Driving skills retention of young drivers after period of driving inactivity

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**NANYANG
TECHNOLOGICAL
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Driving skills retention of young drivers after period of driving inactivity

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2018

DRIVING SKILLS RETENTION OF YOUNG DRIVERS AFTER PERIOD OF DRIVING INACTIVITY

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Preface

This thesis was written in British English.

All the work presented in this thesis was conducted in the Transport and Geospatial (TGS) Laboratory, School of Civil and Environmental Engineering (CEE) at the Nanyang Technological University (NTU), Singapore. The experiment on data collection from human participants using driving simulator was approved by NTU's Institutional Review Board, which serves as the University's ethics committee.

A version of the fifth Chapter of this thesis has been submitted to a journal (*Transportation Research Part F: Transportation Psychology and Behaviour*, submitted on 8th March 2017, currently under review since 1st July 2017). I was the first author and lead investigator, responsible for all major areas of concept formation, data collection, data extraction, analysis, and manuscript composition. Wong Y.D. and Lum K.M. were the supervisory authors for this study and were involved in the concept formation and manuscript edits.

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The following are my other relevant publications:

- **Upahita, D.P.**, Wong, Y.D., Lum, K.M. "The effect of fatigue on detection and response latency towards on-road hazards", International Conference on Traffic and Transport Psychology, Brisbane, Australia, 2nd – 5th August 2016.
- **Upahita, D.P.**, Wong, Y.D., Lum, K.M. "Advancing driver hazard perception dynamics via eye-tracked virtual reality driving" submitted to Journal of Transportation Safety and Security on 6th January 2018

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Abstract

Overall on-road driving skill is a cumulated acquisition of driving skills learned during the training period and furthered tempered with post-licensing driving exposure on the roads. Training serves to develop a person's basic driving skills to survive safely on the roads at first, while subsequent on-road driving hones the driving skills further. Inactivity from on-road driving can result in deterioration of the driving skills. Particularly for the case of inactivity immediately following licensure, which is not uncommon in Singapore, the learned skills can degrade rapidly. This research addresses the issue on skills degradation of learned driving skills as a result of driving inactivity, specifically for young-inexperienced drivers.

This study is divided into two stages: passive mode and active mode. The first stage, passive mode driving assessment served as the preliminary stage to examine the effect of training, driving experience and inactivity using a simple task. A series of experiments were conducted on a driving simulator for different subject groups involving active, inactive (ever since licensure), and no licence subjects. The participants watched a video of driving along a road that contains several types of hazard and were instructed to initiate a braking response every time they detect a hazard. The response latency between onset of hazard till the response was registered is used as the performance indicator. The hazards (stimuli) are characterised in terms of collision damage potential, including personal injury, and collision avoidance potential. The results indicate that training and inactivity (lack of experience) affect the hazard identification strategy and perception towards risk. However, the passive driving simulation mode setting comes with limitations. It is not able to replicate the complexity of the driving task (i.e. no vehicle control required) and only limited data can be obtained. Therefore, an active mode driving assessment was conducted in the second stage.

For the second stage involving active mode driving assessment, a series of experiments were conducted on a driving simulator for different subject groups involving active driver, novice driver (freshly licensed driver), inactive driver (never ever drive upon licensure), and no licence subjects. In the second stage, the participants were given a full control over the vehicle. The experiment was divided into two parts: vehicle handling performance, and hazard perception and anticipation. For the first part, the participants drove through a stretch of expressway under free-flow conditions, and lane positioning control was monitored. It is

found that without on-road driving exposure, driving skills like maintenance of lane positioning control in terms of lane wandering and lane encroachment may deteriorate after some periods of inactivity. The deterioration varies at a different rate, with faster deterioration for more complex tasks. In complex driving tasks, the skills level can regress close to untrained level.

The second part of the active driving assessment is a hazard perception and anticipation test. This part was modified from a conventional hazard perception test. In this experiment, instead of watching hazard contained in a video, the participants drove a car along a specified route in which several hazards had been planted. An eye tracker was used in this experiment to examine the eye behaviour when participant identifies the hazards. Response latency was further refined into three sub-components: lag time (LT), time-to-fixation (TF) and PIEV (Perception-Intellection-Emotion-Volition) time. The results show that driving experience gives a dominant effect in improving the ability to respond to hazardous situations. Meanwhile, inactivity not only prevents the drivers to gain more experiences and improve their skills but also can cause deterioration of their driving skills.

The overall results show that training builds up the level of competency in driving. It also demonstrates that inactivity from driving, especially for young recently-licensed drivers, can affect their driving performance as well as their perception of risk. The results indicate that without any on-road exposure, some driving skills, i.e. lane wandering control and lane encroachment control, may deteriorate after some periods of inactivity. The deterioration may vary for different set of skills, with more complex (e.g. lane encroachment control) tasks having faster deterioration rate. For more complex driving skills, the deterioration can result in the level of competency being relegated close to untrained level. The deterioration of driving skills is especially more sensitive for young-inexperienced driving licence holders, as the skills that they have gained may not be 'deeply rooted' yet.

The results also suggest that post-licensing driving exposure is needed not only to retain but also to improve the lateral control skills. With regular practice, the skills can be strongly retained and lasted longer as well. Exposure to real road driving experience also helps to familiarise with road conditions and thus further improves and enhances the driving skills.

Hereby, authorities may consider a mandatory refresher course for driving licence holders who have been inactive for a long-term period, especially for young licenced subjects who

have never ever progressed to on-road driving. It will help the drivers to refresh the skills that they have learned during licensure as well as familiarise them to the real road situations. It is to make sure that the drivers will be at least be back to the skill level when they passed the driving licence test.

List of publications

Journal Paper(s)

1. **Upahita, D.P.**, Wong, Y.D., Lum, K.M. "Effect of driving inactivity on driver's lateral control: A driving simulator study" submitted to Transportation Research Part F: Transportation Psychology and Behaviour (8th March 2017; Under review as per 1st July 2017)
2. **Upahita, D.P.**, Wong, Y.D., Lum, K.M. "Effect of driving experience and driving inactivity on driver's hazard perception and accident avoidance skills" submitted to Transportation Research Part F: Transportation Psychology and Behaviour (7th September 2017)
3. Upahita, D.P., Wong, Y.D., Lum, K.M. "Advancing driver hazard perception dynamics via eye-tracked virtual reality driving" submitted to Journal of Transportation Safety and Security (6th January 2018)

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4. **Upahita, D.P.**, Wong, Y.D., Lum, K.M. "The effect of fatigue on detection and response latency towards on-road hazards", International Conference on Traffic and Transport Psychology, Brisbane, Australia, 2 – 5 August 2016

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List of abbreviations

ADReS	Assessment of Driving Related Skills
ANOVA	Analysis of Variance
BCST	Bern Cognitive Screening Test
BTT	Basic Theory Test
CI	Centrality Index
CR	Corneal Reflection
DALYs	Disability-Adjusted Life Years
ETG	Eye Tracking Glasses
FTT	Final Theory Test
GDL	Graduated Driving Licensing
GNP	Gross National Product
HPT	Hazard Perception Test
HVS	Human Visual System
IRL	Interactive Response Latency
KRRS	Knowledge-Representation/Retrieval Structure
LT	Lag Time
LTA	Land Transport Authority
MMSE	Mini Mental State Examination
NHTSA	National Highway Transport Safety Authority
NTU	Nanyang Technological University
OECD	Organisation for Economic Co-operation and Development
PDL	Provisional Driving Licence
PDO	Property Damage Only

PDT	Practical driving test
PFS	Piper Fatigue Scale
PIEV	Perception Intellection Emotion Volition
PLO	Percentage of Lane Overrun
RL	Response Latency
RT	Reaction Time
RTA	Road Traffic Accidents
SMI	SensoMotoric Instrument
SPF	Singapore Police Force
SSQ	Simulator Sickness Questionnaire
TF	Time to Fixation
TGS Lab	Transport and Geospatial Laboratory
TMT	Trail Making Test
TP	Traffic Police
TTC	Time-to-Collision
UFOV	Useful Field of Visual
USAFSAM	U.S. Air Force School of Aerospace Medicine
VLP	Variance of Lateral Position
WHO	World Health Organisation

List of symbols

LP_e	Mean lateral placement of right side of the vehicle tyre with respect to the right edge of the travelled lane
LP_c	Mean lateral placement of the left side of the vehicle tyre with respect to the centreline of the travelled lane
LW	Width of the travelled lane
VW	Vehicle width
TW	Width between the right and left reference boundaries
X_1	Distance from the outer face of the right wheel to the right boundary (driver's perspective)
X	Offset distance of the vehicle centreline with respect to travelled lane centreline
CL_{car}	Centreline of the test vehicle
CL_{lane}	Centreline of the travelled lane
$\overline{CI}$	Average of centrality index
CI_i	Centrality index of segment i
$JT_{encroach}$	Time of journey when parts of test vehicle encroach on adjacent lane
JT_{total}	Total journey time

