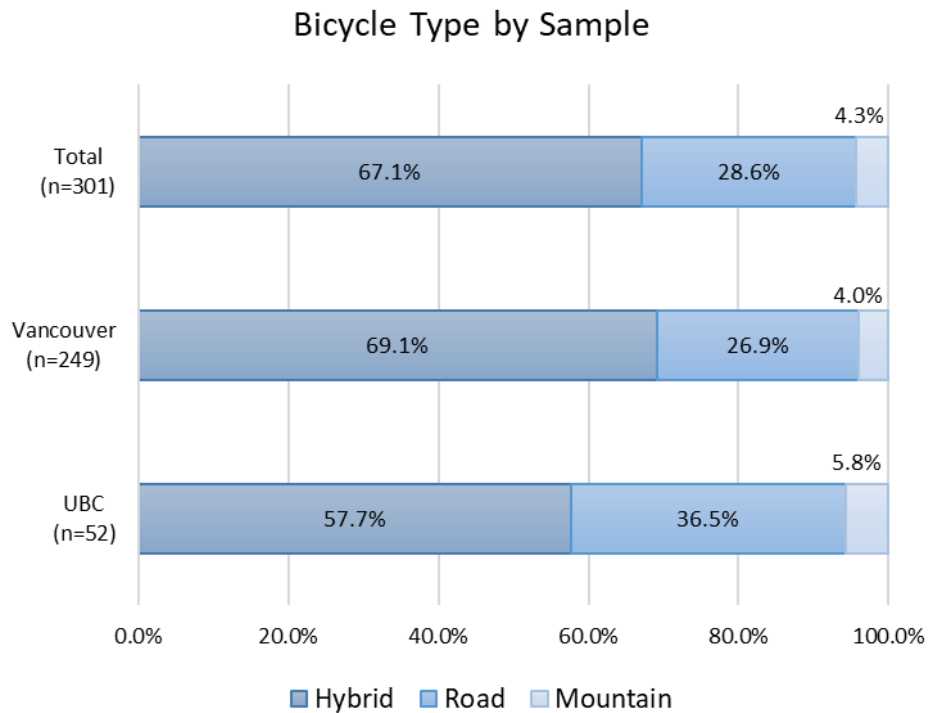


Figure 28 - Bicycle Type by Sample

Additionally, 3 electric-assist bicycles (5.8%) were observed in the UBC sample, and 41 electric-assist bicycles (16.4%) were observed in the Vancouver sample. No bike share bicycles were used to participate in the UBC sample, but 3 (1.2%) were used in the Vancouver sample. While the research team’s loaner bicycle was not available to participants of the UBC trials, it was used by 12 participants (4.8%) in the Vancouver sample.

### 3.1.3 Brake Type

Disc brakes emerged as the dominant brake type observed in this study, accounting for 56% of all bicycles, followed by rim brakes at 43%. The less common drum brakes (1%) were only observed

on bike share devices. A breakdown of the brake types observed in this study is provided in Figure 29.

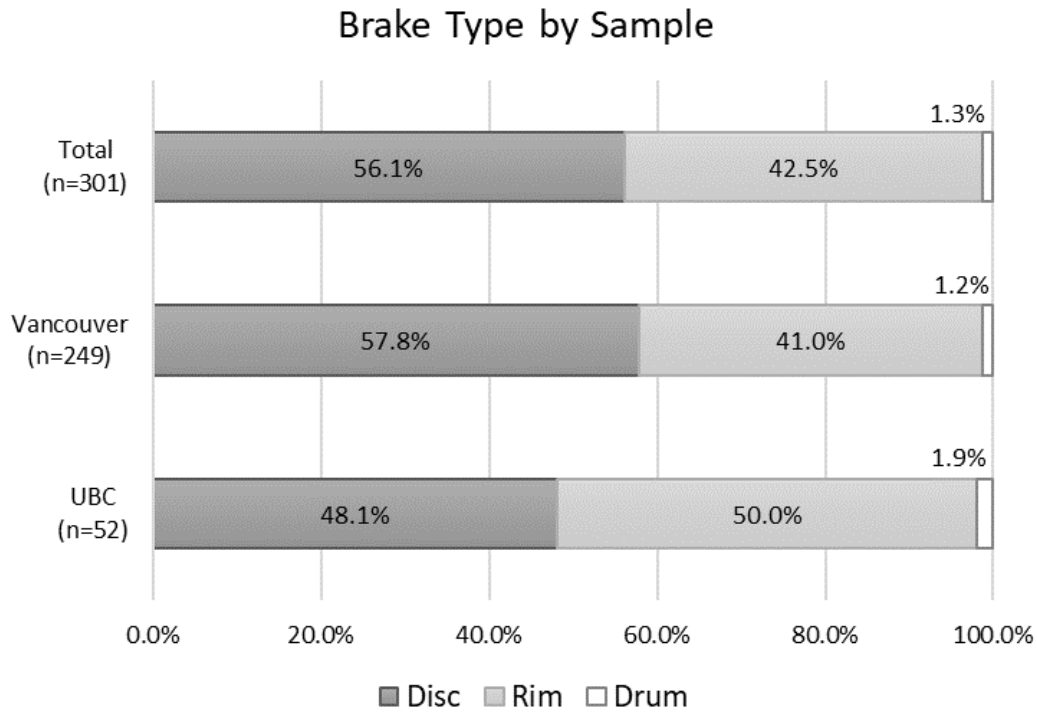


Figure 29 - Brake Type by Sample

A comparison of the deceleration rates between the three brake types is provided in Table 11. Participants using bicycles fitted with disc brakes demonstrated the largest deceleration rates across all brake types, followed by rim and drum brakes.

Table 11 - Weighted Deceleration Rates by Brake Type

Brake Type	# of Observations	Average Deceleration [g]		Maximum Deceleration [g]	
		Mean	85 <sup>th</sup> Percentile	Mean	85 <sup>th</sup> Percentile
Disc	260	-0.32	-0.22	-0.43	-0.32
Rim	199	-0.28	-0.17	-0.39	-0.27
Drum	10	-0.23	-0.17	-0.32	-0.27

### 3.2 Perception-Reaction Time

This study aimed to provide evidence-based grounding for the perception-reaction time value to use in the design of bicycle facilities. It was hypothesized that the perception-reaction time of bicyclists would be longer than the previously measured values for motor vehicle drivers, due to the maneuvering complexities of operating a bicycle in addition to users' safety considerations.

As an initial step to investigate the alerted effect of each participant in the UBC sample, unexpected and average expected perception-reaction times were plotted, as shown in Figure 30. A strong trend between unexpected and expected PRT could not be found, prompting a new approach to estimate a mixed-effect model that estimates perception-reaction time as a function of whether the reaction was expected or not.

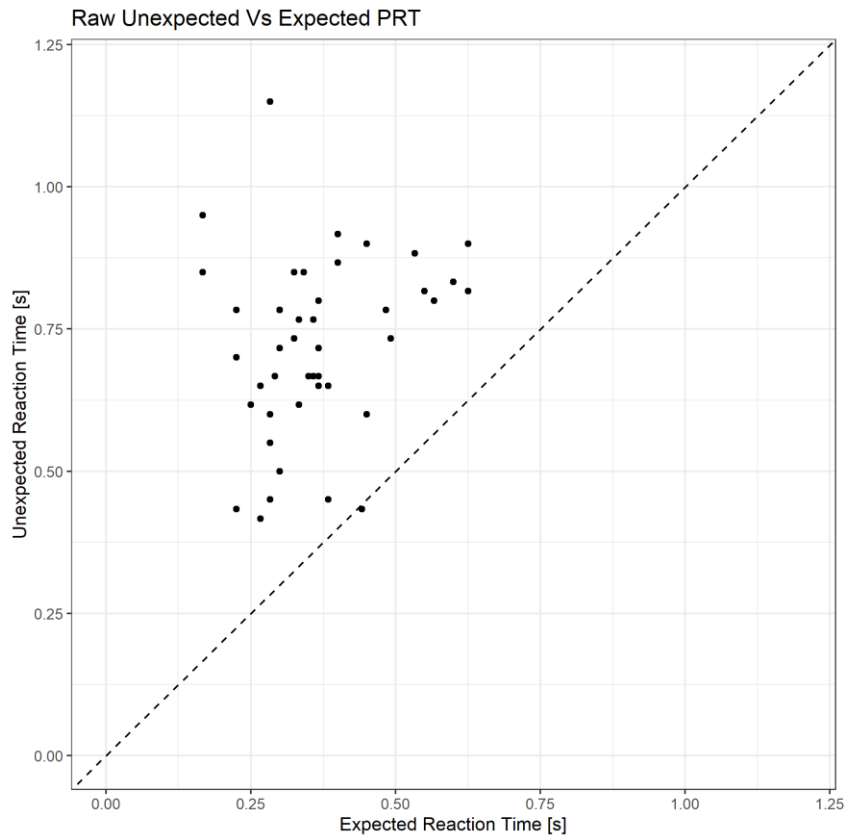


Figure 30 - Unexpected vs. Expected PRT

### 3.2.1 Offset Model

Estimating a mixed effect model using the data from the UBC sample (N=99, 46 participant-level random effects) yields a base PRT model shown by Equation 10.

*Equation 10 - Base PRT Model*

$$PRT \sim 0.75 - 0.372 * (ExpectedTrial) \quad (10)$$

The negative sign associated with the coefficient on the expected trial variable indicates that participants demonstrated a faster reaction when the perception-reaction time was measured in an expected trial. The magnitude of the coefficient indicates the difference between the unexpected and expected PRT, such that a greater magnitude represents a faster expected reaction. When testing individual fixed effects, only the Speed variable emerged as a significant predictor of PRT. Neither Age nor Gender was determined to be a significant predictor of reaction time in the model. Subsequently, when investigating interaction terms, 'BrakeType' was identified as a significant interaction term with the 'ExpectedTrial' predictor, while Gender showed significance at the 10% confidence level. However, both interaction term variables became insignificant in Step 5 when combined with Speed as a fixed effect in the model specification. Consequently, the final model comprised of 'ExpectedTrial' and 'Speed' as fixed effects, with no interaction term predictors included. Random effects of each participant were defined by participant identifier numbers. The final model is illustrated in Equation 11.

*Equation 11 - Final PRT Model*

$$PRT \sim 1.095 - 0.359 * (ExpectedTrial) - 0.075 * (Speed) \quad (11)$$

Interpreting each of the coefficients in the final PRT offset model, the intercept (1.095) signifies the baseline unexpected PRT before accounting for other predictors. The coefficient on 'ExpectedTrial' (-0.359) indicates the fixed offset between unexpected and expected PRT values. This fixed offset relationship has been referenced in literature, with previous studies determining the difference between unexpected and expected PRT to be in the range of 0.1 to 0.35 s (Johansson and Rumar, 1971) or even as high as ~0.8 s (Koppa, 1999); however, it has also been mentioned that this offset varies based on driver information content (AASHTO, 2001). The 'ExpectedTrial' coefficient is the primary focus for addressing the hypothesis concerning perception-reaction time

of bicyclists, since this offset is used to estimate the unexpected reactions for the Vancouver sample.

The coefficient on 'Speed' (-0.075) suggests that for every additional unit of Speed [m/s], the reaction time decreases by 0.075 seconds. This suggests that as the user's speed increases, their reaction time tends to decrease, reflecting a faster response.

The Marginal  $R^2$  was 0.554, while the Conditional  $R^2$  was 0.766, indicating that 55% of the PRT variance is explained by the fixed effects (Expected Trial and Approach Speed), and another 21% explained by the intra-participant random effects.

### **3.2.2 Explanatory Model**

The final PRT explanatory model estimated using the entire dataset (N=699, 275 participant-level random effects) is provided in Table 12. Interpreting each of the coefficients in the final PRT model, the intercept (+0.987) signifies the baseline unexpected PRT before accounting for other predictors. The coefficient on 'ExpectedTrial' (-0.811) indicates the fixed offset between unexpected and expected PRT values. This offset is noticeably higher than the offset value determined from the previous model, due to the interaction terms of this model with cycling confidence and speed. For example, if we take a cyclist that identifies as “Strong and Fearless” (i.e., a high confidence), travelling at the full sample average of 3.92 m/s, the estimated offset between this cyclist's unexpected and expected PRT would be:  $-0.81 + 0.18*(0) + 0.09*(3.92 \text{ m/s}) = 0.46 \text{ s}$ . A lower confidence cyclist travelling at the same speed would have an offset of around 0.28 s, demonstrating a more consistent reaction time between expected and unexpected reactions. These results are comparable to the offset of 0.359 s determined in the previous model.

Table 12 - Final PRT Explanatory Model

Variable	Coefficient	P-Value	Standard Error
Intercept	0.987	<0.01	0.196
Expected Trial	-0.811	<0.01	0.105
Gender (Not Man)	0.025	0.15	0.017
Age (60 and Over)	0.027	0.13	0.018
Cycling Confidence (Interested but Concerned)	-0.185	0.01	0.068
Eye Height	0.0005	0.65	0.001
Bike Type - Road	0.014	0.43	0.017
Bike Type - Mountain	-0.006	0.86	0.036
Brake Type (Rim + Drum)	0.008	0.62	0.015
Speed (m/s)	-0.072	<0.01	0.021
<i>ExpectedTrial:Confidence</i>	0.177	<0.01	0.068
<i>ExpectedTrial:Speed</i>	0.085	<0.01	0.022

Marginal  $R^2 = 0.307$ ; Conditional  $R^2 = 0.492$

Another interesting result comes from the comparable magnitudes but opposite signs of the two interaction terms and their complimentary fixed effect terms. This result suggests that ‘Speed’ and ‘Cycling Confidence’ collectively have a close to net zero impact on PRT in expected reactions, but a non-zero effect in unexpected reactions. During expected reactions, participants anticipate the need to react, thereby reducing the influence of speed or confidence on their reaction time. However, in unexpected responses, the user is unaware a reaction is coming, and thus the approach speed could increase the braking maneuver complexity, resulting in a longer reaction time, or heighten the user’s vigilance, resulting in a shorter reaction time. In this case, a negative sign on the fixed term speed coefficient (-0.072) implies that users travelling at higher speeds require less time to react, which could be attributable to increased vigilance when navigating at higher speeds.

The negative coefficient on confidence (-0.185) suggests that users with lower confidence in their bicycling ability require less time to react to an unexpected stimulus. While this result may seem counterintuitive, it could be attributed again to variations in user vigilance. Users with higher confidence levels may exhibit more complacency when riding a bicycle, thus requiring a longer time to react compared to users who are less confident and maintain a higher level of vigilance when riding.

Finally, consistent with the findings of the offset model, ‘Gender’ and ‘Age’ were not found to be significant predictors of PRT, alongside the bicycle type, brake type, and participants eye height. The influence of a participant’s bicycle being electric-assist or part of a bike share program was also tested, and neither factor was found to be significant in predicting PRT.

### 3.2.3 Distributions

Applying the fixed offset determined from the UBC sample (N=52) to each expected PRT observation in the Vancouver sample (N=250) resulted in a distribution of unexpected PRT estimates. The weighted distributions for the expected and unexpected perception-reaction times in both the UBC and Vancouver samples are provided in Figure 31.

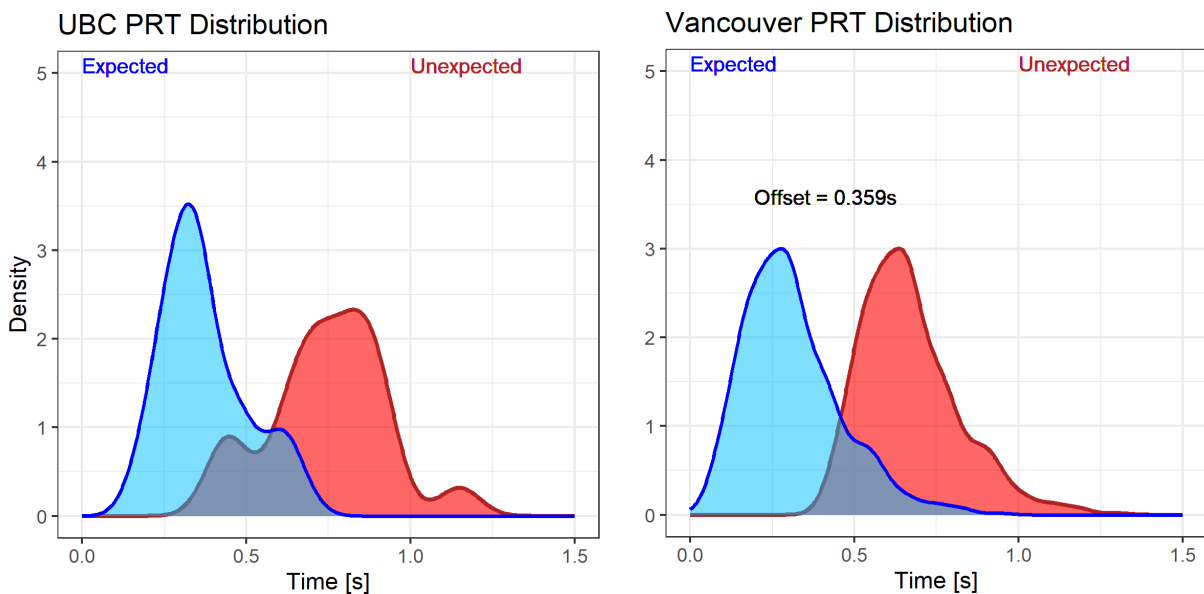


Figure 31 - UBC and Vancouver Sample Expected and Unexpected Weighted PRT Distributions

In the UBC sample, the inter-person PRT variance (calculated using each participant’s average PRT) was 0.032 for expected and 0.025 for unexpected scenarios. The reduced variance observed

in the unexpected PRTs suggests a more consistent pattern of reaction times in unexpected scenarios compared to the expected scenarios. The covariance of 0.0045, equivalent to a correlation coefficient of  $\sim 0.24$ , between the unexpected reaction times and the participant's average expected reaction time in the UBC sample suggests a moderate positive correlation between unexpected and expected reaction times. In the Vancouver sample, the inter-person variance for the expected trials was 0.025.

The critical design values for perception-reaction time are the upper percentiles, to consider users with a diverse range of abilities. Table 13 highlights the resulting percentiles for the expected and unexpected trials across all samples, with CDFs and 85<sup>th</sup> percentiles illustrated in Figure 32.

*Table 13 - Weighted Percentiles of Perception-Reaction Time*

Percentile	Expected PRT [s]			Unexpected PRT [s]		
	UBC	Vancouver	Full Sample	UBC	Vancouver*	Full Sample*
50 <sup>th</sup>	0.32	0.30	0.30	0.76	0.66	0.66
75 <sup>th</sup>	0.47	0.40	0.40	0.86	0.76	0.76
85 <sup>th</sup>	0.55	0.45	0.48	0.90	0.81	0.84
90 <sup>th</sup>	0.62	0.53	0.53	0.92	0.89	0.89
95 <sup>th</sup>	0.71	0.58	0.62	0.99	0.94	0.94
99 <sup>th</sup>	0.93	0.77	0.81	1.15	1.13	1.15

*\*Estimated using unexpected offset from PRT Model*

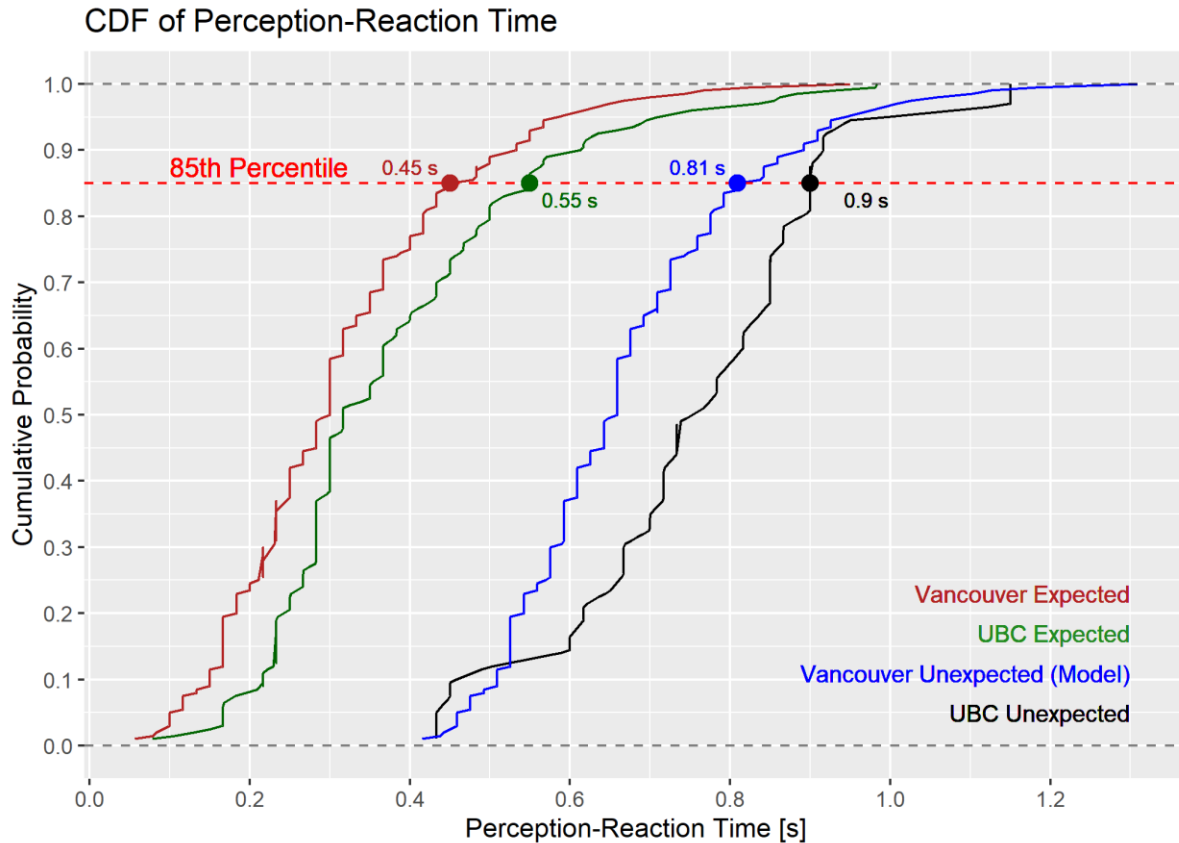


Figure 32 - CDF of Perception-Reaction Time

These results suggest that the perception-reaction times of bicyclists are relatively shorter than previously measured PRT values for motor vehicle drivers. One explaining factor for this difference may come from stopping complexity versus user vigilance. While riding a bicycle does introduce considerations such as user safety and balance which may result in a more complex braking maneuver, the user may also compensate for this increased risk by navigating with increased vigilance leading to more attentiveness and a faster reaction time in emergency stop scenarios. Another contributing factor for the difference between PRT values previously observed for motor vehicle drivers and the shorter values observed in this study could come from the physical mechanism of applying the brakes. Laterally shifting the foot from the accelerator to the brake pedal could require slightly more time than moving hands or fingers onto the brake lever of a bicycle.

A breakdown of the descriptive statistics (average, minimum, maximum, standard deviation) for the perception-reaction time of each sample is provided in Appendix F.

### 3.3 Deceleration Rate

The second hypothesis of this study aimed to establish deceleration rates of bicyclists in unexpected scenarios, in addition to exploring the relationship between deceleration rate and perception-reaction time, suggesting that a slower reaction time may be compensated by a heightened sense of urgency and an increased deceleration rate.

In this study, the deceleration rate for bicyclists was measured directly instead of relying on a coefficient of friction; even though current design guidance utilizes a coefficient of friction for the SSD procedure in the design of bicycle facilities (Transportation Association of Canada, 2017; Ministry of Transportation and Infrastructure, 2019). Opting to measure the deceleration rate encourages universal understanding, directly relates to braking performance, was easily implemented in the study design, and creates consistency with vehicular SSD guidance.

#### 3.3.1 Explanatory Model

Estimating a mixed effect model using the combined dataset from both the UBC and Vancouver samples (N=699, with 275 participant-level random effects), again predicted by whether the trial was expected or not, yields a base deceleration model shown by Equation 12.

