Motorcycle rider perception response times to abrupt- and gradual-onset hazards in a simulator

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**MOTORCYCLE RIDER PERCEPTION RESPONSE TIMES TO
ABRUPT- AND GRADUAL-ONSET HAZARDS IN A SIMULATOR**

**WONG MIAO EN GRACE
SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING**

2019

**MOTORCYCLE RIDER PERCEPTION RESPONSE TIMES TO
ABRUPT- AND GRADUAL-ONSET HAZARDS IN A SIMULATOR**

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School of Civil and Environmental Engineering

A thesis submitted to the Nanyang Technological University
in partial fulfilment of the requirements for the degree of
Master of Engineering

Statement of Originality

I hereby certify that the work embodied in this thesis is the result of original research, is free of plagiarised materials, and has not been submitted for a higher degree to any other University or Institution.

9 Dec 2019

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A handwritten signature in black ink, appearing to read 'Grace Wong', written in a cursive style.

Wong Miao'En Grace

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SUMMARY

This project involves the development of a simple motorcycle simulator which, together with an eye tracking device, was then used to study the response times (RTs) and eye gaze patterns of motorcycle riders. The simulator was built by integrating a scrap motorcycle frame with the necessary controls (steer, throttle, brake) and a virtual reality program to render the 3D environment and customised hazard scenarios. The data records of the eye tracking device combined with the recording of the responses of participants on the simulator is a safe and objective way to study the response behaviour of motorcycle riders in the context of their RTs.

Test subjects of motorcycle riders were presented with hazards in two modes: hazards that appeared abruptly from behind some visual occlusion (abrupt-onset), and with hazards that appeared gradually (gradual-onset), having been in the field of view of the motorcycle riders for some time before transitioning into a hazard. The hazards occurred in two environments, at the junction and at the link. The hazards entailed right-of-way violation on the part of the other vehicle conflicting with the path of the motorcycle rider.

Overall, 88 participants were recruited for this study. In order to control for and examine the effects of experience, three groups of participants were recruited – namely experienced riders, novice riders and unlicensed subjects (not holding a motor-vehicle licence).

From the findings of the study, the unlicensed group of participants consistently underperformed relative to the licensed riders (experienced and novice riders). Performance measures included the manner and celerity of accelerator response, their eye gaze behaviour, and their RTs in response to the hazard scenarios. On the other hand, between the two licensed groups, the experienced and novice riders

generally performed similarly in terms of their response patterns, propensity of already looking at the hazard area at hazard onset, and the overall RTs.

In comparing scenario types, junction scenarios appeared to provoke more anticipatory eye gaze behaviour than link scenarios, consistent with a more top-down cognitive approach in hazard perception when faced with a higher conflict zone. This study also found that gradual-onset hazards resulted in longer overall RTs than abrupt-onset hazards, mainly contributed by the initial time-to-first-fixation sub-component of the RT for gradual-onset hazards, rather than the remaining fixation to response sub-component. The performance advantage to riders responding to abrupt-onset hazards may be attributed to the attention-capturing nature of the sudden appearance of an object in the visual field, but other reasons such as a narrower search field cannot be ruled out.

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CHAPTER 1: INTRODUCTION

1.1 Background

Motorcycle riders are known to be a particularly vulnerable group of road users and are usually over-represented in terms of the number of accidents and fatalities across many countries (Davoodi et al., 2012; Shahar et al., 2010; NHTSA, 2015). As riders and their pillioners are not protected by the external structure of their vehicles, there is greater potential for harm to motorcycle riders than for drivers (Rosenbloom et al., 2011). In Singapore, motorcycles contribute more than 50% of injury road traffic accident counts (SPF, 2018). This is not the whole picture, as registered motorcycles form 15% of Singapore's vehicle population (141,916 motorcycles) (LTA, 2018) and Singapore also sees a relatively large transient motorcycle population of more than 40,000 motorcycles crossing the border from Peninsula Malaysia.

Several epidemiological studies have looked into the characteristics of the motorcycle crashes (or powered two-wheelers). For example, (Hurt et al., 1981) found that in 65% of multi-vehicle accidents, the driver of the other vehicle had violated the motorcycle rider's right-of-way. Despite this, compared to car drivers, hazard perception behaviour of motorcycle riders is not as well studied. Locally, about 25%-40% of the cases encountered by the Forensic Chemistry and Physics Laboratory (FCPL)¹ involve a seriously or fatally injured motorcycle rider, and in most situations, there is a right-of-way violation on the part of the other vehicle (e.g. a right-turning vehicle in the opposite direction not giving way to a straight-through oncoming motorcycle, or a lead vehicle making a sudden U-turn in front of the motorcycle going in the same direction).

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¹ FCPL, part of the Health Science Authority (HSA) deals with traffic accident reconstruction cases on behalf of the Singapore Police Force (SPF).

Human factors are involved in 95% of motor vehicle crashes. They are the biggest contributing factors in motor vehicle crashes (Austroads, 2002). In particular, hazard perception skill has been shown to be associated with one's likelihood of getting involved in a crash (Hosking et al., 2010; Horswill and McKenna, 2004). Response time (RT) is an important aspect of human factors when investigating traffic accidents, and can be used as a performance indicator of hazard perception skill. The RT and its constituent components can provide valuable insights into motorist (driver/rider) behaviour, and how he perceives and anticipates hazards.

From a practical standpoint, RT measures are inherently constrained by the need to define a start point, or "hazard onset". In straight-forward situations where the hazard appears abruptly (called abrupt-onset hazard) from behind an obstruction, hazard onset is typically defined as when the hazard is first visible to the motorist. However, in scenarios where there is no clearly defined point of entry, and as the event unfolds, it transitions from a potential hazard to an immediate hazard situation (called gradual-onset hazard), the hazard onset point is more ambiguous. There is limited research into how riders respond differently to an abrupt hazard onset compared with a gradual one.

The choice of a simulator setting to study the behaviour of motorcycle riders when responding to hazards is to provide a controlled and safe environment that would otherwise be too dangerous to test in real life. This is also timely because the Singapore Police Force (SPF) has announced the incorporation of simulator training to all driving schools starting in 2019 (The Straits Times, 2017). The simulator training curriculum is reported to include training on how to react to difficult traffic situations like wet weather and hazard scenarios.

With the backdrop of the introduction of simulator training in Singapore's licensing system, it would be interesting to find out if training and riding experience improves the RT of motorcycle riders. Although riding experience is often studied in the

context of hazard perception performance, its effect on the RT may not be always apparent (Crundall, 2016).

1.2 Objective and scope

Motorcycle riders are particularly vulnerable when they approach the junctions where the chances of a conflict with other vehicles is highest. According to a study by Hurt et al. (1981), the most common accident configuration is for a situation where the other lower-priority vehicle makes a turn across the path of the straight-going motorcycle rider; this has also been called “turn across path” violation (Muttart et al., 2017). Many studies have focussed on this problem from the perspective of the driver of the other vehicle, where this violation has been called the “look but failed to see” phenomenon (Pai, 2011).

Perception response time has been shown to be linked to a person’s likelihood of having a crash (Horswill and McKenna, 2004). Anticipatory eye gaze behaviour is associated with a shorter perception response time as the initial time to fixate on the hazard is minimised (Crundall et al., 2011). Furthermore, much of the hazard perception research has focused on car drivers and there is limited data on whether the motorcycle riders perform comparably.

In order to understand motorcycle rider behaviour in emergency incident situations, it is necessary to present the rider with a hazard situation. This is not possible in a real environment for obvious ethical reasons, hence the use of a riding simulator to provide a safe environment to study behaviour in hazardous situations. Also, the simulator allows for experimental control, and the onset and types of the hazards can be controlled to systematically study the hazard perception performance of motorcycle riders under emergency situations.

The primary objective of this research is to examine the differences in motorcycle rider RTs and eye gaze behaviour to hazards that appear abruptly from behind a

visual occlusion ('abrupt-onset hazards'), versus those that have a less clearly defined starting point ('gradual-onset hazards'). In order to control for the effects of riding experience, as well as having a baseline for comparison, experienced, novice and unlicensed participants were recruited for the motorcycle simulator study.

Gradual-onset hazards are particularly challenging scenarios to study as they have a more ambiguous starting point. Hence, a secondary aim of this study was to address the issue of an appropriate hazard onset start point. With the aid of eye tracking equipment, eye scanning behaviour of riders can be evaluated. The visual cues available to the rider can be evaluated in order to assess this issue of hazard onset.

1.3 Organisation of this thesis

This thesis is organised into 5 chapters.

Chapter 1 provides background and context concerning the over-representation of motorcycle accidents. The use of RT in evaluating motorcycle rider performance as well as in the context of crash reconstruction analysis is discussed.

Chapter 2 covers the literature review on the issues of abrupt- and gradual-onset hazards, hazard perception, RTs, and the use of simulators and eye tracking equipment in hazard research studies.

Chapter 3 details the methodology used in this research, the study design, participant groups controlled for, and equipment used.

Chapter 4 describes and discusses the findings from the study in terms of the RTs across different scenario types (abrupt- and gradual-onset/with or without visual occlusions), and rider experience level.

Chapter 5 concludes on the results obtained on the RTs to hazard scenarios, describes the limitations in this study, and describes alternative avenues that may be worthwhile pursuing as a continuation of this study.

CHAPTER 2: REVIEW OF THEORY AND PREVIOUS WORK

This chapter provides some background on global and local motorcycle crash statistics for context, and introduces the issues associated with abrupt and gradual-onset hazards. The concept of hazard perception and its relationship with response times (RTs) are also presented, together with an overview of the use of simulators and eye tracking equipment in hazard research studies.

2.1 Motorcycle accidents

Globally, motorcycle riders and pillion tend to be over-represented in terms of the number of accidents and fatalities (Davoodi et al., 2012; Shahar et al., 2010; NHTSA, 2015). According to a report by WHO (2015), powered two- and three-wheelers contributed 34% of road traffic deaths in Southeast Asia, compared with the World average of 23% (refer to Figure 2.1). Table 2.1 shows motorcycle accident rates compared with the proportion of motorcycles in the vehicle population in selected countries. By and large, this trend is consistently observed in different parts of the world.

Table 2.1: Motorcycle accident rate compared with proportion of motorcycle population

Country	motorcycles % of vehicle population	casualties % in accidents
Singapore ¹	15%	36% fatalities
Malaysia ²	50%	>60% fatalities
Thailand ³	63%	70% fatalities
Indonesia ³	73%	61% fatalities
Hong Kong ⁴	6.7%	10.8% casualties
Australia ⁵	4.5%	14.8% fatalities
United Kingdom ⁶	3.7%	19.4% fatalities

¹ LTA (2018); SPF (2018)

² Davoodi et al. (2012)

³ World Health Organization Regional Office for South-East Asia (2009)

⁴ Census & Statistics Department HKSARG (2017); Transport Department HK (2016)

⁵ Johnston et al. (2008)

⁶ Shahar et al. (2010)

Figure 2.1: Infographic on road traffic deaths by road user (WHO, 2015)

Espié et al. (2013) lamented that worldwide, there is limited research done about motorcycle riders and their hazard perception behaviour. This lack of scientific literature on motorcycle riders is perhaps more relevant to Singapore than other parts of the world where the motorcycle population is smaller. Furthermore, the motorcycle issue in Singapore is not purely local. In 2016, it was reported in the local Straits Times newspaper that more than 40,000 motorcycles cross the border from Malaysia into Singapore daily (Lim, 2016). Given that there were 143,000 motorcycles registered in Singapore in 2016 (LTA, 2016), the transient Malaysia-registered motorcycles formed at least 24% of the motorcycles on Singapore roads. This value is likely to be higher, as not all of Singapore's motorcycles are riding actively on Singapore's roads, but Malaysian motorcycle riders commute on a daily basis, especially for work. It was reported in a Straits Times article that 42% of serious injured motorcycle riders seen by the local Khoo Teck Puat Hospital were Malaysians, while Singaporeans made up 54% (Yusof, 2015). This may suggest that Malaysian motorcycle riders are highly involved in road traffic accidents. As a ballpark approximation, after correcting for the presence of the Malaysia-registered

motorcycles, of the registered motor vehicles in Singapore, 19% of the 956,430 vehicles on Singapore roads are motorcycles, but motorcycle riders and pillion still contribute to 36% of overall fatalities (SPF, 2017; LTA, 2016) and make up more than 50% of overall traffic accidents.