Glossary

Avoidance potential	Potential to avoid a collision as a result of hazardous situation
Centrality index	A dimensionless parameter to represent the lateral position of a vehicle with respect to the centre of driving lane
Collision damage potential	Potential damage as a result of collision if avoidance action failed
Deterioration	The process of becoming progressively worse
Driving skill	The ability to drive/control a car successfully/efficiently
Driving performance	The capabilities of a driver to successfully/efficiently drive a car
Fitness-to-drive	A required and necessary condition to drive a vehicle
Hazard detection-response window	Time span on the hazard perception video where the response is deemed as a valid response, or; Time span between first appearance of hazard to test vehicle coming to a complete stop
Hazard perception	The ability to see, hear or become aware of hazardous situations through the senses
Interactive response latency	A span of time between onset of hazard until anticipation action is taken on interactive and dynamic environment
Lag time	A span of time between onset of hazard until eye gaze starts to move
Lane encroachment	Unintentional intrusion of the vehicle on the other lane ~control: the ability to control the vehicle so that it will stay within the designated lane

Lane wandering	The tendency of a vehicle to move in the lateral direction (left and right) ~control: the ability to control the vehicle so that it will stay in a stable lateral position
Percentage of lane overrun	The proportion of the time of journey where parts of vehicle encroach onto another lane
PIEV time	A span of time between the eye fixation until anticipation action is taken
Potential collision zone	Potential area where a collision can take place
Response latency	A span of time between onset of hazard until anticipation action is taken
Time-to-collision	The elapsed time from the instant the hazardous object first appears on the screen to the instant whereby collision just about to occur with the hazardous object without any braking action.
Time-to-fixation	A span of time between the start of eye gaze movement until it fixates onto a hazard
Variance of lateral position	The variance of vehicle position along the test journey

Chapter 1 Introduction

1.1 Introduction

This Chapter introduces the broad issues of road safety, driving inactivity, driving experience and driving training, and other aspects as related to the thesis research. The problem statement that motivates this research on driving skills retention and inactivity and training is stated and the objectives and scope of work for this research are explained. The last part of this Chapter concludes with an overview of the organisation of the report.

1.2 Background

Human beings, in order to fulfil their daily needs, have to travel from one place to another, since the human needs cannot always be fulfilled in only one place. Transportation is defined as an activity to move people or goods from one place to another in a safe and efficient manner. In transportation activities, safety is one of the important aspects that need to be considered. In any form of transportation, one should ensure that the activity will not cause any harm to the people involved and the surrounding community.

Safety continues to be a big problem in transportation, especially in road transportation. In 2015, road traffic injury is ranked at 10th position for the cause of death and 6th position for the cause of disability-adjusted life years (DALYs). Globally, 1.342 million people died as a result of road traffic accidents (RTAs) in 2015 (WHO, 2016), averaging about 3,676 persons each day. In terms of economic loss, the average accident cost is about 1 - 3% of Gross National Product (GNP) (WHO, 2015). In Singapore, according to Traffic Police data (Singapore Police Force, 2012 - 2016), on average about 161 fatal accidents and 7,969 injury accidents occurred annually from 2011 - 2015.

There are three main groups of contributing factors in motor vehicle crashes: human factors, road environment factors, and vehicle factors. Human factors are involved in 95% of motor vehicle crashes and are the biggest contributing factors in motor vehicle crashes, while road environment factors and vehicle factors are involved in 28% and 8% of crashes, respectively (Austroads, 2002). Human factors in driving activity reflect the driver's performance and are related to the driver's driving skills. One can argue that a driver's driving skills are shaped by the skills that are learned in driving training and further developed by on-road driving

experience. Driving training means to develop the basic driving skills of a person and familiarise him (both genders) with the driving task and environment, in order to prepare him to drive on-road, while on-road experience develops one's driving style and behaviour. Some studies have shown the effect of driving experience on several aspects of driving such as eye scanning (Crundall et al., 1999), visual attention (Konstantopoulos et al., 2010) and risk perception (Borowsky, 2006; Sagberg & Bjornskau, 2006). Unlike age and medical conditions that affect drivers on their visual, cognitive and psychomotor ability, findings from some studies show that experience is more likely to affect a driver on his driving strategy and risk perception.

On the other hand, driving inactivity may have a reverse effect than driving experience. The skills that have been obtained through training may deteriorate if it is not used for some periods of time. Previous studies in the field of sports (Garcia-Pallares et al., 2009; Neufer et al., 1987) and military (Ammons et al., 1958; Farr, 1987; Wisher et al., 1999) have shown that some periods of inactivity may cause deterioration in skills and performance. In effect, skills gained in the training process and (subsequently) reinforced with persistent practice may deteriorate upon disruptions in applying these skills. Furthermore, the deterioration rate may vary for different types of skills. Deteriorated driving capability can lead to poor driving performance to the extent of resulting in a traffic accident. The concept of regular practice to maintain skills proficiency is attested in the example of a recreational aircraft pilot having to chalk up certain quantum of flying hours as a condition of licence renewal. It shows the general premise of maintaining skills through sufficient exposure to real world practices. Whereas several studies have pointed out that on-road driving serves to further develop the driving skill after initial training period (to gain licence), to the authors' best knowledge, there is yet any study on the effect of driving inactivity upon getting a licence on the driving performance of young drivers. Certain driving skills learned in the licensing process but never put to practice shall, after some length of time, deteriorate over time. Herein, it is rationalised that driving inactivity for novice drivers shall result in deteriorated driving performance. In particular, young-inexperienced drivers who never put their driving skills to practice are expected to be particularly prone to driving skills deterioration from inactivity. This situation of young-inexperienced drivers is rather prevalent in Singapore, which has thus provided a strong motivation and a well-fitting setting to undertake the present study.

With the extremely high cost of car ownership, there are many people in Singapore who hold a valid driving licence but yet have a very limited opportunity to drive regularly since many do not have access to a personal vehicle. Every year, many people received driving training and eventually got their driving licence. According to data from Singapore Police Force (SPF) and Land Transport Authority (LTA), the number of Classes 3 and 3A licence holders (for licensure to drive a car, minivan or light good vehicle) continues to increase, from 1,686,272 in 2011 to 1,913,161 in 2015 (a 13.5% increase)(Singapore Police Force, 2017b). On the other hand, the car and light good vehicle population remains relatively stable at 725,484 in 2011 to 724,586 in 2015 (Land Transport Authority, 2017). This is a unique characteristic of driving licence holder populations in Singapore constituting a large number of inactive driving licence holders who can take up on-road driving anytime after licensure. Figure 1.1 shows the comparison between Singapore vehicle population and number of qualified licence holders.

Figure 1.1 Vehicle population and qualified licence holders in Singapore

During driving training, the driver is trained on various driving skills and familiarisation with driving rules and task, so that he can drive properly on the road. Herein, the driving licensing process distinguishes fit-to-drive drivers from the unfit-to-drive ones. This is one of the ways

to improve safety by not letting an unfit-to-drive person to handle a vehicle on the road. However, there is no standard regulation to assess driver post-licensing period. Every jurisdiction has its own regulation related to licensing period and re-assessment. In countries like Belgium, France, Germany and Sweden, older drivers are effectively 'licensed for life', while in other countries, e.g. Denmark, Italy, the United Kingdom, the Netherlands and Portugal, drivers are required to go through periodic assessment when they reach a certain age (OECD, 2001). The type of assessment also varies across the jurisdictions. Most regulations and assessment for refresher/renewal are for cases related to elderly drivers, traffic rules offender and health problem. However, such assessment may not be suitable to address issues related to driving inactivity. It may be due to the fact that no studies have addressed the issues of driving inactivity. Therefore, this research aims to address the issue on retention of driving skills in relation to driving inactivity. The effect of on-road driving exposure is also studied. With better understanding of the issues of driving skills retention and inactivity, a better strategy of licensing and retraining process can be developed. Inactivity from driving not only restrains licensees from gaining more experience but also limit their opportunity to practise their skills. Well-managed driving licensing and refresher programme is a way to filter out unfit-to-drive drivers, including (inactive) licence-holders. The refresher programme can be undertaken with a cost-effective strategy by intervening on critical skills and conditioned upon certain cut-off period of inactivity. By filtering out the unfit drivers, especially those resulting from inactivity, the number of traffic accidents can be expected to reduce which shall commensurately reduce the economic losses associated with road traffic accidents.