*Equation 12 - Base Average Deceleration Model*

$$\mathbf{Average\ Deceleration\ (in\ g)} \sim -\mathbf{0.2195} - \mathbf{0.109} * (\mathbf{ExpectedTrial}) \quad (12)$$

The negative sign associated with the coefficient on the expected trial variable indicates that participants demonstrated a larger average deceleration rate (i.e., more abrupt) in expected reaction trials. When testing all the fixed effects simultaneously, cycling confidence, brake type, and PRT were determined to be significant. By introducing the interaction terms between each variable and the 'ExpectedTrial' predictor and iteratively removing the least significant interaction term, a final model form was derived. The final model summary is provided in Table 14.

Table 14 - Final Average Deceleration Explanatory Model

Variable	Coefficient	P-Value	Standard Error
Intercept	-0.273	<b>0.05</b>	0.138
Expected Trial	0.090	<b>0.20</b>	0.070
Gender (Not Man)	0.012	<b>0.34</b>	0.013
Age (60 and Over)	0.003	<b>0.80</b>	0.013
Cycling Confidence (Interested but Concerned)	0.042	<b>&lt;0.01</b>	0.012
Eye Height (cm)	-0.001	<b>0.33</b>	0.001
Bike Type - Road	0.021	<b>0.13</b>	0.014
Bike Type - Mountain	-0.010	<b>0.73</b>	0.028
Brake Type (Rim + Drum)	0.023	<b>0.05</b>	0.012
PRT	0.182	<b>0.051</b>	0.093
<i>ExpectedTrial:PRT</i>	-0.421	<b>&lt;0.01</b>	0.096

Marginal  $R^2 = 0.171$ ; Conditional  $R^2 = 0.454$

Interpreting each of the coefficients in the final average deceleration model, the intercept (-0.273) signifies the baseline unexpected average deceleration, in g, before accounting for other predictors. The coefficient on 'ExpectedTrial' (+0.090) as a fixed effect was not found to be significant, most likely due to its significant interaction with the 'PRT' variable. This model also suggests that gender, age, eye height, and bicycle type were not significant predictors of average deceleration rate. Additionally, the influence of whether a participant's bicycle had electric-assist or was part of a bike share program was tested, but neither factor was found to be significant in predicting deceleration rate.

The 'CyclingConfidence' coefficient (+0.042) demonstrates that participants who were less confident braked slightly softer than participants of the "Strong and Fearless" or "Enthusied but Confident" categories. 'BrakeType' (+0.023) indicates that bicycles with rim or drum brakes

tended to demonstrate lower deceleration rates (i.e., “softer” decelerating) than bicycles with disc brakes.

Finally, the coefficient on PRT (0.182) did not meet the 95% confidence threshold ( $p = 0.051$ ). It is important to interpret the 'PRT' coefficient together with the coefficient on the interaction term of 'PRT' and 'ExpectedTrial' (-0.421). This result suggests that in unexpected reactions, a longer perception-reaction time results in a lower deceleration rate. However, in expected reactions, a longer perception-reaction time leads to a more abrupt braking response, before considering other variables. This finding implies that the relationship between deceleration rate and perception-reaction time depends on the expectation of the reaction. One explaining factor could come from the observed differences in braking behaviors between the unexpected and expected trials. In the expected trials, participants were instructed to stop as quickly as possible, potentially leading to harder braking compared to the participants in the unexpected scenarios. In the latter, participants could initially react by applying the brakes, realize that they were not in any exceptional danger, then gradually come to a full stop.

### **3.3.2 Distributions**

Another important concept surrounding the deceleration rate of bicyclists is its omission from the stopping sight distance formula in current design guidance, opting for a coefficient of friction instead to represent locked wheel braking. Reporting the measured deceleration from this study in units of g permits a direct comparison to the coefficients of friction that are used as friction factors in current design guidance. Figure 33 shows that across all trials, the 85<sup>th</sup> percentile average and maximum deceleration rates were found to be 0.20 g (1.962 m/s<sup>2</sup>) and 0.29 g (2.845 m/s<sup>2</sup>), respectively.

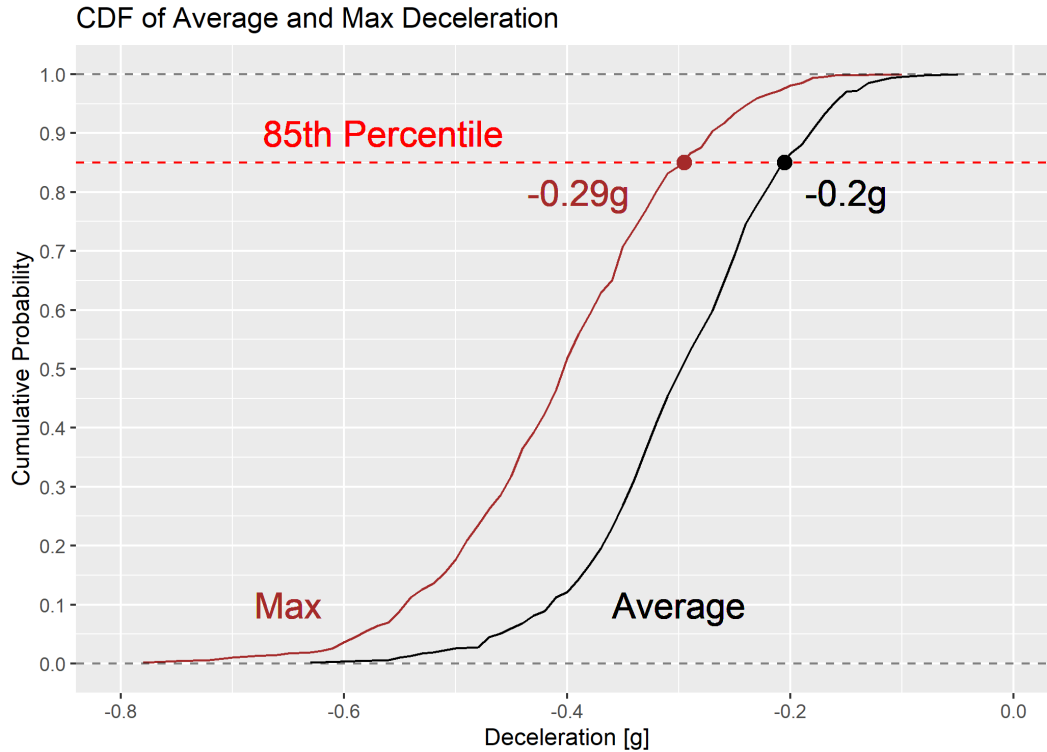


Figure 33 - CDF of the Full Sample Average and Maximum Deceleration Rate

Analyzing the patterns of average and maximum deceleration, participants in the expected trials were able to achieve higher (i.e., more negative) deceleration rates than participants in the unexpected trials, which may be a result of expected participants being more prepared to initiate a stopping maneuver. The relatively low values for average deceleration of the unexpected trials are in part due to the braking behaviour of unexpected participants, which included a more abrupt initial deceleration followed by a gradual deceleration until full stop was achieved. Full percentile breakdowns for each trial’s average and maximum deceleration rates are provided in Table 15 and Table 16, respectively.

Table 15 - Weighted Percentiles of Average Deceleration Rate

Percentile	Average Deceleration [g]			
	UBC Unexpected	UBC Expected	Vancouver Expected	Full Sample
50 <sup>th</sup>	-0.18	-0.30	-0.30	-0.29
75 <sup>th</sup>	-0.13	-0.26	-0.24	-0.24
85 <sup>th</sup>	-0.13	-0.18	-0.22	-0.20
90 <sup>th</sup>	-0.12	-0.17	-0.20	-0.17
95 <sup>th</sup>	-0.09	-0.16	-0.17	-0.16
99 <sup>th</sup>	-0.05	-0.15	-0.13	-0.12

Table 16 - Weighted Percentiles of Maximum Deceleration Rate

Percentile	Maximum Deceleration [g]			
	UBC Unexpected	UBC Expected	Vancouver Expected	Full Sample
50 <sup>th</sup>	-0.28	-0.40	-0.41	-0.40
75 <sup>th</sup>	-0.23	-0.35	-0.34	-0.33
85 <sup>th</sup>	-0.21	-0.28	-0.31	-0.29
90 <sup>th</sup>	-0.20	-0.25	-0.28	-0.27
95 <sup>th</sup>	-0.18	-0.25	-0.25	-0.24
99 <sup>th</sup>	-0.18	-0.24	-0.18	-0.18

Compared to the braking classifications suggested by Parkin (2018), the 85<sup>th</sup> percentile maximum deceleration measured in this study falls somewhere between comfortable braking (0.25 g) and emergency braking (0.365 g), whereas the average deceleration is below the comfortable threshold. A smaller absolute value (i.e., closer to 0) for deceleration rate is conservative for use in design, since a lower deceleration rate requires a longer distance to come to a full stop. These results, in addition to the ‘comfortable’ classification by Parkin, imply that the current design guidance of

0.25 g may not be a conservative estimate for use in design, and lower deceleration should be investigated.

A breakdown of the descriptive statistics (average, minimum, maximum, standard deviation) for the average and maximum deceleration rates of each sample is provided in Appendix F.

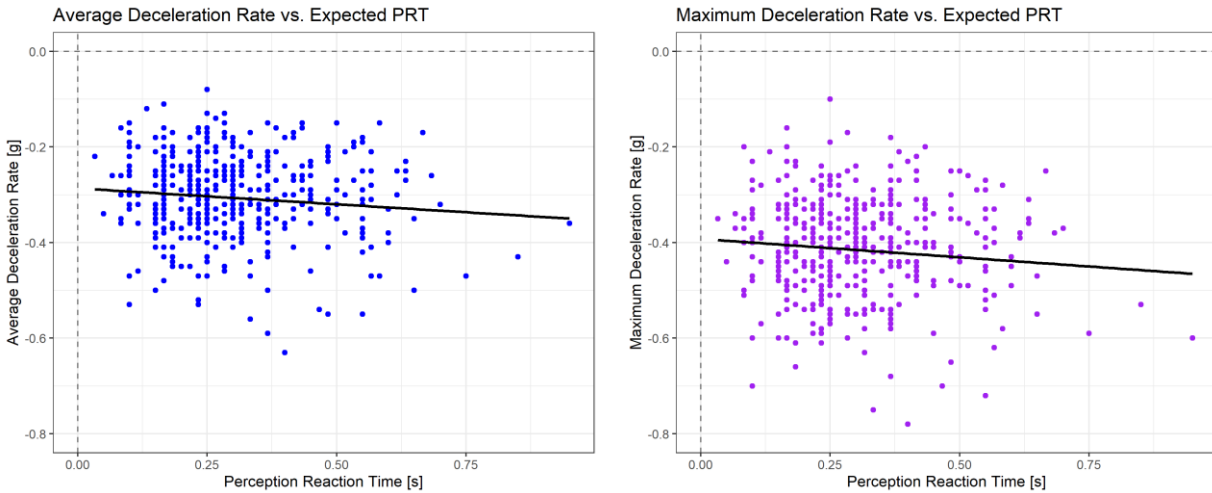
Another interesting comparison arises when examining the ratio between the average and maximum deceleration rates. This ‘deceleration ratio’ provides insights into the participant’s braking behaviour: a ratio closer to 1 suggests a consistent and abrupt braking pattern, whereas a lower ratio indicates a short burst of maximum deceleration. As shown in Table 17, these ratios were consistent across the expected trials, where participants were instructed to a stop as quick as possible. Conversely, in the unexpected trials, participants typically initiated an immediate, abrupt braking action, followed by a gradual deceleration until coming to a complete stop. A contributing factor for the lower average deceleration rates observed in the unexpected trials is the longer braking time. The average braking time for the UBC unexpected participants was 2.59 s, whereas the average expected brake time from the same sample was shorter, at only 1.42 s.

*Table 17 - Weighted Percentiles of Deceleration Ratio (Average to Maximum)*

Percentile	Deceleration Ratio (Average/Maximum)			
	UBC Unexpected	UBC Expected	Vancouver Expected	Full Sample
50 <sup>th</sup>	0.68	0.75	0.75	0.74
75 <sup>th</sup>	0.73	0.79	0.79	0.78
85 <sup>th</sup>	0.74	0.83	0.81	0.81
90 <sup>th</sup>	0.74	0.84	0.84	0.83
95 <sup>th</sup>	0.77	0.85	0.86	0.86
99 <sup>th</sup>	0.80	0.87	0.89	0.89

### 3.3.3 Deceleration Rate and PRT

As shown in Figure 34, fitting a linear trendline to the deceleration data from all expected trials, obtained from the accelerometer and passing the ‘SpeedCheck’ test (n=439), suggests that a longer PRT is associated with a more abrupt braking maneuver and a higher deceleration rate.



*Figure 34 - Average and Maximum Deceleration Rates vs. Expected PRT*

Conversely, when examining the same trend in unexpected trials that passed the ‘SpeedCheck’ test (n=30), the result reverses, and a shorter perception-reaction time is associated with a higher deceleration rate (see Figure 35). It is important to highlight the notably small sample size of the unexpected trials test compared to the expected trials. However, performing a linear regression analysis on both trials revealed a statistically significant relationship between deceleration rate and perception-reaction time at the 95% confidence level.

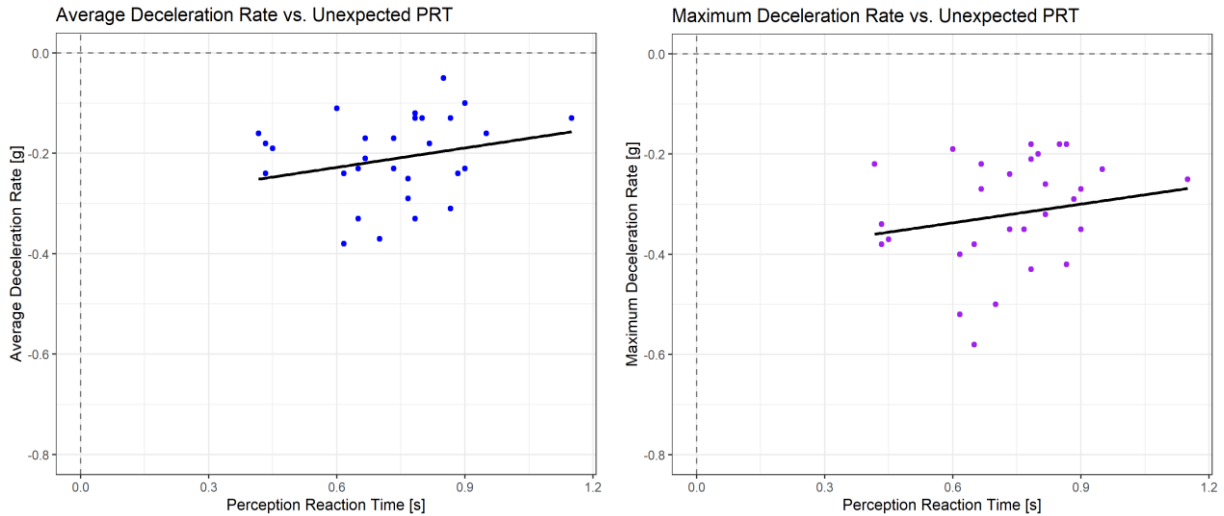


Figure 35 - Average and Maximum Deceleration vs. Unexpected PRT

In addition to the examination of the bivariate relationship between perception-reaction time and deceleration rates, a mixed-effects model was developed to further investigate the significant predictors of average deceleration rate. As previously discussed in Section 3.3.1, the coefficient associated with the perception-reaction time variable (+0.182) suggests that for each additional second required by the user to react in unexpected scenarios, the corresponding average deceleration rate decreases by  $\sim 0.18 \text{ g}$  ( $1.77 \text{ m/s}^2$ ). However, the interaction effect between the response expectation and the user's perception reaction time revealed a negative coefficient (-0.421), which suggests that in expected scenarios, the relationship between deceleration rate and PRT reverses, such that for each additional second required by the user to react, the corresponding average deceleration rate increases by  $\sim 0.24 \text{ g}$  ( $2.35 \text{ m/s}^2$ ). These model findings support the secondary hypothesis of this study that a relationship does exist between perception-reaction time and deceleration rate among bicyclists. However, this finding does not perfectly align with previous research (Hancock et al., 2003; Wood and Zhang, 2017) that found a positive relationship between the two variables, which was only observed in expected reactions in this study. Further research is recommended to explore the observed difference of the PRT-deceleration rate relationship between expected and unexpected reactions.

### 3.4 Approach Speed

In both the PRT offset model and the explanatory model, approach speed was found to be a significant predictor of perception-reaction time, indicating that higher speeds resulted in quicker

reactions. This finding suggests that the concept of heightened vigilance while riding, leading to faster reaction times, may be favoured over the hypothesis suggesting that an increased speed results in increased braking scenario complexity which leads to slower reaction times.

### 3.4.1 Distributions

Figure 36 shows that in the unexpected trials, the 85<sup>th</sup> percentile approach speed was found to be 5.63 m/s (20.3 km/hr). It is worth noting that this study measured speed around a blind corner, and thus may be lower than previously determined design speeds. Given that corners are locations prone to sightline issues, it is crucial to study the speeds of bicyclists while navigating these turns. In contrast, the linear expected trials exhibited a combined 85th percentile speed of 4.74 m/s (17.1 km/hr). These speed measurements are provided to offer context for the perception-reaction time and deceleration rates observed in this study.

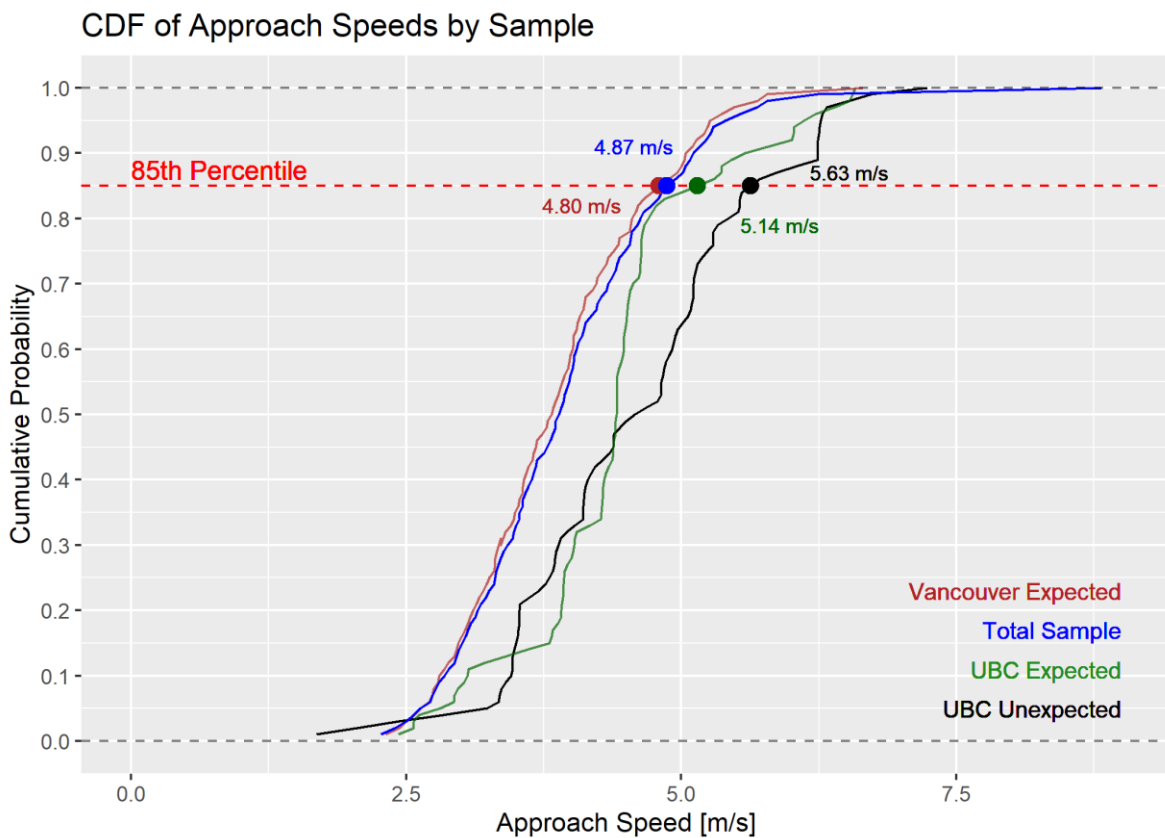


Figure 36 - CDF of Approach Speed

Speeds were highest in the unexpected trials, which is unsurprising given that participants had a longer approach to the test corner compared to the expected trials. In the expected trials, the UBC

sample demonstrated a higher distribution of speeds compared to their Vancouver counterparts. A full breakdown of each sample's approach speeds is provided in Table 18.

*Table 18 - Weighted Percentiles of Approach Speed*

Percentile	Approach Speed [m/s]			
	UBC Unexpected	UBC Expected	Vancouver Expected	Full Sample
50 <sup>th</sup>	4.58	4.41	3.82	3.89
75 <sup>th</sup>	5.24	4.64	4.39	4.49
85 <sup>th</sup>	5.63	5.14	4.80	4.87
90 <sup>th</sup>	6.24	5.59	5.04	5.11
95 <sup>th</sup>	6.27	6.12	5.26	5.40
99 <sup>th</sup>	6.73	6.56	5.78	6.24

The current design guidance for stopping sight distance recommends a design speed of 30 km/hr (8.33 m/s), therefore it is recommended that future studies explore the perception-reaction time and deceleration rate of bicyclists navigating at these higher design speeds. However, based on the relationship between speed and perception-reaction time determined in this study, lower speeds were associated with longer reaction times, leading to a more conservative result. Additionally, investigating cornering speeds is important to understand the behaviours of bicyclists while navigating a location with reduced sight lines, since assuming a higher design speed for use in the SSD calculation may be unrepresentative of bicyclists' true behaviours.

A breakdown of the descriptive statistics (average, minimum, maximum, standard deviation) for the approach speed of each sample is provided in Appendix F.

### **3.4.2 Speed Profiles**

As described in Section 2.2.5, speed profiles were generated for each trial. These profiles were generated using the approach speed determined by the GPS, the braking time from the video footage, and the integral of the deceleration rate from the data logger. In the event that any of these

variables were not extracted from the data, the speed profile could not be generated. Table 19 highlights a summary of the total sample size with available data for each variable.

*Table 19 - Summary of Available Speed and Deceleration Data for Speed Profile Generation*

<b>Sample</b>	<b>Trial</b>	<b>Total Trials</b>	<b>Speed Check Pass</b>	<b>Speed Check Fail</b>	<b>GPS Speed Not Calculated</b>
UBC	Unexpected	52	30 (58%)	10 (19%)	12 (23%)
UBC	Expected	104	38 (37%)	21 (20%)	45 (43%)
Vancouver	Expected	750	401 (53%)	201 (27%)	148 (20%)

The 'Speed Check Pass' column represents observations where both GPS speeds and the change in speed over the brake event from the deceleration data were within 1 m/s of each other. Conversely, the 'Speed Check Fail' column shows trials where both sets of data were available, but did not meet the 1 m/s difference threshold. The 'GPS Speed Not Calculated' column indicates trials lacking GPS speed due to corrupted GPS data or an incomplete braking time calculation, caused by either the brake light not activating or the participant not coming to a full stop. The percentages of failed tests are high, which is in part due to the noise levels observed in the deceleration data. Further, a good portion of the participants in the expected trials did not come to a full stop, despite the study instructions provided to them.

To highlight the consistency in braking maneuvers among different participants, all the UBC trial unexpected speed profiles are depicted in Figure 37. In many cases, the decrease in speed follows an 'S-curve' shape, illustrating an initial sharp maximum deceleration followed by a gradual decrease until coming to a full stop. Conversely, other profiles exhibit a more linear pattern, suggesting a constant deceleration behaviour until reaching a full stop.