2.1.1 Collision configuration and right-of-way violations

Studies on motorcycle (or powered two-wheelers) accidents suggested that motorcycle riders are particularly vulnerable to right-of-way violations. For example, the study by (Hurt et al., 1981) found that the driver of the other vehicle had violated the right-of-way of the motorcycle and caused the accident two-thirds of the time. Allen et al. (2017) found that a frequent crash scenario involves the other vehicle failing to give way to the motorcycle, and most of the time the main contributor to motorcycle crashes is traffic scan error on the part of the motorist in the conflicting vehicle. Brooks et al. (2005) who studied the conspicuity of powered two-wheelers noted that the motorcycle has priority in 81% of cases. Overall, this phenomenon has been sometimes referred to as “looked but failed to see” errors on the part of the other vehicle (Shahar et al., 2010).

The Hurt Study (Hurt et al., 1981) concluded that the most common accident configuration involving motorcycles is when the motorcycle proceeds straight and the car makes a turn across the front of the motorcycle. This is consistent with research from other parts of the world, for example a study by TRL Ltd (2004) on motorcycle accidents in Scotland found that accidents on built-up roads tended to be the fault of the other vehicle turning across or U-turning across the path of the motorcycle.

2.1.2 Abrupt (visual occlusion) versus gradual-onset hazards

According to the MAIDS study into powered two-wheeler accidents (ACEM, 2009), there were one-fifth of time stationary visual obstructions (e.g. vegetation), and

about 10% of time for mobile visual obstructions (e.g. buses), reported in these accidents.

A hazard that appears from behind a visual occlusion is sometimes referred to as a “pop up” situation. In this study, these situations are referred as ‘abrupt-onset hazards’ as there is a sudden change in the visual background. It is theorised that RTs for these types of situations are faster, due to the natural attention capturing effect of abrupt-onsets. According to Theeuwes (1994), abrupt-onsets generate involuntary shifts of one’s visual attention. Schreij et al. (2008) also studied abrupt-onsets and concluded that the appearance of objects in the visual field supersedes any top-down search strategy. The effect of abrupt-onset hazards therefore should provide a natural performance advantage to motorists reacting to a hazard suddenly appearing from behind a visual obstruction. This is alluded to in a study by Uchida et al. (2011) who studied the reaction of motorists to a scenario where the hazard vehicle was travelling perpendicular to the path of the subject motorist, although they commented that this screening effect (occlusion effect) was not very large. On the other hand, the issue of gradually developing hazards is more difficult to examine, both from a conceptual and a practical standpoint. D’Addario and Donmez (2019) noted that when studying RTs, a start point has to be defined, which in the case of gradual-onset hazards, the transition point between potential hazard and immediate hazard is fundamentally ambiguous because there is no obvious point of entry into the field of view. Advances in eye tracking equipment may help to shed some light on this issue (see also Section 2.5). Underwood et al. (2013) attempted to study gradual and abrupt hazards in the context of experience levels, and concluded that gradual-onset hazards were responded to more slowly than abrupt-onset hazards, but did not note any differences between participants of different experience levels.

2.1.3 Influence of traffic density

Motorcycle accidents tend to occur under light to moderate traffic conditions, which some have suggested is because other road users are not expecting the presence of the motorcycles (ACEM, 2009; Brooks et al., 2005). This alludes to the idea of 'safety in numbers', where drivers in countries like Thailand and Indonesia in which powered two- or three- wheelers which form 63% and 73% respectively of the motor vehicle population (refer to Table 2.1) are well adapted in navigating their environment, with motorcycles being the dominant vehicle type. Indeed, the road traffic deaths related to powered two- or three- wheelers are more commensurate to their population proportions, 70% and 61% respectively for Thailand and Indonesia (World Health Organization Regional Office for South-East Asia, 2009).

The scenarios for the present research are designed such that the effect of abrupt-onset hazards from behind visual occlusions can be studied in the context of two types of environments. The pair of scenarios involving right-of-way violations at junctions (hazard car turning across the path of the subject motorcycle proceeding straight), and a second set involving right-of-way violations that occur when both vehicles are proceeding straight prior to the incursion.

2.2 Hazard perception

2.2.1 Definition of hazard perception

Hazard perception has been defined as (Underwood et al., 2011):

- “the process of detecting, evaluating and responding to dangerous events on the road that have a high likelihood of leading to a collision” (Crundall et al., 2011);
- “the ability to read the road and anticipate forthcoming events” (McKenna et al., 2006); and
- “a motorist’s situation awareness for a dangerous configuration of roadway and road users”.

Hazard perception, in the context of driving, has been noted to be a form of situation awareness. (Endsley, 1995) described three levels of situation awareness – level 1, the perception of elements in the environment; level 2, the comprehension of the current state of events; and level 3 – the projection of future events.

Poor hazard perception performance has been attributed to shortcomings in the detection process due to poor visual orientation, insufficient searching, scanning and limited use of peripheral vision, rather than poor perception and evaluation (Evans and MacDonald, 2002). Hence, it will be interesting to see whether the eye tracking glasses, as used in this study, will be able to detect underlying differences when participants are presented with several hazard scenarios.

2.2.2 Experience and age as factors affecting hazard perception performance

A review of the literature showed that mixed results have been obtained when studying the effect of motoring experience on hazard perception performance, particularly those that measured RTs (Crundall, 2016). For example, Sagberg and Bjørnskau (2006) concluded that based on their pushbutton hazard RT study, there was no strong relationship between RT and driving experience. This mixed bag of results is true not only between studies, but also within the same study; certain situations may elicit differences between driver groups and some situations do not. Liu et al. (2009) found that in one of the scenarios tested, one that involved high traffic density and the sudden appearance of hazards, performance was not associated with experience, while the other scenario that involved a central business district (CBD) with medium traffic density showed some contrast. Other studies on the effect of riding experience reported that abrupt-onset hazards did not differentiate between experience levels, because that effect is masked by the attention-capturing phenomenon but for gradual-onset hazards, experienced motorists were faster in responding (Underwood et al., 2013).

Many factors have been posited to affect RT. The issue of experience is also further confounded with age (Liu et al., 2009). Between 'age' and 'experience', the effects from these two factors are rather difficult to isolate, as younger drivers tend to be inexperienced, similarly older drivers tend to be more experienced. However, due to limited resources, the present study will mainly be focussing on probing the difference in the RT for different scenario types, with the background awareness that training and experience may affect RTs. Furthermore, from a crash reconstruction perspective, an involved party's experience level is not typically factored into the considerations. In order to control for the effects of experience, the strategy was to recruit both experienced and novice riders first to get a preliminary sensing if this was going to be a determining factor in affecting RT, followed by a comparison with completely unlicensed participants, with no training nor roadcraft so as to provide a baseline for comparison.

2.2.3 Hazard perception performance of motorcycle riders versus car drivers

A few studies have evaluated the performance of motorcycle riders against car drivers, and have concluded superior hazard perception skill for riders than drivers (Hosking et al., 2010; Shahar et al., 2010; Muttart et al., 2017). Hosking et al. (2010) also commented that visual scanning behaviour of motorcycle riders may differ from those of car drivers.

2.3 Response time

Response time (RT) functions as a performance indicator of hazard perception skill. A shorter RT means a higher likelihood of avoiding an accident in any particular circumstance. In the context of crash reconstruction, RT is used to estimate whether an involved party would have sufficient time to respond to a hazard to avoid it.

2.3.1 Response times used in crash reconstruction

In crash reconstruction, collision investigators are often required to make an assessment of whether a crash was avoidable by the involved parties (Attalla et al., 2018). A key component of this evaluation is the 'typical' motorist response time to the particulars of the scenario. In this regard, this usually entails a time-distance analysis to evaluate if the time required for the operator to detect, perceive and begin an evasive manoeuvre was sufficient against a baseline of 'typical' response times, or whether the operator in the current case performed within 'normal' range.

In practice amongst crash reconstructionists, there is a danger of applying oversimplified, ambiguously defined, rule-of-thumb estimates (Muttart, 2003). For example, some cited Olson (1989) to support the use of '1.5 seconds' to represent most drivers' responses to a straightforward and clear stimulus, or Green (2000) on the use of '1.25 seconds' for normal expected situations. This practice in adopting a single RT value in crash reconstruction has been subject to much criticism, mainly because it does not account for case specificities. This issue is further compounded for motorcycle riders, as response time research (and scientific literature in general) on riders is much harder to come by than those on car drivers (Espíe et al., 2013). As mentioned in Section 2.2.3, some studies have shown that hazard perception and visual scanning behaviour of motorcycle riders may be different from drivers, hence there is a need for scientific research that specifically deals with the response times of riders to bridge this gap. Herein, there are many different types of hazard situations that motorists face on the road, hence, there is much room for more research on exploring different hazard types and from different road user perspectives.

2.3.2 Response time terminology

Furthermore, the complex issue with response time (RT) research is that there are many terms used in the literature (e.g. Perception Reaction Time, Brake Reaction Time, Perception Response Time, etc.). The variety of terms highlights the diversity

of ways in which these terms are defined in the studies. For instance, the start of RT measurements is usually when the intruding object first enters the field of view, typically referred to as the 'hazard onset'. This is particularly troublesome when the hazard is at first only a potential hazard, already present in the rider's field of view, that eventually develops into an immediate hazard, i.e. a gradual-onset hazard. A further discussion on the arbitrary nature of start of the RT measure is included in the next section, Section 2.3.3. On the other end of the scale, the end of RT measurements also exhibits variability; it can be measured up to when the brake lights light up, when the foot is taken off the accelerator, up to maximum braking, etc. This myriad of terms in the start and end points contributes to the ambiguity in characterising the RTs (Muttart, 2003).

Other terms that appear closely related, and used in relation to the concept of gradual-onset include the terms like 'potential hazard' (Muttart and Fisher, 2017) and 'precursors' (Pradhan and Crundall, 2017; Crundall et al., 2011). Conceptually, a non-hazard that has the potential to transition to become a hazard leaves precursor cues that would aid faster identification of the hazard at its onset. With the use of modern eye tracking technology (see also Section 2.5), it is envisaged that some insights can be gained into the currently ambiguous and arbitrarily defined gradual hazard. Abrupt- and gradual-onset hazards are discussed next (see also Section 2.1.2).

Part of the ambiguity in studying RT stems from studies that discussed RT more conceptually and those that discussed them based on the observable 'section-breaks', afforded to them due to added instrumentation. For example, in an example of a more conceptual approach, (Olson, 1989) described four segments: (1) detection, (2) identification, (3) decision, and (4) response. Upahita et al. (2018a) subdivided the RT into: (1) Lag time (2) Time to First Fixation, and (3) PIEV Time²,

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² "PIEV Time" was defined in Upahita (2018a) to refer to the construct that describes the Perception – Intellection – Emotion – Volition process of perception response.

defined respectively by the event of hazard onset, start of saccadic movement, first fixation on the hazard, and brake application. These subcomponents are defined by measurable data points provided by added instrumentation (e.g. eye tracking glasses and a simulator).

In the context of this study and to avoid ambiguity, the RT intervals in the present study are defined by observable events using the SensoMotoric Instruments (SMI) wearable eye tracking glasses and appropriate simulator controls. The details regarding the specific measured intervals are provided in Section 3.1.

2.3.3 Start of the response time interval

Studies largely defined the start of the measured response time (RT) interval from the first possible instant that the rider can identify the intruding vehicle as an immediate hazard. For abrupt-onset hazards, i.e. those that feature some form of visual occlusion prior to the hazards' appearance, the literature is mostly consistent in defining the hazard onset point as when the hazard first appears from behind the obstruction (Yeung and Wong, 2015; D'Addario and Donmez, 2019). For gradual-onset hazards, the choice of a start point is not as clear cut, and in overall there are much fewer RT studies that feature them. D'Addario and Donmez (2019) studied gradual-onset hazards in the context of a left-turning vehicle (right-turning under Singapore's driving convention) that starts from stop within the field of view of a straight-through driver, and used the start of movement of the former to mark the start of the RT interval of the latter. Toxopeus et al. (2018) presented drivers with a cyclist path intrusion hazard that did not stop at a stop sign, and used the point where the cyclist crossed the stop sign as the start of the RT interval. In summary, the hazard onset points for gradual-onset hazards are more varied and largely depend on the context of the scenarios being examined.