1.3 Problem statements

As human factors are involved in approximately 95% of traffic accidents, accident remediation strategies must take human factors into account. One way to improve traffic safety from the driver's aspect is to ensure that a driver fulfils certain requirements through driving licensing and fitness-to-drive assessment before he can drive on the road. However, there does not exist any worldwide standard protocol for driving licensing, especially on regular assessment in the post-licensing period. Some jurisdictions have a "licensed for life" policy, while others apply certain regular renewal policy.

During driving training, an untrained person will learn driving-related skills to prepare him to pass a certain level of competency in order to get a driving licence. Upon getting the driving

licence, on-road driving experience further enhances his driving skills. In contrast, a licence holder who never had an opportunity to put his driving skills into practices, in another word being inactive, may lose some of his driving skills. Previous studies from the military and sports have shown that inactivity period does affect the skills obtained from regular training as well as the attendant performance. Figure 1.2 illustrates hypotheses of this study on different levels of driving competency. It should be noted that there is no direct metric to quantify the precise skill level on Figure 1.2. While many previous studies have pointed out the effect of driving experience on driving performance, no studies have addressed the issues on the effect of driving inactivity on driving performance. Therefore, this research aims to address the issue on retention of driving skills upon a period of driving inactivity.

Driving environment in Singapore, with the high cost of vehicle ownership, limits the opportunity to drive regularly for many licensed subjects. This lack of regular driving over a period of driving inactivity may affect experience-building opportunity (for younger drivers) as well as the retention of driving skills that have been gained from training sessions. It is a suitable setting for research into retention of driving skills upon a period of driving inactivity.

Figure 1.2 Hypothetical level of driving competency

Driving licence renewal regulations are mostly limited for age-based renewal or post-medical condition renewal. Clinical medical assessment that usually forms a part of driving license renewal requirement may not be able to capture the degraded driving performance caused

by lack of driving experience and driving inactivity. The result from this research may serve as a basis for the development of regulations related to driving licence renewal.

1.4 Research aims

In general, this research aims to examine the retention of driving skills for young driving licence holders upon period of driving inactivity. In order to achieve this main aim, specific objectives are identified, namely:

1. Using driving assessment on the driving simulator, examine the effect of a period of driving inactivity on the driving skills, i.e. vehicle control skills and hazard perception and anticipation.
2. Evaluate the effectiveness of driving training programme to fulfil the basic requirement of driving skills.
3. Examine the effect of post-licensing on-road driving experience in retaining and enhancing driving skills.

1.5 Research scope

This research is focused on retention of driving skills after a period of driving inactivity. The research is undertaken by conducting an off-road driving assessment (using a driving simulator) to measure the driving performance of different groups of participants. This research is divided into two stages, the first stage being a preliminary assessment using passive mode driving simulator, and the second stage is conducted using active mode driving simulator. A driving simulator is thus developed for the assessment, which replicates the real-world driving conditions.

This research focuses on young-inexperienced drivers as young-inexperienced drivers have relatively less mature driving skills compared to the older drivers with more years of driving experience. Since they have less experience in driving, only several years into getting their licence, and have less mature driving skills, thus their skills are expected to be more prone to degradation from factors such as inactivity.

In the early phase of this research, factors that can affect driving skills retention, as well as the driving assessment parameters, were identified based on the literature review. It included the analysis of the feasibility of the parameters to be measured in a driving simulator. Then, the identified fitness-to-drive indicators and influencing factors were collected for subsequent

testing on the driving simulator. A preliminary experiment by way of passive mode driving simulator was first conducted to examine the effect of training, experience and inactivity on driving performance. The result from this preliminary stage was used to improve and design the experiment in the subsequent stage. In the subsequent stage, in-lab experiment was conducted on an active mode driving simulator. The data collection in this latter experiment can be divided into two parts: vehicle control assessment, and hazard perception and anticipation assessment. Both parts were conducted on the driving simulator at Nanyang Technological University (NTU) Transport and Geospatial Laboratory. The vehicle control assessment was focused on the ability of the participants to control the vehicle in terms of lateral control. As for the hazard perception and anticipation assessment, the performance of the participants on detecting a hazard and making a decision to avoid collision with the hazard was measured. The performance profiles of different groups of drivers were collected from the driving simulator experiment, and an analysis of how driving inactivity can affect the driving performance was done. The feasibility of various driving assessment parameters was also analysed.

The driving assessment parameters in the driving simulator consisted of vehicle control performance and hazard perception parameters. The results from vehicle control assessment and hazard perception and anticipation tests are related to the participant's driving inactivity and training status for the purpose of establishing relationships between driving performance and driving experience and inactivity. Figure 1.3 summarises the framework of the research.

1.6 Organisation of report

This report consists of seven chapters, including this introduction chapter that covers the background of the research, objectives, and scope of work.

Chapter 2 reviews the literature and previous studies on driver fitness-to-drive, skills retention, etc. This chapter also discusses the issues related to driving performance, including the type of driving performance parameters. It highlights the gaps of current knowledge and research.

Chapter 3 covers the methodology that is used in this research, especially in the data collection. In-lab experimental design is described in this chapter. In-lab experiment is used to examine performance indicators and the effect of driving inactivity and training on driving

performance. In-lab experiments are divided into two stages: passive mode driving assessment and active mode driving assessment.

Chapter 4 explains the result of passive mode driving assessment. The experiment is conducted in the format of hazard perception test. The results are analysed as an early stage examination on the effect of training, experience and inactivity on driving performance.

Chapter 5 includes the results and findings from the data collected in active mode driving assessment on vehicle-handling assessment. Analysis of results from in-lab experiments is undertaken to examine the differences in the driving performance of active, inactive and no licence subject groups.

Chapter 6 explains the results of active mode driving assessment on hazard perception and anticipation assessment. The performance indicators are analysed to examine the effect of driving inactivity and training on driving performance, specifically on hazard perception and anticipation ability.

Chapter 7 concludes the results of the research and potential future work arising from this research.

Figure 1.3 Research framework

Chapter 2 Literature review

2.1 Overview

This Chapter reviews relevant knowledge and results from existing studies related to traffic safety, driving licensing, fitness-to-drive, skill retention and driving performance issues. The issues related to road traffic safety are examined in general. The issue on fitness-to-drive, driving licensing and long-term skills retention are explained. Vision in driving activities is also discussed. The Chapter concludes with a summary and also identified gaps upon which this thesis is being developed to address selected gaps.

2.2 Road safety and fitness-to-drive

Transportation service and infrastructure should fulfil aspects such as security, convenience, affordability, mobility and safety. Safety is defined as a state of being safe or freedom from danger ("Oxford Learners Pocket Dictionary New Edition," 2000). The adverse effect of inadequate safety on road transportation context is usually reflected in the form of traffic accidents. In Singapore, a road incident can be classified as a road traffic accident (RTA) if it occurs on public roads or car-park and involves at least one moving vehicle (including bicycle) that results in human casualty and/or property damage. RTA is usually classified according to its severity: fatal, injury, and non-injury accident. An RTA is classified as a fatal accident if there are one or more persons killed. The road safety level of a country can be indicated using two different measures: transport measure and public health measure. From the transportation perspective, road safety is indicated in terms of deaths/casualties per million km-travelled or per 10,000 vehicles. On the other hand, from the public health perspective, road safety is computed as deaths/casualties per 100,000 inhabitants which indicate the likelihood of people being killed or injured in a road accident.

Rapid motorisation in some countries has increased the exposure that increases the chance of accident involvement. In fact, data from WHO show that in 2015, road traffic injury is the 10th rank for the cause of death and 6th for disability-adjusted life years (DALYs). Globally, approximately 1.342 million people died as caused by road traffic accidents in 2015 (WHO, 2016). Among the young adult population aged 15 – 29 years old, road traffic accident is the 1st rank cause of death.

Human factors are involved in 95% of motor vehicle crashes and are the biggest contributing group of factors in motor vehicle crashes (Austroads, 2002). There are many human-related aspects that can affect driving performance and safety. Petridou and Moustaki (2000) reviewed behavioural factors in the causation of road traffic crashes and classified the factors into four categories: (1) those that reduce capability on a long-term basis, (2) those that reduce capability on a short-term basis, (3) those that modulate risk-taking behaviour with long-term impact, and (4) those that modulate risk-taking behaviour with short-term impact. Table 2.1 shows the human behavioural factors in each category.