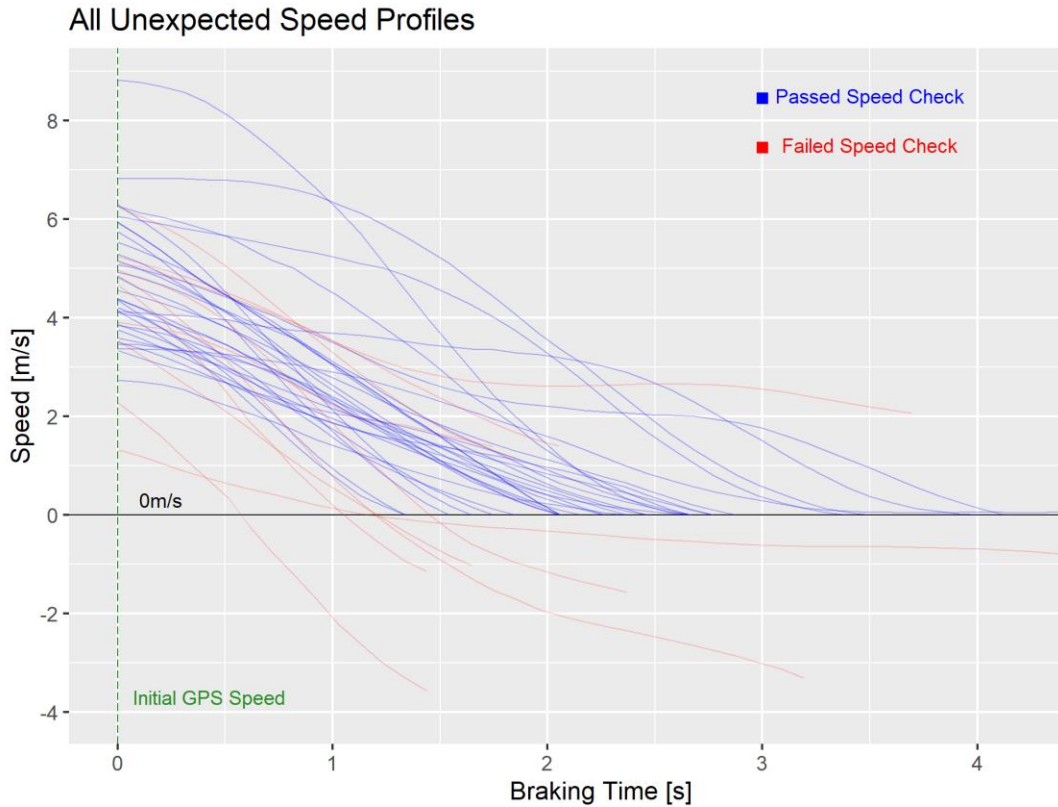


Figure 37 - Unexpected Trial Speed Profiles

These curves also illustrate the approximate braking time for each participant in the unexpected trials, ranging from ~1.3 s to ~4.0 s, with an average braking time of 2.6 s. In comparison, the braking time in the expected trials ranged from 0.5 s to 3 s, with an average braking time of 1.4 s.

A breakdown of the descriptive statistics (average, minimum, maximum, standard deviation) for the braking time of each sample is provided in Appendix F.

### 3.5 Stopping Sight Distance

The methodology adopted for data collection, which involved measuring perception-reaction time around a corner, made it difficult to directly measure each participant's SSD. Although the stopping distance for each trial was not measured, it was estimated by inputting the GPS approach speed, the video-determined perception-reaction time, and accelerometer-reported average deceleration rate for each trial into Equation 1 (Transportation Association of Canada, 2017). The stopping distance is provided to establish a foundation for understanding the stopping distances

associated with the measured variables in this study, including perception-reaction time, deceleration rate, and approach speed.

### 3.5.1 Explanatory Model

Estimating a mixed effect model using the combined dataset from both the UBC and Vancouver samples (N=467, 243 participant-level random effects), again predicted by whether the trial was expected or not, yields a base stopping sight distance model shown by Equation 13. Since this model predicted stopping sight distance that was calculated from the data logger acceleration readings, only observations where the ‘SpeedCheck’ between the GPS speed and the total change in speed measured by the accelerometer was less than 1 m/s were considered.

*Equation 13 - Base Stopping Distance Model*

$$\mathbf{Stopping\ Distance\ (in\ m) \sim 5.15 - 2.55 * (ExpectedTrial)} \quad (13)$$

The negative sign associated with the coefficient on the expected trial variable indicates that participants demonstrated a lower average stopping distance in expected reaction trials. This result makes sense, since participants tended to be traveling at lower speeds in the expected trial and demonstrated faster reaction times. When testing all the fixed effects simultaneously, gender and eye height were determined to be significant. By introducing the interaction terms between each variable and the 'ExpectedTrial' predictor and iteratively removing the least significant interaction term, a final model form was derived. The final model summary is provided in Table 20.

Table 20 - Final Stopping Distance Explanatory Model

Variable	Coefficient	P-Value	Standard Error
Intercept	9.458	<0.01	1.760
Expected Trial	-2.904	<0.01	0.311
Gender (Not Man)	-0.454	0.01	0.176
Age (60 and Over)	-0.026	0.89	0.190
Cycling Confidence (Interested but Concerned)	-2.607	<0.01	0.761
Eye Height (cm)	-0.024	0.02	0.010
Bike Type - Road	0.241	0.20	0.188
Bike Type - Mountain	-0.355	0.35	0.375
Brake Type (Rim + Drum)	0.197	0.22	0.160
<i>ExpectedTrial:Confidence</i>	2.478	<0.01	0.768

Marginal R<sup>2</sup> = 0.167; Conditional R<sup>2</sup> = 0.316

Interpreting each coefficient in the final stopping distance model, the intercept (9.458) represents the baseline unexpected stopping distance before accounting for other predictors. The ‘Gender’ coefficient (-0.45) suggests that participants who did not identify as men required a slightly shorter distance to come to a full stop. The coefficient on ‘EyeHeight’ (-0.024) suggests that riders with a taller eye height required less distance to come to a stop. For context, this coefficient implies that when comparing two riders with an eye height difference of 20 cm, the taller rider would require approximately 0.5 meters less distance to come to a stop, before considering any other variables. Age, bicycle type, and brake type were not found to be significant predictors of stopping distance. Additionally, the influence of whether a participant's bicycle had electric-assist or was part of a bike share program was tested, but neither factor was found to be significant in predicting stopping distance.

In general, the coefficient on 'ExpectedTrial' (-2.904) suggests that participants who were anticipating a braking maneuver required a shorter distance to come to a stop, by approximately

2.9 m. Additionally, the coefficient on the ‘CyclingConfidence’ variable (-2.607) suggests that riders with a lower confidence also required a lower distance to come to a stop, which may be attributable to faster reaction times and/or lower approach speeds. However, the interaction term between these fixed effects (+2.478) suggests that lower confidence bicyclists tended to demonstrate a more consistent stopping distance between unexpected and expected conditions (-3.0 m in the expected compared to -2.6 m in the unexpected for a difference of 0.4 m) compared to high confidence bicyclists who demonstrated a 2.9 m shorter distance when anticipating a braking maneuver.

### **3.5.2 Distributions**

The 85<sup>th</sup> percentile stopping sight distance is provided in Figure 38 for each set of trials. A comparison of the unexpected stopping distance values to the expected reveals a large difference, which is attributable to the slower reaction times, higher speeds, and lower average deceleration rates observed in the unexpected trials. In general, the participants in the Vancouver trial required the shortest stopping distance, most likely due to their lower observed speeds. A full breakdown of each sample’s calculated stopping distance is provided in Table 21.

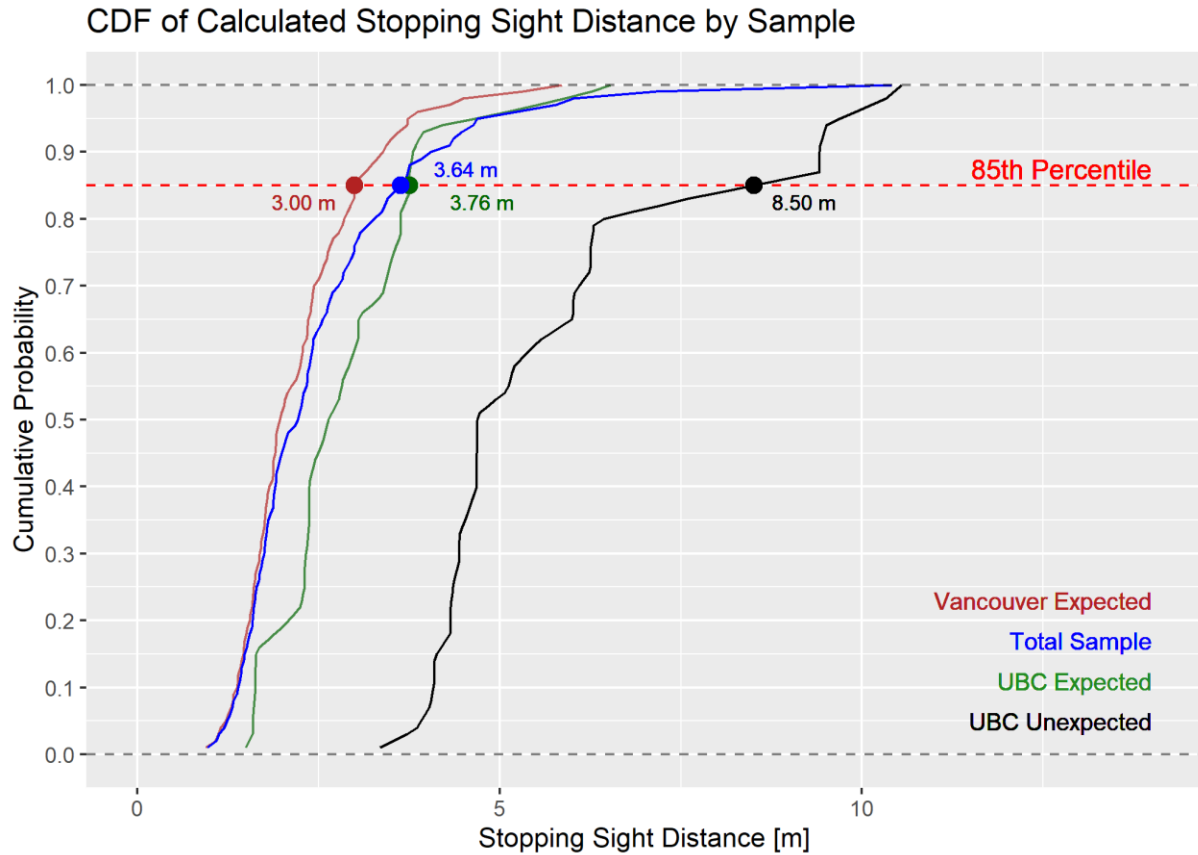


Figure 38 - CDF of Calculated Stopping Distance

Table 21 - Weighted Percentiles of Calculated Stopping Sight Distance

Percentile	Stopping Distance [m]			
	UBC Unexpected	UBC Expected	Vancouver Expected	Full Sample
50 <sup>th</sup>	4.69	2.64	1.97	2.21
75 <sup>th</sup>	6.26	3.53	2.63	2.98
85 <sup>th</sup>	8.50	3.76	3.00	3.64
90 <sup>th</sup>	9.41	3.80	3.39	4.05
95 <sup>th</sup>	9.69	4.66	3.73	4.69
99 <sup>th</sup>	10.44	6.27	5.32	7.16

Comparing the unexpected stopping sight distance distribution to current design guidance, a bicycle travelling at a speed of 20 km/hr, with a perception-reaction time of 2.5 s, and a coefficient of friction of 0.25 (accounting for wet conditions) requires 20 m to come to a full stop (p.G13, Ministry of Transportation and Infrastructure, 2019). This minimum stopping sight distance is larger than double the observed 85<sup>th</sup> percentile stopping distance in this study of 8.50 m; however, the guidance accounts for wet conditions which were not tested in this experiment. Using the 85<sup>th</sup> percentile values measured in this study for speed (20.3 km/hr), average deceleration rate (0.2), and unexpected PRT (0.84 s), the minimum stopping distance would be 12.8 m, still noticeably smaller than current design guidance of 20 m.

When travelling at 20 km/hr, a bicyclist can come to a stop 5.5 m sooner if they react to the stimulus 1 s faster (assuming a consistent deceleration rate), while initiating softer braking of 0.2 g compared to 0.25 g requires only an additional 1.6 m to come to a stop (assuming a consistent PRT). This suggests that the observed difference between the perception-reaction time measured in this study and current PRT guidance dominates compared to the impact of a smaller (i.e., less abrupt) deceleration rate.

A breakdown of the descriptive statistics (average, minimum, maximum, standard deviation) for the stopping distance of each sample is provided in Appendix F.

### **3.5.3 Gender and Confidence Trends**

In the stopping distance model, gender was identified as a significant predictor. Analyzing the age-weighted average and 85<sup>th</sup> percentiles of the primary variables influencing stopping distance, shown in Table 22, revealed gender-based patterns. Although gender was not identified as significant in the PRT or deceleration rate model, men exhibited slightly faster perception-reaction times and higher average deceleration rates, both contributing to shorter stopping distances. However, the higher approach speeds observed for men ultimately led to longer calculated stopping distances.

Table 22 - Key Variables by Gender (Full Sample)

Variable	Weighted Statistic	Man	Not Man
PRT [s]	Mean	0.33 s	0.36 s
	85 <sup>th</sup> Percentile	0.52 s	0.55 s
Average Acceleration [g]	Mean	-0.32 g	-0.27 g
	85 <sup>th</sup> Percentile	-0.22 g	-0.18 g
Speed [m/s]	Mean	4.11 m/s	3.62 m/s
	85 <sup>th</sup> Percentile	5.11 m/s	4.40 m/s
SSD [m]	Mean	2.40 m	3.05 m
	85 <sup>th</sup> Percentile	3.36 m	4.69 m

In the stopping distance model, self-identified cycling confidence was also found to be a significant predictor. Analyzing the weighted average and 85<sup>th</sup> percentiles of the primary variables influencing stopping distance revealed confidence-based patterns. Cycling confidence was found to be significant in the perception-reaction time, deceleration rate, and stopping sight distance models. From the stopping distance model, lower confidence bicyclists required a shorter distance to come to a stop, which is attributable to faster overall reaction times and lower speeds as illustrated in Table 23. Although higher confidence bicyclists demonstrated slightly more abrupt braking behaviours, it was not sufficient to compensate for the higher speeds, thus requiring a longer overall stopping distance.

Table 23 - Key Variables by Confidence (Full Sample)

<b>Variable</b>	<b>Weighted Statistic</b>	<b>Low Confidence</b>	<b>High Confidence</b>
PRT [s]	Mean	0.32 s	0.38 s
	85 <sup>th</sup> Percentile	0.48 s	0.61 s
Average Acceleration [g]	Mean	-0.29 g	-0.32 g
	85 <sup>th</sup> Percentile	-0.19 g	-0.22 g
Speed [m/s]	Mean	3.71 m/s	4.21 m/s
	85 <sup>th</sup> Percentile	4.57 m/s	5.26 m/s
SSD [m]	Mean	2.29 m	2.82 m
	85 <sup>th</sup> Percentile	3.31 m	4.37 m

## Chapter 4: Conclusion

### 4.1 Summary

The aim of this research was to address the knowledge gap stemming from a lack of empirical research investigating specific design parameters of bicyclists for use in bicycle facility design. In particular, this study aimed to provide evidence-based grounding for the design parameters of perception-reaction time and deceleration rate used in stopping sight distance calculations.

Bicyclists' unexpected perception-reaction times were measured using a behavioral deception study, which involved inserting a banner hazard around a test corner in a controlled experiment conducted on the University of British Columbia campus. Perception-reaction times were measured using a GoPro HERO5 camera and a pressure-sensor brake light, while deceleration rate and speed were measured using a 3-Space Data Logger and a Garmin Edge 530 cycling computer, respectively. This experimental procedure is comparable to the approach undertaken by Davoodi et al. (2012) to measure motorcyclists' perception-reaction times. Expected perception-reaction times were also collected from this sample to estimate a relationship between unexpected and expected responses, which was subsequently applied to a larger, more representative sample collected in Vancouver.

The outcomes of this study are twofold. First, the perception-reaction times of bicyclists, as measured in this study, were determined to be noticeably shorter than previously measured values for motor vehicle drivers. Personal characteristics of the user such as age and gender were not identified as significant predictors of perception-reaction time, but operationally, the speed was found to be significant such that a higher speed resulted in a faster reaction time. This finding suggests that user vigilance and readiness to react could have a greater impact on the perception-reaction time than the complexity of stopping when navigating at higher speeds.

Second, this study has indicated that current design guidance on deceleration rates for bicyclists may not be conservative. The current North American design value of 0.25 g, deemed to “[account] for the poor wet weather braking characteristics of many bicycles” (p.G12, Ministry of Transportation and Infrastructure, 2019), is larger (less conservative) than the average deceleration rate observed in this study of 0.20 g on dry terrain. This research has also provided compelling evidence that a relationship exists between perception-reaction time and deceleration rate in

braking maneuvers; however, the relationship was different in unexpected and expected reactions. For instance, when a bicyclist anticipates a reaction, there may be a positive correlation, meaning a longer reaction time leads to a more abrupt braking maneuver.

Additionally, this study provided 85<sup>th</sup> percentile cornering speeds of 5.63 m/s (20.3 km/hr), which is useful in understanding bicyclist speed behaviours while navigating a blind corner.

The 85<sup>th</sup> percentile unexpected stopping distance calculated in this study of 8.50 m is noticeably less than that of current design guidance at 20 km/hr of 20 m. This result suggests that current guidance is conservative for application in bicycle facilities.

The results of the study, including comparisons to current design guidance and findings from previous research on both bicycles and motor vehicles, are summarized in Table 24.

Table 24 - Summary of Results

Parameter	Sample	Critical 85 <sup>th</sup> Percentile	Design Guidance		Previous Research
			Bicycles	Motor Vehicles	
Perception-Reaction Time	Full Sample Unexpected	0.84 s	North America: 2.5 s <sup>1,4,5</sup> Europe: 2.0 s <sup>2,3</sup>		<i>Motor Vehicle, Unexpected:</i> 1.6 s (Olson and Sivak, 1986) 2.0 s (Fambro et al., 1997) <i>Motorcycle, Unexpected:</i> 2.12 s (Davoodi et al., 2012)
Deceleration Rate	Full Sample	Avg: 0.20 g (1.96 m/s <sup>2</sup> ) Max: 0.29 g (2.84 m/s <sup>2</sup> )	0.15 g <sup>2</sup> 0.25 g <sup>3,4</sup> 0.16-0.32 g <sup>5</sup>	3.4 m/s <sup>2</sup> <sup>1</sup>	3.3 m/s <sup>2</sup> (Landis, 2004) 3.0-3.6 m/s <sup>2</sup> (Dozza, 2023)
Speed	UBC Unexpected	20.3 km/hr*	**30 km/hr <sup>2,3,4,5</sup>	Varies	22 km/hr (Landis, 2004) 26 km/hr (Hassanpour, 2024)
Eye Height	Full Sample	151 cm	80-220 cm <sup>2</sup> 137 cm <sup>1,4,5</sup>	108 cm <sup>1</sup>	150 cm (Landis, 2004)

\*Speed while cornering

\*\*20 km/hr minimum in specific circumstances, 30 km/hr typical, 40 km/hr on large grades

<sup>1</sup>Transportation Association of Canada, 2017

<sup>2</sup>CROW, 2017

<sup>3</sup>Highways England, 2020

<sup>4</sup>Ministry of Transportation and Infrastructure, 2019

<sup>5</sup>American Association of State Highway and Transportation Officials, 2012

The key findings from this study are:

- A value of 2.5 s for PRT is conservative for use in bicycle facility design; the 85<sup>th</sup> percentile unexpected perception-reaction time was 0.84 seconds.
- Gender and age were not significant predictors of PRT, but user speed was significant, indicating the importance of user vigilance when riding.
- Current design guidance for bicycle braking deceleration rate of 0.25 g may not be safe, since the 85<sup>th</sup> percentile average deceleration rate in this study was found to be 0.20 g on dry terrain.

## **4.2 Recommendations**

In this section, recommendations are provided to guide design practice, accompanied by suggestions for future research directions. These recommendations aim to enhance the safety of bicycle facilities by promoting forgiving infrastructure and pursuing empirical research to establish evidence-based design values.

### **4.2.1 Practice**

These research findings suggest that the current PRT design value of 2.5 s is conservative for use in bicycle facility design. A shorter design value of 2.0 s, consistent with guidance in Europe (CROW, 2017; Highways England, 2020), would offer a less conservative but still adequate design value for stopping sight distance for bicycles. As this is the first study measuring unexpected perception-reaction time during emergency stopping scenarios for bicycles, further research is recommended prior to adopting a less conservative value for PRT, especially since bicyclist behaviours could vary across different regions.

On the topic of deceleration rate for bicycles, current guidance on stopping sight distance should be reviewed regarding the assumption of locked-wheel braking and the use of a coefficient of friction over a deceleration rate. Further, these findings suggest adopting a smaller design deceleration rate that is more comparable to the conservative estimate used in the Netherlands of 0.15 g (CROW, 2017) or the wet-weather value considered in the USA of 0.16 g (AASHTO, 2012). This recommendation is accompanied by a suggestion to comprehensively investigate the braking of bicycles across a diverse sample of users in a variety of weather conditions.

### **4.2.2 Research**

Further study into the unexpected reaction times of bicyclists is imperative to confirm the validity of a reduced perception-reaction time (PRT) for application in bicycle facility design. Given the importance of bicyclist perception-reaction times in stopping sight distance design guidance, additional research is recommended before considering alterations to current standards. Future research studies should attempt to replicate real-world situations by investigating perception-reaction times of bicycles, as well as other micromobility devices, along straight segments incorporating vertical curvature, closer to the typical design speed of 30 km/hr, and in response to more complex stimuli such as other road users. A comparison of perception-reaction times, speeds, decelerations, and the resulting stopping distances between cornering and straight segments should

be conducted to determine conservative design values that consider the abilities of all users. Exploring the effect of a user's collision history on braking response should also be considered for future study, as it may be associated with the user's attentiveness and response behaviour when operating a bicycle.

Braking behaviours of bicycles and other micromobility devices should be studied in both dry and wet weather, to generate an understanding of the difference in user braking response under adverse weather conditions. Furthermore, the relationship between perception-reaction time and deceleration rate should be further explored in the context of bicycle and micromobility applications, to visualize whether this relationship holds true across a range of devices.

Finally, empirical research is needed in the field of active travel design to validate the assumptions borrowed from motor vehicle design guidance for implementation in bicycle facility design. As the population increasingly embraces micromobility as a mode of transportation, it is crucial for professionals to acknowledge active transportation facilities as independent entities requiring dedicated research efforts, rather than treating them as afterthoughts to the research and design of motor vehicle roadways.

### **4.3 Study Limitations**

This study has several study limitations that should be acknowledged. First, unexpected perception-reaction time was measured on a university campus where it was suitable for the study purpose and execution. Using a university campus as a sample location could potentially lead to an overrepresentation of participants in the 20-24 age category, which is typical for university students. This limitation was accounted for by collecting demographic information and weighing the sample to a representative regional cyclist population.

The unexpected perception-reaction time observations were measured through a corner, potentially leading to participants being more vigilant compared to cycling in a straight line. Bicycles have lower speeds than motor vehicles, making it difficult to develop a test methodology to simulate an unexpected emergency response along a straight stretch without sacrificing participant safety. Further, cornering into an unexpected hazard is a common scenario for bicyclists, and this study investigates a realistic hazard encountered daily by bicycle users.

One of the major limitations of this study comes from the use of a model and correction factor between unexpected and expected perception-reaction time. This model assumes that individuals react similarly according to personal or operational characteristics, which may not be accurate. Nevertheless, when conducting a behavioral study involving risk to participants, prioritizing participant safety is crucial. Therefore, reducing the number of participants undertaking the unexpected trial was essential to emphasize participant safety.

Finally, avid bicyclists may be more prone to participate in a bicycling research study. This could result in participants being more vigilant and experienced than a cyclist in the representation population. This was accounted for by collecting information on self-identified cycling confidence and frequency of bicycling. Further, during data collection, discussions with participants revealed that collision history may be a potential factor influencing reaction time. Some participants expressed hesitancy to participate due to past bicycle collisions, while others noted increased vigilance during their rides following previous incidents. This collision-history characteristic should be collected in future studies investigating the behaviours of bicyclists.