2.4 Simulator research vs field studies

Simulator studies have greater experimental power in that they allow experimenters the ability to create repeatable scenarios at greater efficiency and lower cost (Carsten and Jamson, 2011). The investigation into hazard perception performance of motorcycle riders is particularly suitable for simulator research, not only due to the ethical considerations or the benefits of a controlled standardised test environment, but also because the subjects' reactions can be studied in much greater detail (Underwood et al., 2011; Upahita et al., 2018a). Motorcycles are more vulnerable than car drivers, hence instrumenting motorcycle riders on actual roads and tasking them to carry out hazard response experiments, is almost guaranteed to be rejected from an ethics review point of view. As such, motorcycle riders and their visual search behaviour is likely confined to 'normal' riding scenarios, under relatively safe road conditions.

It is accepted that there are some drawbacks for simulator studies, and that simulators cannot mimic full reality. Some have questioned the validity of test results from simulators, citing issues such as the lack of relevant visual cues, crude visual displays not being able to represent the visual complexity experienced in real world driving (Underwood et al., 2011). (Meuleners and Fraser, 2015) conducted a study comparing driving errors while on an UC-Win/Road driving simulator and while on-road. They concluded that in general their results supported that driving performance on a simulator approximates (relative validity) driving tasks such as mirror checks, speed at junctions, obeying traffic lights etc., when compared with on-road behaviour. In their study, however, they acknowledged some differences in speed violation behaviour, gap selection and lane positioning.

Nevertheless, some literature on driving simulators suggested that the RT in simulated environments tend to be slightly faster than in real life, as the drivers in real life have more 'environmental noise' and mental workload to contend with. The simulator study will still be able to give a lower limit estimate (less conservative from

a traffic safety and road design perspective i.e. a lower safety factor) on the expected RT in particular hazard situations. The relative validity of the results should also be comparable, i.e. when comparing the relative RTs between two scenario types or two groups of riders (Branzi et al., 2017; Underwood et al., 2011).

2.5 Eye tracking research

Wearable eye tracking technology has changed the way hazard perception behaviour can be studied. Eye tracking glasses have found applications in many fields such as psychology and market research. However, use of eye tracking technology in driving studies is relatively new (Gao et al., 2015). There are many types of eye trackers available, and portable video-based eye trackers, such as used in this study (see Figure 3.8), are more popular because they are suitable for use in a mobile setting, and look like a pair of glasses that remains relatively unobtrusive (Vidal et al., 2012).

Recent studies that utilise eye tracking technology in a driving context have attempted to make use of shifts in the motorist's gaze to approximate when a hazard was first detected (D'Addario and Donmez, 2019; Huestegge and Bockler, 2016). With the incorporation of eye tracking technology, researchers can probe the underlying structure of how riders respond to hazards, and whether the RT variability under different scenarios, experience levels, etc., can be related to the eye movements.

2.6 Summary

In summary, based on the literature, motorcycle accidents commonly feature right-of-way violations and visual occlusions, and typically occur under light to moderate traffic conditions. There are limited studies that firstly look into the hazard responses from the motorcycle rider's perspective, and secondly examine the differences in gradual- and abrupt-onset hazards that appear from behind a visual

occlusion. A simulator together with eye tracking equipment is a safe and objective way to study motorcycle riders' hazard perception behaviour in a controlled environment.

CHAPTER 3: METHODOLOGY AND STUDY DESIGN

This chapter describes the various hardware and software used in the development of the motorcycle simulator and the application of the eye tracking glasses. Details on the study design, participant groups and hazard scenarios are also provided.

3.1 Study performance measures (outcome variables)

In general, there could be three possible physical responses to any given hazard:

1. Accelerator release response → Accelerator release time (ART);
2. Braking response → Braking reaction time (BRT); and
3. Steering response → Steer response time (SRT).

With modern instrumentation by way of wearable eye tracking equipment during motorcycle simulation, the start, end, and duration of each RT constituent segment can be decomposed. The dependent variables measured in this study as an indicator of rider performance include the sub-components of overall RT (see Figure 3.1).

Figure 3.1: Illustration of sub-components of the overall response time measured for this study

Practically, due to the limitations of the motorcycle simulator rig with regard to the lack of a tilting base to simulate roll and pitch, for the purpose of this study, any steering response initiated by each participant was not further analysed.

Furthermore, in the course of collecting data, several participants had feedback that the loss of power from the release of the accelerator was sufficient for them to avoid colliding with the hazard vehicle, hence some respondents did not fervently apply the brakes. Moreover, there were some concerns over the motorcycle simulator being set up as a scooter without clutch and a footbrake. As such, it was judged that the braking response time (BRTs) would not be a suitable primary performance measure in this study.

Overall, the instrumentation of the brake and steering systems on the motorcycle simulator are still necessary as a means to slow the vehicle down when making a turn or negotiating a bend. However, the hazard scenarios did not require any significant braking/steering action, and mostly required the participant to release the accelerator and continue straight both at the junction and along the link. Hence, the outcome variable of the ART and its sub-components were deemed a suitable performance measure to achieve the study goals.

3.2 Equipment: Motorcycle Simulator (frame and sensors)

3.2.1 Motorcycle frame

A first-generation motorcycle simulator was developed for this study using a non-functional Honda Wave motorcycle body and set up in the Nanyang Technological University (NTU) Transportation Laboratory. The engine was removed and sensors for steering, throttle and brakes were installed to capture and integrate the various controls with the 3D rendered virtual environment in UC-Win/Road (Upahita et al., 2018b; Feng et al., 2017; Upahita et al., 2018a). The motorcycle simulator was not connected to a motion platform. Participants operate the motorcycle in response to the traffic scenarios as presented on a 100 cm wide x 62 cm tall display screen with an approximately 45° (horizontal) and 26° (vertical) field of view (see Figure 3.2).

Figure 3.2: View of first-generation motorcycle simulator

The use of a single forward display screen is to reduce the risk and severity of simulator sickness to the participants, given the relatively high experiment design speed of 60 km/h. According to (So et al., 2001), symptoms of simulator sickness tend to increase with higher navigation speeds. Based on past experience, it was also noted that there was higher risk of simulator sickness when participants were presented with three display screens in a wraparound configuration instead of one

single forward display screen. This has been attributed to the optical flow effect particularly at the peripheral vision sensors and this effect can be minimised by reducing the effective field of view of the simulator (Stoner et al., 2017). Herein, only one display screen was thus used in the experiment.

The choice of a fixed base motorcycle frame instead of a one with a pitch and roll hydraulics was to reduce the cost and time it took to develop the simulator. A Tacx Neo Track stationary bicycle base was used to support the stationary turning action of the motorcycle simulator's front wheel (see Figure 3.3).

Source: (Tacx B.V., 2018)

Figure 3.3: View of the Tacx Neo Track front wheels support

Overall, it is acknowledged that there will be some compromises on visual and physical realism with the current set up of the motorcycle simulator, particularly without the aid of hydraulic pumps to simulate pitch while braking and lean while steering. However, since the hazard portions of the scenarios only the motorcycle/participant to travel straight through and their steering reaction times were not part of the set of outcome variables, it was rationalised that this compromise was acceptable.

3.2.2 Sensor system configuration

Due to the similarities of the steering, throttle and braking systems for the motorcycle simulator and the bicycle and electric scooter simulators previously

developed by the Laboratory, the portions of the sensor set up and configuration were adapted for use on the motorcycle frame. Furthermore, based on past experience developing the bicycle and electric scooter simulators, it was determined that sensors with electrical signals simplified the interface with UC-win/Road, hence, the original throttle/brake were removed from the motorcycle body and replaced with electric ones. These are easily obtained as replacement kits for e-bicycles/e-scooters. In these experiments, the motorcycle simulator was designed as a scooter, i.e. there was no clutch and footbrake controls. This was to simplify the development process.

As discussed previously, the target response variable was the time participants took to release the accelerator after being presented the hazard scenario. The handling requirements of this task was simple and did not involve any gear shifts during the intervals of interest surrounding the hazard scenarios. The release of the accelerator only requires movement of the right hand to release the spring-loaded throttle grip. Hence, the lack of a clutch (left hand) and footbrake was assessed to have minimal impact on the outcome variable of ART.

3.2.2.1 Steering

The steering control system made use of a contact wheel-rotary encoder-amplifier-cum-'decoder' set-up attached to the steering column of the motorcycle frame (see Figure 3.4). The mechanical rotary encoder's wheel attachment was fixed in contact with the steering column, which allows it to measure the rotational displacement of the motorcycle handlebar. The encoder then sends a corresponding signal to an electronic counter that generates an electrical voltage output with amplitude proportional to the turning angle on the handlebar. This electrical signal is then used to control the steering movement of the virtual motorcycle via the Arduino microcontroller. This system of detecting changes in the steering angle input by the participant was determined to be stable, fast and accurate. The specifications of

the steering system used on the motorcycle simulator is included in Appendix A: Steering system.

Figure 3.4: View of the rotary encoder and wheel contact with the steering column of the motorcycle simulator

3.2.2.2 Throttle

When the participant rotates the right handgrip of the motorcycle handlebar (see Figure 3.5), the virtual motorcycle responds by accelerating because the sensor voltage output increases with the angular displacement of the handgrip. The UC-win/Road software is able to read the electronic signal via the interface Arduino microcontroller and responds accordingly to increase the speed of the virtual motorcycle. The specifications of the throttle setup used on the motorcycle simulator is included in Appendix B: Throttle system.

Figure 3.5: View of the replaced throttle control on the right handgrip of the motorcycle simulator

3.2.2.3 *Braking*

An electrical brake lever was substituted for the original mechanical brake lever and effectively functioned as a switch, i.e. either 'on' or 'off'. The signal was transmitted to the UC-win/Road software via the Arduino microcontroller and allows the participant to slow the virtual motorcycle accordingly. The specifications of the brake lever set up used on the motorcycle simulator is included in Appendix C: Brake system. A magnetic switch was attached to a brake lever and served as an additional indicator to the experiment administrator that the participant had actuated the brake.

3.2.2.4 *Interfacing with UC-win/Road*

The steering, throttle and brake signals were interfaced with the UC-win/Road program via an Arduino microcontroller (Leonardo). The specifications of the Arduino microcontroller interface module used on the motorcycle simulator to facilitate signal transmission from the various sensors to the UC-win/Road program is included in Appendix D: Arduino microcontroller and Delphi plugin.

Lastly, UC-win/Road required an additional software program – Embarcadero® Delphi development tool – to create a plugin that is able to read the read and interpret the data output from the Arduino microcontroller. This was similarly modified from the bicycle simulator previously developed by the Laboratory. Technical details on *D3 Delphi plugin development* tool is continued in Appendix D3.

3.3 *Equipment: Virtual Environment*

The virtual urban road network environment was built using UC-win/Road, a 3D-Virtual Reality software program developed by Forum 8 Japan. The program is able to generate roads, render 3D models, simulate traffic flows, run driving simulations with a high degree of realism. Table 3.1 lists some features of UC-win/Road.

The network was populated with medium and high-rise buildings and vehicular and pedestrian traffic. For the purpose of supporting the hazard scenarios, the road network mainly consisted of dual carriageways with 2 lanes in each direction and designed with a road speed limit of 60 km/h. The views of the 3D virtual network are shown in Figure 3.6 and Figure 3.7.