Table 2.1 Human factors that affect the likelihood of traffic injuries (Source: Petridou and Moustaki (2000))

	Long-term	Short-term
Reduce capability	Inexperience Age Disease and disability Accident proneness Alcoholism and drug abuse	Drowsiness, fatigue Acute alcohol intoxication Short-term drug effect Binge eating Acute psychological stress Temporary distraction
Modulate risk taking	Overestimation of capabilities Habitual speeding Habitual disregard of traffic regulations Non-use of seat belt or helmet Inappropriate sitting while driving Accident proneness Alcoholism	Moderate alcohol intake Psychotropic drugs Motor vehicle crime Suicidal behaviour Compulsive acts

Age and physical disability are factors that can affect a driver's physiological capability in the long-term. Elderly and young inexperienced drivers are sometimes over-represented in serious injury and fatal crashes if the distance travelled is considered. A U-shape curve of accident rates (per distance travelled) with respect to age has been found in many previous studies that show a higher involvement of young-inexperienced and elderly drivers as compared with middle-aged driver (Massie et al., 1995; McGwin & Brown, 1999). Young driver involvement in RTA is usually related to inexperience, overconfidence and fatigue, while on the other hand the older driver involvement is usually related to illness or reduced capability (Cooper, 1990; Doherty et al., 1998; Hakamies-Blomqvist, 1993; Macdonald, 1994). However, while an elderly driver experiences reduced cognitive, motor and sensory-

perceptual ability, he compensates his reduced capability in various ways, e.g. adapting to a longer headway than a younger driver (Andrews & Westerman, 2012). Therefore, driving assessment should be applied from a multi-dimensional perspective of the driver (Morgan & King, 1995), and not only on his medical conditions.

Driving licensing process, including fitness-to-drive assessment, is a way to distinguish fit-to-drive driver from the unfit-to-drive one. This is one of the ways to improve safety by not letting an unfit-to-drive person to be driving on the road. Many countries, including Singapore, require older drivers who have reached a certain age to regularly undergo a medical examination to renew his licence. In Singapore, a driver is required to undergo a medical examination that assesses his physical and mental conditions every three years, once he reaches 65 years old. The medical examination is covered by the “Medical guidelines on fitness to drive” from The Singapore Medical Association. The guidelines are based on medical conditions and medications that are related to accident involvement. However, fitness-to-drive assessment should be able to assess fitness-to-drive from multi-dimensional evaluation. Performance-based assessment of driving ability through driving assessment, either on-road or off-road, should complement the medical condition assessment in order to evaluate fitness-to-drive from various perspectives.

2.3 Driving licensing

2.3.1 Driving licensing around the world

The driving licensing policies vary for different jurisdictions around the world. There is no standard driving licensing policy and procedure. The policy varies in term of driving training system, driving test content, medical examination, and renewal policy.

Some jurisdictions have a systematic driving training system that includes theory and practical lesson through driving school or certified driving instructor, e.g. Singapore, Hong Kong. On the other hand, many countries do not have a systematic and standardised driving training systems, e.g. Indonesia, India. Some jurisdictions are giving the privilege of full driving licences in a gradual manner, through a programme commonly known as Graduated Driving Licensing (GDL), e.g. some States in the US, some regions in Australia, some provinces in Canada, etc. GDL is mainly targeting on the teen-novice drivers, because of their high involvement in road traffic accident. In this GDL programme, the young novice driver will be given the permission to drive independently on several stages: supervised

driving, restricted passenger and night-time driving, until the obtained privilege of full driver's licence which allows them to drive without adult-driver supervision.

The coverage of driving test content tends to be somewhat different for every jurisdiction. The driving test usually consists of the theory test and practical driving test. Some jurisdictions, e.g. Hong Kong, allow the applicant to take the theory test and practical driving at the same time. Other jurisdictions separate theory test and practical driving test at different stages, e.g. Singapore in which theory test is a pre-requirement to take driving lessons and driving practical test. The content of the theory test and practical driving test can also vary for every jurisdiction. Most of the theory tests cover the topics around road rules and regulations, traffic signs, etc. Other jurisdictions, e.g. the UK and some jurisdictions in Australia, include hazard perception test (HPT) on their driving licence test. It is usually included as a part of the theory test. In HPT, the applicant needs to identify the hazard that appears on the screen within a certain time duration. Some jurisdictions include eyesight check as part of the driving licence test.

The renewal policy can be different for each jurisdiction. Some jurisdictions apply practically 'licence for life', while other jurisdictions require the driver to do periodical renewal when he reaches a certain age. Other jurisdictions require the driver to do a periodical renewal right from the start (not only for elderly drivers). The period of renewal and the requirement for the renewal is not the same for every jurisdiction. Some jurisdictions include medical examinations, mainly eyesight test, while others only require reporting driver's particulars to renew the driving licence.

With the variations of the driving licensing process, the outputs from the process will also vary from one jurisdiction to the other. One thing that all the driving licensing policies have in common is the fact that there is no comprehensive post-licensing renewal processing. Some renewal processes are only specifically for elderly drivers, or only limited to medical examination as the evaluation criterion. There is also renewal policy that includes evaluation of the driving skills. Hence, there is no sufficient system that continuously evaluates driving skills of the driver on-road. Such variations may not be important when the opportunity to regularly driving is enough. However, for driving population situation like Singapore, where some may not have regular access to drive a vehicle, an evaluation to make sure that the learned driving skills are not forgotten due to inactivity becomes an important issue. Although

driving refresher course is offered to make sure that one's driving skill still meets certain required level, a refresher course is not compulsory unless the driver was involved in a major traffic violation or on certain medical condition that leads to revocation of the driving licence.

2.3.2 Driving licensing in Singapore

Singapore has a systematic driving licensing procedure which includes driving training curriculum and driving licensing test – both theoretical and practical tests (Singapore Police Force, 2017a). It has several levels of test to make sure that a person who passes the driving licensing process will have sufficient driving skills to drive on-road independently. Figure 2.1 shows the diagram of driving licensing process in Singapore, specifically for the motorcar.

Before someone can start to go for the practical lesson (driving training), he needs to pass the basic theory test. Basic theory test (BTT) covers the topics related to rules and regulations of the road, traffic signs and signals. After he passes the BTT, he can obtain a provisional driving licence (PDL) which allows him to take on-road practical driving lessons. Practical driving lessons can only be conducted by the authorised driving centre or licensed private driving instructors. It is to make sure that the student will receive a standard and sufficient driving training that he needs before the practical driving test and furthermore before he independently drives on road, which include aspects such as vehicle control and safe driving procedure.

Final theory test (FTT) tests the knowledge related to safety aspects and proper techniques of driving, in form of several situational scenarios. FTT needs to be done before one can apply for the practical driving test (PDT). PDT consists of two parts: driving circuit and public roads. The driving circuit part serves to test the driving skills and judgement. Meanwhile, the public roads part is conducted to test the ability to interact with other road users and compliance with the traffic rules and regulations.

A checklist with all possible driving errors is used by the tester. Each mistake will gain 2 – 10 penalty points. The candidate fails the test if his penalty points exceed the pre-determined cut-off points or he commits any serious mistakes.

The checklist will be given to the student so that he can learn from the mistakes to improve his driving. All of the above procedures are done to ensure that every person who drives on the roads in Singapore has sufficient driving skills to drive safely.

Figure 2.1 Driving licensing procedure for motorcar in Singapore (adapted from Singapore Police Force, 2017a)

2.4 Driving inactivity and fitness-to-drive

There are many factors that can affect a person's capability to perform the driving task, and hence his fitness-to-drive. As mentioned before, factors that can affect capability can be classified into two categories: long-term and short-term. There are previous studies that

explored the effect of factors such as age and medical conditions on fitness-to-drive. Fitness-to-drive assessments usually focus on the older driver and person with medical conditions, involving those factors that can affect driving capabilities in the long-term. On a shorter term, factors such as fatigue and alcohol intoxication affect driving performance temporarily (Petridou & Moustaki, 2000).

Driving training means to develop the driving skills of a person and familiarise him with the driving task and environment. Experience also helps to further develop drivers' skills and behaviour as well as to familiarise with the driving conditions. Some studies have shown the effect of driver's experience in several aspects of driving such as eye scanning, visual attention and risk perception. Different from age and medical conditions that affect drivers on their visual, cognitive and psychomotor ability, findings from some studies show that experience is more likely to affect driver on the driving strategy and risk perception.