#### **4.4 Contributions**

This study is the first of its kind in measuring empirical values for bicyclist perception-reaction time and braking in unalerted conditions to help inform design guidance for bicycle facilities. Moreover, this research aspires to act as a catalyst for future studies focusing on bicycle behaviours, instead of relying on design assumptions borrowed from motor vehicle guidance. Lastly, this study emphasizes the importance of holding public safety paramount, by providing evidence-based parameters for use in the design of active transportation facilities which is increasingly vital as the popularity of active transportation continues to rise.

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# Appendices

## Appendix A: Consent Forms, Demographic Survey, and Unexpected Debrief Script

### *Unexpected Consent Form*



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Faculty of Applied Science

### Bicycle Design Parameters Study Consent Form

**Project Title:** *Evidence-based design of off-street paths and cycleways: fundamental traffic engineering parameters for bicycles and micromobility devices* (funded by the Natural Sciences and Engineering Research Council of Canada)

#### Study Team and Purpose

*Principal Investigator:* Dr. Alexander Bigazzi, Associate Professor, Civil Engineering

*Co-Investigator:* Mr. Stephen Martin, MAsc Candidate, Civil Engineering

Contact e-mail: [react.lab@ubc.ca](mailto:react.lab@ubc.ca)

We are studying fundamental parameters that are critical for the design of safe bicycling facilities such as acceleration and operating speed. This research project is for the graduate thesis of Mr. Martin. To participate in this study, you must have access to a bicycle, be able to ride a bicycle, and be at least 14 years old.

#### Study Procedures and Participation

Participation in this study requires 20-25 minutes. After completing this form, participants will:

- Agree to have your bicycle instrumented with a GPS (location/speed data), brake light, and data logger (acceleration data)
- Once ready, you will set off on the marked path for a total of four (4) laps
- After completion of the laps, the study team will download the data from the instruments and your participation in the trial is complete.

You may choose to withdraw your consent and terminate your participation at any time.

The primary risk of this study is falling off the bicycle and sustaining an injury. Participants will be provided time to get used to the instrumented bike and helmets will be required during the trial. Benefits include improved design guidance for off-street paths, resulting in safer facilities.

Participants who agree to take part in the trial will receive a \$5 gift card for their participation.

We will record video data during the trials. Study data will remain confidential and no personally identifying information will be included when the study findings are presented or published. At the end of each day, all data will be stored on a password-protected computer kept in locked areas on UBC campus.

#### Questions & Concerns

If you have any questions or concerns about what we are asking of you, please ask the study team.

If you have any concerns or complaints about your rights as a research participant and/or your experiences while participating in this study, contact the Research Participant Complaint Line in the UBC Office of Research Ethics at 604-822-8598 (or 1-877-822-8598) or if long distance e-mail [RSIL@ors.ubc.ca](mailto:RSIL@ors.ubc.ca) (ethics ID: H23-01234).

*By agreeing to participate, you do not give up any of your legal rights. If you become physically injured from participating in this study, medical treatment will be provided at no additional cost to you; it will be paid for by your provincial medical plan. Click on "I Agree" below to indicate your consent to participate in this study:*

I Agree

I Disagree

## Expected Consent Form



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## Bicycle Design Parameters Study Consent Form

**Project Title:** *Evidence-based design of off-street paths and cycleways: fundamental traffic engineering parameters for bicycles and micromobility devices* (funded by the Natural Sciences and Engineering Research Council of Canada)

### Study Team and Purpose

**Principal Investigator:** Dr. Alexander Bigazzi, Associate Professor, Civil Engineering

**Co-Investigator:** Mr. Stephen Martin, MSc Candidate, Civil Engineering

Contact e-mail: [react.lab@ubc.ca](mailto:react.lab@ubc.ca)

We are studying fundamental parameters that are critical for the design of safe bicycling facilities: perception-reaction time and deceleration rate. This research project is for the graduate thesis of Mr. Martin. To participate in this study, you must be able to ride a bicycle and be at least 14 years old.

### Study Procedures and Participation

Participation in this study requires 10-15 minutes. After completing this form, participants will:

- Either use the instrumented bicycle provided or agree to have your bicycle instrumented with a GPS (location/speed data), brake light, and data logger (acceleration data)
- Once ready, you will line up at the starting line and begin bicycling along the straight, coned path when the red-green light in front of you turns to green. The moment the red-green light changes to red, you are to apply the brakes of the bicycle as quickly as reasonably safe and come to a full stop
- The trial will be completed three (3) times, then the study is complete

You may choose to withdraw your consent and terminate your participation at any time.

The primary risk of this study is falling off the bicycle and sustaining an injury. Participants will be provided time to get used to the instrumented bike and helmets are recommended and will be available upon request. Benefits include improved design guidance for off-street paths, resulting in safer facilities.

Participants who agree to take part in the trial can enter their email address for a chance to win 1 of 4 \$25 gift cards. Chances of receiving a card are approximately 1 in 60.

We will record video data during the trials. Study data will remain confidential and no personally identifying information will be included when the study findings are presented or published. At the end of each day, all data will be stored on a password-protected computer kept in locked areas on UBC campus.

### Questions & Concerns

If you have any questions or concerns about what we are asking of you, please ask the study team.

If you have any concerns or complaints about your rights as a research participant and/or your experiences while participating in this study, contact the Research Participant Complaint Line in the UBC Office of Research Ethics at 604-822-8598 (or 1-877-822-8598 ) or if long distance e-mail [RSIL@ors.ubc.ca](mailto:RSIL@ors.ubc.ca) (ethics ID: H23-01234).

*By agreeing to participate, you do not give up any of your legal rights. If you become physically injured from participating in this study, medical treatment will be provided at no additional cost to you; it will be paid for by your provincial medical plan. Click on "I Agree" below to indicate your consent to participate in this study:*

I Agree

I Disagree

## Demographic Survey

Demographic Information (*collected through the Qualtrics survey platform*)

**Gender:** Man, Woman, Non-binary, Not Listed: \_\_\_\_\_

**Age:** Less than 15, 15-19, 20-24, 25-29, 30-34, 35-39, 40-44, 45-49, 50-54, 55-59, 60-64, 65+

**What description best describes your confidence as a bicyclist?**

- Strong and Fearless* – willing to bicycle regardless of conditions or what facilities are in place
- Enthusied and Confident* – comfortable sharing the roadway with motor vehicle traffic, but prefer their own facilities
- Interested but Concerned* – enjoy biking and may choose to bike, but need more separated, safe facilities away from motor vehicle traffic
- No Way No How* – will not choose to bike regardless of what facilities are present due to topography, safety concerns, lack of interest, or other reasons

**How many days per week do you typically ride a bicycle in summer months?** 0, 1-2, 3-4, 5+

If you would like to enter for a chance to win 1 of 4 \$25 gift cards, please enter your e-mail address: \_\_\_\_\_ (chance of receiving a gift card is approximately 1 in 60).

**Would you like to receive a copy of the published results once the study is complete?** [YES / NO]

[SUBMIT BUTTON]

## *Unexpected Debrief Script*



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### **Bicycle Design Parameters Study Unexpected Trial Debrief Script**

Thank you for taking part in our experiment.

As you are aware, on the second lap of the course, a banner hazard was inserted into your path prompting you to come to a stop. The true purpose of this study was to measure perception-reaction time and deceleration rate for bicyclists in response to a fixed object; a hazard that is all too common in the day-to-day operation of a bicycle.

We apologize for deceiving you, but in order to obtain a meaningful estimate for this critical design value, we had to make sure that you were not expecting to come to a stop. Remember, you have the right to stop participating at any time and withdraw your data from the study.

At this time, your participation in the trial is almost complete, we just need to collect some expected reaction times from you. This will involve you biking through the same corner until a red-green light turns from green to red, where you will come to a full stop. Do we have your consent to continue with the trials?

## Appendix B: Full List of Model Variables Considered

Category	Variable	Specification/Classification	Tested in model?		
			PRT	Avg Accel	SSD
Personal	Gender	<i>Binary</i> : Participant identified gender: Man (exclusive) vs. Not Man-exclusive (Woman + Non-Binary)	Yes	Yes	Yes
Personal	Age	<i>Binary</i> : Participant identified age in Bins, converted to 60 and over or not	Yes	Yes	Yes
Personal	Cycling Confidence	<i>Binary</i> : Self-identified cycling confidence, Interested but Concerned or not	Yes	Yes	Yes
Personal	Cycling Frequency	<i>N/A</i> : Self-identified cycling frequency (1,2,3,4,5+ per week)	No	No	No
Personal	Eye Height	<i>Continuous</i> : Measured eye height of the participant	Yes	Yes	Yes
Bicycle	Bike Type	<i>Categorical</i> : Photo-classified bicycle type (Road, Hybrid-ref, Mountain)	Yes	Yes	Yes
Bicycle	Brake Type	<i>Binary</i> : Photo-classified brake type (Disc vs. Not Disc)	Yes	Yes	Yes
Bicycle	Handlebar Orientation	<i>N/A</i> : Photo-classified handlebar orientation (horizontal vs. vertical)	No	No	No
Bicycle	Cargo	<i>N/A</i> : Photo-classified cargo from the bicycle	No	No	No
Operational	Trial Type	<i>Binary</i> : Expected trial reaction or not	Yes	Yes	Yes
Operational	Speed	<i>Continuous</i> : Approach speed prior to braking	Yes	No	No
Operational	PRT	<i>Continuous</i> : Video-measured participant perception-reaction time	-	Yes	No
Operational	Average Deceleration	<i>N/A</i> : Analysis-determined average deceleration rate of the user	No	-	No

Category	Variable	Tested in model?			Rationale For Exclusion
		PRT	Avg Accel	SSD	
Personal	Gender	Yes	Yes	Yes	N/A – tested in all models
Personal	Age	Yes	Yes	Yes	N/A – tested in all models
Personal	Cycling Confidence	Yes	Yes	Yes	N/A – tested in all models
Personal	Cycling Frequency	No	No	No	Potential correlation to cycling confidence. Assumed response bias from participants.
Personal	Eye Height	Yes	Yes	Yes	Not anticipated to have a meaningful effect on PRT or Avg Accel, but was tested due to its direct influence on SSD
Bicycle	Bike Type	Yes	Yes	Yes	N/A – tested in all models
Bicycle	Brake Type	Yes	Yes	Yes	N/A – tested in all models
Bicycle	Handlebar Orientation	No	No	No	Correlation to Bicycle Type, since classification was determined based on handlebar orientation
Bicycle	Cargo	No	No	No	Complex, requires further classification to categorize into bins. Not assumed to have a meaningful effect on the expected-unexpected relationship
Operational	Trial Type	Yes	Yes	Yes	N/A – tested in all models
Operational	Speed	Yes	No	No	AvgAccel here was defined as the GPS Speed divided by the Braking Time, therefore could not be used as a predictor. Direct input to the SSD calculation
Operational	PRT	-	Yes	No	Direct input to the SSD calculation
Operational	Average Deceleration	No	-	No	Should be dependent on the PRT Direct input to the SSD calculation

## Appendix C: Sample Characteristics Table

Characteristic	UBC Sample (n=52)		Vancouver Sample (n=250)		Total Sample	
	<i>n</i>	%	<i>n</i>	%	<i>n</i>	%
<b>Gender</b>						
Man	29	56%	158	63%	187	62%
Woman	20	38%	87	35%	107	35%
Non-Binary	3	6%	5	2%	8	3%
<b>Age</b>						
Less than 15	1	2%	0	0%	1	0%
15 to 19	3	6%	7	3%	10	3%
20 to 24	10	19%	20	8%	30	10%
25 to 29	1	2%	19	8%	20	7%
30 to 34	5	10%	22	9%	27	9%
35 to 39	6	12%	22	9%	28	9%
40 to 44	4	8%	17	7%	21	7%
45 to 49	5	10%	20	8%	25	8%
50 to 54	1	2%	13	5%	14	5%
55 to 59	7	13%	24	10%	31	10%
60 to 64	5	10%	29	12%	34	11%
65 and over	4	8%	57	23%	61	20%
<b>Cycling Confidence</b>						
Strong and Fearless	17	33%	73	29%	90	30%
Enthusied and Confident	29	56%	160	64%	189	63%
Interested but concerned	6	12%	17	7%	23	8%
No Way No How	0	0%	0	0%	0	0%

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<b>Cycling Frequency (days per week)</b>						
0 days	0	0%	8	3%	8	3%
1 day	4	8%	15	6%	19	6%
2 days	5	10%	25	10%	30	10%
3 days	5	10%	35	14%	40	13%
4 days	14	27%	40	16%	54	18%
5+ days	24	46%	127	51%	151	50%

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## Appendix D: Demographic and Bicycle Data

Participant ID	Location (#)	Gender	Age (years)	Cycling Confidence <sup>1</sup>	Cycling Frequency (trips per week) <sup>2</sup>	Eye Height (cm)	Bike Type	Brake Type
1	UBC-1	Woman	40 to 44	Enthused and Confident	5 or more	157	Hybrid	Rim
2	UBC-1	Woman	30 to 34	Enthused and Confident	5 or more	150	Hybrid	Disc
3	UBC-1	Woman	65 and over	Interested but Concerned	5 or more	162	Cruiser	Rim
4	UBC-1	Man	40 to 44	Strong and Fearless	5 or more	169	Road	Disc
5	UBC-1	Woman	15 to 19	Enthused and Confident	4	166	Hybrid	Rim
6	UBC-1	Woman	60 to 64	Enthused and Confident	5 or more	159	Road	Disc
7	UBC-1	Woman	20 to 24	Enthused and Confident	3	164	Hybrid	Rim
8	UBC-1	Woman	30 to 34	Enthused and Confident	2	166	Hybrid	Rim
9	UBC-1	Man	65 and over	Strong and Fearless	4	150	Hybrid	Disc
10	UBC-1	Man	35 to 39	Strong and Fearless	5 or more	167	Hybrid	Disc
11	UBC-1	Man	Less than 15	Enthused and Confident	4	151	Mountain	Disc
12	UBC-1	Man	20 to 24	Strong and Fearless	4	164	Hybrid	Rim
13	UBC-1	Man	55 to 59	Strong and Fearless	5 or more	165	Hybrid	Rim
14	UBC-1	Man	20 to 24	Enthused and Confident	4	168	Road	Rim
15	UBC-1	Woman	15 to 19	Enthused and Confident	5 or more	168	Mountain	Rim
16	UBC-1	Non-binary	45 to 49	Interested but Concerned	4	153	Road	Rim
17	UBC-1	Man	65 and over	Enthused and Confident	4	166	Road	Disc
18	UBC-1	Woman	20 to 24	Interested but Concerned	3	161	Hybrid	Rim
19	UBC-1	Man	30 to 34	Strong and Fearless	5 or more	160	Road	Disc
20	UBC-1	Man	55 to 59	Enthused and Confident	5 or more	163	Hybrid	Rim
21	UBC-1	Woman	60 to 64	Enthused and Confident	3	163	Cruiser	Disc
22	UBC-1	Woman	20 to 24	Enthused and Confident	5 or more	149	Hybrid	Rim
23	UBC-1	Woman	60 to 64	Enthused and Confident	4	157	Cruiser	Drum
24	UBC-1	Woman	65 and over	Enthused and Confident	4	143	Hybrid	Disc
25	UBC-1	Man	55 to 59	Strong and Fearless	5 or more	141	Road	Disc
26	UBC-1	Woman	20 to 24	Enthused and Confident	1	153	Hybrid	Rim
27	UBC-1	Man	55 to 59	Enthused and Confident	5 or more	157	Hybrid	Disc
28	UBC-1	Man	55 to 59	Enthused and Confident	5 or more	157	Hybrid	Disc
29	UBC-1	Woman	45 to 49	Enthused and Confident	2	144	Mountain	Disc
30	UBC-1	Woman	40 to 44	Enthused and Confident	4	153	Hybrid	Disc
31	UBC-1	Man	20 to 24	Enthused and Confident	2	151	Road	Rim
32	UBC-1	Man	35 to 39	Strong and Fearless	5 or more	154	Road	Rim
33	UBC-1	Man	45 to 49	Enthused and Confident	5 or more	174	Road	Disc
34	UBC-1	Man	30 to 34	Interested but Concerned	1	166	Hybrid	Rim
35	UBC-1	Man	50 to 54	Strong and Fearless	5 or more	152	Hybrid	Disc
36	UBC-1	Man	45 to 49	Interested but Concerned	1	156	Hybrid	Rim
37	UBC-1	Man	20 to 24	Enthused and Confident	2	152	Hybrid	Rim
38	UBC-1	Woman	35 to 39	Enthused and Confident	5 or more	155	Hybrid	Disc

39	UBC-1	Non-binary	20 to 24	Enthused and Confident	5 or more	139	Hybrid	Rim
40	UBC-1	Woman	35 to 39	Enthused and Confident	5 or more	152	Hybrid	Disc
41	UBC-1	Man	55 to 59	Strong and Fearless	3	169	Road	Rim
42	UBC-1	Man	40 to 44	Enthused and Confident	3	162	Road	Disc
43	UBC-1	Man	25 to 29	Enthused and Confident	5 or more	162	Road	Disc
44	UBC-1	Man	20 to 24	Strong and Fearless	4	162	Road	Rim
45	UBC-1	Man	15 to 19	Interested but Concerned	1	143	Other	Rim
46	UBC-1	Man	45 to 49	Strong and Fearless	4	157	Road	Disc
47	UBC-1	Woman	35 to 39	Strong and Fearless	4	160	Road	Disc
48	UBC-1	Man	30 to 34	Enthused and Confident	2	165	Hybrid	Disc
49	UBC-1	Woman	55 to 59	Strong and Fearless	5 or more	167	Other	Rim
50	UBC-1	Man	60 to 64	Strong and Fearless	4	156	Road	Rim
51	UBC-1	Non-binary	35 to 39	Strong and Fearless	5 or more	164	Road	Rim
52	UBC-1	Man	60 to 64	Strong and Fearless	5 or more	162	Road	Disc
53	VAN-2	Man	65 and over	Enthused and Confident	5 or more	163	Hybrid	Rim
54	VAN-2	Woman	65 and over	Enthused and Confident	4	151	Hybrid	Rim
55	VAN-2	Man	40 to 44	Strong and Fearless	5 or more	158	Other	Disc
56	VAN-2	Man	35 to 39	Enthused and Confident	0	163	Hybrid	Disc
57	VAN-2	Man	25 to 29	Strong and Fearless	5 or more	167	Road	Disc
58	VAN-2	Man	65 and over	Enthused and Confident	4	161	Hybrid	Rim
59	VAN-2	Man	65 and over	Strong and Fearless	5 or more	151	Hybrid	Rim
60	VAN-2	Man	20 to 24	Interested but Concerned	0	162	Hybrid	Disc
61	VAN-2	Man	35 to 39	Strong and Fearless	5 or more	160	Road	Rim
62	VAN-2	Man	65 and over	Enthused and Confident	5 or more	157	Hybrid	Disc
63	VAN-2	Man	30 to 34	Enthused and Confident	5 or more	161	Hybrid	Disc
64	VAN-2	Man	30 to 34	Enthused and Confident	2	160	Hybrid	Disc
65	VAN-2	Woman	35 to 39	Enthused and Confident	3	150	Hybrid	Rim
66	VAN-2	Man	65 and over	Enthused and Confident	3	155	Other	Disc
67	VAN-2	Man	35 to 39	Strong and Fearless	3	167	Other	Disc
68	VAN-2	Man	65 and over	Enthused and Confident	5 or more	147	Hybrid	Disc
69	VAN-2	Man	20 to 24	Strong and Fearless	5 or more	176	Mountain	Disc
70	VAN-2	Man	30 to 34	Enthused and Confident	5 or more	165	Hybrid	Disc
71	VAN-2	Man	20 to 24	Enthused and Confident	1	163	Hybrid	Disc
72	VAN-2	Man	15 to 19	Strong and Fearless	1	163	Cruiser	Drum
73	VAN-2	Man	20 to 24	Interested but Concerned	0	165	Cruiser	Disc
74	VAN-2	Man	55 to 59	Strong and Fearless	5 or more	160	Hybrid	Disc
75	VAN-2	Man	20 to 24	Enthused and Confident	4	141	Road	Rim
76	VAN-2	Man	65 and over	Enthused and Confident	4	144	Road	Rim
77	VAN-2	Woman	25 to 29	Enthused and Confident	5 or more	158	Other	Disc
78	VAN-2	Man	40 to 44	Interested but Concerned	4	160	Hybrid	Disc
79	VAN-2	Man	50 to 54	Strong and Fearless	5 or more	169	Road	Disc
80	VAN-2	Man	55 to 59	Enthused and Confident	5 or more	178	Cruiser	Disc

81	VAN-2	Man	65 and over	Interested but Concerned	4	155	Cruiser	Disc
82	VAN-2	Woman	55 to 59	Enthused and Confident	2	161	Hybrid	Rim
83	VAN-2	Man	65 and over	Enthused and Confident	3	162	Cruiser	Rim
84	VAN-2	Woman	55 to 59	Strong and Fearless	5 or more	143	Road	Rim
85	VAN-2	Woman	50 to 54	Enthused and Confident	5 or more	170	Hybrid	Disc
86	VAN-2	Man	55 to 59	Enthused and Confident	5 or more	154	Mountain	Rim
87	VAN-2	Woman	55 to 59	Enthused and Confident	2	156	Mountain	Disc
88	VAN-2	Woman	25 to 29	Enthused and Confident	3	158	Cruiser	Disc
89	VAN-2	Man	15 to 19	Strong and Fearless	4	141	Road	Rim
90	VAN-2	Man	35 to 39	Enthused and Confident	5 or more	154	Road	Rim
91	VAN-2	Woman	55 to 59	Enthused and Confident	3	167	Hybrid	Rim
92	VAN-2	Man	65 and over	Enthused and Confident	3	163	Hybrid	Rim
93	VAN-2	Woman	45 to 49	Enthused and Confident	4	158	Hybrid	Rim
94	VAN-2	Man	30 to 34	Enthused and Confident	2	160	Mountain	Disc
95	VAN-2	Woman	45 to 49	Strong and Fearless	5 or more	162	Hybrid	Disc
96	VAN-2	Woman	45 to 49	Enthused and Confident	2	168	Hybrid	Disc
97	VAN-2	Man	40 to 44	Enthused and Confident	5 or more	162	Hybrid	Disc
98	VAN-2	Woman	65 and over	Enthused and Confident	2	148	Cruiser	Rim
99	VAN-2	Man	35 to 39	Strong and Fearless	4	165	Road	Rim
100	VAN-2	Woman	45 to 49	Enthused and Confident	3	160	Hybrid	Disc
101	VAN-2	Man	65 and over	Enthused and Confident	1	157	Hybrid	Rim
102	VAN-2	Man	35 to 39	Strong and Fearless	0	168	Hybrid	Disc
103	VAN-2	Man	20 to 24	Enthused and Confident	0	161	Hybrid	Disc
104	VAN-2	Man	65 and over	Strong and Fearless	5 or more	177	Hybrid	Disc
105	VAN-2	Woman	60 to 64	Enthused and Confident	4	158	Hybrid	Rim
106	VAN-2	Man	65 and over	Enthused and Confident	5 or more	166	Hybrid	Rim
107	VAN-2	Man	35 to 39	Enthused and Confident	4	169	Hybrid	Disc
108	VAN-2	Woman	45 to 49	Enthused and Confident	3	148	Other	Disc
109	VAN-2	Non-binary	30 to 34	Strong and Fearless	5 or more	153	Road	Rim
110	VAN-2	Man	15 to 19	Strong and Fearless	4	167	Mountain	Disc
111	VAN-2	Man	30 to 34	Strong and Fearless	5 or more	171	Hybrid	Disc
112	VAN-2	Woman	35 to 39	Enthused and Confident	3	162	Hybrid	Disc
113	VAN-2	Woman	40 to 44	Enthused and Confident	5 or more	156	Hybrid	Rim
114	VAN-2	Man	45 to 49	Enthused and Confident	5 or more	160	Hybrid	Rim
115	VAN-2	Woman	25 to 29	Strong and Fearless	5 or more	149	Road	Rim
116	VAN-2	Woman	60 to 64	Enthused and Confident	4	154	Hybrid	Disc
117	VAN-2	Man	20 to 24	Enthused and Confident	4	171	Cruiser	Drum
118	VAN-2	Man	65 and over	Enthused and Confident	3	171	Hybrid	Disc
119	VAN-2	Woman	45 to 49	Enthused and Confident	5 or more	151	Hybrid	Disc
120	VAN-2	Woman	50 to 54	Enthused and Confident	5 or more	164	Hybrid	Rim
121	VAN-2	Woman	35 to 39	Enthused and Confident	2	173	Hybrid	Disc
122	VAN-2	Man	60 to 64	Enthused and Confident	5 or more	157	Hybrid	Disc