Figure 3.6: Satellite view of the 3D virtual network

Figure 3.7: Views of the 3D virtual network

Table 3.1: Features of UC-win/Road

No.	Description of UC-win/Road simulation software functionalities
1	3D models/characters/buildings/objects import, export, editing and movement tools, allowing scaling up and down, movement, rotation, inclination and arrangement of models in virtual environment. Programmable motion control of moving models including realistic animated movement of pedestrians, vehicles, cyclist riding on moving bicycle etc...
2	Automatic creation of roads, rivers, lakes, tunnels, bridges, flight paths, walking routes, railways, pathways etc...
3	Traffic simulation including traffic flow generation, based on traffic volume, car profiles and traffic lights, and road hazards.
4	Control of time, weather and light. Support of artificial light function, expression of day and night, and shadow.
5	Automatic fly-thru or walk-thru in the virtual world using flight path setting.
6	Road/pathway obstruction and hazard simulation.
7	Driving simulation function provides user to select and drive around in the virtual world using their preferred vehicle dynamics model. The dynamics algorithms integrated the vehicle numerous parameters that can be calibrated including the engine power, RPM, weight, Anti-lock Brake System, gear shift time etc.
8	Support of different driving modes (speed of vehicle, lane changing, height of viewpoint, viewpoint switching in 8 directions) and dynamic movement of viewpoint (from other cars, up and down, turn head). Manual driving and support for a 3D cockpit and multi-monitors.
9	Function providing sound effect feedback including vehicle engine sound, break wind sound, slipping sound, engine sound of surrounding vehicles, etc.
10	Function supporting tyre and road surface contact friction simulation using tyre slip data. Data input includes road surface condition (dry, wet, snow, ice) definition.
11	Scenario Editor – Setting of event based triggering of various pre-defined movements of or changes to any 3D models including human avatar and vehicles. For example, when a vehicle reaches a set position, pre-set model activity and various scenarios can be 'triggered', such as "signal changes to red", "vehicle pushes in at the intersection", "traffic congestion occurs", "a man starts walking" By using these scenarios, realistic events can be re-enacted.
13	Data Logging System that records and outputs coordinate information, direction, speed and steering angle of a moving vehicle, 3D moving characters and traffic flow, in CSV format.
14	Replay Option - This function is needed to record vehicles, pedestrians, etc. movement in real time video format and able to reproduce the recorded video when required.
15	Configurable viewing angle and viewing distance displays in the virtual world.
16	Provision of API (Application Programming Interface) to develop customized options and functionalities.

3.4 Equipment: Eye Tracking glasses

A SensoMotoric Instruments (SMI) wearable eye tracking glasses (ETG) was used to capture participants' eye movements for the various hazard scenarios on the display (see Figure 3.8 and Figure 3.9). The SMI ETG consists of one forward-facing camera that captures the forward scene (recording at a resolution of 1280 x 960 pixels and 24 frames per second), and two infrared (IR) cameras that capture eye gaze and eye movements from both eyes, set to record at 60 Hz or at 60 frames per second. The eye tracker records and indicates the location of a participant's eye gaze at any particular instant by means of a cursor which can be extracted from SMI's BeGaze Qualitative Analytical Software. This allows analysis of the eye gaze movements of participants to be conducted at 0.017s intervals (Upahita et al., 2018a).

Source: (Business Wire, 2019)

Figure 3.8: SMI eye tracking glasses

Figure 3.9: SMI eye tracking glasses on a participant

3.5 Participants

Eighty-eight participants (35 experienced riders, 24 novice riders and 29 unlicensed subjects) took part in the study. IRB approval was granted to perform the experiments on human subjects (IRB reference IRB-2018-05-046). The participants were recruited via posters and flyers and provided an honorarium of \$20 for their participation in this research study. For the study, participants' names were not

reported. Unique identification was generated for each participant to conceal their real identity. They were pre-screened to ensure they met the necessary criteria for the different target groups, namely:

- Experienced riders ('E') with more than 1 year's effective riding experience with a valid Singapore Class 2B/2A/2 rider's licence (or equivalent), and
- Novice riders ('N') with less than 1 year's effective riding experience with a valid Singapore Class 2B rider's licence (or equivalent).
- Unlicensed subject ('U') with no training in operating a motor vehicle.

Experienced and novice rider participants were included in the study as a precautionary measure to contrast the effect of riding experience on the RT measures (see Section Experience and age as factors affecting hazard perception performance). The literature is ambivalent on the effect of experience on response times or hazard perception abilities (Crundall, 2016; Jackson et al., 2009; Liu et al., 2009). The unlicensed category was included as a baseline for comparison against the licensed rider participants.

The participants' age ranged from 21 to 50 years old. A review of past literature indicated that motorist behaviour/traffic psychology studies involving simulators typically proceed with 10 to 35 subjects. Hence, 88 participants was deemed sufficient for this study.

Participants had to have normal or corrected-to-normal visual acuity; no known neurological or visual disorders; good physical and mental health. They were excluded if they had abnormal visual acuity; with known neurological or visual disorders; poor physical and mental health. In each instance, a participant was briefed and informed consent was obtained as per the procedures in Appendix E: Forms.

3.6 Procedures

Participants were asked to report to the NTU Geotechnical Transport and Geospatial (GTGS) Laboratory based on their time availability. Upon arrival, they were briefed about the experiment and its procedure. Participants are informed at this stage that they could elect to discontinue at any time without penalty, especially if they felt any dizziness or motion sickness. Because un-primed reactions are sought for, the participants were not told that they will be presented with hazards and were only told that they will be presented with several scenarios and to ride as per normal. The participant, if agreeable to participate, then proceeded to sign a consent form and fill out a pre-experiment questionnaire. The experiment took each participant less than 1 hour and they were debriefed after the session.

Once ready, the participant was introduced to the motorcycle simulator controls and asked to wear the SMI ETG. A calibration step is required for recording of the eye gaze positions on the ETG. The participant was then initiated by way of a short adaptation ride-through to familiarise them to the motorcycle simulator setup and the eye tracker, prior to the actual hazard scenarios. During the actual set of hazard scenarios, some navigational messages were provided along the route, and one hazard was planned per scenario.

After the session, the participant was asked to answer several questions and fill out the post experiment questionnaire on things like whether the hazard was expected, and what cues they picked up if they had anticipated the hazard. Only after taking a rest, will be participant be released from the GTGS lab.

3.7 Roadway hazard design

Epidemiological studies indicate that motorcycle riders are primarily vulnerable to right-turn-across-path (RTAP) hazards at the junction and to situations where both vehicles were originally travelling straight (i.e. along a link) on a secondary level (see

Section 2.1.1). Hence the research question on abrupt versus gradual-onset hazards RTs were studied in the above context.

3.7.1 Description of junction type hazards (Right Turn Across Path)

Two types of hazards at the junction were presented to the participants. They were RTAP hazards programmed to occur at signalised junctions with a permissive right-turn phase. The junctions consisted of two-lane carriageways in either direction and the hazard vehicle was a taxi on the right lane of the opposite carriageway turning right across the path of the subject's forward-moving motorcycle. Both junction RTAP hazards were designed with a time-to-conflict (TTC) of about 1.5 seconds for a participant travelling at the speed limit of 60 km/h. TTC was calculated based on the time it would take for participant's motorcycle to reach the projected conflict point between the path of the right-turning taxi and the participant's motorcycle from when the taxi just entered the junction. The solid line in Figure 3.10 and Figure 3.11 represents participant's travel path and dashed line represents hazard taxi's travel path.

With occlusion / abrupt-onset (JO) – see Figure 3.10

For the RTAP hazard with a visual occlusion to the motorcycle rider, a queue of stationary vehicles waiting to make a right turn was present on the right lane upon the participant's approach to the junction. These queuing stationary vehicles served to obstruct the motorcycle rider's view of the oncoming right-turning taxi on the right lane of the opposite carriageway. The hazard posed by the taxi would be first visible to the participant at or soon after it entered the junction, and served as an abrupt-onset hazard.

Without occlusion / gradual-onset (JX) – see Figure 3.11

In contrast, for the RTAP hazard without visual occlusion (JX) to the motorcycle rider, the view of the oncoming hazard by way of a right-turning taxi was not obstructed on its approach to the junction. The hazard taxi provided a potential hazard (as it

was travelling straight at first) that, upon turning, develops into an immediate hazard, forming the basis of a gradual-onset hazard.

Figure 3.10: Attendant trajectories and rendered 3D view of the JO junction hazard (abrupt-onset)

Figure 3.11: Attendant trajectories and rendered 3D view of the JX junction hazard (gradual-onset)

3.7.2 Description of link hazards

Two types of link hazards were presented to the participants. These occurred along a straight stretch of road away from the junction. Both link hazards were designed with a TTC of about 1.0 second for a participant travelling at the speed limit of 60 km/h. TTC was calculated based on the time it would take the participant's motorcycle to reach the projected conflict point between the path of the right-turning taxi and the participant's motorcycle from the onset of the relevant hazard. The solid line in Figure 3.12 and Figure 3.13 represents participant's travel path and dashed line represents hazard taxi's travel path.

With occlusion / abrupt-onset (LO) - see Figure 3.12

For the link hazard with a visual occlusion to the rider, a stopped truck by the side of the road occluded the participant's view of the hazard posed by the taxi turning right, out from a petrol kiosk. Hazard onset was defined as when the taxi just entered the carriageway. The taxi would first be visible at or soon after it entered the carriageway, appearing abruptly from behind the stopped truck.

Without occlusion / gradual-onset (LX) – see Figure 3.13

For the link hazard without visual occlusion to the motor-cyclist, the hazard taxi was programmed to travel ahead of the participant's motorcycle in the adjacent lane for some time before it suddenly made a "U"-turn across the path of the participant. Hazard onset was defined as when the taxi started its "U"-turning manoeuvre, i.e. when it started deviating from its straight path. Since the taxi in this case was always in the field of view of the participant, this scenario encapsulates a gradual-onset hazard along a straight section of road.

Figure 3.12: Attendant trajectories and rendered 3D view of the LO link hazard

Figure 3.13: Attendant trajectories and rendered 3D view of the LX link hazard

3.7.3 Summary of hazards and hazard onset points

The four hazard scenarios were deliberately designed to have very short TTCs to ensure that the hazards appear unambiguously as immediate hazards. The abrupt/gradual scenario pairs were also deliberately designed to have similar conflict vehicle trajectories and TTCs, 1.5 s for JO/JX and 1.0 s for LO/LX, whilst ensuring a certain level of realism.

For the purpose of this study, the four hazards' onsets are defined as follows:

- **Junction abrupt-onset (JO):** 1st appearance of the hazard taxi past the vehicles lined up along the right side of the carriageway waiting to turn right.
- **Junction gradual-onset (JX):** When the hazard taxi starts to deviate from a straight path and initiates its rightward movement.
- **Link abrupt-onset (LO):** 1st appearance of the hazard taxi past the stationary lorry on the left side of the road.
- **Link gradual-onset (LX):** When the hazard taxi starts to deviate from its straight path and begins its rightward movement.

The above hazard onset points were defined based on the first possible point where the rider can identify the intruding vehicle as an immediate hazard (see Section 2.3.3). The first appearance of the hazard taxi was used in the abrupt-onset hazards, and the start of the directional deviation from a straight-ahead trajectory was used in the case of gradual-onset hazards. The appropriateness of the onset point of gradual-onset hazards are discussed further in Section 4.4 in light of the eye tracking records and ARTs.

3.8 Study design

In order to study the effects of abrupt- versus gradual-onset hazards, the experiment was conducted in two sets, a set of two junction hazard scenarios (JO and JX), and a second set of link hazard scenarios (LO and LX). The rationale was to verify the effect (if any) of the onset type to two different hazard topographies, at the junction and along a link. Each participant completed the two pairs of hazard scenarios (JO, JX, LO and LX), in one of the following order:

- **Set 1:** JO – JX | **Set 2:** LO – LX
- **Set 1:** JX – JO | **Set 2:** LX – LO

Table 3.2 provides a summary of the experimental design used in this study.

Table 3.2: Summary of overall study design

JUNCTION HAZARD SCENARIOS (JO & JX)		Onset type	
		JO: Abrupt (Occluded)	JX: Gradual (Not occluded)
Experience Level	Licensed (Experienced)	<i>E1, E2, E3 ...</i>	<i>E1, E2, E3...</i>
	Licensed (Novice)	<i>N1, N2, N3 ...</i>	<i>N1, N2, N3...</i>
	Unlicensed	<i>U1, U2, U3 ...</i>	<i>U1, U2, U3 ...</i>

LINK HAZARD SCENARIOS (LO & LX)		Onset type	
		LO: Abrupt (Occluded)	LX: Gradual (Not occluded)
Experience Level	Licensed (Experienced)	<i>E1, E2, E3 ...</i>	<i>E1, E2, E3...</i>
	Licensed (Novice)	<i>N1, N2, N3 ...</i>	<i>N1, N2, N3...</i>
	Unlicensed	<i>U1, U2, U3 ...</i>	<i>U1, U2, U3 ...</i>

*order of exposure counterbalanced within each set

Participants were always exposed to junction hazard scenarios first before moving on to the link hazard scenarios. Exposure to abrupt and gradual-onset hazards were counterbalanced for each participant group (experienced, novice and unlicensed), i.e. about half the participants were exposed to scenario JO followed by JX in Set 1, and likewise exposed to scenario LO followed by LX in Set 2. Because of the limitations in the number of participants, the order sets, Junction (JO/JX) and Link (LO/LX), were not scrambled. Therefore care should be taken when interpreting results that compared the RTs between the hazards JO/JX and LO/LX.