Konstantopoulos et al. (2010) performed a study on the visual attention of learner driver and driving instructions. The study found that learner drivers tend to have a narrower scanning area and longer processing time compared to driving instructors. Learner drivers fixate less on the side mirror than driving instructors. A study by Borowsky (2006) also showed similar condition. Eye movement analysis on some situations showed that young-inexperienced drivers tend to only direct their gaze to the forward scene, while older-experienced drivers direct their gaze to the right and left sides in addition to the forward scene. It may be because, from the knowledge they develop from their experience, older-experienced drivers are more aware of the possible hazard locations. A study on the functional field of view by Crundall et al. (1999) showed that experienced drivers tend to have a faster reaction time and a higher detection rate on peripheral detection task compared to novice drivers and non-drivers. The result also suggested that driving experience can improve perceptual skills and strategy that leads to a more efficient functional field of view.

Besides visual behaviour, driving experience also can affect driver hazard perception. Borowsky (2006) did a research on hazard perception of young-inexperienced drivers and experienced drivers. The research found that driver perception of hazard frequency and severity of the possible outcome of the hazard improves with more driving experience. As a driver gains more driving experience, he can better predict the likelihoods that hazards might appear in certain situations. He may also be more cognisant of the possible outcomes for

certain hazardous situations. The study also found that young-inexperienced drivers tend to be reactive toward hazards, while experienced drivers are more likely to prevent a hazardous situation from happening. The study by Sagberg and Bjørnskau (2006) found that experienced drivers are better at anticipating and identifying hazardous situations, indicated by faster reaction toward hazards compared to novice drivers. The experiences that a driver gained from driving on the road develop the driver's risk perception and also hazard awareness.

2.4.1 Long-term retention of driving skills

While many studies have pointed out that driving experience helps to maintain and further develops the driving skill gained from the training period, limited experience coupled with driving inactivity degrade the driving performance. Certain skills that have not been used for some periods of times may be forgotten or degraded over time. Such situations can result in poor driving performance.

Young and beginner drivers, as different from older and experienced driver, have less on-road driving experience. While the older and experienced drivers have matured their skills and knowledge through miles of on-road driving, the young and novice drivers may not have fully matured their knowledge. Therefore, a period of inactivity, away from the opportunity to drive, may have different degradation rates for them.

While hardly any reported study related inactivity period on driving skills retention, some examples can be found in other fields, such as in sports. In sports studies, detraining is examined as referring to the partial or complete loss of training-induced adaptations, in response to an insufficient training stimulus (Mujika & Padilla, 2000). Insufficient training stimulus can be in the form of reduced training frequency or complete training cessation. Some studies have shown that 4 – 5 weeks of reduced and complete training cessation can cause a decline in physiological condition as well as sporting performance (Garcia-Pallares et al., 2009; Neufer et al., 1987). The other example of the effect of inactivity is in the case of return-to-play after injury. Some athletes need to take some period of rest because of injury. When they return to play after their rest period, there are several factors that can affect their performance such as medical factors, psychological factors and physical function (Herring et al., 2012). Verrall et al. (2006) investigated the playing performance of football players following return-to-play after a hamstring injury. They found that the playing performance,

evaluated by the team coach, on the two first games after the return is reduced compared to the two last games before the injury. Another study by Mithoefer et al. (2009) found that only 65% of athletes can achieve the same level of performance as their pre-injury level after return to sport. Podlog and Eklund (2004) pointed out that there are some concerns and/or difficulties that are commonly experienced by returning athletes. One of the concerns is related to their performance upon returning to sports. These concerns might cause loss of confidence and further affect their playing performance.

The examples from the sports field show that inactivity at a certain level can affect skills and performance gained from training, as well as affecting the psychology of the person. The same condition might also be applicable to driving. Drivers may lose, after periods of inactivity, some driving skills that they have gained through driver training. Drivers may also lose their confidence in handling a vehicle and interaction with the real road environment. Such conditions could then affect drivers' driving performance that can lead to safety issues.

Another field that has related study on the retention of knowledge and skills after a period of inactivity is the military field. During their training period, military personnel are trained on a set of military skills. However, some of the skills may not be applicable on a regular basis. This situation mostly happens for reserve personnel, whom the main occupation is not in the military field. During training, knowledge or skills was received as series of event and registered as series of memory traces that form a knowledge-representation/retrieval structure (KRRS)(Farr, 1987; Wisher et al., 1999). With an inactivity, this knowledge is forgotten or 'decay'. Different components of KRRS will have different deterioration rates. The knowledge and skills that are regularly practised will less likely to deteriorate. Wisher et al. (1999) pointed out that soldiers who spend more time on active duty have more opportunities to practise their trained skills. This practice opportunity is related to the experience of over-learning which is predictive of resistance against forgetting. Figure 2.2 illustrates the learning curve and over-learning phase, with the dashed lines representing deterioration due to inactivity.

Figure 2.2 Illustration of learning curve and deterioration due to inactivity

2.5 Fitness-to-drive assessment

Fitness-to-drive assessment is aimed at minimising the risk in road safety by not letting people who do not meet certain requirements of fitness-to-drive to drive on the roads. On the other hand, the fitness-to-drive assessment also has to balance with maintaining a driver's mobility independence. To achieve such aims, the decisions on fitness-to-drive assessment have to carefully consider several aspects in the assessment criteria. There are two main assessment methods to assess driver's fitness-to-drive: clinical medical assessment and driving assessment. Medical assessment usually consists of clinical-based assessments of those medical components that can affect a driver's driving ability, while driving assessment usually is in the form of on-road assessment or simulated driving environment to assess the driver's performance.

2.5.1 Medical examination

Most fitness-to-drive assessment guidelines use the medical examination as the main component in the assessments, especially for older drivers and people with certain medical conditions (Austroads, 2012; Laycock, 2011; Singapore Medical Association, 2011). Driving is a complex task that requires a certain level of skills and health condition. There are three main components of the medical assessment that are related to fitness-to-drive assessment, namely cognition, visual abilities and motor function.

A good cognitive ability is a basic requirement for good driving performance. The important component of good cognitive ability consists of strategising, organising, attention and planning. There are several types of tests that are used to assess cognitive ability, most of which are paper-based tests. Each test deals with different components of cognitive ability. Table 2.2 shows some types of cognitive assessment. The study by Niewoehner et al. (2012) has shown that some paper-based cognitive tests, e.g. Trail Making Test (TMT) A and Maze Test, are good predictors of driving performance. Woolnough et al. (2013) found that Assessment of Driving-Related Skills (ADReS), which includes cognitive test, does not have a significant correlation with driving performance. Hence, the consistent reliability of these pen-and-paper-based cognitive tests to assess fitness-to-drive is arguable. On the other hand, Bern Cognitive Screening Test (BCST) is claimed as being a more reliable method to assess cognitive ability than pen-and-paper tests, such as the Mini-Mental State Examination (MMSE), TMT A and B and Clock Drawing Test (Bieri et al., 2014). Figure 2.3 shows several examinations for cognitive ability.

Table 2.2 Examinations for cognitive ability

Assessment	Format	Tested component	Result
Mini-mental state examination	Pencil-and-paper test	Cognition	Quantitative measure
Trail making test A & B	Examiner administers, paper and pencil test	Visual attention and switch-making	Score is based on time (in seconds) to complete
The maze test	Pen-and-paper test	Visual-spatial and route-planning skills	Time to complete the maze and number of error
Clock drawing test	Pen-and-paper test, examinee is asked to draw a face of the clock and hands of a clock	Visual perception	Score based on six-point scoring system related to number of error
Bern cognitive screening test	Computer-assisted test battery	Visio-spatial attention, eye-hand coordination, distance judgement and speed regulation	Total number of errors from each subtest

Figure 2.3 Cognitive assessments: (a) Trail Making A and (b) Bern Cognitive Screening Test

Visual ability is another component that is required in driving activity. The medical assessment of visual ability usually consists of general questions and observation of examinee's eye health, as well as several types of visual testing. Table 2.3 shows the list of assessments for visual ability. Visual acuity test using Snellen E Chart is a common test that has been used for fitness-to-drive assessment. Although some guidelines have mentioned a certain level of visual acuity as a cut-off point, some studies have shown that there is no crash risk escalation between drivers with visual acuity 20/40 and 20/70 (Wang et al., 2003). Hence, the static visual acuity alone may be inadequate to assess fitness-to-drive (Laycock, 2011). Confrontation test is a common test to assess a person's visual field. However, it has been reported that for detecting visual field impairment, the confrontation is inadequate (Laycock, 2011).