123	VAN-2	Man	15 to 19	Strong and Fearless	4	157	Hybrid	Disc
124	VAN-2	Man	20 to 24	Strong and Fearless	3	161	Hybrid	Disc
125	VAN-2	Man	20 to 24	Enthused and Confident	1	152	Hybrid	Rim
126	VAN-2	Woman	55 to 59	Interested but Concerned	5 or more	153	Hybrid	Rim
127	VAN-2	Man	30 to 34	Enthused and Confident	5 or more	162	Road	Disc
128	VAN-2	Man	40 to 44	Enthused and Confident	4	161	Road	Disc
129	VAN-2	Non-binary	30 to 34	Enthused and Confident	5 or more	168	Road	Disc
130	VAN-2	Man	40 to 44	Enthused and Confident	5 or more	163	Road	Disc
131	VAN-2	Man	55 to 59	Enthused and Confident	5 or more	167	Road	Disc
132	VAN-2	Man	20 to 24	Strong and Fearless	5 or more	143	Hybrid	Rim
133	VAN-2	Man	60 to 64	Enthused and Confident	3	153	Road	Rim
134	VAN-2	Man	60 to 64	Strong and Fearless	5 or more	161	Road	Disc
135	VAN-2	Man	65 and over	Enthused and Confident	1	158	Hybrid	Rim
136	VAN-2	Man	30 to 34	Strong and Fearless	5 or more	167	Road	Rim
137	VAN-2	Man	65 and over	Enthused and Confident	2	171	Hybrid	Rim
138	VAN-2	Man	60 to 64	Strong and Fearless	5 or more	164	Hybrid	Disc
139	VAN-2	Man	55 to 59	Enthused and Confident	5 or more	175	Hybrid	Disc
140	VAN-2	Man	65 and over	Enthused and Confident	5 or more	157	Hybrid	Disc
141	VAN-2	Man	65 and over	Enthused and Confident	2	179	Hybrid	Disc
142	VAN-2	Woman	65 and over	Enthused and Confident	0	164	Hybrid	Disc
143	VAN-2	Man	25 to 29	Enthused and Confident	5 or more	158	Hybrid	Disc
144	VAN-2	Man	60 to 64	Enthused and Confident	1	169	Hybrid	Disc
145	VAN-2	Woman	60 to 64	Enthused and Confident	5 or more	157	Other	Disc
146	VAN-2	Woman	35 to 39	Enthused and Confident	4	158	Road	Rim
147	VAN-2	Man	35 to 39	Interested but Concerned	0	169	Hybrid	Disc
148	VAN-2	Man	60 to 64	Strong and Fearless	3	170	Hybrid	Disc
149	VAN-2	Woman	55 to 59	Enthused and Confident	3	157	Hybrid	Rim
150	VAN-2	Woman	60 to 64	Enthused and Confident	5 or more	138	Hybrid	Rim
151	VAN-2	Man	60 to 64	Strong and Fearless	5 or more	170	Hybrid	Disc
152	VAN-2	Woman	60 to 64	Enthused and Confident	5 or more	160	Hybrid	Disc
153	VAN-2	Woman	55 to 59	Enthused and Confident	5 or more	149	Hybrid	Rim
154	VAN-2	Woman	65 and over	Strong and Fearless	4	162	Hybrid	Rim
155	VAN-2	Man	50 to 54	Enthused and Confident	5 or more	172	Road	Disc
156	VAN-2	Woman	55 to 59	Enthused and Confident	5 or more	145	Road	Disc
157	VAN-2	Man	20 to 24	Enthused and Confident	3	159	Hybrid	Rim
158	VAN-2	Man	55 to 59	Enthused and Confident	5 or more	175	Cruiser	Disc
159	VAN-2	Man	40 to 44	Enthused and Confident	5 or more	162	Road	Disc
160	VAN-2	Man	30 to 34	Strong and Fearless	5 or more	152	Road	Disc
161	VAN-2	Man	60 to 64	Strong and Fearless	4	158	Road	Rim
162	VAN-2	Woman	25 to 29	Enthused and Confident	5 or more	152	Road	Rim
163	VAN-2	Man	65 and over	Enthused and Confident	4	163	Hybrid	Rim
164	VAN-2	Woman	65 and over	Enthused and Confident	5 or more	154	Mountain	Disc

165	VAN-2	Man	65 and over	Enthused and Confident	3	160	Hybrid	Disc
166	VAN-2	Man	30 to 34	Enthused and Confident	4	152	Road	Rim
167	VAN-2	Woman	65 and over	Interested but Concerned	3	150	Hybrid	Rim
168	VAN-2	Man	65 and over	Enthused and Confident	2	166	Road	Disc
169	VAN-2	Man	40 to 44	Enthused and Confident	5 or more	165	Hybrid	Rim
170	VAN-2	Man	60 to 64	Enthused and Confident	5 or more	160	Hybrid	Rim
171	VAN-2	Woman	30 to 34	Enthused and Confident	5 or more	150	Hybrid	Disc
172	VAN-2	Man	65 and over	Enthused and Confident	4	161	Hybrid	Rim
173	VAN-2	Woman	50 to 54	Enthused and Confident	2	151	Hybrid	Disc
174	VAN-2	Man	25 to 29	Enthused and Confident	5 or more	172	Hybrid	Rim
175	VAN-2	Man	40 to 44	Strong and Fearless	5 or more	157	Cruiser	Rim
176	VAN-2	Man	65 and over	Strong and Fearless	5 or more	159	Road	Disc
177	VAN-2	Man	65 and over	Enthused and Confident	5 or more	151	Hybrid	Rim
178	VAN-2	Man	20 to 24	Enthused and Confident	2	155	Road	Disc
179	VAN-2	Woman	65 and over	Enthused and Confident	1	158	Road	Rim
180	VAN-2	Man	65 and over	Enthused and Confident	5 or more	173	Hybrid	Rim
181	VAN-2	Woman	60 to 64	Enthused and Confident	4	162	Hybrid	Disc
182	VAN-2	Man	20 to 24	Strong and Fearless	5 or more	159	Road	Rim
183	VAN-2	Woman	65 and over	Enthused and Confident	2	162	Hybrid	Rim
184	VAN-2	Man	65 and over	Enthused and Confident	5 or more	164	Hybrid	Disc
185	VAN-2	Woman	25 to 29	Interested but Concerned	1	171	Hybrid	Rim
186	VAN-2	Woman	45 to 49	Enthused and Confident	5 or more	152	Hybrid	Rim
187	VAN-2	Man	35 to 39	Enthused and Confident	5 or more	153	Road	Disc
188	VAN-2	Man	60 to 64	Strong and Fearless	2	171	Hybrid	Disc
189	VAN-2	Man	65 and over	Enthused and Confident	3	165	Hybrid	Disc
190	VAN-2	Man	50 to 54	Enthused and Confident	5 or more	156	Road	Rim
191	VAN-2	Woman	65 and over	Enthused and Confident	3	163	Hybrid	Rim
192	VAN-2	Man	65 and over	Enthused and Confident	5 or more	164	Hybrid	Rim
193	VAN-2	Man	35 to 39	Strong and Fearless	5 or more	168	Hybrid	Disc
194	VAN-2	Woman	25 to 29	Enthused and Confident	5 or more	147	Hybrid	Disc
195	VAN-2	Woman	60 to 64	Enthused and Confident	5 or more	153	Cruiser	Disc
196	VAN-2	Man	35 to 39	Enthused and Confident	3	168	Hybrid	Disc
197	VAN-2	Man	35 to 39	Enthused and Confident	5 or more	162	Hybrid	Rim
198	VAN-2	Man	25 to 29	Enthused and Confident	2	159	Hybrid	Disc
199	VAN-2	Woman	25 to 29	Enthused and Confident	4	149	Hybrid	Rim
200	VAN-2	Man	60 to 64	Enthused and Confident	5 or more	167	Hybrid	Disc
201	VAN-2	Woman	45 to 49	Interested but Concerned	1	148	Cruiser	Disc
202	VAN-2	Man	40 to 44	Interested but Concerned	5 or more	168	Cruiser	Disc
203	VAN-2	Man	65 and over	Strong and Fearless	5 or more	164	Hybrid	Rim
204	VAN-2	Non-binary	60 to 64	Enthused and Confident	4	143	Road	Rim
205	VAN-2	Woman	50 to 54	Enthused and Confident	4	158	Cruiser	Disc
206	VAN-2	Man	65 and over	Enthused and Confident	5 or more	179	Hybrid	Rim

207	VAN-2	Man	30 to 34	Strong and Fearless	3	158	Mountain	Disc
208	VAN-2	Woman	30 to 34	Strong and Fearless	5 or more	151	Road	Rim
209	VAN-2	Man	20 to 24	Strong and Fearless	5 or more	169	Hybrid	Rim
210	VAN-2	Woman	55 to 59	Enthused and Confident	4	165	Hybrid	Rim
211	VAN-2	Woman	25 to 29	Strong and Fearless	2	158	Hybrid	Rim
212	VAN-2	Man	45 to 49	Strong and Fearless	5 or more	172	Hybrid	Disc
213	VAN-2	Man	50 to 54	Enthused and Confident	5 or more	152	Road	Disc
214	VAN-2	Man	60 to 64	Enthused and Confident	2	170	Cruiser	Disc
215	VAN-2	Man	45 to 49	Strong and Fearless	5 or more	162	Mountain	Disc
216	VAN-2	Man	40 to 44	Strong and Fearless	5 or more	144	Road	Disc
217	VAN-2	Woman	65 and over	Enthused and Confident	3	158	Cruiser	Disc
218	VAN-2	Woman	65 and over	Enthused and Confident	1	158	Cruiser	Rim
219	VAN-2	Man	20 to 24	Enthused and Confident	0	158	Hybrid	Disc
220	VAN-2	Man	55 to 59	Strong and Fearless	5 or more	163	Hybrid	Disc
221	VAN-2	Woman	60 to 64	Enthused and Confident	3	163	Hybrid	Disc
222	VAN-2	Man	40 to 44	Strong and Fearless	5 or more	157	Road	Disc
223	VAN-2	Woman	55 to 59	Interested but Concerned	2	144	Hybrid	Disc
224	VAN-2	Woman	65 and over	Interested but Concerned	4	163	Cruiser	Disc
225	VAN-2	Woman	55 to 59	Enthused and Confident	5 or more	161	Hybrid	Rim
226	VAN-2	Man	65 and over	Strong and Fearless	3	161	Mountain	Disc
227	VAN-2	Woman	60 to 64	Enthused and Confident	1	163	Hybrid	Disc
228	VAN-2	Woman	30 to 34	Enthused and Confident	5 or more	159	Road	Rim
229	VAN-2	Man	65 and over	Enthused and Confident	5 or more	169	Cruiser	Disc
230	VAN-2	Woman	45 to 49	Enthused and Confident	5 or more	145	Road	Rim
231	VAN-2	Man	35 to 39	Strong and Fearless	5 or more	169	Hybrid	Disc
232	VAN-2	Woman	20 to 24	Enthused and Confident	3	151	Hybrid	Disc
233	VAN-2	Man	30 to 34	Strong and Fearless	5 or more	164	Road	Rim
234	VAN-2	Woman	30 to 34	Enthused and Confident	5 or more	142	Road	Disc
235	VAN-2	Woman	40 to 44	Interested but Concerned	2	168	Hybrid	Rim
236	VAN-2	Non-binary	35 to 39	Strong and Fearless	3	159	Hybrid	Rim
237	VAN-2	Woman	60 to 64	Enthused and Confident	4	163	Hybrid	Rim
238	VAN-2	Man	25 to 29	Strong and Fearless	5 or more	162	Hybrid	Rim
239	VAN-2	Man	50 to 54	Enthused and Confident	5 or more	172	Hybrid	Disc
240	VAN-3	Woman	45 to 49	Interested but Concerned	2	156	Hybrid	Disc
241	VAN-3	Man	40 to 44	Strong and Fearless	2	149	Road	Disc
242	VAN-3	Man	40 to 44	Enthused and Confident	5 or more	159	Hybrid	Disc
243	VAN-3	Woman	60 to 64	Enthused and Confident	5 or more	153	Hybrid	Rim
244	VAN-3	Man	30 to 34	Enthused and Confident	5 or more	152	Road	Rim
245	VAN-3	Woman	50 to 54	Enthused and Confident	5 or more	152	Hybrid	Rim
246	VAN-3	Woman	50 to 54	Enthused and Confident	1	159	Hybrid	Disc
247	VAN-3	Man	65 and over	Enthused and Confident	5 or more	152	Mountain	Rim
248	VAN-3	Man	25 to 29	Strong and Fearless	5 or more	151	Road	Rim

249	VAN-3	Woman	15 to 19	Enthused and Confident	5 or more	146	Hybrid	Disc
250	VAN-3	Man	15 to 19	Interested but Concerned	5 or more	155	Hybrid	Rim
251	VAN-3	Woman	60 to 64	Enthused and Confident	5 or more	157	Cruiser	Disc
252	VAN-3	Man	20 to 24	Strong and Fearless	5 or more	146	Road	Rim
253	VAN-3	Woman	25 to 29	Enthused and Confident	3	149	Road	Disc
254	VAN-3	Non-binary	55 to 59	Strong and Fearless	5 or more	165	Cruiser	Drum
255	VAN-3	Man	35 to 39	Strong and Fearless	5 or more	153	Road	Disc
256	VAN-3	Man	65 and over	Enthused and Confident	5 or more	154	Road	Rim
257	VAN-3	Man	35 to 39	Enthused and Confident	3	159	Hybrid	Rim
258	VAN-3	Man	45 to 49	Enthused and Confident	2	160	Road	Disc
259	VAN-3	Man	45 to 49	Enthused and Confident	4	149	Hybrid	Disc
260	VAN-3	Man	65 and over	Enthused and Confident	4	157	Road	Rim
261	VAN-3	Man	65 and over	Enthused and Confident	4	160	Road	Disc
262	VAN-3	Man	65 and over	Strong and Fearless	4	169	Hybrid	Rim
263	VAN-3	Man	35 to 39	Strong and Fearless	5 or more	164	Road	Disc
264	VAN-3	Woman	65 and over	Strong and Fearless	5 or more	143	Hybrid	Disc
265	VAN-3	Man	20 to 24	Strong and Fearless	4	148	Hybrid	Disc
266	VAN-3	Woman	55 to 59	Enthused and Confident	3	165	Hybrid	Rim
267	VAN-3	Woman	20 to 24	Interested but Concerned	2	148	Hybrid	Disc
268	VAN-3	Man	60 to 64	Enthused and Confident	3	178	Hybrid	Disc
269	VAN-3	Man	65 and over	Strong and Fearless	5 or more	157	Hybrid	Disc
270	VAN-3	Woman	65 and over	Enthused and Confident	5 or more	148	Hybrid	Disc
271	VAN-3	Man	65 and over	Enthused and Confident	5 or more	156	Hybrid	Disc
272	VAN-3	Man	45 to 49	Strong and Fearless	5 or more	165	Hybrid	Disc
273	VAN-3	Woman	50 to 54	Enthused and Confident	3	158	Hybrid	Rim
274	VAN-3	Woman	55 to 59	Enthused and Confident	5 or more	168	Hybrid	Rim
275	VAN-3	Man	55 to 59	Strong and Fearless	4	160	Road	Rim
276	VAN-3	Man	65 and over	Enthused and Confident	1	154	Road	Rim
277	VAN-3	Man	60 to 64	Strong and Fearless	4	156	Hybrid	Disc
278	VAN-3	Man	65 and over	Enthused and Confident	2	157	Road	Disc
279	VAN-3	Woman	30 to 34	Enthused and Confident	5 or more	172	Other	Disc
280	VAN-3	Man	20 to 24	Interested but Concerned	1	154	Road	Rim
281	VAN-3	Man	25 to 29	Enthused and Confident	5 or more	160	Hybrid	Disc
282	VAN-3	Man	25 to 29	Enthused and Confident	4	164	Hybrid	Disc
283	VAN-3	Man	30 to 34	Strong and Fearless	5 or more	156	Road	Rim
284	VAN-3	Woman	65 and over	Enthused and Confident	3	162	-	-
285	VAN-3	Man	30 to 34	Strong and Fearless	3	171	Cruiser	Disc
286	VAN-3	Man	55 to 59	Strong and Fearless	5 or more	155	Hybrid	Disc
287	VAN-3	Man	55 to 59	Strong and Fearless	5 or more	155	Road	Disc
288	VAN-3	Man	15 to 19	Strong and Fearless	5 or more	165	Hybrid	Rim
289	VAN-3	Man	40 to 44	Strong and Fearless	1	170	Hybrid	Disc
290	VAN-3	Man	50 to 54	Enthused and Confident	5 or more	162	Hybrid	Disc

291	VAN-3	Man	65 and over	Enthused and Confident	4	152	Road	Rim
292	VAN-3	Woman	35 to 39	Strong and Fearless	4	159	Road	Rim
293	VAN-3	Man	25 to 29	Enthused and Confident	5 or more	153	Road	Disc
294	VAN-3	Man	45 to 49	Enthused and Confident	5 or more	153	Road	Disc
295	VAN-3	Woman	40 to 44	Enthused and Confident	3	156	Cruiser	Rim
296	VAN-3	Man	25 to 29	Enthused and Confident	5 or more	158	Hybrid	Disc
297	VAN-3	Woman	45 to 49	Enthused and Confident	2	147	Hybrid	Disc
298	VAN-3	Woman	60 to 64	Strong and Fearless	5 or more	158	Road	Rim
299	VAN-3	Man	45 to 49	Enthused and Confident	5 or more	163	Hybrid	Both
300	VAN-3	Woman	60 to 64	Strong and Fearless	5 or more	143	Road	Rim
301	VAN-3	Woman	45 to 49	Strong and Fearless	4	153	Hybrid	Disc
302	VAN-3	Woman	30 to 34	Enthused and Confident	5 or more	146	Road	Disc

<sup>1</sup> Self-identified cycling confidence assessed through the question: “Which description best describes your confidence as a bicyclist?” options provided: **Strong and Fearless**: will ride regardless of roadway conditions, **Enthused and Confident**: prefer biking on separated facilities, **Interested but Concerned**: hesitant to bike and require their own facilities, and **No Way No How**: will not ride a bicycle (Dill and McNeil, 2013)

<sup>2</sup> Question asked to participants: “How many days per week do you typically ride a bicycle in the summer months?”

## Appendix E: Operational Trial Data

Participant ID	Trial Type	Perception-Reaction Time (s)	Initial Speed (m/s)	Speed Check1	Average Deceleration (g)	Maximum Deceleration (g)	Braking Time (s)	Stopping Sight Distance (m)
1	Unexpected	0.82	3.84	Pass	-0.18	-0.26	2.27	4.04
1	Expected	0.55	NA	NA	NA	NA	1.17	NA
1	Expected	0.70	NA	NA	NA	NA	0.87	NA
2	Unexpected	0.78	5.08	Pass	-0.12	-0.21	4.18	9.41
2	Expected	0.48	NA	NA	NA	NA	1.3	NA
2	Expected	NA	NA	NA	NA	NA	NA	NA
3	Unexpected	0.85	3.36	Pass	-0.05	-0.18	7.1	9.51
3	Expected	0.35	NA	NA	NA	NA	1.27	NA
3	Expected	0.30	NA	NA	NA	NA	1.57	NA
4	Unexpected	0.45	6.82	Pass	-0.19	-0.37	2.18	10.31
4	Expected	0.05	NA	NA	NA	NA	1.87	NA
4	Expected	0.52	NA	NA	NA	NA	1.63	NA
5	Unexpected	1.15	3.47	Pass	-0.13	-0.25	2.7	4.69
5	Expected	0.28	NA	NA	NA	NA	1.57	NA
5	Expected	0.28	NA	NA	NA	NA	NA	NA
6	Unexpected	0.67	3.86	Pass	-0.17	-0.22	2.38	4.1
6	Expected	0.45	4.12	Pass	-0.29	-0.34	1.45	2.78
6	Expected	0.28	4.36	Fail	-0.18	-0.23	1.72	4.42
7	Unexpected	0.78	3.59	Pass	-0.13	-0.18	2.82	4.61
7	Expected	NA	NA	NA	NA	NA	NA	NA
7	Expected	0.30	4.43	Pass	-0.22	-0.27	2.1	3.81
8	Unexpected	0.85	3.53	Fail	-0.28	-0.34	1.7	2.55
8	Expected	0.32	4.48	Fail	-0.38	-0.46	1.65	2.43
8	Expected	0.37	4.42	Pass	-0.29	-0.35	1.55	3.05
9	Unexpected	0.85	NA	NA	NA	NA	NA	NA
9	Expected	0.17	6.58	Pass	-0.33	-0.5	1.97	5.37
9	Expected	NA	NA	NA	NA	NA	NA	NA
10	Unexpected	NA	NA	NA	NA	NA	NA	NA
10	Expected	0.25	5.37	Pass	-0.43	-0.57	1.25	2.96
10	Expected	0.43	NA	NA	NA	NA	NA	NA
11	Unexpected	NA	NA	NA	NA	NA	NA	NA
11	Expected	NA	NA	NA	NA	NA	NA	NA
11	Expected	NA	NA	NA	NA	NA	NA	NA
12	Unexpected	0.77	5.93	Pass	-0.29	-0.35	2.1	5.95
12	Expected	0.30	5.86	Pass	-0.35	-0.47	1.7	4.28
12	Expected	0.37	3.44	Pass	-0.21	-0.29	1.65	2.53
13	Unexpected	0.78	4.35	Pass	-0.33	-0.43	1.42	3.16
13	Expected	0.08	6.19	Fail	-0.28	-0.4	1.55	5.43

13	Expected	0.37	6.52	Fail	-0.33	-0.41	1.52	5.64
14	Unexpected	NA	NA	NA	NA	NA	NA	NA
14	Expected	0.62	6.1	Fail	-0.22	-0.3	2	7.58
14	Expected	0.03	NA	NA	NA	NA	NA	NA
15	Unexpected	0.90	5.29	Pass	-0.23	-0.35	2.33	6.02
15	Expected	NA	NA	NA	NA	NA	NA	NA
15	Expected	NA	NA	NA	NA	NA	NA	NA
16	Unexpected	0.72	NA	NA	NA	NA	3.28	NA
16	Expected	0.23	NA	NA	NA	NA	NA	NA
16	Expected	0.37	NA	NA	NA	NA	NA	NA
17	Unexpected	NA	NA	NA	NA	NA	NA	NA
17	Expected	NA	NA	NA	NA	NA	NA	NA
17	Expected	NA	NA	NA	NA	NA	NA	NA
18	Unexpected	0.67	NA	NA	NA	NA	2.25	NA
18	Expected	0.23	NA	NA	NA	NA	1.47	NA
18	Expected	0.35	NA	NA	NA	NA	1.2	NA
19	Unexpected	0.70	5.74	Pass	-0.37	-0.5	1.62	4.56
19	Expected	0.28	NA	NA	NA	NA	1.15	NA
19	Expected	0.17	NA	NA	NA	NA	1.45	NA
20	Unexpected	0.65	2.28	Fail	-0.41	-0.59	1.53	0.9
20	Expected	0.28	NA	NA	NA	NA	NA	NA
20	Expected	0.25	NA	NA	NA	NA	NA	NA
21	Unexpected	0.87	4.13	Pass	-0.31	-0.42	1.43	3.12
21	Expected	0.50	3.94	Fail	-0.25	-0.33	0.92	2.95
21	Expected	0.30	4.03	Pass	-0.33	-0.43	1.22	2.24
22	Unexpected	0.60	2.73	Pass	-0.11	-0.19	2.4	3.07
22	Expected	0.38	6.07	Pass	-0.31	-0.41	2	5.24
22	Expected	0.52	4.87	Pass	-0.21	-0.26	2.37	5.06
23	Unexpected	0.95	3.75	Pass	-0.16	-0.23	2.43	4.38
23	Expected	NA	NA	NA	NA	NA	NA	NA
23	Expected	0.17	5.08	Pass	-0.31	-0.4	1.67	3.45
24	Unexpected	0.80	3.51	Pass	-0.13	-0.2	2.8	4.44
24	Expected	0.87	3.07	Fail	-0.14	-0.16	0.6	3.34
24	Expected	0.27	4.64	Pass	-0.41	-0.51	1.12	2.37
25	Unexpected	0.67	4.39	Pass	-0.21	-0.27	2.12	4.36
25	Expected	0.37	4.04	Pass	-0.33	-0.45	1.22	2.32
25	Expected	0.35	4.51	Pass	-0.37	-0.46	1.25	2.56
26	Unexpected	0.88	4.21	Pass	-0.24	-0.29	1.8	3.89
26	Expected	0.62	4.46	Fail	-0.19	-0.28	1.05	4.81
26	Expected	0.45	4.82	Pass	-0.31	-0.4	1.58	3.5
27	Unexpected	0.83	4.96	Fail	-0.27	-0.47	2.4	4.67
27	Expected	0.22	4.54	Pass	-0.39	-0.59	1.15	2.31
27	Expected	0.98	3.62	Fail	-0.31	-0.36	0.47	2.62