In other studies, when participants are exposed to the same hazard two or more times, some degree of learning can be expected. Lechner and Malaterre (1991) exposed participants to the same hazard three times and concluded that the RTs were significantly longer for the first trial, but the RTs to the second and third trials were not. Similar findings were noted in repeated exposures to the same hazard in the studies by Schweitzer et al. (1995) and Toxopeus et al. (2018). As for the present study, the hazard scenarios presented to the participants were different hence it is not possible to quantify the effect (if any) of the first presented hazard versus the subsequent ones. Under these circumstances, the order of the hazards (JO/JX and LO/LX), were counterbalanced within each experiment set, but the order of junction

and link hazards were not counterbalanced. Herein, any comparison made between the RTs of junction and link hazards should note this limitation.

3.9 Summary

The first-generation motorcycle simulator integrating steer, throttle and brake controls with a virtual environment was developed to showcase four hazards, a pair each at the junction and link. The junction and link hazards contrasted abrupt-onset hazards that featured a visual occlusion by means of stationary vehicles, and gradual-onset hazards where the hazard vehicle was in the field of view for a period of time. Participants belonging to 3 experience levels (experienced, novice and unlicensed) were put through the scenarios and equipped with eye tracking glasses so that the sub-components of their ARTs can be measured.

CHAPTER 4: DATA ANALYSIS AND DISCUSSION

This chapter presents and discusses the findings from the study in terms of the participants' response types, their eye gaze movements and RTs across different scenario types (abrupt- and gradual-onset) and experience level (experienced, novice and unlicensed).

4.1 Data analysis

4.1.1 Vehicle speed, steering, throttle and braking

Figure 4.1 shows a typical time sequence of the data streams logged by UC-win/Road for a hazard scenario (see also Figure 3.1).

Figure 4.1: Example of typical time sequence of response to a hazard

Based on the above example:

- The participant was approaching the hazard at about 55 km/h;
- Onset of hazard was defined as when the hazard vehicle was first visible behind the occlusion (abrupt-onset scenario);
- At 0.76 s after the hazard's onset, the participant released the accelerator; and
- At 1.27 s after the hazard's onset, the participant applied the brake.

4.1.2 Eye gaze position

Data from the SMI ETG can be extracted in the form of an eye gaze scan path video (see Figure 4.2) using the BeGaze Qualitative Analysis Software. This allows the points like the start of saccadic movement towards the hazard and start of fixation to be identified (see also Figure 3.1).

*Figure 4.2: Example snapshot of output from SMI ETG for JO scenario.
Yellow circle indicates eye gaze location.*

When incorporating the eye tracking data into the framework of RT sub-components as shown in Figure 3.1, if the participant was looking at the hazard area at the point of onset, the saccade latency (SL) was set to zero. Similarly, if the participant was already fixating on the hazard at the point of hazard, time-to-first-fixation (TFF) was set to zero. Data on whether the participants were looking at the hazard at the point of onset were coded 'Yes' or 'No' and tabulated in Section 4.3. As a recap, hazard onset point for abrupt-onset hazards that appeared from behind occlusions (JO and LO) was defined to be along the edge of the stopped vehicle(s). For the gradual-onset hazards (JX and LX), the hazard vehicle was in the field of the rider the whole time, and hazard onset was referenced to the juncture when the hazard vehicle started deviating from its straight path (refer to Section 3.7.3).

4.1.3 Invalid data

There were instances where a full data set was not obtainable from a participant. These were due to equipment failure and interference from ambient traffic. The ambient traffic in the virtual environment was generated using the traffic generation engine of UC-win/Road. If it could not be determined if the participant's reaction was due to the ambient traffic or to the hazard, the data set for that hazard scenario was eliminated. There were a total of 309 valid runs across the two pairs of JO/JX and LO/LX scenarios after excluding the invalid runs, as summarised in Table 4.1.

Table 4.1: Number of valid experimental runs by scenario type and experience level

Experience Level	Set 1		Set 2	
	JO	JX	LO	LX
Experienced	30	33	28	32
Novice	22	22	23	19
Unlicensed	26	25	23	26
Total	78	80	74	77
	158		151	

4.2 Accelerator response type

In analysing the ARTs of participants, their response types were classified into four categories:

- **'Responded'** – accelerator was released after the hazard onset points (defined in Section 3.7.3) and ART was measurable;
- **'Pre-onset response'** – accelerator released (in part or full) up to 0.25 seconds after afore-defined hazard onset point. This cut-off value was based on a review of the literature on simple response times, i.e. response time studies where the participants were reacting to a known visual stimulus and there was no choice involved in their decision making (Hick, 1952; Hart and Reeve, 2007; Carlton et al., 1987). Because the riding task is more complex than a simple response, where the participant has several response options available, any ART < 0.25 seconds is likely a continuation of a pre-onset release of the accelerator;

- **‘Accelerated’** – sped up instead of releasing the accelerator; and
- **‘No response’** – did not respond.

As mentioned in the earlier chapters, the focus of this research study is on the RT of participants, hence only ART from the participants that responded appropriately were further analysed using analysis of variance (ANOVA). The other response types (no response, pre-onset and accelerated) are tabulated for reference, and will only be discussed qualitatively.

Figure 4.3 consolidates the proportions of response types to all four hazard scenarios and presents them as a breakdown by participant category.

Figure 4.3: Breakdown of response types by participant group

Table 4.2: Proportion of response types by participant group

Response Type	E	N	U
Pre-onset	7%	9%	4%
Responded	92%	84%	82%
No response	1%	7%	9%
Accelerated	-	-	5%

Qualitatively, based on Figure 4.3 and Table 4.2, the unlicensed participants (U) generally showed poorer hazard response behaviour than the licensed participants (E and N). The former had the highest proportion of non-responders (9%), and were the only category that had participants accelerate in response to the hazard (5%). The proportion of pre-onset responders was also the lowest (4%) for unlicensed participants. The licensed participants, E and N, showed similar proportions of pre-

onset responders at 7% and 9% respectively, but the proportion of non-responders were relatively lower for E (1%) than N (7%).

Note that pre-onset responses make for a very interesting but complex study in itself, but is beyond the scope of this research. Potentially, pre-onset responses may represent a Level 3 situation awareness – the projection of future events – (Endsley, 1995), or they may simply be a primitive instinctual response. Understanding why some participants respond prematurely may help in the design of simulator-based training in driving schools. Further work can be done in future to specifically target this response type.

4.3 Participants looking at the hazard area at the point of onset

A qualitative examination of the data on the proportion of participants who were looking at the hazard area at the defined point of onset revealed the following general observations (refer to Table 4.3 and Figure 4.4). Firstly, the junction hazards generally had a higher proportion of participants who were looking at the hazard at the onset point JO/JX (31% Yes) and LO/LX (10% Yes). Secondly, unlicensed participants consistently under-performed when compared with the licensed experienced and novice participants, in the context of the former having the lowest proportion of participants who were already looking at the hazard area across the four different scenarios, i.e. “Look”=‘Yes’. In this regard, the experienced and novice participants generally appeared to perform at a similar level.

Table 4.3: Proportion of participants who were looking at the hazard area at the onset point by scenario type

“Look”	Scenario type			
	JO	JX	LO	LX
‘No’	65%	73%	94%	85%
‘Yes’	35%	27%	6%	15%
Total	69% (No)		90% (No)	
	31% (Yes)		10% (Yes)	

Figure 4.4: Proportion of “Look” (Yes & No) by scenario and participant group

Worth mentioning at this juncture is that participants who were already looking at the hazard area at the point of onset would naturally perform better by way of shorter ARTs, because they have shorter saccadic latency (SL) and/or time-to-first-fixation (TFF) sub-components. This is apparent from Figure 4.5 and Figure 4.6, where the mean ART of participants who were already looking at the hazard area at onset (i.e. “Look”=Yes), were generally lower than those who were not. This general pattern is even more apparent when the unlicensed was excluded from the dataset (Figure 4.6). The effect of riding experience level will be discussed in further detail in subsequent sections.

Figure 4.5: ART for the two pairs of scenarios compared by “Look” (all participant groups)

Figure 4.6: ART for the two pairs of scenarios compared by “Look” (licensed participants only)

4.4 Evaluation of the response time interval for gradual-onset hazards

Because in the abrupt hazard onset points there is a natural and consistent choice of onset point (i.e. 1st appearance), this section only evaluates the choice for gradual-onset hazard. The hazard onset points for gradual-onset hazards were defined as the start of directional deviation of the hazard taxi from its straight path (see Section 3.7.3). These are evaluated against alternative onset points as shown in Table 4.4, which uses travel lane delineations as reference lines.

Table 4.4: Possible alternatives to selected gradual hazard onset points

Scenario	Onset point defined in Section 3.7.3	Alternative onset point
JX	Start of lateral deviation	Just enters the rider’s carriageway
LX	Start of lateral deviation	Just enters the rider’s travel lane

Figure 4.7 (eye tracking data) shows the proportion of participants who were already looking at the hazard area by the time of the alternative onset point. Contrasting the results shown in Figure 4.4 and

Figure 4.7, for both JX and LX scenarios, a large majority of the participants had already had their eye gaze directed towards the hazard taxi if the alternative onset point was used.

Figure 4.7: Proportion of “Look” (Yes & No) for gradual-onset hazards with the alternative onset points

Based on Figure 4.8 (accelerator response type), if the alternative travel-lane-type reference points were used, almost half the participants had initiated a response by that time. This would not follow the model for hazard perception-response as described in Figure 3.1, and a large proportion of the ARTs would not be measurable as a positive value. Whereas based on the onset points defined in Section 3.7.3, majority of the participants followed the model described (see Figure 4.9).

Figure 4.8: Breakdown of response types for gradual-onset hazards with alternative onset points

Figure 4.9: Breakdown of response types for gradual-onset hazards based on onset points defined in Section 3.7.3

Upon further examination of the ETG data, during the development of the hazard, the eye gaze behaviour of participants do not systematically transition between roadway references (e.g. edge of travel lane or carriageway) and the potential hazard vehicle. Neither do the participants appear to 'stare' at the wheels of the potential vehicle in order to gather information on whether the intruding vehicle is going to be on a collision course. As such, in the gradual-onset hazard scenarios presented in this study, the alternative travel lane reference points appear to be less suitable as a hazard onset starting point.

4.5 Statistical Model

Descriptive statistics of the ART, TFF and FxAR results are presented in Table 4.5.

Table 4.5: Descriptive statistics of ART, TFF and FxAR by scenario and experience level

Scenario		ART			TFF			FxAR		
		E	N	U	E	N	U	E	N	U
JO	N	26	11	19	26	11	19	26	11	19
	Mean	0.77	0.92	1.00	0.25	0.46	0.28	0.49	0.40	0.58
	Std Dev	0.14	0.30	0.47	0.21	0.22	0.22	0.21	0.27	0.55
JX	N	29	22	20	29	22	20	29	22	20
	Mean	0.96	0.90	1.1	0.36	0.40	0.56	0.49	0.50	0.54
	Std De	0.27	0.29	0.26	0.35	0.31	0.22	0.26	0.17	0.31
LO	N	27	20	20	27	20	20	27	20	20
	Mean	0.88	0.93	0.98	0.40	0.44	0.45	0.49	0.46	0.48
	Std De	0.19	0.22	0.42	0.19	0.23	0.16	0.15	0.18	0.45
LX	N	32	19	23	32	19	23	32	19	23
	Mean	1.06	1.05	1.29	0.49	0.45	0.53	0.54	0.54	0.59
	Std De	0.21	0.23	0.46	0.27	0.26	0.24	0.25	0.33	0.59

For each set of scenarios, at the junction and the link, 3 x 2 repeated measures analysis of variance (ANOVA) were separately performed on the dependent variables of overall ART, and response time sub-intervals of TFF and Fix-AR (see Figure 3.1), that included the between-subject variable of Experience Level (3 levels, 'Experienced' (E), 'Novice' (N), or 'Unlicensed' (U)), and the within-subject variable of Onset Type (2 levels, 'Abrupt' (JO/LO) and 'Gradual' (JX/LX)). The results from the statistical tests are shown on Figure 4.10, Figure 4.11, Table 4.6 and Table 4.7.