Table 2.3 Examination tests for visual and visual perception

Assessment	Format	Tested component	Result
Motor free visual perceptual test	Test plate, paper and pencil	Visual perception	One point for each correct response, range of total score: 0 - 36
The Snellen E chart	Reading a standard chart for far visual acuity from approximately 20 ft. (6.06 m) from the chart, both eyes together and separately	Visual acuity	Visual acuity, based on lowest fully-completed row
Confrontation test	Detecting the movement of the examiner's finger, when one of the eyes is closed	Visual field peripheral vision	Visual field in degrees
Hooper visual organisation test (VOT)	Identify 30 objects represented in line drawings as puzzle places	Neurological impairment	T score and cut-off point

The last component in the medical examination of fitness-to-drive is the motor function. Table 2.4 shows the list of assessments and their specific testing focus. Good neuro-musculoskeletal abilities such as range of motion, muscle strength, and hand-eye-foot coordination, are needed in driving activities (Singapore Medical Association, 2011). A person with the neuro-musculoskeletal problem may experience some pain and difficulties in his driving activity. Other than the tests mentioned in Table 2.4, there are other aspects such as sensation, proprioception, kinesthesia, balance, mobility and transfer that are also assessed. Reaction time is also tested using brake and reaction if necessary.

Table 2.4 Medical examination tests of motor function

Assessment	Aspects tested
Range of motion	Range of motion of joint movement: Neck rotation Trunk rotation Shoulder adduction, abduction, and flexion Elbow and wrist flexion-extension Hip abduction, adduction, flexion and extension Knee extension and flexion Ankle dorsi-flexion and plantar flexion
Manual test of strength	Motor strength for some movements: Shoulder adduction, abduction, and flexion Elbow and wrist flexion and extension Handgrip strength Hip abduction, adduction, flexion and extension Knee extension and flexion Ankle dorsi-flexion and plantar flexion

In assessing medical fitness-to-drive, other than testing on the three main components, there are several conditions that the doctors or examiners should look out. Those conditions are called “Red Flags”. In Singapore’s context, Medical Guidelines on Fitness-to-Drive include several aspects under “Red Flags”: Frequently experienced general symptoms like fatigue or weakness; disease affecting vision; ENT-related symptoms; respiratory symptoms; cardiac symptoms; musculoskeletal changes; neurologic symptoms; psychiatric symptoms; and medication that can cause drowsiness or impair judgment.

Although medical examinations have been widely used in the assessment of fitness-to-drive, some studies have found that relying the decision solely on medical examination is

inadequate (Laycock, 2011). Some studies have also shown that results from the neuropsychological test and cognitive test are not strongly correlated to road test result (Adler et al., 2005; Fox et al., 1997; Lee et al., 2003). Rather than focus on the presence or absence of medical conditions, fitness-to-drive assessment should consider the effect of the overall health status of the driver on his functional capacity, hence functional assessment is necessary.

2.5.2 Driving assessment

Since there are some limitations in using medical assessment as a sole basis for the assessment of fitness-to-drive, it is desirable to use driving assessment when assessing driver's performance as related to fitness-to-drive (Laycock, 2011). The driving assessment can be in the form of simulated driving test or standardised road test.

Driving tests have been used in many countries and jurisdictions as part of the driving licensing test. Driving assessment is also used for fitness-to-drive assessment for older drivers or people with medical conditions. When the result of the medical assessment is inconclusive, it is preferable to conduct a road test. The study by Fox et al. (1997) claimed that the standardised road test is preferable for determining driver's capability, especially Alzheimer's disease (AD) patient than neurological testing, medical examination or mental status examination. Unlike medical examination that is designed only to detect presence or absence of diseases, impairment or illness, a driving assessment is useful in evaluating how the driver's medical status affects his functional capacity in the driving task and how he adapts to the driving task. There are several factors that are usually evaluated in the driving assessment: observation, speed control, planning and judgement, vehicle positioning, and physical control. Using a driving test in the fitness-to-drive assessment gives a more comprehensive assessment of the driving performance.

On-road driving assessment is usually used for either driving licensing for a new driver or fitness-to-drive assessment for older drivers and persons with medical conditions. In the fitness-to-drive assessment, on-road driving assessment usually complements the medical examination. Some guidelines use driving assessment only when the result of the medical examination is unclear (Austroads, 2012; Canadian Medical Association, 2006). On-road driving assessment can give the picture of real-world driving conditions and how the driver's functional capacity of the driving task is affected by his condition. However, on-road driving

assessment has limitations such as: nearly impossible to control the road condition, and safety risk since the person being tested is someone whose impaired conditions may not have recovered. Unrepeatable and uncontrollable road conditions make an on-road driving assessment to be unfair to the examinee. It also can be very risky both for the examiner and examinee and also other people on the roads, since the person on driving test may not yet be fit to drive.

Simulated driving can be an alternative to create a fairer assessment environment where the examinee is tested under the same situation and scenario. A driving simulator also minimises or even removes the risk of crashes as in on-road assessment. The assessor can also create one's own scenario that meets the needs of the assessment. Some studies have found that there is good correlation between errors committed on simulated driving test with failure on road test such as lane boundary crossing (Szlyk et al., 2002); impairments in speed control, changing lanes and signalling, qualitative judgements and reacting to other drivers (Duchek et al., 2003). Other studies have established the relative validity of several driving performance indicators in simulated driving as compared to real-world driving (Mullen et al., 2011).

Laycock (2011) suggested that simulated driving test can replace the physician-based assessment model, complemented by a road test if the results remain unclear. Since driving assessment has been found as a better method to assess driving capability than medical assessment, the study also suggested moving towards more study in this direction. Therefore, testing procedures and criteria that are designed to clearly and fairly indicate pass or fail are needed.

2.6 Driving simulator

2.6.1 Driving simulator as research tools on human factors in transport

Driving behaviour studies using driving simulator are getting more popular nowadays because it gives a safer and more controllable environment. There is a growing body of research on driving that uses a driving simulator. A driving simulator offers a relatively risk-free environment to assess difficult and high-risk scenarios. One can also control the road environment and traffic conditions in a driving simulator to make sure that every participant in the study has the same experience using the same defined scenarios. On the other hand, a full-control environment with repeatable conditions is near impossible to obtain in the real

world and may cost a lot of time and resources for such real-world experiment. Hence, there is a huge increase in research activities using the driving simulator.

According to the level of technology used, a driving simulator can be divided into three categories: low-level, mid-level and high-level (Carsten & Jamson, 2011; Kaptein et al., 1996). A low-level driving simulator is usually built using very simple components such as PC, monitors and a driver seat equipped with a controller. A mid-level driving simulator usually uses advanced imaging component and realistic vehicle cabs, which are sometimes complemented with a simple motion base. A high-level simulator uses an advanced imaging system with close to the 360-degree field of view, full vehicle cab and a sophisticated moving base. This classification is, however, not always exact. A driving simulator can have a high capability in one component, but low capability in other components. In essence, the purpose of the application of the driving simulator defines what the level of the simulator is required.

The application of a driving simulator nowadays varies from training purposes to behavioural research. Unlike in the aviation field, where the application of simulator is mostly for training purpose, the application of a simulator in the driving field is more for research purpose than training. The ability to control the experimental conditions and produce a repeatable scenario is a major consideration that motivates the use of simulators in driving-related research. The ability to control the conditions makes conducting a driving experiment in a driving simulator to be more efficient than in the real world where it is difficult to control factors such as weather, traffic conditions, etc. Other factors that motivate driving research using a simulator are health and safety issues. Some types of experiments are too risky and could lead to issues of ethics such as research that involves distracted driving or impaired driving (e.g. driving under alcohol influence).

Notwithstanding the advantages of the driving simulator, there are also some limitations on the driving simulator such as the validity of the simulations and participant's motivation. Although the driving simulator is designed to replicate the real-world conditions, the participant may never be as motivated as when he is driving in the real-world. The participant is aware that he is being observed by the researcher, and the time pressure may not be the same as what he feels in the real-world driving (Carsten & Jamson, 2011). The driving simulator may not be suitable for research related to driving laws and norms, as one can

become more obedient upon being observed, resulting in compliance bias; or he may believe that the laws and norms are not applicable in the simulated environment.

Another problem with the application of driving simulator is simulation sickness. Simulation sickness is usually indicated by symptom such as headache, sweating, drowsiness, disorientation, vertigo, nausea, dizziness, and vomiting (Brooks et al., 2010; Kennedy et al., 1993). Some researchers treat simulator sickness as one kind of motion sickness. However, they can also be treated as related but separate syndromes. The mismatch between the visual perception of acceleration and deceleration and the vestibular sensation of the motion in driving simulator can cause motion sickness that is referred as simulator sickness (Bles et al., 1998; Brooks et al., 2010; Carsten & Jamson, 2011). It occurs when the participant's body does not feel the matched motion he expects to feel when looking at the visual display. The effect of simulator sickness can be different from one person to the other. Simulator sickness cannot be treated as just an inconvenience in a driving simulator. Simulator sickness can affect the participant's performance, especially for emergency scenarios (Bittner et al., 1997; Cassut et al., 2014). Therefore, it is not recommended to force a participant with simulator sickness to complete the test or include performance data from participants with simulator sickness which would otherwise generate misleading results.