28	Unexpected	0.77	5.15	Pass	-0.25	-0.35	2.1	5.2
28	Expected	0.28	3.83	Pass	-0.34	-0.43	1.18	1.97
28	Expected	0.43	2.94	Pass	-0.32	-0.41	0.98	1.4
29	Unexpected	0.45	NA	NA	NA	NA	NA	NA
29	Expected	0.45	NA	NA	NA	NA	NA	NA
29	Expected	0.32	NA	NA	NA	NA	NA	NA
30	Unexpected	0.72	NA	NA	NA	NA	1.72	NA
30	Expected	0.38	NA	NA	NA	NA	1.25	NA
30	Expected	0.35	NA	NA	NA	NA	1.28	NA
31	Unexpected	0.65	8.82	Pass	-0.33	-0.58	2.73	10.7
31	Expected	0.55	3.88	Pass	-0.42	-0.5	0.95	1.98
31	Expected	0.22	5.38	Pass	-0.18	-0.33	3	6.53
32	Unexpected	0.62	6.29	Pass	-0.38	-0.52	1.73	5.1
32	Expected	0.28	NA	NA	NA	NA	NA	NA
32	Expected	0.38	NA	NA	NA	NA	NA	NA
33	Unexpected	0.73	5.53	Pass	-0.23	-0.35	2.53	6.26
33	Expected	0.55	5.61	Pass	-0.39	-0.46	1.5	3.97
33	Expected	0.43	6.02	Fail	-0.3	-0.38	1.58	5.39
34	Unexpected	0.92	1.32	Fail	-0.06	-0.16	5.75	1.46
34	Expected	0.50	2.27	Pass	-0.15	-0.25	1.5	1.64
34	Expected	0.30	2.57	Pass	-0.18	-0.24	1.5	1.63
35	Unexpected	0.60	5.11	Fail	-0.08	-0.21	3.73	13.46
35	Expected	0.30	4.01	Pass	-0.27	-0.38	1.42	2.63
35	Expected	0.27	NA	NA	NA	NA	NA	NA
36	Unexpected	NA	NA	NA	NA	NA	NA	NA
36	Expected	0.62	4.52	Fail	-0.24	-0.28	1.4	4.06
36	Expected	0.30	4.66	Pass	-0.28	-0.38	1.62	3.38
37	Unexpected	0.43	6.05	Pass	-0.18	-0.38	3.42	8.58
37	Expected	0.25	4.75	Pass	-0.35	-0.48	1.32	2.82
37	Expected	0.63	2.54	Pass	-0.27	-0.31	1	1.37
38	Unexpected	0.42	4.55	Pass	-0.16	-0.22	2.93	5.52
38	Expected	0.23	3.81	Fail	-0.2	-0.26	1.32	3.05
38	Expected	0.30	4.38	Pass	-0.3	-0.38	1.48	2.84
39	Unexpected	0.55	5.24	Fail	-0.19	-0.24	2.18	6.38
39	Expected	0.28	4.27	Pass	-0.26	-0.31	1.7	3.04
39	Expected	NA	NA	NA	NA	NA	NA	NA
40	Unexpected	NA	NA	NA	NA	NA	NA	NA
40	Expected	0.42	4.73	Fail	-0.31	-0.38	1.13	3.34
40	Expected	0.85	4.46	Fail	-0.37	-0.48	0.87	3.13
41	Unexpected	0.50	4.85	Fail	-0.26	-0.5	3.2	4.17
41	Expected	0.12	NA	NA	NA	NA	NA	NA
41	Expected	0.48	NA	NA	NA	NA	NA	NA
42	Unexpected	0.87	3.33	Pass	-0.13	-0.18	2.7	4.1

42	Expected	NA	NA	NA	NA	NA	NA	NA
42	Expected	NA	NA	NA	NA	NA	NA	NA
43	Unexpected	0.73	4.11	Pass	-0.17	-0.24	2.5	4.68
43	Expected	0.40	4.42	Pass	-0.24	-0.4	1.82	3.64
43	Expected	0.25	4.4	Fail	-0.17	-0.27	1.63	4.7
44	Unexpected	0.80	4.66	Fail	-0.4	-0.56	1.53	3.13
44	Expected	NA	NA	NA	NA	NA	NA	NA
44	Expected	0.37	NA	NA	NA	NA	NA	NA
45	Unexpected	0.43	4.82	Pass	-0.24	-0.34	2.12	4.32
45	Expected	0.22	4.63	Fail	-0.15	-0.25	2.38	5.8
45	Expected	0.23	3.93	Pass	-0.17	-0.28	2.22	3.76
46	Unexpected	0.90	6.24	Fail	-0.27	-0.38	1.98	7.13
46	Expected	0.57	4.5	Fail	-0.22	-0.31	1.6	4.26
46	Expected	0.68	4.28	Pass	-0.26	-0.38	1.65	3.53
47	Unexpected	0.62	4.38	Pass	-0.24	-0.4	1.9	3.84
47	Expected	0.18	4.8	Pass	-0.43	-0.49	1.15	2.31
47	Expected	0.32	2.93	Pass	-0.28	-0.4	1.07	1.44
48	Unexpected	0.67	3.91	Fail	-0.14	-0.27	1.85	4.94
48	Expected	0.23	4.29	Pass	-0.34	-0.45	1.27	2.37
48	Expected	0.47	3.91	Pass	-0.54	-0.7	0.73	1.6
49	Unexpected	0.90	4.13	Pass	-0.1	-0.27	4.03	7.62
49	Expected	0.45	2.95	Fail	-0.36	-0.46	1.15	1.3
49	Expected	NA	NA	NA	NA	NA	NA	NA
50	Unexpected	0.65	6.26	Pass	-0.23	-0.38	2.7	7.71
50	Expected	0.57	4.32	Pass	-0.41	-0.51	1.03	2.44
50	Expected	0.17	4.4	Pass	-0.35	-0.48	1.25	2.34
51	Unexpected	0.82	4.92	Pass	-0.18	-0.32	2.73	6.31
51	Expected	NA	NA	NA	NA	NA	NA	NA
51	Expected	0.55	3.05	Fail	-0.31	-0.39	1.72	1.63
52	Unexpected	NA	NA	NA	NA	NA	NA	NA
52	Expected	0.63	5.36	Fail	-0.24	-0.32	0.92	5.57
52	Expected	0.75	4.38	Fail	-0.4	-0.45	0.9	2.77
53	Expected	0.37	3.3	Fail	-0.18	-0.2	0.83	2.67
53	Expected	0.25	3.12	Pass	-0.33	-0.41	0.98	1.36
53	Expected	0.32	2.7	Pass	-0.32	-0.39	0.82	1.12
54	Expected	0.25	NA	NA	NA	NA	NA	NA
54	Expected	0.35	NA	NA	NA	NA	NA	NA
54	Expected	0.43	NA	NA	NA	NA	NA	NA
55	Expected	NA	NA	NA	NA	NA	NA	NA
55	Expected	NA	NA	NA	NA	NA	NA	NA
55	Expected	NA	NA	NA	NA	NA	NA	NA
56	Expected	0.42	2.4	Pass	-0.18	-0.22	1.33	1.51
56	Expected	0.28	2.66	Pass	-0.25	-0.33	1.02	1.3

56	Expected	0.43	NA	NA	NA	NA	NA	NA
57	Expected	0.20	3.49	Pass	-0.33	-0.44	1.02	1.62
57	Expected	0.27	4.06	Fail	-0.35	-0.47	1.5	2.12
57	Expected	0.42	3.13	Pass	-0.3	-0.4	1.07	1.62
58	Expected	0.23	3.94	Fail	-0.35	-0.41	0.82	1.97
58	Expected	0.25	3.56	Pass	-0.38	-0.44	0.98	1.54
58	Expected	0.17	3.91	Fail	-0.4	-0.46	0.58	1.66
59	Expected	0.15	5.04	Pass	-0.35	-0.47	1.48	3.01
59	Expected	0.22	5.12	Pass	-0.25	-0.4	2.07	4.36
59	Expected	0.18	4.29	Pass	-0.2	-0.29	2.13	3.77
60	Expected	NA	NA	NA	NA	NA	NA	NA
60	Expected	NA	NA	NA	NA	NA	NA	NA
60	Expected	NA	NA	NA	NA	NA	NA	NA
61	Expected	0.55	4.66	Pass	-0.37	-0.54	1.25	2.98
61	Expected	0.52	5.9	Pass	-0.38	-0.49	1.52	4.39
61	Expected	0.20	4.61	Fail	-0.24	-0.48	2.48	3.68
62	Expected	0.30	NA	NA	NA	NA	NA	NA
62	Expected	0.22	NA	NA	NA	NA	NA	NA
62	Expected	0.17	NA	NA	NA	NA	NA	NA
63	Expected	0.18	3.61	Fail	-0.29	-0.51	1.82	1.92
63	Expected	0.05	3.99	Pass	-0.34	-0.44	1.2	1.86
63	Expected	0.37	4.54	Pass	-0.33	-0.54	1.32	2.88
64	Expected	0.20	NA	NA	NA	NA	NA	NA
64	Expected	0.43	NA	NA	NA	NA	NA	NA
64	Expected	0.35	3.52	Pass	-0.24	-0.35	1.47	2.34
65	Expected	0.23	5.44	Pass	-0.29	-0.52	1.85	4.29
65	Expected	0.18	4.4	Pass	-0.28	-0.4	1.58	2.89
65	Expected	0.23	4.08	Fail	-0.36	-0.51	1.5	2.05
66	Expected	0.28	2.55	Pass	-0.15	-0.25	1.67	1.88
66	Expected	0.68	NA	NA	NA	NA	NA	NA
66	Expected	0.77	NA	NA	NA	NA	NA	NA
67	Expected	0.25	3.09	Pass	-0.43	-0.49	0.8	1.07
67	Expected	0.33	4.13	Pass	-0.44	-0.54	0.92	1.88
67	Expected	0.17	3.38	Pass	-0.41	-0.49	0.83	1.23
68	Expected	0.28	3.98	Fail	-0.15	-0.28	1.33	4.39
68	Expected	0.62	4.02	Pass	-0.25	-0.38	1.57	3.19
68	Expected	0.48	NA	NA	NA	NA	NA	NA
69	Expected	0.35	6.89	Fail	-0.62	-0.94	1.48	3.63
69	Expected	0.43	5.31	Fail	-0.63	-0.99	1.4	2.37
69	Expected	0.28	3.61	Fail	-0.43	-0.67	1.83	1.45
70	Expected	0.57	4.13	Pass	-0.31	-0.4	1.38	2.78
70	Expected	0.25	3.96	Pass	-0.29	-0.37	1.37	2.36
70	Expected	0.27	3.61	Pass	-0.29	-0.42	1.23	2

71	Expected	0.12	3.23	Fail	-0.19	-0.27	1.05	2.23
71	Expected	0.15	3.19	Pass	-0.25	-0.42	1.27	1.71
71	Expected	0.17	3.17	Pass	-0.34	-0.4	0.93	1.29
72	Expected	0.35	2.74	Pass	-0.24	-0.32	1.18	1.47
72	Expected	0.17	2.8	Pass	-0.24	-0.32	1.12	1.39
72	Expected	0.42	2.5	Pass	-0.17	-0.27	1.42	1.71
73	Expected	0.32	3.76	Fail	-0.26	-0.33	0.93	2.43
73	Expected	NA	NA	NA	NA	NA	NA	NA
73	Expected	0.35	3.72	Pass	-0.26	-0.34	1.5	2.42
74	Expected	0.23	3.47	Fail	-0.13	-0.2	1.57	3.8
74	Expected	0.30	NA	NA	NA	NA	NA	NA
74	Expected	0.35	NA	NA	NA	NA	NA	NA
75	Expected	0.38	3.9	Pass	-0.31	-0.45	1.22	2.31
75	Expected	0.55	4.66	Pass	-0.32	-0.46	1.47	3.33
75	Expected	0.37	3.55	Pass	-0.23	-0.32	1.57	2.48
76	Expected	0.55	4.8	Pass	-0.31	-0.45	1.6	3.6
76	Expected	0.18	3.59	Fail	-0.3	-0.45	1.53	1.84
76	Expected	0.35	5.1	Pass	-0.35	-0.54	1.43	3.37
77	Expected	0.25	3.15	Pass	-0.18	-0.28	1.72	2.35
77	Expected	0.10	2.97	Pass	-0.2	-0.29	1.48	1.79
77	Expected	0.17	2.62	Pass	-0.18	-0.23	1.43	1.59
78	Expected	0.18	NA	NA	NA	NA	NA	NA
78	Expected	0.15	4.63	Pass	-0.34	-0.47	1.37	2.63
78	Expected	0.53	4.23	Fail	-0.6	-0.79	1.03	1.78
79	Expected	0.57	3.53	Fail	-0.27	-0.32	0.85	2.34
79	Expected	0.17	3.92	Fail	-0.23	-0.3	0.95	2.76
79	Expected	0.07	3.83	Pass	-0.26	-0.37	1.5	2.25
80	Expected	0.08	4.04	Fail	-0.26	-0.36	1.15	2.52
80	Expected	0.27	4.51	Fail	-0.35	-0.46	0.95	2.58
80	Expected	0.48	3.79	Pass	-0.41	-0.48	0.97	1.86
81	Expected	0.33	2.09	Fail	-0.13	-0.15	0.65	1.49
81	Expected	0.22	3.13	Fail	-0.24	-0.3	0.82	1.77
81	Expected	0.23	3.07	Fail	-0.19	-0.23	0.75	2.11
82	Expected	0.33	2.87	Pass	-0.21	-0.31	1.38	1.78
82	Expected	0.43	3.87	Pass	-0.27	-0.35	1.42	2.61
82	Expected	0.17	3.93	Pass	-0.34	-0.44	1.15	1.94
83	Expected	0.37	3.09	Pass	-0.25	-0.32	1.27	1.79
83	Expected	0.43	3.67	Pass	-0.29	-0.4	1.3	2.24
83	Expected	0.20	4.21	Pass	-0.31	-0.45	1.37	2.44
84	Expected	0.55	3.36	Pass	-0.25	-0.41	1.35	2.26
84	Expected	0.37	3.39	Pass	-0.25	-0.3	1.4	2.12
84	Expected	0.10	3.36	Pass	-0.47	-0.6	0.78	1.02
85	Expected	0.17	3.59	Fail	-0.49	-0.74	1.03	1.18

85	Expected	0.30	3.24	Pass	-0.19	-0.39	1.62	2.4
85	Expected	0.17	3.56	Fail	-0.21	-0.36	1.12	2.5
86	Expected	0.13	3.69	Fail	-0.29	-0.5	1.85	1.95
86	Expected	0.03	3.17	Pass	-0.22	-0.35	1.43	1.79
86	Expected	0.10	NA	NA	NA	NA	NA	NA
87	Expected	0.27	2.16	Pass	-0.23	-0.3	1	0.94
87	Expected	0.70	2.35	Pass	-0.32	-0.37	0.72	1.12
87	Expected	0.28	3.14	Pass	-0.38	-0.49	0.87	1.25
88	Expected	0.43	2.96	Fail	-0.3	-0.34	0.63	1.48
88	Expected	0.08	3.05	Pass	-0.3	-0.35	1.02	1.27
88	Expected	NA	NA	NA	NA	NA	NA	NA
89	Expected	0.32	5.78	Pass	-0.4	-0.63	1.42	3.73
89	Expected	0.22	3.78	Fail	-0.4	-0.63	1.53	1.61
89	Expected	0.22	4.01	Pass	-0.24	-0.39	1.68	2.83
90	Expected	NA	NA	NA	NA	NA	NA	NA
90	Expected	0.35	3.58	Fail	-0.38	-0.53	1.27	1.65
90	Expected	NA	NA	NA	NA	NA	NA	NA
91	Expected	0.23	2.43	Pass	-0.16	-0.26	1.48	1.58
91	Expected	0.48	2.72	Pass	-0.22	-0.35	1.28	1.66
91	Expected	0.25	2.14	Pass	-0.21	-0.27	1.03	0.99
92	Expected	0.22	3.4	Fail	-0.49	-0.6	0.93	1.12
92	Expected	0.35	2.63	Fail	-0.28	-0.31	0.58	1.21
92	Expected	0.18	2.96	Pass	-0.36	-0.42	0.88	1.09
93	Expected	0.27	3.53	Pass	-0.38	-0.47	0.95	1.53
93	Expected	0.30	3.08	Pass	-0.3	-0.39	1.08	1.48
93	Expected	0.25	3.94	Fail	-0.28	-0.35	0.97	2.42
94	Expected	0.05	NA	NA	NA	NA	NA	NA
94	Expected	0.12	NA	NA	NA	NA	NA	NA
94	Expected	0.10	3.07	Pass	-0.24	-0.4	1.3	1.6
95	Expected	NA	NA	NA	NA	NA	NA	NA
95	Expected	0.23	2.75	Pass	-0.3	-0.35	0.97	1.15
95	Expected	0.18	3.47	Fail	-0.24	-0.31	0.95	2.11
96	Expected	0.23	NA	NA	NA	NA	NA	NA
96	Expected	NA	NA	NA	NA	NA	NA	NA
96	Expected	0.07	4.04	Pass	-0.26	-0.34	1.52	2.5
97	Expected	0.30	4.73	Fail	-0.2	-0.42	3.15	4.71
97	Expected	0.53	3.99	Pass	-0.2	-0.38	1.98	3.67
97	Expected	0.32	4.44	Pass	-0.25	-0.48	1.73	3.44
98	Expected	0.78	NA	NA	NA	NA	NA	NA
98	Expected	0.33	3.92	Pass	-0.31	-0.44	1.3	2.28
98	Expected	0.42	3.89	Pass	-0.27	-0.35	1.43	2.62
99	Expected	0.25	4.23	Pass	-0.27	-0.46	1.52	2.85
99	Expected	0.17	4.05	Fail	-0.49	-0.76	1.45	1.48

99	Expected	0.35	3.9	Fail	-0.18	-0.33	1.07	3.64
100	Expected	0.30	2.72	Pass	-0.24	-0.31	1.17	1.42
100	Expected	0.75	2.49	Fail	-0.24	-0.29	0.62	1.52
100	Expected	0.23	3.28	Pass	-0.31	-0.41	1.08	1.55
101	Expected	0.35	3.05	Pass	-0.33	-0.42	0.95	1.39
101	Expected	0.17	3.03	Fail	-0.23	-0.27	0.82	1.68
101	Expected	0.30	3.36	Pass	-0.41	-0.49	0.83	1.34
102	Expected	0.30	2.68	Pass	-0.32	-0.38	0.9	1.09
102	Expected	NA	NA	NA	NA	NA	NA	NA
102	Expected	0.23	2.58	Pass	-0.22	-0.31	1.17	1.34
103	Expected	0.18	NA	NA	NA	NA	1.2	NA
103	Expected	0.17	NA	NA	NA	NA	0.85	NA
103	Expected	0.12	NA	NA	NA	NA	0.58	NA
104	Expected	0.27	4.12	Pass	-0.28	-0.39	1.48	2.65
104	Expected	0.17	NA	NA	NA	NA	NA	NA
104	Expected	0.45	4.35	Fail	-0.2	-0.27	1.32	4.2
105	Expected	0.13	2.99	Pass	-0.12	-0.21	2.43	2.99
105	Expected	0.17	NA	NA	NA	NA	NA	NA
105	Expected	NA	NA	NA	NA	NA	NA	NA
106	Expected	0.28	NA	NA	NA	NA	NA	NA
106	Expected	0.55	3.22	Pass	-0.19	-0.35	1.62	2.6
106	Expected	0.67	3.63	Fail	-0.28	-0.36	0.78	2.49
107	Expected	0.23	3.83	Pass	-0.53	-0.61	0.72	1.32
107	Expected	0.32	3.35	Pass	-0.32	-0.46	1.1	1.65
107	Expected	0.23	3.95	Fail	-0.26	-0.31	0.73	2.57
108	Expected	0.25	2.61	Pass	-0.13	-0.19	1.93	2.21
108	Expected	0.15	2.96	Pass	-0.28	-0.33	1.03	1.33
108	Expected	0.43	3.45	Fail	-0.23	-0.29	1.03	2.41
109	Expected	0.57	4.17	Fail	-0.29	-0.47	0.97	2.97
109	Expected	0.32	3.57	Fail	-0.34	-0.46	1.37	1.76
109	Expected	0.05	4.38	Fail	-0.22	-0.31	1.38	3.43
110	Expected	0.33	5.21	Pass	-0.56	-0.75	0.98	2.35
110	Expected	0.30	5.03	Fail	-0.42	-0.62	0.9	2.75
110	Expected	0.40	5.26	Pass	-0.63	-0.78	0.87	2.28
111	Expected	0.17	3.34	Fail	-0.2	-0.27	0.83	2.31
111	Expected	0.18	4.23	Pass	-0.45	-0.66	0.98	1.75
111	Expected	0.23	3.82	Pass	-0.52	-0.59	0.78	1.33
112	Expected	0.42	3.04	Fail	-0.34	-0.38	0.52	1.4
112	Expected	0.45	3.23	Pass	-0.31	-0.41	1.08	1.7
112	Expected	0.30	3.16	Fail	-0.12	-0.27	1.12	3.48
113	Expected	0.23	3.71	Fail	-0.3	-0.36	0.83	2.01
113	Expected	NA	NA	NA	NA	NA	NA	NA
113	Expected	NA	NA	NA	NA	NA	NA	NA