Figure 4.10: ART, TFF and FxAR results for junction and link scenarios compared by onset type

Figure 4.11: ART, TFF and FxAR results for junction and link scenarios compared by experience level

Table 4.6: Results of statistical tests for junction hazards

Dependent variable	Independent variable	ANOVA		Pairwise comparison*		
		F-value	p-value*	Level	p-value	Mean diff.
ART	Exp Level	F(2,69)=4.47	0.02	E vs U	0.01	-0.19
	Onset	F(1,51)=4.74	0.03	JO vs JX	0.03	-0.11
	Exp Level*Onset	F(2,51)=1.43	0.25			
TFF	Exp Level	F(2,78)=3.11	0.05	E vs N	0.05	-0.11
				E vs U	0.04	-0.11
	Onset	F(2,79)=6.11	0.02	JO vs JX	0.02	-0.12
	Exp Level*Onset	F(2,78)=3.56	0.03			
FxAR	Exp Level	F(2,73)=0.46	0.63			
	Onset	F(1,45)=0.00	0.99			
	Exp Level*Onset	F(2,45)=0.07	0.94			

*pairwise comparison results included only for ANOVA p-value <0.05

Table 4.7: Results of statistical test for link hazards

Dependent variable	Independent variable	ANOVA		Pairwise comparison*		
		F-value	p-value*	Level	p-value	Mean diff.
ART	Exp Level	F(2,81)=3.00	0.06			
	Onset	F(1,72)=28.70	<0.001	LO vs LX	<0.001	-0.20
	Exp Level*Onset	F(2,72)=1.52	0.23			
TFF	Exp Level	F(2,71)=1.42	0.25			
	Onset	F(1,69)=4.62	0.04	LO vs LX	0.04	-0.08
	Exp Level*Onset	F(2,69)=0.58	0.56			
FxAR	Exp Level	F(2,82)=0.04	0.96			
	Onset	F(1,74)=3.60	0.06			
	Exp Level*Onset	F(2,74)=0.04	0.96			

*pairwise comparison results included only for ANOVA p-value <0.05

4.5.1 Overall ART

Based on the results shown in Table 4.6 and

Table 4.7, notably, significant main effects were observed for onset type on overall ARTs for both junction and link scenarios. Pairwise comparisons of the junction scenarios revealed that gradual-onset JX scenario had a significantly longer mean ART by 0.11 s than the abrupt-onset JO scenario. Pairwise comparison of the link scenarios similarly revealed that the gradual-onset LX scenario had a significantly longer mean ART by 0.20 s than the abrupt-onset LO scenario.

Experience level reached significance for the junction scenarios ($p=.02$). Pairwise comparisons of the 3 experience level subgroups revealed that the unlicensed participants had significantly longer mean ARTs than experienced riders. Although experience level for the link scenarios did not reach significance ($p=.06$), the p -value was close to 0.05, and qualitatively from Figure 4.11, the unlicensed subjects (U) appeared to have longer overall ARTs than licensed riders (E, N).

4.5.2 TFF sub-component

In terms of the first sub-component of ART, TFF, onset type reached significance for both junction and link scenarios. Pairwise comparison of the junction scenarios showed that the mean TFFs to the gradual-onset JX hazard was 0.12 s longer than for the abrupt-onset JO hazard. Similarly for the link scenarios, mean TFFs to the gradual-onset LX hazard were 0.08 s longer than for the abrupt-onset LO hazard.

Experience level reached significance for the junction scenarios ($p=.05$) but not the link scenarios ($p=.25$). Pairwise comparisons revealed the difference mainly between experienced riders and both the novice riders and unlicensed subjects. (Figure 4.11).

Interestingly, there was a significant interaction effect between Experience Level*Onset for junction scenarios, where the novice riders had longer TFFs than

the experienced riders and unlicensed subjects. More in depth investigation is needed into this observation to determine if this is due to the small sample size at the sub-group level.

4.5.3 Fx-AR sub-component

The remaining part of the ART, FxAR, in contrast was not significantly influenced by onset type and experience level.

4.5.4 BRTs

For completeness, although the BRTs were not studied in this research, the average difference between the ARTs and BRTs were recorded and can be computed. In general, for licensed participants, if the accelerator was not already released at the time the hazard was presented, the participants either applied brakes *after* they had released the accelerator, or not at all (likely because the release of the accelerator was sufficient to avoid crashing onto the intruding vehicle). The average time delay between accelerator release and brake application to junction and link scenarios were 0.21 seconds and 0.22 seconds respectively for licensed participants.

Table 4.8: Time delay between accelerator release and brake application for licensed participants

Scenario	Junction	Link
N	58	88
Mean	0.21	0.22
Median	0.18	0.20
Min	-0.10	-0.21
Max	0.94	1.79
Std. Dev.	0.19	0.29

4.5.5 Summary of findings

In terms of contrasting abrupt and gradual-onset hazards, the results from both junction and link scenarios consistently showed that gradual-onset hazards resulted

in significantly longer mean ARTs and TFFs, but did not appear to significantly affect the FxAR component.

In terms of contrasting experience levels, the results were less clear cut, but it was observed that the unlicensed participants consistently underperformed relative to the experienced riders. This comparison was most apparent for overall ART and can be seen in a general sense from Figure 4.11 (ART). It was also noted that the contrasts between novice riders and experienced riders generally did not reach significance for any of the three measures of ART, TFF or FxAR, and can be concluded that they performed similarly. These findings echo the observations in Section 4.2, on accelerator response types, and Section 4.3, on the proportion of participants who were looking at the hazard area onset.

4.6 Discussion

This study investigated the response time performance of motorcycle riders of varying degrees of training/experience to abrupt-onset and gradual-onset hazards in a virtual environment. Participants were equipped with ETGs to record their eye movements to understand more on where their eyes were directed when the hazards developed.

4.6.1 Effect of training and on-road experience

On several findings in this study, the unlicensed participants were generally shown to be poorer performers than the licensed participants consisting of experienced and novice riders. Firstly, their response types (Figure 4.3) showed lowest proportion of pre-onset responses, and the highest proportions of irrational response behaviour such as accelerating or a non-response. Secondly, unlicensed participants had the lowest proportion of participants who were already looking at the hazard area at onset across the four scenarios when compared with the licensed participants (Figure 4.4). Thirdly, the ANOVA of the effect of experience level on

ART/TFF/FxAR showed that in a general sense, some underlying phenomenon exists where unlicensed participants tended to perform worst amongst the 3 groups (see Figure 4.11).

The remaining two licensed participant groups, experienced and novice riders, generally performed similarly, in terms of their response types (Figure 4.3), propensity to be looking at the hazard area at onset (Figure 4.4) and overall ART (Figure 4.11). Only in the TFF of the junction scenarios did the experienced riders outperform both the novice riders and unlicensed subjects.

Therefore, based on the assessment of the performance of the participants on account of their experience levels, it is reassuring to know that the training that riders get in driving school before licensing motorcycle riders to operate on the road does appear to generally translate to better search strategies, better chances of identifying the most likely source of hazard, more rational behaviour and overall superior performance in the face of hazardous situations. On the other hand, the general lack of significance of the effects of on-road riding experience on the part of licensed participants, contribute to the bag of mixed results when it comes to whether the years of effective on-road riding experience improves hazard perception skill when measured in terms of RTs. From a crash reconstruction practitioner perspective, often times the experience level of an involved party is not a factor for contention, and this non-significance of experience level lends support that this is not a major issue of practical concern when applying RT research to accident reconstruction cases, at least in the context of these scenarios studied. Now, dealing with an unlicensed individual who had illegally obtained use of a vehicle, that would be another issue altogether. From a road safety perspective, this can join the mixed bag of results from other studies dealing with the issue. As discussed in Crundall (2016), the lack of consistency across studies could be due to things like variations in hazard stimulus being presented, the somewhat fluid definitions of what makes a novice, or that overall RT is a coarse measure, and not

suitable for discriminating the two groups. One may propose also that perhaps the issues between different levels of expertise are predominantly behavioural in nature, as opposed to physiological, hence licensed riders as individuals exhibit variations fundamentally affected by the large number of confounding variables that practically would also come into play in day-to-day operations of a motor-vehicle anyway. Rather than focussing on the differences in experience level, perhaps it is more worthwhile focussing on what differs on the visual stimulus e.g. the scenario type.

4.6.2 Effect of abrupt versus gradual-onset hazards

The main issue of interest in this study was whether RTs were faster when the hazards appeared abruptly from behind a visual occlusion (e.g. a parked vehicle or queuing vehicles as they wait to turn right at a junction). Most hazard perception studies deal with abrupt-onset hazards, where the starting point of the RT interval is clearly demarcated. This study deliberately presented participants with hazards that were in the rider's field of view for some time before transitioning to become a hazard. These scenarios were contrasted with scenarios where the hazard appeared abruptly from behind a visual occlusion, in order to provide a baseline for comparison.

For the gross measure of overall ART, this study showed that gradual-onset hazards consistently resulted in longer ARTs when compared with abrupt-onset hazards for both junction and link scenarios. In delving into the sub-components of the ART, the results appeared to suggest that time-to-first-fixation (TFF), rather than fixation-to-accelerator release (FxAR) is where the difference occurs. Hence, it does seem that abrupt-onsets do provide a natural performance advantage to riders reacting to a hazard. This has been attributed in the literature to involuntary shifts of one's visual attention superseding any top-down search strategy (Theeuwes, 1994; Schreij et al., 2008). However, another possibility is that the presence of a visual occlusion narrows the active visual field necessary for scanning. This study does not deal with

this issue, but future studies can probe further the reasons why TFF to abrupt-onset hazards from behind visual occlusion tends to be faster than gradual-onset hazards. The remaining segment of RT, the FxAR component, did not reach significance for onset type, which may suggest that after riders have fixated on the hazard the remaining fraction and response of releasing the accelerator is akin to a physiological response.

Overall, these scenarios have been designed to have very short times to collision, hence are obvious immediate hazards. From a crash reconstruction perspective, particularly for link hazards, abrupt-onset hazards perhaps entail slightly shorter RTs, possibly due to the effect of provoking involuntary shifts in visual attention to the abrupt change in the environment affording a natural advantage. Whereas gradual-onset hazards at the link perhaps entail a slightly longer RTs, because at the hazards onset the visual information change is not so clearly demarcated, thereby corresponding to generally longer overall RTs and TFFs. On the other hand, junctions are generally seen as high conflict zones, hence a higher likelihood of an improved RT from anticipation as shown in Muttart (2003). Perhaps the cognitive (top-down) effect of this vigilance functioned to mask the performance improvement contributed by the abrupt change in visual scene. This sets up a case for a good search strategy, and the importance of constant vigilance and defensive driving, when riding a motorcycle.

4.6.3 Insights from eye tracking data

In the context of the current study, the ETG results in Table 4.3 indicated that the visual search patterns of riders tended to be more successful at identifying the source of the junction hazards than the link hazards, as shown by the larger proportion of participants who were looking at the hazard at the onset point for JO/JX compared with LO/LX. This is consistent with prior research that more cues and information were available at junctions, hence RTs were faster (Muttart, 2003).

Within the same scenario, riders who were looking at the hazard at onset had faster ARTs (see Figure 4.5 and Figure 4.6). This definitely lends support for training riders to have better search strategies, where Beanland et al. (2013) have noted that such training may reduce RTs by a fraction of a second, not sufficient to avoid a crash but could significantly reduce its severity which, for a motorcycle with limited physical protection, can mean the difference between life and death.

On the other hand, when considering the ETG data between scenarios, the propensity for riders to look at the hazard at onset does not appear to correlate with the mean ARTs. For example, for the link pair of hazards, there was a higher proportion of riders who were already looking at the hazard vehicle at onset for the LX scenario compared with the LO scenario (see Figure 4.4). However, the average ARTs to gradual-onset LX hazard was 0.2 s longer than the ARTs to the abrupt-onset LO hazard. Of the four scenarios presented, the U-turn link hazard (LX) appeared to be particularly difficult for riders to avoid. One explanation why LX posed greater difficulty to riders could be because the level of this “right-of-way violation” was grossly over the level that the junction right-turn-across path hazard presents, and in general less common than junction right-turn-across path violations. Hence, the degree of anticipation and learning from past experience is less so for the LX hazard.