Simulator sickness questionnaire (SSQ) developed by Kennedy et al. (1993) is commonly used to measure the symptoms of simulator sickness. It contains 16 items that need to be rated by the participants, which can be categorised into three subscales: nausea, oculomotor disturbance and disorientation. Bouchard et al. (2007) tried to re-examine and revise the structure of the scoring for SSQ. They suggested two subscales of simulator sickness: nausea and oculomotor disturbance, instead of three subscales used by Kennedy et al. (1993).

2.6.2 Driving simulator validity

Conducting driving behaviour studies using a driving simulator faces certain constraints. Even a high-level simulator may still give different feelings from the real-world conditions to the driver, thus affecting the participant's behaviour. The feeling of being assessed by the researcher may also influence the driving performance of the participant (Carsten & Jamson, 2011). Therefore, validity is a very important issue as related to the application of the driving simulator. In general, validity refers to how suitable is the simulation for its application.

Validity becomes very important to ensure that the result from the virtual environment in the driving simulator is relevant to be generalised to the real world. The validity of a driving simulator can be divided into the absolute validity and relative validity. Absolute validity refers to validity that is related to the value as obtained. Good absolute validity can be achieved if the value obtained in the driving simulator is not significantly different from the real-world value. On the other hand, relative validity is related to the trend of the value. Good relative validity will be obtained if there is a similar trend in the simulator and real-world condition. Absolute validity is more difficult to obtain than relative validity. For some studies, the relative validity is adequate to bring their results to be generalised to the real-world conditions.

Validity also can be categorised into the physical validity and behavioural validity (Carsten & Jamson, 2011). Physical validity is related to the physical component and sub-system of the driving simulator. Physical validity is affected by some aspects such as accuracy of underlying software; the capability of the visual system; the realism of the sound system; elaborateness of the physical vehicle control and displays with which the driver interacts; and motion component. On the other hand, behavioural validity is related to how close the experience of the participant's driving in the simulator elicits the driving experience in the real vehicle on real roads. Behavioural validity can be in the form of behavioural validity for the basic level of driving performance as well as behavioural validity in demanding tasks, such as dealing with hazard.

With the increase of the use of the driving simulator in driving research, there are several studies related to the validity of the driving simulator. These studies have demonstrated the validity related to several behavioural aspects such as speed (Bella, 2005, 2008; Bittner et al., 2002; Blauuw, 1982; Godley et al., 2002; Klee et al., 1999; Tornros, 1998), maintenance of lateral position (Wade & Hammond, 1998), and braking response (Hoffman et al., 2002). Most of these studies could show the relative validity but failed to show absolute validity except Blauuw (1982), Bella (2008) and McGehee et al. (2000). Simulators are found to be sensitive to age-related variation in real-world driving performance, hence simulators can be used to study older drivers on future traffic violation risk. Mullen et al. (2011) also noted that most of the studies found that driving simulator behaviour reflects similar trends (relative validity) but does not reflect the exact value (absolute validity) of on-road driving behaviour. When applying the driving simulator, one must be aware that the driving behaviour that is

found from a simulator study does not always reflect the accurate picture. The validation of simulator should be considered as an important component in driving simulator research.

2.7 Vision and eyesight in driving

2.7.1 Eye structure

Vision holds an important aspect of driving activities for information acquisition process. The information that is acquired through the vision of the drivers becomes the basis for their decision-making and action. Vision is included in many assessments for fitness-to-drive. It shows the importance of vision in driving. Degradation in vision may hinder information acquisition of the drivers and could thereby affect their decision-making process. Vision is commonly included in driving licensing and renewal screening test with focus on visual acuity.

The eye is an organ in the human vision system (HVS) that acts as the window of the information. In general, the eye can be divided into two parts: the neural part, which is the retina, and the non-retinal part (Hubel, 1988). Non-retinal part of the eye has a collective function to supply the retina with a focused and clear image of the outside world. Each eye is roughly like a ball with six extra-ocular muscles attached to each. These muscles function to control the position of the eye. Figure 2.4 shows the structure of the eyeball and its muscle. The cornea is the transparent front part of the eye. Cornea together with the lens work similarly like a camera lens, in focusing the light from the outside world. They focus the eye by changing the shape of the lens by pulling or relaxing the tendon in its margin. The change in shape of the lens is controlled by a set of muscles called ciliary muscles. Pupil adjusts the amount of the light that enters the eye by changing its diameter.

Figure 2.4 Eyeball structure (source: Encyclopædia Britannica (2013))

Retina's function is to translate the lights into neural signals, through the receptors called photoreceptors that are sensitive to light (Duchowski, 2003; Hubel, 1988). The photoreceptors are located at the back of the retina and can be classified into rod and cones. Rod is sensitive to dim and achromatic light, while cones respond to brighter light and are responsible for the colour vision and fine details. The retina consists of different types of cells that are constructed in three layers (including photoreceptors). Figure 2.5 shows the structure of the retina. Since the position of the photoreceptors is at the back of the retina, the light that comes in must go through the outer two layers. The middle layer of the retina contains bipolar cells, horizontal cells, and amacrine cells. The neural signals from receptors are received by bipolar cells and many of them are delivered directly to the ganglion cells in the front layer. Horizontal cells link the receptors to bipolar cells while amacrine cells link bipolar cells to ganglion cells. The front layer contains the retinal ganglion cells. The axon of ganglion cells passes across the surface of the retina, form a bundle at the optic disc and form the optic nerve when leaving the eye.

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Figure 2.5 Structure of retina (source: van Lookeren Campagne et al. (2014))

2.7.2 Eye movement

As mentioned above, the eyeball has six (3 pairs) extra-ocular muscles attached to each of it. These muscles are responsible for controlling the position and movement of the eye. The movement of the eyes is the result of excitation of one muscle and inhibition of the opponent in just the same amount. All the movement is controlled by the brain. Each of the extra-ocular muscles is connected with a small cluster of a few hundred motor neurones in the part brain stem called oculomotor nuclei. Figure 2.6 shows the muscle that is responsible for eye movement and its mechanism.

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Figure 2.6 Illustrations of eye movement controlled by extra-ocular muscle (source: OpenStax (2013))

In order to collect information from the outside world, humans employ saccade and fixate strategy in their eye movements. A saccade is defined as a fast eye movement between fixations, while fixation is defined as the more stabilised eye gaze that is related to information collection (Gilchrist, 2011). The saccade is usually related to the quick scanning process of the area of interest, while in fixation the human looks at an area of interest for a certain amount of time to gather the information. There is a threshold value of the duration to consider an eye gaze as a fixation, with 100 milliseconds being normally used as the minimum duration.

2.7.3 Vision and driving

As mentioned before, driving is a complex task that combines several sub-tasks. One of the tasks is the acquisition of information related to the surrounding environment through the human visual system. Therefore, vision holds a very important role in driving activities. Many studies related to vision and driving have been done, to give more understanding on how vision affects the driving performance and furthermore safety.

Visual test has been included in the screening for licensing and renewal in many jurisdictions. It usually focuses on visual acuity and sometimes includes visual field.

However, there is no universally standardised value for the cut-off point for both visual acuity and visual field. Every jurisdiction has different cut-off values. Meanwhile, many previous studies have shown that there is no significant association between visual acuity and accident involvement (Cross et al., 2009; Hills & Burg, 1978; Owsley & McGwin, 2010; Rubin et al., 2007), especially for young drivers. Meanwhile, other studies have shown that the effect of acuity and visual field are mainly on sign recognitions but not directly to the vehicle control performance (i.e. speed estimation, stopping distance) (Wood & Troutbeck, 1992). It might be due to compensatory mechanism that drivers adopt as their vision is impaired. Studies also found that visually impaired drivers also tend to restrict themselves to only drive in familiar area, thus less risk exposure.

While many studies have shown weak to no association between the human visual condition and driving performance, several studies have shown that driving experience affects human visual behaviour while driving. The visual behaviour will then be related to the information acquisition process. Some previous studies have shown that driving experience affects the visual behaviour of driver during driving activities, especially the eye movement pattern. Land and Tatler (2009) found that during driving, drivers will try to gain input from surrounding cues involving both feedback information from a close region and feed-forward information from the distant region. Experienced drivers are able to estimate the future direction of the car and use it to direct their gaze to gain feed-forward information. Meanwhile, novice drivers tend to rely on feedback information than apply anticipatory strategy. Other studies also have found different visual behaviour between novice and experienced drivers. Underwood et al. (2002) found that novice drivers tend to direct their eye gaze in more limited scanning area than experienced drivers. Meanwhile, Konstantopoulos et al. (2010) found that learner drivers have narrower scanning area and longer fixation time than driving instructor, indicating less flexible scanning behaviour and longer time needed to process the visual information. They also found that driving instructors looked at side mirror more frequently, suggesting more effort to look out for potential hazards.