114	Expected	0.35	3.4	Fail	-0.39	-0.42	0.58	1.48
114	Expected	0.23	3.18	Pass	-0.39	-0.45	0.82	1.21
114	Expected	0.15	4.24	Pass	-0.41	-0.55	1.03	1.87
115	Expected	0.32	4.01	Pass	-0.32	-0.41	1.22	2.29
115	Expected	0.15	3.67	Pass	-0.25	-0.35	1.48	2.23
115	Expected	0.17	3.61	Fail	-0.22	-0.3	1.15	2.46
116	Expected	0.60	4.18	Pass	-0.4	-0.49	1.1	2.38
116	Expected	0.37	3.94	Pass	-0.42	-0.56	0.95	1.83
116	Expected	0.40	3.5	Pass	-0.37	-0.47	0.97	1.67
117	Expected	0.22	4.32	Pass	-0.3	-0.45	1.43	2.66
117	Expected	0.27	NA	NA	NA	NA	NA	NA
117	Expected	0.33	4.75	Pass	-0.21	-0.32	2.22	4.59
118	Expected	0.25	3.01	Pass	-0.19	-0.3	1.57	2.05
118	Expected	0.43	3	Pass	-0.16	-0.37	1.85	2.53
118	Expected	0.48	3.53	Fail	-0.16	-0.24	0.8	3.48
119	Expected	0.37	3.61	Pass	-0.38	-0.44	0.93	1.69
119	Expected	0.25	3.09	Pass	-0.25	-0.34	1.28	1.69
119	Expected	0.45	3.79	Pass	-0.36	-0.48	1.07	2.02
120	Expected	0.27	3.17	Pass	-0.2	-0.28	1.58	2.18
120	Expected	0.37	2.94	Fail	-0.32	-0.36	1.32	1.34
120	Expected	0.37	3.53	Pass	-0.34	-0.4	1.02	1.78
121	Expected	0.43	2.71	Pass	-0.26	-0.33	1.08	1.42
121	Expected	0.37	3.06	Pass	-0.23	-0.27	1.35	1.88
121	Expected	0.53	2.32	Pass	-0.19	-0.29	1.28	1.44
122	Expected	0.22	2.77	Pass	-0.29	-0.38	0.98	1.19
122	Expected	0.48	2.24	Pass	-0.21	-0.3	1.02	1.22
122	Expected	NA	NA	NA	NA	NA	NA	NA
123	Expected	NA	NA	NA	NA	NA	NA	NA
123	Expected	NA	NA	NA	NA	NA	NA	NA
123	Expected	NA	NA	NA	NA	NA	NA	NA
124	Expected	0.25	4.12	Pass	-0.44	-0.54	0.97	1.78
124	Expected	0.30	3.06	Fail	-0.46	-0.58	0.93	1.04
124	Expected	0.18	4.54	Pass	-0.44	-0.61	1.02	2.04
125	Expected	0.20	3.2	Pass	-0.24	-0.33	1.33	1.83
125	Expected	0.23	3.33	Pass	-0.23	-0.35	1.42	2.08
125	Expected	NA	NA	NA	NA	NA	NA	NA
126	Expected	0.15	3.2	Pass	-0.39	-0.44	0.87	1.15
126	Expected	0.22	3.39	Pass	-0.3	-0.39	1.2	1.68
126	Expected	0.08	3.79	Pass	-0.36	-0.51	1.02	1.63
127	Expected	0.25	4.06	Fail	-0.19	-0.28	1.13	3.63
127	Expected	0.43	3.9	Fail	-0.39	-0.46	0.65	1.98
127	Expected	0.17	3.85	Pass	-0.48	-0.54	0.85	1.37
128	Expected	NA	NA	NA	NA	NA	NA	NA

128	Expected	0.32	5.22	Pass	-0.36	-0.55	1.45	3.38
128	Expected	0.22	5.5	Pass	-0.35	-0.54	1.58	3.67
129	Expected	0.17	5.11	Pass	-0.31	-0.5	1.65	3.49
129	Expected	NA	5.1	Pass	-0.3	-0.49	1.67	NA
129	Expected	0.42	3.99	Fail	-0.43	-0.62	1.52	1.89
130	Expected	0.37	4.42	Pass	-0.24	-0.32	1.87	3.59
130	Expected	0.42	4.14	Pass	-0.3	-0.51	1.32	2.69
130	Expected	0.25	2.97	Fail	-0.4	-0.57	1.38	1.06
131	Expected	0.27	4.3	Pass	-0.26	-0.35	1.62	3.07
131	Expected	0.30	NA	NA	NA	NA	NA	NA
131	Expected	0.17	5.28	Pass	-0.3	-0.44	1.73	3.83
132	Expected	0.07	3.42	Fail	-0.25	-0.29	0.82	1.87
132	Expected	0.10	4.28	Pass	-0.3	-0.39	1.5	2.48
132	Expected	NA	NA	NA	NA	NA	NA	NA
133	Expected	NA	NA	NA	NA	NA	NA	NA
133	Expected	0.63	4.99	Fail	-0.25	-0.39	1.43	4.73
133	Expected	0.45	4.35	Pass	-0.23	-0.4	1.88	3.72
134	Expected	0.30	3.7	Fail	-0.37	-0.47	1.32	1.74
134	Expected	0.55	4.44	Fail	-0.28	-0.36	1.2	3.4
134	Expected	0.23	4.82	Pass	-0.34	-0.41	1.45	2.95
135	Expected	0.23	2.57	Fail	-0.29	-0.31	0.37	1.05
135	Expected	0.15	1.98	Pass	-0.38	-0.45	0.53	0.48
135	Expected	0.25	2.56	Pass	-0.31	-0.37	0.87	0.99
136	Expected	NA	3.92	Pass	-0.47	-0.56	0.85	NA
136	Expected	0.17	3.86	Pass	-0.37	-0.48	1.1	1.73
136	Expected	0.17	4.27	Fail	-0.33	-0.43	0.98	2.33
137	Expected	0.23	4.33	Fail	-0.42	-0.55	1.32	2
137	Expected	0.33	NA	NA	NA	NA	NA	NA
137	Expected	0.30	3.93	Fail	-0.53	-0.76	1.05	1.45
138	Expected	0.95	5.64	Pass	-0.36	-0.6	1.57	4.9
138	Expected	0.53	5.57	Fail	-0.32	-0.48	1.28	4.57
138	Expected	0.08	5.78	Pass	-0.35	-0.5	1.65	3.82
139	Expected	0.22	3.82	Pass	-0.36	-0.53	1.07	1.8
139	Expected	0.48	4.93	Fail	-0.31	-0.39	0.93	3.69
139	Expected	0.85	4.9	Pass	-0.43	-0.53	1.17	3.31
140	Expected	NA	NA	NA	NA	NA	NA	NA
140	Expected	NA	NA	NA	NA	NA	NA	NA
140	Expected	NA	NA	NA	NA	NA	NA	NA
141	Expected	0.63	3.46	Fail	-0.4	-0.45	0.53	1.77
141	Expected	0.28	3.82	Pass	-0.46	-0.55	0.85	1.53
141	Expected	0.25	3.38	Pass	-0.47	-0.56	0.75	1.17
142	Expected	0.43	2.51	Pass	-0.24	-0.32	1.02	1.32
142	Expected	0.43	2.52	Pass	-0.24	-0.31	1.07	1.33

142	Expected	0.30	2.86	Pass	-0.25	-0.38	1.18	1.5
143	Expected	0.27	4.74	Fail	-0.27	-0.35	0.93	3.57
143	Expected	0.15	3.86	Pass	-0.36	-0.46	1.07	1.76
143	Expected	0.53	4.59	Fail	-0.42	-0.51	0.65	2.62
144	Expected	0.45	NA	NA	NA	NA	NA	NA
144	Expected	NA	NA	NA	NA	NA	NA	NA
144	Expected	0.30	2.32	Fail	-0.22	-0.33	1.67	1.14
145	Expected	0.08	3.22	Pass	-0.26	-0.37	1.25	1.61
145	Expected	0.45	3.08	Pass	-0.3	-0.41	1.03	1.61
145	Expected	0.23	3.68	Pass	-0.25	-0.39	1.48	2.33
146	Expected	NA	NA	NA	NA	NA	NA	NA
146	Expected	0.30	2.8	Pass	-0.34	-0.44	0.87	1.12
146	Expected	0.30	3.13	Fail	-0.26	-0.28	0.78	1.72
147	Expected	0.22	2.95	Pass	-0.28	-0.44	1.08	1.38
147	Expected	0.30	3.27	Pass	-0.27	-0.38	1.22	1.8
147	Expected	0.40	3.36	Pass	-0.36	-0.44	0.92	1.58
148	Expected	0.22	3.36	Fail	-0.24	-0.31	0.98	2.02
148	Expected	0.23	2.77	Pass	-0.27	-0.36	1.02	1.28
148	Expected	0.17	2.97	Pass	-0.26	-0.34	1.15	1.45
149	Expected	0.27	3.62	Pass	-0.35	-0.47	1.08	1.71
149	Expected	0.38	3.31	Pass	-0.35	-0.44	0.92	1.56
149	Expected	0.10	3.34	Pass	-0.32	-0.4	1.03	1.44
150	Expected	0.32	3.86	Pass	-0.2	-0.32	1.98	3.22
150	Expected	0.45	3.55	Pass	-0.33	-0.49	1.08	1.92
150	Expected	0.18	3.88	Pass	-0.24	-0.36	1.68	2.62
151	Expected	0.15	3.55	Pass	-0.5	-0.6	0.78	1.12
151	Expected	NA	NA	NA	NA	NA	NA	NA
151	Expected	0.13	4.12	Fail	-0.3	-0.39	0.95	2.34
152	Expected	0.25	2.78	Fail	-0.24	-0.39	1.88	1.44
152	Expected	0.32	3.77	Fail	-0.24	-0.33	1.2	2.62
152	Expected	0.23	3.21	Pass	-0.28	-0.42	1.18	1.63
153	Expected	0.35	NA	NA	NA	NA	NA	NA
153	Expected	0.18	3.57	Pass	-0.2	-0.23	1.85	2.64
153	Expected	0.08	2.87	Pass	-0.16	-0.2	1.72	2.05
154	Expected	0.38	3.13	Pass	-0.27	-0.32	1.13	1.73
154	Expected	0.27	2.8	Pass	-0.21	-0.3	1.32	1.65
154	Expected	0.22	3	Pass	-0.24	-0.35	1.25	1.63
155	Expected	NA	NA	NA	NA	NA	NA	NA
155	Expected	0.10	4.4	Pass	-0.33	-0.47	1.32	2.39
155	Expected	0.37	5.15	Pass	-0.5	-0.58	1.07	2.57
156	Expected	0.57	3.48	Fail	-0.29	-0.33	0.9	2.16
156	Expected	0.15	3.23	Pass	-0.21	-0.32	1.58	2.05
156	Expected	NA	NA	NA	NA	NA	NA	NA

157	Expected	0.23	3	Fail	-0.29	-0.38	1.45	1.39
157	Expected	0.63	NA	NA	NA	NA	NA	NA
157	Expected	0.37	NA	NA	NA	NA	NA	NA
158	Expected	0.27	2.83	Pass	-0.28	-0.37	1.08	1.31
158	Expected	0.18	3.03	Pass	-0.22	-0.31	1.32	1.77
158	Expected	0.25	3.4	Pass	-0.33	-0.39	1.07	1.59
159	Expected	0.18	3.51	Pass	-0.28	-0.35	1.25	1.88
159	Expected	0.28	3.48	Fail	-0.33	-0.48	1.43	1.69
159	Expected	0.28	2.81	Fail	-0.33	-0.48	1.33	1.15
160	Expected	0.20	3.73	Pass	-0.37	-0.5	1.05	1.66
160	Expected	0.32	3.56	Pass	-0.26	-0.37	1.35	2.2
160	Expected	0.43	3.86	Fail	-0.28	-0.37	1	2.52
161	Expected	0.42	5.16	Fail	-0.25	-0.41	1.6	4.71
161	Expected	0.55	4.54	Fail	-0.12	-0.21	1.22	7.33
161	Expected	0.42	5.93	Fail	-0.21	-0.31	1.72	7.15
162	Expected	0.53	3.66	Fail	-0.29	-0.33	0.75	2.33
162	Expected	0.48	3.58	Pass	-0.31	-0.41	1.15	2.08
162	Expected	0.27	4.53	Fail	-0.14	-0.22	1.87	6
163	Expected	0.38	3.36	Pass	-0.16	-0.27	2.1	3.08
163	Expected	0.37	3.24	Pass	-0.15	-0.24	2.13	3.03
163	Expected	0.48	3.62	Pass	-0.23	-0.33	1.55	2.69
164	Expected	0.22	NA	NA	NA	NA	NA	NA
164	Expected	NA	NA	NA	NA	NA	NA	NA
164	Expected	NA	NA	NA	NA	NA	NA	NA
165	Expected	0.50	NA	NA	NA	NA	1.7	NA
165	Expected	0.23	NA	NA	NA	NA	1.85	NA
165	Expected	NA	NA	NA	NA	NA	NA	NA
166	Expected	0.40	3.3	Pass	-0.3	-0.38	1.17	1.77
166	Expected	0.60	5.13	Fail	-0.27	-0.32	0.93	4.62
166	Expected	0.28	5.08	Pass	-0.32	-0.6	1.52	3.51
167	Expected	0.33	2.66	Pass	-0.17	-0.29	1.55	1.85
167	Expected	0.55	3.13	Fail	-0.18	-0.24	1.03	2.58
167	Expected	0.22	3.3	Pass	-0.35	-0.44	0.93	1.4
168	Expected	0.38	2.44	Pass	-0.16	-0.21	1.52	1.7
168	Expected	0.23	3	Pass	-0.37	-0.43	0.88	1.13
168	Expected	0.10	2.78	Pass	-0.15	-0.23	1.97	2.07
169	Expected	0.17	3.86	Pass	-0.41	-0.49	0.93	1.58
169	Expected	0.17	3.98	Pass	-0.38	-0.5	1.08	1.79
169	Expected	0.55	3.53	Pass	-0.42	-0.5	0.88	1.69
170	Expected	0.42	4.53	Pass	-0.26	-0.31	1.75	3.57
170	Expected	0.22	NA	NA	NA	NA	NA	NA
170	Expected	0.57	4.76	Pass	-0.47	-0.62	1.08	2.61
171	Expected	0.30	2.74	Pass	-0.34	-0.41	0.88	1.08

171	Expected	0.50	2.59	Pass	-0.27	-0.35	0.98	1.32
171	Expected	0.23	3.3	Pass	-0.32	-0.41	1.08	1.53
172	Expected	0.25	3.42	Pass	-0.3	-0.4	1.18	1.74
172	Expected	NA	NA	NA	NA	NA	NA	NA
172	Expected	0.37	4.2	Pass	-0.31	-0.41	1.38	2.63
173	Expected	0.08	3.25	Fail	-0.12	-0.19	1.88	3.47
173	Expected	0.42	3.66	Pass	-0.35	-0.46	1.1	1.9
173	Expected	0.10	3.3	Pass	-0.25	-0.34	1.35	1.77
174	Expected	0.50	4.05	Pass	-0.32	-0.44	1.25	2.54
174	Expected	0.43	3.36	Pass	-0.32	-0.41	1.07	1.77
174	Expected	0.15	4.12	Fail	-0.22	-0.4	1.28	3.15
175	Expected	0.38	NA	NA	NA	NA	NA	NA
175	Expected	0.45	3.26	Pass	-0.26	-0.4	1.27	1.99
175	Expected	0.37	4.43	Fail	-0.19	-0.3	1.48	4.44
176	Expected	0.30	4.65	Pass	-0.34	-0.47	1.33	2.84
176	Expected	0.23	5.24	Pass	-0.37	-0.49	1.47	3.21
176	Expected	0.18	5.92	Pass	-0.41	-0.53	1.42	3.6
177	Expected	0.72	3.84	Fail	-0.27	-0.32	0.5	2.87
177	Expected	0.25	3.77	Fail	-0.12	-0.29	1.38	4.84
177	Expected	0.22	3.87	Fail	-0.13	-0.34	1.32	4.68
178	Expected	0.10	3.37	Pass	-0.29	-0.43	1.2	1.61
178	Expected	0.12	3.05	Pass	-0.36	-0.44	0.88	1.1
178	Expected	0.10	3.66	Fail	-0.39	-0.54	1.33	1.43
179	Expected	0.10	3.51	Pass	-0.24	-0.35	1.48	2.08
179	Expected	0.55	3.49	Fail	-0.24	-0.32	1	2.49
179	Expected	0.08	3.52	Pass	-0.26	-0.4	1.33	1.92
180	Expected	0.35	NA	NA	NA	NA	NA	NA
180	Expected	0.15	3.56	Fail	-0.27	-0.32	0.85	1.96
180	Expected	0.15	3.4	Pass	-0.36	-0.45	0.95	1.38
181	Expected	0.28	3	Pass	-0.26	-0.35	1.13	1.57
181	Expected	0.17	2.31	Pass	-0.25	-0.3	0.98	0.93
181	Expected	NA	NA	NA	NA	NA	NA	NA
182	Expected	0.38	4.01	Pass	-0.32	-0.53	1.28	2.37
182	Expected	0.35	3.83	Pass	-0.29	-0.42	1.37	2.33
182	Expected	0.32	3.48	Pass	-0.33	-0.51	1.1	1.72
183	Expected	0.58	3.1	Pass	-0.15	-0.28	2.03	2.98
183	Expected	0.43	NA	NA	NA	NA	NA	NA
183	Expected	0.43	3.4	Pass	-0.15	-0.2	2.4	3.39
184	Expected	0.45	4.01	Fail	-0.38	-0.57	1.52	2.14
184	Expected	0.37	4.32	Fail	-0.21	-0.32	1.43	3.87
184	Expected	0.25	4.7	Pass	-0.34	-0.51	1.35	2.84
185	Expected	0.22	3.59	Fail	-0.16	-0.25	1.02	3.33
185	Expected	0.10	2.82	Fail	-0.29	-0.32	0.65	1.14

185	Expected	0.17	2.99	Fail	-0.31	-0.34	0.68	1.25
186	Expected	0.28	3.56	Pass	-0.13	-0.17	2.75	4.05
186	Expected	0.25	3.01	Pass	-0.08	-0.1	3.85	4.58
186	Expected	0.42	3.42	Pass	-0.17	-0.25	2.1	3.05
187	Expected	0.38	4.37	Pass	-0.21	-0.37	2.03	3.98
187	Expected	0.63	3.91	Pass	-0.25	-0.35	1.53	3.05
187	Expected	0.55	4.54	Pass	-0.29	-0.39	1.52	3.44
188	Expected	0.23	3.81	Pass	-0.37	-0.43	1.07	1.76
188	Expected	0.50	3.34	Pass	-0.29	-0.43	1.13	1.95
188	Expected	0.28	4.24	Fail	-0.22	-0.33	1.38	3.49
189	Expected	0.55	3.59	Pass	-0.35	-0.45	1.05	1.97
189	Expected	0.62	3.62	Fail	-0.19	-0.32	0.9	3.28
189	Expected	0.18	3.98	Fail	-0.06	-0.22	1.65	10.4
190	Expected	0.83	3.2	Fail	-0.21	-0.26	1.43	2.62
190	Expected	0.37	3.25	Fail	-0.16	-0.23	1.07	2.88
190	Expected	0.62	3.5	Fail	-0.24	-0.26	0.52	2.57
191	Expected	0.55	2.58	Pass	-0.19	-0.27	1.32	1.75
191	Expected	0.15	2.43	Fail	-0.1	-0.14	1.15	2.38
191	Expected	0.15	2.46	Pass	-0.18	-0.27	1.38	1.4
192	Expected	0.23	2.84	Pass	-0.21	-0.29	1.37	1.67
192	Expected	0.32	NA	NA	NA	NA	NA	NA
192	Expected	0.57	3.66	Fail	-0.3	-0.33	0.77	2.3
193	Expected	0.17	2.34	Fail	-0.17	-0.19	0.68	1.35
193	Expected	0.15	3.84	Pass	-0.41	-0.48	0.95	1.55
193	Expected	NA	NA	NA	NA	NA	NA	NA
194	Expected	NA	NA	NA	NA	NA	NA	NA
194	Expected	0.22	4.18	Pass	-0.45	-0.57	0.93	1.75
194	Expected	0.10	4.43	Pass	-0.53	-0.7	0.88	1.55
195	Expected	0.30	3.14	Pass	-0.33	-0.42	0.98	1.42
195	Expected	0.70	NA	NA	NA	NA	NA	NA
195	Expected	0.42	4.07	Pass	-0.33	-0.47	1.23	2.41
196	Expected	0.22	2.67	Pass	-0.21	-0.27	1.23	1.47
196	Expected	0.10	3	Pass	-0.19	-0.27	1.57	1.91
196	Expected	0.23	2.73	Fail	-0.27	-0.38	1.65	1.24
197	Expected	0.25	3.54	Pass	-0.29	-0.39	1.25	1.91
197	Expected	0.18	3.31	Pass	-0.26	-0.36	1.23	1.8
197	Expected	0.12	3.81	Fail	-0.38	-0.53	1.43	1.6
198	Expected	0.18	2.87	Pass	-0.17	-0.24	1.63	2.02
198	Expected	0.57	2.89	Pass	-0.21	-0.33	1.33	1.99
198	Expected	0.10	2.85	Pass	-0.17	-0.27	1.63	1.92
199	Expected	0.18	3.15	Pass	-0.17	-0.23	1.85	2.41
199	Expected	0.28	3.32	Pass	-0.17	-0.25	1.92	2.77
199	Expected	0.28	3.48	Pass	-0.24	-0.33	1.48	2.22

200	Expected	0.33	NA	NA	NA	NA	0.6	NA
200	Expected	0.53	NA	NA	NA	NA	NA	NA
200	Expected	0.35	NA	NA	NA	NA	1.08	NA
201	Expected	0.28	2.78	Pass	-0.18	-0.25	1.53	1.88
201	Expected	0.22	3.06	Pass	-0.25	-0.32	1.3	1.63
201	Expected	0.30	2.93	Pass	-0.28	-0.35	1.02	1.43
202	Expected	0.53	4.09	Fail	-0.36	-0.41	0.62	2.4
202	Expected	0.42	3.42	Pass	-0.41	-0.48	0.82	1.5
202	Expected	0.45	3.9	Pass	-0.46	-0.59	0.85	1.76
203	Expected	0.23	3.88	Pass	-0.37	-0.51	1.07	1.82
203	Expected	0.10	3.66	Pass	-0.26	-0.34	1.43	2.09
203	Expected	0.42	4.27	Fail	-0.29	-0.37	0.95	2.92
204	Expected	NA	NA	NA	NA	NA	NA	NA
204	Expected	0.23	2.69	Fail	-0.25	-0.34	2.17	1.29
204	Expected	NA	NA	NA	NA	NA	NA	NA
205	Expected	0.40	3.97	Fail	-0.25	-0.31	0.58	2.88
205	Expected	0.10	3.11	Fail	-0.11	-0.19	0.97	3.48
205	Expected	0.12	3.65	Pass	-0.46	-0.57	0.83	1.24
206	Expected	NA	NA	NA	NA	NA	NA	NA
206	Expected	0.22	NA	NA	NA	NA	NA	NA
206	Expected	0.18	3.56	Pass	-0.21	-0.31	1.62	2.51
207	Expected	0.30	3.46	Fail	-0.28	-0.42	1.73	1.94
207	Expected	0.53	NA	NA	NA	NA	NA	NA
207	Expected	0.17	3.98	Pass	-0.28	-0.37	1.48	2.37
208	Expected	0.48	3.07	Pass	-0.33	-0.42	0.97	1.52
208	Expected	0.57	2.88	Pass	-0.25	-0.37	1.17	1.74
208	Expected	0.28	3.32	Pass	-0.32	-0.41	1.1	1.59
209	Expected	0.23	4.05	Pass	-0.2	-0.24	2.07	3.43
209	Expected	0.28	4.01	Fail	-0.22	-0.39	2.32	3.14
209	Expected	0.17	4.8	Fail	-0.17	-0.23	1.9	5.46
210	Expected	0.33	2.72	Fail	-0.1	-0.15	1.63	3.11
210	Expected	0.67	2.44	Pass	-0.17	-0.25	1.48	1.8
210	Expected	0.62	2.9	Fail	-0.08	-0.16	1.05	4.56
211	Expected	0.25	2.27	Pass	-0.31	-0.45	0.77	0.8
211	Expected	0.30	2.21	Pass	-0.31	-0.33	0.8	0.79
211	Expected	0.67	2.88	Fail	-0.28	-0.29	0.17	1.68
212	Expected	0.20	4.02	Pass	-0.39	-0.48	1.08	1.82
212	Expected	0.23	4.34	Pass	-0.47	-0.58	0.98	1.83
212	Expected	0.28	3.69	Pass	-0.36	-0.54	1.07	1.75
213	Expected	0.30	5.24	Pass	-0.27	-0.37	1.95	4.36
213	Expected	0.30	4.23	Pass	-0.27	-0.43	1.58	2.91
213	Expected	0.12	5.01	Pass	-0.3	-0.38	1.68	3.39
214	Expected	0.33	3.22	Pass	-0.22	-0.37	1.5	2.12