Overall, this further supports that RTs are very much scenario dependent, and there is no ‘one-size-fits-all’ when it comes to RTs for use in crash reconstruction. As Singapore introduces simulator training at all driving schools in 2019, it would benefit the riders to be exposed to these types of “right-of-way violation” hazards, particularly those where the hazard vehicle was in full view of the rider leading up to the hazard but gradually transitioned into an immediate hazard. Simulator training and reviewing past drives can improve hazard perception skill significantly (Beanland et al., 2013).

4.6.4 Comparison with other studies

In this study, the average ARTs for licensed participants to the four scenarios ranged from 0.77 s to 1.06 s (see Table 4.5), and braking typically occurred about 0.2 s after accelerator release (see Table 4.8). This is generally consistent with the results reported by Davoodi et al. (2012) of 1.29 s, a study that measured unexpected brake response times of motorcycle riders to a hazard that appeared directly in front of them under controlled test-track road conditions.

From the car driving simulator point of view, Attalla et al. (2018) reported average BRTs of 2.02 s for a turn across path without stopping scenario. This difference could be attributed to the longer TTC utilised in their study of 3.66 s. Other research has indicated that shorter TTCs tend to result in shorter RTs (Mazzae et al., 2003; D'Addario and Donmez, 2019). As discussed earlier in Section 2.2.3, other studies have also concluded that riders tend to have superior hazard perception skill than drivers (Hosking et al., 2010; Shahar et al., 2010; Muttart et al., 2017), which may result in the faster RTs observed in the current study. Notwithstanding, it cannot be ruled out that the fidelity of the simulator setup may have hastened RTs.

In the evaluation of an appropriate start time for ART values for gradual onset hazards, the findings in Section 4.4 determined that if onset was set to when the hazard vehicle just enters the nearest adjacent lane, majority of the participants would have already shifted their eye gaze to the hazard and almost half the participants had initiated a response by that time. These explain the results obtained by Dinakar and Muttart (2019) very nicely. They reported RTs in a naturalistic driver study for junction turn-across-path hazards as measured based on the onset entering the nearest adjacent lane to be an average close to 0 s, and a spread of values above and below 0 s. The negative values, they noted, indicated that some drivers were already responding to the hazard vehicle before it crossed the lane edge. The current study found that riders did not perceive the intruding vehicle by referencing its position against lane boundaries and the like, instead

detection and identification of the hazard appeared to be a general appreciation of a collision course trajectory. Hence, a potential application based on these observations for crash reconstruction work, is that the data suggests that in a junction turn-across-path scenario where the hazard vehicle makes the turn from the next adjacent lane, a 'typical' driver/rider can be expected to start his response when the hazard vehicle crosses the adjacent lane boundary, i.e. $RT = 0$ s.

Overall, there are limited comparable studies, particularly dealing with motorcycle riders in hazard scenarios. Nevertheless, against the backdrop of the body of research in this area, the results appear generally robust and consistent. The shorter RTs when compared with a turn-across-path scenario that involves a vehicle not stopping may be explained by other scenario specific differences.

CHAPTER 5: CONCLUSIONS, LIMITATIONS & OTHER CONSIDERATIONS

5.1 Conclusions

This study presented participants with two sets of hazards, a pair at the junction, and a second pair at the link, on a motorcycle simulator equipped with wearable eye tracking glasses. Each pair of hazards contrasted an abrupt- and a gradual-onset hazard. The overall accelerator release response times (ARTs) were analysed, alongside its sub-components, the time-to-first-fixation (TFF) and the fixation to accelerator release (FxAR).

The hazard onset point of gradual-onset hazards were evaluated and it was determined that the start of directional deviation by the conflicting vehicle was a more appropriate starting point compared with a travel lane delineation reference line. Use of the latter would result in almost half the participants having had initiated a response by that time. Furthermore, the eye gaze behaviour of participants did not appear to involve fixating on the lane/carriageway lines to determine the position of the intruding vehicle.

In terms of riding experience level, unlicensed participants consistently underperformed than licensed participants, but the study did not differentiate the performance of licensed experienced motorcycle riders from licensed novice riders. These results suggest that the training riders get in driving school before obtaining their licence does serve to improve their search strategies to better identify potential sources of hazard and produce more rational hazard avoidance behaviour in operational controls. The lack of a significant difference between the experienced and novice riders to the hazards presented may be because the factors that affect this are many and confounding, and not practical to separate out for day-to-day operation of a motor-vehicle in any case. Nevertheless, this simplifies crash

reconstruction analysis in that there is no persuasive argument on the need to account for differences in the experience levels of involved parties.

On the part of scenario type, there was a higher proportion of riders who looked at the hazard area at the onset point for junction hazards as compared with the link hazards. This may be an indication of enhanced vigilance or anticipation by virtue that junctions are seen as conflict zones, suggested by (Muttart, 2003), and a more top-down cognitive approach is applied.

Significant effect of onset type (abrupt vs gradual) on TFF was observed for both junction and link hazards, suggesting that the sudden change in the visual scene does promote a performance advantage for attracting visual attention, and acts to reduce RTs. This result is consistent with the results from D'Addario and Donmez (2019), that concluded that the abrupt-onset hazard (pedestrian hazard not visible on approach) appeared to capture attention more readily than more gradual-onset motions of the other turns across path hazards presented.

The remaining segment of ART, the FxAR portion, does not appear to be affected by scenario type, and may suggest that it is mainly a physiological response to a hazard. The link gradual hazard appeared to be performed significantly poorer than the others, and it is suggested that the top-down cognitive model is not in play at links, hence the behaviour of the u-turning vehicle was more unexpected. In any case, this further supports the idea that simulator hazard training is essential to teach riders that other vehicles do not always 'follow the rules' and they should always be on the lookout for unexpected behaviour, be it at the junction or along a link.

The results from this study are generally consistent with the available literature on hazard perception and response. They also shed some light into the trends observed in other naturalistic studies that do not have access to accompanying eye tracking data.

5.2 Limitations and recommendations

This experiment used the first fixation of a participant's gaze data to study how fast a participant's eye gaze is attracted to a developing hazard, and has been helpful in understanding the differences between abrupt- and gradual-onset hazards. The first fixation point, however, may not necessarily equate to when the participant has identified the hazard or decided on a response (see Olson (1989)). There are some studies, for example Huestegge and Bockler (2016), that suggested that the processing of the hazard level can start prior to first fixation with the use of peripheral vision.

The sub-components of the older, more conceptual breakdowns of the hazard perception response process, cannot be directly measured, such as those used by Olson (1989). They were generally proposed at a time where researchers did not have access to eye tracking equipment that can record precisely where a person was looking, and instead was only able to report the gross RT from an arbitrarily defined hazard onset point to a recorded response. Hence correlating these more modern RT sub-components to older concepts of hazard processing should be done with caution. Nevertheless, there is a wealth of information potentially obtainable from eye tracking recordings, for example, according to Privitera et al. (2008) pupil dilation can be correlated to visual detection events, although the extent may be small and not necessarily detectable.

Hazards on the roadway can come from many directions. Because this study only tested very specific scenarios, the conclusions made about the hazard onset points for the gradual-onset hazards may not be relevant for other types of gradual-onset hazards, e.g. those where vehicles start from stop.

There is a trade-off in an active riding hazard perception study done on a simulator, where the participants' responses are less controlled and behavioural effects can

creep in. On the other hand, there are also limitations stemming from the use of a fixed base simulator that does not have feedback like pitch while braking and lean while steering. Overall, it is expected that the responses of participants contain more variability compared with video-based hazard perception response time tests, but the simulator takes one step closer to mimicking the mental workload in a more realistic environment requiring active input.

5.3 Other considerations

5.3.1 Motorcycle simulator options

Several motorcycle simulator options were explored in the course of pursuing this research.

First, the author attempted to procure a de-registered motorcycle frame. This came with issues with Land Transport Authority (LTA) regulations that only allow de-registered vehicles to be kept on-site for display purposes (mainly for collectable motorcycles), they be bolted to the ground and secured, written permission is granted by the owner of the land (which, in this case, would be the Ministry of Education), among other things.

Second, the author explored the option of procuring and modifying a commercially available motorcycle simulator, such as arcade game units (e.g Daytona) to either integrate with the UC-win/Road software or come with it a customisable hazard scenario developer. In most cases, for the arcade game types, the software development kit was not available and could not be integrated with UC-win/Road software. The other full-suite motorcycle simulators with customisable hazard scenarios were too costly.

As a side note, towards the end of the developmental phase of this project, the author came across a successfully crowdfunded motorcycle simulator (<https://leangp.com>) by a company in Spain that costs €1,900. The motorcycle

simulator (see Figure 5.1) was designed for plug and play home use with motorcycle video games. It comes with two axis lean, throttle and brakes. As far as integration with UC-win/Road is concerned, this could potentially be easily achieved, as UC-win/Road readily accepts gaming remote control inputs.

Source: (LeanGP, 2018)

Figure 5.1: LeanGP Simulator Home

Third, Bukit Batok Driving Centre (BBDC) was approached as a possible collaborator. Mr Tham Kok Choon, Assistant Manager (Training) at BBDC was the point of contact. BBDC has a Honda motorcycle simulator with two-axis lean attached to a large single screen display. Six hazard scenarios are pre-programmed, each containing 4-8 hazards and takes a person about 5 minutes to complete. However, their simulator unit had several parts that could not be repaired, and the collaboration was thus not pursued.

5.3.2 On-road study

As part of the initial exploration of this thesis, an on-road study was planned to study the eye gaze behaviour of motorcycle riders at junction approach in non-hazard situations. A 20-minute riding route requiring the participant to go straight at several right-turn-across-path junctions was planned.

It was originally proposed that if the on-road study proceeded, the same participants may be approached to complete the on-road riding aspect in order to obtain a matched set of data. However, the scope and logistical requirements for this endeavour was eventually determined to be unfeasible.

Two insurance quotations, from CHUBB and Allied World, were obtained as part of the preparatory groundwork in planning the feasibility of the on-road field study. These quotations are included in Appendix F.

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Appendix A: Steering system

A 200 mm circumference wheel/rotary encoder (power supply voltage: +8V to +30V, resolution 400 pulses/rotation) was installed connected to the steering column of the motorcycle body. The steering column on the motorcycle had -45° (left) and $+35^\circ$ (right) limits to its rotation. Any rotation of the steering column is measured mechanically by the rotary encoder and fed into the electronic counter that generates a voltage output proportional to the turning angle on the steering column. This voltage signal is finally used to control the turning movement of the virtual motorcycle via the Arduino microcontroller.

Figure A1: Signal flow from the steering column to the microcontroller

Figure A2: Dimensions of the rotary encoder

Appendix B: Throttle system

The electric throttle was a Hall Effect sensor that consisted of three wires (power, ground and signal), and produced a continuous electrical signal. This sensor works by voltage output increasing in line with the angular displacement of the grip in the twisting motion. By twisting the grip on the throttle, the voltage output increases in line with the angular displacement, via the Arduino microcontroller, the forward motion and speed of the virtual motorcycle can be controlled.

Figure B1: Signal flow from the throttle to the microcontroller

Appendix C: Brake system

The electrical brake connection consisted of two wires (power and signal), and essentially functioned as an on/off switch. When the lever was depressed, it would send a voltage signal through to the microcontroller, thereby retarding the forward motion of the virtual motorcycle.

Figure C1: Signal flow from the brake lever to the microcontroller

Appendix D: Arduino microcontroller and Delphi plugin

Figure D1: Arduino Leonardo board used to interface the various motorcycle simulator controls with the UC-win/Road program

Source: (Arduino, 2019)

D1 Technical specifications of the Arduino microcontroller

The Arduino Leonardo microcontroller was used to receive the signals from the various simulator sensors and transmit the signals to the computer via Universal Serial Bus (USB). The following list shows the specifications of this interfacing development board.