214	Expected	0.60	1.96	Pass	-0.38	-0.43	0.58	0.72
214	Expected	0.42	2.91	Pass	-0.41	-0.45	0.72	1.13
215	Expected	0.25	5.11	Fail	-0.14	-0.25	1.08	7.56
215	Expected	0.32	5.4	Fail	-0.48	-0.76	1.35	2.82
215	Expected	0.37	4.08	Pass	-0.43	-0.55	0.92	1.91
216	Expected	0.20	5.48	Fail	-0.39	-0.6	2.03	3.28
216	Expected	0.35	NA	NA	NA	NA	NA	NA
216	Expected	0.35	5.12	Fail	-0.17	-0.28	2.17	6.45
217	Expected	NA	NA	NA	NA	NA	NA	NA
217	Expected	NA	NA	NA	NA	NA	NA	NA
217	Expected	NA	NA	NA	NA	NA	NA	NA
218	Expected	0.93	3.38	Fail	-0.28	-0.33	0.53	2.45
218	Expected	0.22	3.56	Pass	-0.35	-0.44	1.02	1.61
218	Expected	0.50	3.66	Fail	-0.22	-0.3	0.67	2.86
219	Expected	0.12	NA	NA	NA	NA	0.6	NA
219	Expected	NA	NA	NA	NA	NA	NA	NA
219	Expected	NA	NA	NA	NA	NA	NA	NA
220	Expected	0.50	NA	NA	NA	NA	NA	NA
220	Expected	0.37	3.64	Pass	-0.59	-0.68	0.7	1.24
220	Expected	0.15	3.51	Fail	-0.44	-0.61	1.23	1.23
221	Expected	0.28	3.98	Fail	-0.31	-0.42	0.97	2.29
221	Expected	0.23	4.66	Pass	-0.35	-0.5	1.32	2.7
221	Expected	0.42	4.79	Fail	-0.29	-0.33	1.18	3.61
222	Expected	0.65	4.6	Pass	-0.5	-0.55	0.93	2.47
222	Expected	0.48	4.24	Pass	-0.34	-0.43	1.23	2.61
222	Expected	0.30	3.77	Pass	-0.26	-0.35	1.48	2.43
223	Expected	0.32	3.49	Pass	-0.24	-0.33	1.42	2.27
223	Expected	0.23	3.06	Pass	-0.25	-0.34	1.27	1.65
223	Expected	0.37	3.15	Pass	-0.22	-0.27	1.43	2.06
224	Expected	0.30	2.63	Fail	-0.28	-0.3	0.57	1.17
224	Expected	0.37	2.55	Pass	-0.24	-0.34	1.03	1.31
224	Expected	0.18	3.04	Pass	-0.37	-0.43	0.83	1.12
225	Expected	0.30	2.89	Pass	-0.28	-0.36	1.1	1.39
225	Expected	0.27	2.8	Pass	-0.25	-0.37	1.18	1.42
225	Expected	0.25	3.09	Fail	-0.01	-0.03	1.12	37.09
226	Expected	0.18	3.39	Pass	-0.28	-0.32	1.28	1.76
226	Expected	0.15	NA	NA	NA	NA	NA	NA
226	Expected	0.10	3.86	Pass	-0.22	-0.33	1.78	2.72
227	Expected	0.37	NA	NA	NA	NA	0.77	NA
227	Expected	0.35	NA	NA	NA	NA	1.07	NA
227	Expected	0.42	NA	NA	NA	NA	0.8	NA
228	Expected	0.13	NA	NA	NA	NA	1.17	NA
228	Expected	0.43	NA	NA	NA	NA	0.57	NA

228	Expected	NA	NA	NA	NA	NA	NA	NA
229	Expected	0.17	2.95	Pass	-0.11	-0.16	2.65	3.19
229	Expected	0.17	2.75	Pass	-0.27	-0.33	1.07	1.21
229	Expected	0.25	3.09	Fail	-0.26	-0.3	0.75	1.63
230	Expected	0.37	3.68	Pass	-0.24	-0.36	1.52	2.55
230	Expected	0.23	3.04	Pass	-0.21	-0.31	1.5	1.9
230	Expected	0.22	3.31	Pass	-0.27	-0.35	1.28	1.77
231	Expected	0.58	4.35	Pass	-0.47	-0.58	0.95	2.26
231	Expected	0.22	3.86	Pass	-0.26	-0.37	1.5	2.45
231	Expected	0.17	5.11	Pass	-0.38	-0.52	1.37	2.89
232	Expected	0.20	3.48	Pass	-0.31	-0.36	1.18	1.7
232	Expected	0.17	3.49	Pass	-0.16	-0.26	2.15	3.1
232	Expected	0.17	3.82	Pass	-0.26	-0.39	1.5	2.34
233	Expected	0.37	2.96	Pass	-0.15	-0.24	1.98	2.56
233	Expected	0.82	NA	NA	NA	NA	NA	NA
233	Expected	0.55	3.94	Pass	-0.25	-0.33	1.52	3
234	Expected	0.10	2.94	Pass	-0.2	-0.29	1.48	1.75
234	Expected	0.20	3.33	Pass	-0.25	-0.39	1.33	1.9
234	Expected	0.12	3.11	Fail	-0.33	-0.48	1.22	1.23
235	Expected	0.17	2.63	Pass	-0.23	-0.35	1.18	1.28
235	Expected	0.17	3.74	Pass	-0.23	-0.4	1.58	2.52
235	Expected	0.18	4.13	Pass	-0.36	-0.46	1.17	2.04
236	Expected	0.52	4.03	Fail	-0.22	-0.44	1.2	3.43
236	Expected	0.75	NA	NA	NA	NA	NA	NA
236	Expected	0.17	4.94	Pass	-0.43	-0.6	1.12	2.42
237	Expected	0.30	3.36	Fail	-0.27	-0.33	1.67	1.9
237	Expected	0.50	3.28	Fail	-0.3	-0.38	1.55	1.84
237	Expected	0.28	4.53	Pass	-0.27	-0.38	1.7	3.29
238	Expected	0.22	3.86	Pass	-0.34	-0.48	1.18	1.93
238	Expected	0.25	3.65	Fail	-0.21	-0.26	0.95	2.7
238	Expected	0.18	3.64	Fail	-0.38	-0.49	1.27	1.53
239	Expected	0.22	4.26	Fail	-0.19	-0.31	0.92	3.95
239	Expected	0.23	4.33	Pass	-0.34	-0.53	1.22	2.41
239	Expected	0.15	3.7	Pass	-0.32	-0.43	1.17	1.81
240	Expected	0.20	2.94	Pass	-0.29	-0.37	1.05	1.31
240	Expected	0.17	3.31	Pass	-0.32	-0.42	1.07	1.48
240	Expected	0.23	2.76	Pass	-0.22	-0.33	1.25	1.52
241	Expected	0.58	4.24	Fail	-0.26	-0.38	0.73	3.36
241	Expected	0.32	4.49	Pass	-0.39	-0.58	1.12	2.39
241	Expected	0.17	4.58	Pass	-0.37	-0.52	1.3	2.4
242	Expected	0.18	4.44	Pass	-0.22	-0.42	1.95	3.69
242	Expected	0.23	4.2	Pass	-0.23	-0.31	1.9	3.23
242	Expected	0.17	5.37	Pass	-0.26	-0.42	2.03	4.53

243	Expected	0.37	3.75	Pass	-0.28	-0.39	1.4	2.32
243	Expected	0.23	4.32	Pass	-0.34	-0.47	1.25	2.4
243	Expected	0.27	4.09	Pass	-0.33	-0.47	1.25	2.26
244	Expected	NA	NA	NA	NA	NA	NA	NA
244	Expected	0.42	NA	NA	NA	NA	NA	NA
244	Expected	0.55	4.82	Pass	-0.18	-0.29	2.58	5.72
245	Expected	0.40	3.98	Fail	-0.34	-0.4	0.85	2.24
245	Expected	0.32	3.53	Pass	-0.38	-0.44	0.97	1.58
245	Expected	0.22	3.97	Pass	-0.35	-0.44	1.18	1.98
246	Expected	0.43	NA	NA	NA	NA	1.33	NA
246	Expected	0.37	NA	NA	NA	NA	1.13	NA
246	Expected	0.12	NA	NA	NA	NA	1.23	NA
247	Expected	0.33	2.98	Pass	-0.29	-0.36	1.07	1.46
247	Expected	0.17	2.38	Pass	-0.16	-0.2	1.58	1.48
247	Expected	0.40	2.44	Pass	-0.18	-0.23	1.35	1.55
248	Expected	0.23	4.12	Fail	-0.2	-0.27	1.3	3.55
248	Expected	0.17	4.43	Fail	-0.51	-0.72	1.27	1.69
248	Expected	0.13	4.39	Fail	-0.14	-0.24	1.12	5.48
249	Expected	0.40	5.04	Fail	-0.48	-0.57	0.87	2.6
249	Expected	0.30	4.61	Fail	-0.25	-0.36	1.38	3.67
249	Expected	0.28	4.02	Pass	-0.39	-0.49	1.03	1.92
250	Expected	0.32	4.96	Pass	-0.37	-0.5	1.35	3
250	Expected	0.48	4.32	Fail	-0.16	-0.28	1.45	5.09
250	Expected	0.12	4.11	Fail	-0.11	-0.28	1.63	6.06
251	Expected	0.50	3.58	Fail	-0.25	-0.33	1.02	2.48
251	Expected	0.48	4.06	Fail	-0.53	-0.77	1.23	1.75
251	Expected	0.43	4.48	Fail	-0.17	-0.26	1.47	5.1
252	Expected	0.30	3.6	Pass	-0.22	-0.31	1.65	2.58
252	Expected	0.30	3.97	Pass	-0.2	-0.32	2	3.37
252	Expected	0.63	5.13	Fail	-0.26	-0.37	1.42	4.81
253	Expected	0.57	3.88	Pass	-0.28	-0.4	1.37	2.69
253	Expected	0.63	3.69	Pass	-0.23	-0.36	1.53	2.94
253	Expected	0.37	4.03	Fail	-0.26	-0.33	1.02	2.82
254	Expected	0.32	4.68	Pass	-0.33	-0.39	1.48	2.98
254	Expected	0.30	4.23	Pass	-0.32	-0.43	1.37	2.51
254	Expected	0.17	4.91	Pass	-0.32	-0.48	1.53	3.14
255	Expected	0.23	5.28	Pass	-0.22	-0.34	2.32	5.24
255	Expected	0.28	4.8	Fail	-0.14	-0.27	2.1	6.73
255	Expected	0.25	5.07	Pass	-0.32	-0.54	1.58	3.45
256	Expected	0.42	NA	NA	NA	NA	NA	NA
256	Expected	0.42	NA	NA	NA	NA	NA	NA
256	Expected	0.32	4.58	Pass	-0.23	-0.39	1.93	3.93
257	Expected	0.22	4.08	Pass	-0.33	-0.46	1.3	2.19

257	Expected	0.30	4.54	Pass	-0.39	-0.55	1.17	2.42
257	Expected	0.23	4.47	Pass	-0.36	-0.45	1.28	2.43
258	Expected	0.17	3.95	Fail	-0.32	-0.54	1.67	2.07
258	Expected	0.23	4.05	Pass	-0.23	-0.34	1.8	3.02
258	Expected	0.17	3.53	Pass	-0.2	-0.32	1.72	2.57
259	Expected	0.23	3.66	Pass	-0.24	-0.32	1.53	2.39
259	Expected	0.25	NA	NA	NA	NA	NA	NA
259	Expected	0.52	3.36	Pass	-0.3	-0.36	1.15	1.94
260	Expected	0.35	5.2	Pass	-0.36	-0.46	1.43	3.41
260	Expected	0.15	4.55	Pass	-0.26	-0.42	1.78	3.27
260	Expected	0.20	4.08	Pass	-0.24	-0.31	1.72	2.91
261	Expected	0.28	3.89	Pass	-0.34	-0.44	1.15	2.03
261	Expected	0.35	4.26	Fail	-0.26	-0.34	1.27	3.11
261	Expected	0.12	4.64	Pass	-0.32	-0.39	1.48	2.75
262	Expected	0.17	4.41	Pass	-0.35	-0.5	1.22	2.35
262	Expected	0.10	4.82	Pass	-0.33	-0.48	1.43	2.85
262	Expected	0.10	4.71	Fail	-0.23	-0.34	1.23	3.86
263	Expected	0.15	5.06	Pass	-0.33	-0.45	1.52	3.21
263	Expected	0.15	5.46	Fail	-0.57	-0.79	1.67	2.25
263	Expected	0.18	5.69	Fail	-0.23	-0.37	1.65	5.73
264	Expected	0.23	3.17	Fail	-0.29	-0.34	0.6	1.54
264	Expected	0.10	4.26	Fail	-0.31	-0.39	0.97	2.38
264	Expected	0.50	3.77	Fail	-0.33	-0.38	0.45	2.19
265	Expected	0.65	4.68	Pass	-0.35	-0.47	1.32	3.26
265	Expected	0.48	3.95	Pass	-0.55	-0.65	0.72	1.63
265	Expected	0.37	5.28	Fail	-0.31	-0.41	1.08	4.01
266	Expected	0.13	NA	NA	NA	NA	NA	NA
266	Expected	0.22	NA	NA	NA	NA	NA	NA
266	Expected	0.18	4.3	Fail	-0.28	-0.41	1.18	2.77
267	Expected	0.37	3.69	Pass	-0.4	-0.49	0.95	1.69
267	Expected	0.32	3.81	Fail	-0.27	-0.39	0.87	2.41
267	Expected	0.20	3.66	Pass	-0.45	-0.54	0.88	1.35
268	Expected	0.58	3.48	Fail	-0.4	-0.42	0.53	1.73
268	Expected	NA	NA	NA	NA	NA	NA	NA
268	Expected	0.12	2.94	Fail	-0.42	-0.52	1.1	0.89
269	Expected	0.43	3.84	Fail	-0.56	-0.72	1.05	1.48
269	Expected	0.48	4.62	Fail	-0.31	-0.44	1.12	3.28
269	Expected	0.48	4.68	Fail	-0.32	-0.39	0.93	3.27
270	Expected	0.37	3.19	Pass	-0.34	-0.42	0.95	1.48
270	Expected	0.25	3.61	Pass	-0.36	-0.47	1.02	1.65
270	Expected	0.57	4.7	Fail	-0.46	-0.54	0.72	2.6
271	Expected	0.25	3.02	Pass	-0.16	-0.26	1.88	2.41
271	Expected	0.12	3.22	Fail	-0.15	-0.23	1.18	2.77

271	Expected	0.22	3.23	Pass	-0.28	-0.4	1.13	1.63
272	Expected	0.47	NA	NA	NA	NA	NA	NA
272	Expected	0.43	NA	NA	NA	NA	NA	NA
272	Expected	NA	NA	NA	NA	NA	NA	NA
273	Expected	0.68	3.99	Fail	-0.32	-0.42	0.92	2.68
273	Expected	NA	NA	NA	NA	NA	NA	NA
273	Expected	NA	NA	NA	NA	NA	NA	NA
274	Expected	0.62	3.37	Pass	-0.3	-0.39	1.12	2.04
274	Expected	0.32	4.24	Pass	-0.34	-0.46	1.25	2.42
274	Expected	0.50	4.28	Fail	-0.35	-0.44	0.9	2.62
275	Expected	0.42	4.73	Pass	-0.3	-0.44	1.58	3.43
275	Expected	0.55	4.52	Pass	-0.55	-0.72	0.87	2.13
275	Expected	0.17	4.94	Fail	-0.32	-0.47	1.18	3.17
276	Expected	0.48	4.21	Pass	-0.2	-0.25	2.12	3.99
276	Expected	0.82	NA	NA	NA	NA	NA	NA
276	Expected	0.37	5.22	Fail	-0.19	-0.26	1.83	6.07
277	Expected	0.33	4.83	Pass	-0.47	-0.53	1.07	2.36
277	Expected	0.32	5.24	Pass	-0.39	-0.54	1.4	3.18
277	Expected	0.25	5.43	Pass	-0.44	-0.55	1.23	2.97
278	Expected	0.38	4.56	Fail	-0.24	-0.31	1.08	3.83
278	Expected	0.25	4.48	Fail	-0.19	-0.24	1.07	4.39
278	Expected	0.23	NA	NA	NA	NA	NA	NA
279	Expected	0.37	3.68	Fail	-0.15	-0.18	1.7	3.86
279	Expected	0.37	3.32	Pass	-0.25	-0.31	1.4	2.04
279	Expected	0.30	3.9	Pass	-0.29	-0.34	1.38	2.35
280	Expected	0.33	3.97	Pass	-0.32	-0.42	1.3	2.27
280	Expected	0.45	NA	NA	NA	NA	NA	NA
280	Expected	0.18	4.3	Fail	-0.24	-0.32	1.3	3.19
281	Expected	0.35	3.31	Pass	-0.32	-0.39	1.02	1.64
281	Expected	0.17	3.02	Pass	-0.26	-0.34	1.13	1.49
281	Expected	0.37	3.57	Pass	-0.31	-0.44	1.12	1.95
282	Expected	0.53	5.68	Pass	-0.27	-0.38	2.07	5.46
282	Expected	NA	NA	NA	NA	NA	NA	NA
282	Expected	0.60	6.4	Pass	-0.33	-0.45	1.92	5.86
283	Expected	0.20	5.28	Fail	-0.16	-0.25	1.37	7.02
283	Expected	0.25	5.34	Fail	-0.18	-0.29	1.8	6.49
283	Expected	0.23	5.71	Fail	-0.54	-0.67	1.42	2.7
284	Expected	NA	NA	NA	NA	NA	NA	NA
284	Expected	NA	NA	NA	NA	NA	NA	NA
284	Expected	NA	NA	NA	NA	NA	NA	NA
285	Expected	0.30	4.74	Pass	-0.39	-0.55	1.3	2.62
285	Expected	0.28	3.66	Pass	-0.45	-0.55	0.82	1.44
285	Expected	0.30	4.56	Fail	-0.24	-0.33	1.38	3.73

286	Expected	NA	NA	NA	NA	NA	NA	NA
286	Expected	0.13	4.12	Fail	-0.13	-0.18	1.17	5.2
286	Expected	0.18	4.21	Fail	-0.11	-0.2	1.43	6.44
287	Expected	0.33	3.89	Pass	-0.31	-0.41	1.22	2.25
287	Expected	0.25	4.53	Pass	-0.4	-0.49	1.15	2.3
287	Expected	0.37	4.13	Pass	-0.36	-0.51	1.13	2.25
288	Expected	0.30	3.56	Pass	-0.31	-0.4	1.2	1.88
288	Expected	0.30	3.31	Pass	-0.32	-0.41	1.07	1.6
288	Expected	0.28	4.55	Fail	-0.43	-0.51	1.5	2.22
289	Expected	NA	NA	NA	NA	NA	NA	NA
289	Expected	NA	NA	NA	NA	NA	NA	NA
289	Expected	NA	NA	NA	NA	NA	NA	NA
290	Expected	0.30	3.98	Pass	-0.29	-0.41	1.32	2.44
290	Expected	0.17	3.76	Pass	-0.22	-0.4	1.67	2.66
290	Expected	0.25	4.05	Fail	-0.15	-0.3	1.88	4.5
291	Expected	0.25	NA	NA	NA	NA	NA	NA
291	Expected	0.83	NA	NA	NA	NA	NA	NA
291	Expected	0.18	4.91	Pass	-0.22	-0.29	2.22	4.48
292	Expected	0.43	NA	NA	NA	NA	1.43	NA
292	Expected	0.35	NA	NA	NA	NA	3.37	NA
292	Expected	0.78	NA	NA	NA	NA	1.02	NA
293	Expected	0.25	4.88	Fail	-0.28	-0.37	1.4	3.62
293	Expected	0.17	3.68	Pass	-0.29	-0.4	1.25	1.97
293	Expected	0.15	4.73	Fail	-0.32	-0.41	1.07	2.9
294	Expected	NA	NA	NA	NA	NA	NA	NA
294	Expected	0.10	NA	NA	NA	NA	NA	NA
294	Expected	0.23	NA	NA	NA	NA	NA	NA
295	Expected	0.27	3.25	Pass	-0.14	-0.26	2.22	3.15
295	Expected	0.23	NA	NA	NA	NA	NA	NA
295	Expected	0.37	3.02	Pass	-0.15	-0.18	2.1	2.66
296	Expected	0.50	4.4	Pass	-0.35	-0.49	1.27	2.75
296	Expected	0.37	5.67	Pass	-0.42	-0.57	1.4	3.53
296	Expected	0.75	4.82	Pass	-0.47	-0.59	1.05	2.91
297	Expected	0.73	4	Fail	-0.22	-0.32	1.27	3.62
297	Expected	0.37	4.06	Fail	-0.22	-0.3	1.25	3.31
297	Expected	0.55	3.93	Pass	-0.38	-0.52	1.1	2.17
298	Expected	0.42	3.06	Pass	-0.27	-0.35	1.18	1.69
298	Expected	0.12	3.14	Pass	-0.2	-0.28	1.53	2.01
298	Expected	NA	NA	NA	NA	NA	NA	NA
299	Expected	NA	NA	NA	NA	NA	NA	NA
299	Expected	NA	NA	NA	NA	NA	NA	NA
299	Expected	NA	NA	NA	NA	NA	NA	NA
300	Expected	0.45	4.23	Pass	-0.24	-0.4	1.78	3.41

300	Expected	NA	NA	NA	NA	NA	NA	NA
300	Expected	NA	NA	NA	NA	NA	NA	NA
301	Expected	0.67	4.02	Fail	-0.56	-0.68	0.93	1.86
301	Expected	0.30	3.48	Fail	-0.61	-0.72	0.97	1.06
301	Expected	0.30	4.53	Fail	-0.34	-0.39	0.9	2.71
302	Expected	0.22	4.11	Pass	-0.33	-0.44	1.27	2.22
302	Expected	0.25	3.66	Pass	-0.17	-0.36	2.03	3.3
302	Expected	0.17	3.89	Pass	-0.34	-0.41	1.2	1.9

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<sup>1</sup>The SpeedCheck test compared the GPS speed to the total change in speed determined by integrating the determined deceleration profile over the braking time. If these values differed by greater than 1 m/s, then the acceleration data was discarded.

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## Appendix F: Descriptive Statistics Table for Each Sample

### Full Sample (n=906 observations)

Stat	PRT [s]	Approach Speed [m/s]	Average Decel Rate [g]	Maximum Decel Rate [g]	Eye Height [cm]	SSD [m]	Braking Time [s]
n	813	701	469	469	302	467	737
Weighted Average	0.344	3.923	-0.299	-0.408	158.782	2.502	1.376
Min	0.033	1.320	-0.050	-0.100	138	0.480	0.170
Max	1.150	8.820	-0.630	-0.780	179	10.70	7.100
Standard Deviation	0.186	0.887	0.091	0.106	8.115	1.330	0.570

### UBC Unexpected (n=52 observations)

Stat	PRT [s]	Approach Speed [m/s]	Average Decel Rate [g]	Maximum Decel Rate [g]	Eye Height [cm]	SSD [m]	Braking Time [s]
n	45	40	30	30	52	30	43
Weighted Average	0.745	4.486	-0.203	-0.311	158.418	5.595	2.694
Min	0.417	1.320	-0.050	-0.180	139	3.070	1.420
Max	1.150	8.820	-0.380	-0.580	174	10.70	7.100
Standard Deviation	0.159	1.338	0.082	0.107	8.034	2.183	1.091

**UBC Expected (n=104 observations)**

Stat	PRT [s]	Approach Speed [m/s]	Average Decel Rate [g]	Maximum Decel Rate [g]	Eye Height [cm]	SSD [m]	Braking Time [s]
n	88	59	38	38	52	38	73
Weighted Average	0.373	4.329	-0.309	-0.415	158.418	2.787	1.428
Min	0.033	2.270	-0.150	-0.240	139	1.370	0.470
Max	0.983	6.580	-0.540	-0.700	174	6.530	3.000
Standard Deviation	0.179	0.962	0.084	0.101	7.995	1.186	0.425

**Vancouver Expected (n=750 observations)**

Stat	PRT [s]	Approach Speed [m/s]	Average Decel Rate [g]	Maximum Decel Rate [g]	Eye Height [cm]	SSD [m]	Braking Time [s]
n	680	602	401	401	250	399	621
Weighted Average	0.311	3.854	-0.310	-0.420	158.825	2.212	1.272
Min	0.033	1.960	-0.080	-0.100	138	0.480	0.170
Max	0.950	6.890	-0.630	-0.780	179	5.860	3.850
Standard Deviation	0.158	0.797	0.089	0.103	8.136	0.862	0.414