Technical specifications of the Arduino Leonardo:

- Microcontroller: ATmega32u4 with clock speed of 16MHz
- Operating Voltage: 5V
- Input Voltage (Recommended): 7-12V
- Input Voltage (limits): 6-20V
- Number of Digital I/O Pins: 20
- Number of PWM (Pulse Width Modulations) Channels: 7
- Number of Analog Input Channels: 12
- DC Current per I/O Pin 40 mA
- DC Current for 3.3V Pin 50 mA
- Flash Memory 32 KB (ATmega32u4) of which 4 KB used by bootloader
- SRAM: 2.5 KB (ATmega32u4), EEPROM : 1 KB (ATmega32u4)
- Dimensions: Length 68.6 mm, Width 53.3 mm (Weight 20g)

D2 Motorcycle simulator Arduino programming code

The Arduino programming code used (see below) was adapted and modified from the bicycle and electronic scooter simulators previously developed by the laboratory.

```
// Define the number of samples to keep track of. The higher the number, the
// more the readings will be smoothed, but the slower the output will respond to
// the input. Using a constant rather than a normal variable lets us use this
// value to determine the size of the readings array.
//int outPin = 8;
const int numReadings = 300;

int readings[numReadings];      // the readings from the analog input
int analogPin = 1;              // reading for brake
int brake = 0;

int readIndex = 0;              // the index of the current reading

long total = 0;                 // the running total

int average = 0;                // the average
float steer = 0;                //change int to float 20180601 float
int inputPin = A2;
char strin[50];

void setup() {
  // initialize serial communication with computer:
  //pinMode(outPin, OUTPUT);      // sets the digital pin as output test 20180612
  Serial.begin(9600);
  // initialize all the readings to 0:
  for (int thisReading = 0; thisReading < numReadings; thisReading++) {
    readings[thisReading] = 0;
  }
}

void loop() {
  // subtract the last reading:
  //Serial.println(total);
  total = total - readings[readIndex];
  // read from the sensor:
  readings[readIndex] = analogRead(inputPin);

  // add the reading to the total:
  total = total + readings[readIndex];
  readIndex = readIndex + 1;
  // if we're at the end of the array...
  if (readIndex >= numReadings) {
    // ..wrap around to the beginning:
    readIndex = 0;
  }

  brake = analogRead(analogPin);

  if (brake < 400 )
  {

    brake = 0;
  }

  // read the input on analog pin 4:
  int speedValue = analogRead(A4);
  //int speedValue = 0;

  // calculate the average:
  steer = total / numReadings;

  // print out the value you read:
  sprintf(strin,"Brake:%5d Speed:%5d Steer:%5d", (int)brake,speedValue, (int)steer);
  //printf("Brake:%f Speed: %d.%02d Steer: %d.%02d",brakeValue,speeds,steer);
  //sprintf(str, "String value: %d.%02d", (int)f, (int)(f*100)%100);
  Serial.println(strin);
  //delay(0.00001);              // delay in between reads for stability
  //delayMicroseconds(1);
}
```

D3 Delphi plugin development tool

In order to facilitate UC-win/Road's communication with the motorcycle simulator sensors, a segment of the Delphi plugin code previously written for use with the laboratory's bicycle simulator was modified for use. This portion of the Delphi code read the output signals from the USB port connected the Arduino microcontroller related to steering, braking and throttle input. The segment of the Delphi plugin code modified for use with the motorcycle simulator is included below in Figure D2.

Figure D2: Delphi plugin code segment modified for use with the motorcycle simulator

```
SetLength(p_onLogMethods, 0);

p_logServer := p_winRoadApplication.GetLogServer;
OnInstanceLogProc(method) := OnLog;
p_logServer.UnRegisterOnLogProcedure(method);
end;

210
procedure TAPPlugin.OnCalculateDrivingInputs(dTimeInSeconds: Double; var throttle, brake, steering, clutch: Single);
var
    i : Integer;
    doAccel : Boolean;
    doBrake : Boolean;
begin
    //steering:=(FormControlViechleInFrontResource.ComInfo.Steer-135)*5.7*2/(135*15.1); //20180612
    steering:=(FormControlViechleInFrontResource.ComInfo.Steer-205)**5.7*2/(205*15.1); 20180612
    steering:= steering/(205*10); //20180622
220
221 brake:= FormControlViechleInFrontResource.ComInfo.Brake/669;
    throttle:= (FormControlViechleInFrontResource.ComInfo.Speed-175)/689;
    writeln(TxtLogMain, 'steering:', steering:6:2, ' brake:', brake:6:2, ' speed:', throttle:6:2);

    {
    doAccel := false;
    doBrake := false;
    for i := 0 to High(p_keys) do
    begin
230         case p_keys[i] of
```


Appendix E: Forms

School of Civil & Environmental Engineering
Motorcycle riding study using a riding simulator

PARTICIPANT INFORMATION SHEET
MOTORCYCLE RIDING STUDY USING A RIDING SIMULATOR

1. Purpose of the study: The main purpose of this study is to understand riders visual scanning behaviour while riding on a riding simulator.

2. Procedures in the study: If you agree to be in this study, you will be outfitted with a mobile eye-tracker. Adjustment and calibration of the eye tracker for each participant will be done by the research assistant. A briefing will be conducted regarding the procedure and riding task to be done for the duration of the experiment. You will be given time to adapt to the equipment. The trial will start once you are ready. You must sign a consent form.

3. Participation: In participating in this study, you must fulfil one the following criteria:

[Experienced Licensed Rider]
Hold a valid Singapore Class 2B/2A/2 driving licence (or equivalent) for at least 1 year.

[Novice Licensed Rider]
Hold a valid Singapore Class 2B/2A/2 driving licence (or equivalent) for less than 1 year.

[Unlicensed / Learner Rider]
Currently unlicensed / learner rider.

You may not participate in this study if you have any known neurological or visual disorders, abnormal visual acuity, or have poor physical or mental health.

4. Withdrawal: Your participation in this study is voluntary, you may choose to withdraw from the study at any time with no penalty.

5. Confidentiality: All data collected in this study will remain confidential and will only be used for research purposes. Your name will not be used in any report for this study, and only identification numbers will be used. There will be no link of the results to your name or true identity.

6. Duration: The entire session is expected to last about 45-60 mins, inclusive of a briefing, equipment set-up and calibration, simulator riding, and a post-experiment interview.

7. Potential risks & insurance: There are no risks expected. The entire procedure will be conducted on a simulator.

8. Potential benefits: There will be no direct benefit to you. However, findings from this study will help researchers better understand the visual scanning behaviour of motorcyclists.

9. Token of appreciation: There will be an honorarium of \$20, which will be paid by NTU/HSA. The honorarium is a token of appreciation for your participation in this study. It should be noted that the honorarium is not, by any means, employment payment to you.

10. Questions: If you have any questions or concerns about this research study, please feel free to contact Ms. Grace Wong at 8198-0057 or Dr. Wong Yik Diew at 6790-5250. NTU Institutional Review Board (IRB) can be contacted at irb@ntu.edu.sg.

[Please retain this page for your reference.]

WRITTEN CONSENT TO PARTICIPATE

Consent (please tick in the box if you consent - ✓)
[copy]

☐ I, _____ give my consent to be part of the study titled "Motorcycle riding study using a riding simulator". I have been informed of the purpose and contents of this research project. I also understand that my participation is voluntary and that I can withdraw from the study at any time with no penalty by informing the Investigator.

Signature: _____ Date: _____

Figure E1: Informed consent form

Date: _____ Name: _____ Participant No. (E/NU): _____

Research Participant Form

General Information

Age: _____ Gender: Female/Male

What type(s) of licence(s) do you have?

☐ None ☐ Class 2/2A/2B (or equivalent) ☐ Other (e.g. Class 3/4/5 or equivalent)

How long have you had your motorcycle licence? _____

How often do you ride?

☐ Never ☐ Less than once a month ☐ About once a month ☐ About once a week ☐ More than once a week

How many kilometres do you operate a motor-vehicle every year, on average?

☐ <5,000 ☐ 5,000 – 10,000 ☐ > 10,000

How often do you operate a vehicle other than a motorcycle?

☐ Never ☐ Less than once a month ☐ About once a month ☐ About once a week ☐ More than once a week

Figure E2: Research Participation Form

Hazard #3 (unobstructed view)

Did you anticipate the hazard?
☐ Yes   ☐ No

If "No" you may skip the rest of this section. If "Yes" please answer the following questions.

When did you realise you were in a hazardous situation? Select ONE.

1

2

3

4

5

What cues did you pick up on prior to the hazard's onset?

Hazard #4 (obstructed view)

Did you anticipate the hazard?
☐ Yes   ☐ No

If "No" you may skip the rest of this section. If "Yes" please answer the following questions.

When did you realise you were in a hazardous situation? Select ONE.

1

2

3

4

5

What cues did you pick up on prior to the hazard's onset?

Hazard #1 (unobstructed view)

Did you anticipate the hazard?
☐ Yes   ☐ No

If "No" you may skip the rest of this section. If "Yes" please answer the following questions.

When did you realise you were in a hazardous situation? Select ONE.

1

2

3

4

5

What cues did you pick up on prior to the hazard's onset?

Hazard #2 (obstructed view)

Did you anticipate the hazard?
☐ Yes   ☐ No

If "No" you may skip the rest of this section. If "Yes" please answer the following questions.

When did you realise you were in a hazardous situation? Select ONE.

1

2

3

4

5

6

What cues did you pick up on prior to the hazard's onset?

Figure E3: Post-experiment questionnaire form

Appendix F: Quotations for on-road study

Quotation 1: CHUBB

Category	Basis of Coverage	Headcount	Sum Insured (SGD)	Premium Per Participant (SGD)	Total Premium (SGD)
Option A	SGD 20,000	35	700,000	6 per headcount	210
Option B	SGD 50,000	35	1,750,000	10 per headcount	350
Option C	SGD 100,000	35	3,500,000	12 per headcount	420

Quotation 2: Allied World

Insured	: Nanyang Technological University																												
Risk Location	: 50 Nanyang Avenue (S) 639798																												
Nature of Business	: Education Institution																												
Period of Insurance	: 60 days from date advised																												
Basis of Coverage	: 24 hours in Singapore whilst participating in research project organized by the Insured																												
	<table> <tr> <th>Category</th><th>Basis of Coverage</th><th>Headcount</th><th>Sum Insured (SGD)</th><th>Premium Per Participant (SGD)</th><th>Total Premium (SGD)</th></tr> <tr> <td>Option A All participants</td><td>Fixed Benefit of SGD20,000 each</td><td>35</td><td>700,000</td><td>7.50</td><td>262.50</td></tr> <tr> <td>Option B All participants</td><td>Fixed Benefit of SGD50,000 each</td><td>35</td><td>1,750,000</td><td>13.00</td><td>455.00</td></tr> <tr> <td>Option C All participants</td><td>Fixed Benefit of SGD100,000 each</td><td>35</td><td>3,500,000</td><td>18.00</td><td>630.00</td></tr> </table>	Category	Basis of Coverage	Headcount	Sum Insured (SGD)	Premium Per Participant (SGD)	Total Premium (SGD)	Option A All participants	Fixed Benefit of SGD20,000 each	35	700,000	7.50	262.50	Option B All participants	Fixed Benefit of SGD50,000 each	35	1,750,000	13.00	455.00	Option C All participants	Fixed Benefit of SGD100,000 each	35	3,500,000	18.00	630.00				
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Estimated Headcount	: 35																												
Administration	: Named basis																												
Age Limit	: 16 to 80 years																												
Total Sum Insured	: To be advised																												
Aggregate Limit	: Total Sum Insured																												
Annual Premium	: To be advised																												
Claims Experience	: Nil claims in the last 3 years																												
Extensions	: 150% Permanent Disability Scale with Burns extension : Riot, Strike, Civil Commotion, Hijack, Murder & Assault : Terrorism Extension (including Nuclear, Chemical & Biological means) : Suffocation by Smoke, Poisonous Fumes, Gas & Drowning : Exposure & Disappearance																												
Additional Benefits	: Accidental Hospital Recuperation – SGD250 : Ambulance Costs – Up to SGD500 : Funeral Expenses – SGD2,000																												
Subjectivities	: All Terms & Conditions as per Allied World GPA policy wording : All premiums and claims to be administered through Insured's Singapore office : This quote is intended to provide coverage for Insured Person(s) participating in research project organized by the Insured. Insured Person(s) will be required to wear eye-tracking glasses whilst riding their personal motorcycle on a pre-defined route for up to 1 hour only. : Insured Person(s) must have a Class 2B license for at least 1 year to be eligible for coverage under this policy : Allied World reserve the rights to revise the quote if there is any change in underwriting information or material facts provided. : Quotation valid till <u>15 Apr 2018</u>																												

*Premium excludes 7% GST