2.8 Driver fatigue

Fatigue can be defined as disinclination and reduced efficiency in performing work (Brown, 1994; Grandjean, 1979, 1988; Lal & Craig, 2001). Fatigue can be differentiated into task-related and sleep-related fatigue (May & Baldwin, 2009). Sleep-related fatigue is usually caused by sleep deprivation, continued wakefulness and circadian rhythm, while task-related

fatigue is caused by either overload or underload task-demand and also the driving environment. Driver fatigue can be measured or indicated using physiological measurement, self-report and also driving performance. Fatigue can also be classified into two categories: physical and mental fatigue. Mental fatigue can be defined as a functional state that can be indicated by reduced attention and alertness. Physical fatigue can be defined as muscular fatigue when muscle performance is reduced after stress, indicated by reduced muscular power and movement, and it can increase the likelihood of errors caused by poor coordination (Lal & Craig, 2001).

There are several factors that can affect a driver's fatigue condition. There are factors that can induce fatigue before a driver starts to drive (e.g. sleep deprivation, physical activities before driving). Meanwhile, fatigue can also be developed during driving activities (e.g. driving for long period, complicated environment, and complex driving task). Fatigue can be categorised with regards to the causal factors into sleep-related and task-related factors. Furthermore, the task-related factors can be divided into underload conditions and overload conditions. Underload conditions occur when the task demand and the stimuli are very low, e.g. very low traffic and monotonous road, while the overload condition is related to high demand task, such as performing a secondary task while driving and driving in complex environments (May & Baldwin, 2009).

Fatigue can affect physical and mental function which can cause reduced alertness and coordination that can lead to poor driver performance. Poor performance can increase the risk of traffic accident involvement. A study by Weiss et al. (2014) in New Zealand found that fatigue is one of the deadliest factors in two-vehicle crashes. Fatigue and sleepiness also contributed to thousands of fatal crashes in the US in 2012 (NHTSA, 2014). According to a study by the National Transportation Safety Board (NTSB) in the United States, from 107 cases of heavy trucks involved in single-vehicle accident, 52% were related to fatigue, and the drivers admitted that they fell asleep in 18% of the cases. In 1990, a fatigue-related study by the United State Department of Transportation showed that in almost 30% of accidents involving heavy commercial transport the causes were related to fatigue (WHO, 2004).

Some studies have shown the effect of driver fatigue on the driving performance such as vehicle lateral and speed control (Baulk et al., 2008; Philip et al., 2003) and reaction time (Baulk et al., 2008; Ting et al., 2008). Lateral control can be indicated by the vehicle lateral

position and lateral velocity as the parameters. Increases in the variability of lateral position and lateral velocity usually come along with the increase of driver fatigue, as related to impairment on control capability. For speed control, longitudinal speed is used as the parameter. Similar with lateral control, increase on the standard deviation of speed is usually related to driver control impairment that is associated with fatigue.

2.8.1 Driver fatigue measurement

Driver fatigue condition is affected by various factors such as driving environment condition and task load; the latter can be measured using either objective assessment (e.g. physiological measure or performance-based measure) or subjective assessment (e.g. diaries, interview or questionnaire). Previous studies have applied objective measures that can be used to indicate driver fatigue, such as physiological traits: eye activity, brain activity, heart rate variability, etc. Performance-based measures include the simple reaction time. For the subjective measure, a self-assessment questionnaire is usually used to rate the alertness, sleepiness and psychological state of the participant. A study by Marsalek and Thoren (2003) developed a set of short tests to identify fitness-to-drive, primarily to assess fatigue, that combines subjective assessment and performance test. The study concluded that an acceptable threshold is required for effective and objective evaluation of the fitness-to-drive criterion.

Subjective assessment is used to let the participant rate on his own current conditions at the time of the studies. The questionnaire is filled by the participants. Therefore, this type of measurement gives freedom to the participant to rate his own conditions. There are several types of subjective fatigue assessments that vary from questionnaire to rating scale. Each type of subjective fatigue assesses different aspects of fatigue, such as general condition (Visual Analogue Scale), mental fatigue (USAFSAM mental fatigue scale), sleepiness (Stanford Sleepiness Scale and Karolinska Sleepiness Scale), and effects of fatigue on the multidimensional aspects (Piper Fatigue Scale).

One example of a subjective fatigue scale is US Air Force School of Aerospace Medicine (USAFSAM) mental fatigue scale also known as Samn-Perelli seven-point fatigue scale (SPS). The USAFSAM mental fatigue scale is developed by Dr William F. Storm and Captain Layne P. Perelli of the Crew Performance Branch of the USAF School of Aerospace Medicine, Brooks AFB, San Antonio, Texas in 1979 and has been used for various purposes

in the field and laboratory tests (Miller, 2013a, 2013b). One of the applications of USAFSAM mental fatigue scale is as an instrument to predict fatigue of the aircrew (Samn & Perelli, 1982). This scale is also used as an instrument in the fitness-for-driving test by DLR, Institute of Aerospace Medicine, Germany (Marsalek & Thoren, 2003). In the DLR Alertness Management Program, USAFSAM is used as one of the measurements of driver fatigue state. This scale uses five as its cut-off point. A person is considered as in concerned condition if his fatigue rating hits five or above. Table 2.5 shows the USAFSAM mental fatigue scale.

Table 2.5 USAFSAM mental fatigue scale

1	2	3	4	5	6	7
Fully Alert. Wide awake	Very lively. Responsive, but not at peak	Okay. Somewhat fresh	A little tired. Less than fresh	Moderately tired. Let down	Extremely tired. Difficult to concentrate	Completely exhausted.

Another example of subjective fatigue measurement is Piper Fatigue Scale (PFS) (Piper et al., 1998). While USAFSAM mental fatigue scale addresses fatigue in a more general aspect, PFS addresses the fatigue level in multi-dimensional aspect. PFS was originally developed to measure fatigue on cancer patients. The original version of FPS consists of 40 items. That version is considered impractical in its application (Chalder et al., 1993). Therefore a revised version of PFS is developed, which consists of 27 questions, including 22 numerically-scaled items and five additional questions (Piper et al., 1998). The numerical scale ranges from 0 (none) to 10 (severe). The 22 numerically-scaled items cover four aspects/subscales of subjective fatigue: behavioural/severity, affective meaning, sensory, and cognitive/mood. Each subscale consists of several items, and the rate of each item is used to form the rating for each subscale. The overall rating for FPS is formed by a combination of the subscale ratings. Five additional questions cover other additional information such as duration, contributing factors, etc. Table 2.6 shows the interpretation of PFS.

However, the results of the measurements for subjective assessment are dependent on the perception of the participant about fatigue. Different people could have different standard or perception about fatigue, so the results might vary between persons. A study by Liu et al.

(2013) showed that there is a direct co-relationship between subjective fatigue level and driving performance indicator, in this case, speed control. That study showed that subjective fatigue level can be used as an indicator to measure fatigue level and how it affects driving performance.

Table 2.6 Interpretation of PFS

Score	Fatigue level
0	None
1 – 3	Mild
4 – 6	Moderate
7 – 10	Severe

2.9 Driving performance

Driving performance represents the ability of the driver to handle a vehicle while driving. The driving performance includes several types of parameters such as lateral control, speed control, hazard anticipation, etc. In this study, driving performance is divided into two aspects: vehicle control performance and interaction with other road users. Vehicle control performance is represented by lateral control, while the interaction with other road user is represented by hazard perception parameters.

2.9.1 Vehicle control performance

There are several aspects of driving performance. In this research, lateral control and speed control are the main focuses. Many studies in different topics of driving have used lateral control as one of the evaluation components of driving performance and behaviour (Abele & Moller, 2011; Antonson et al., 2009; Bella, 2013; Young & Mahfoud, 2007). Lateral control performance is usually represented by the variability of the vehicle centreline position relative to the centre of the lane or its position with respect to the lane centreline. Lateral control is related to how the driver positions his vehicle with respect to the driving lane and other adjacent vehicles. It is closely related to the steering wheel control. Poor ability in lateral control increases the risk of unintentional lane overrun and the possibility of side contact and collision with other vehicles.

Larger variability of vehicle lateral position imposes unstable lateral control. Variance or standard deviation of lateral position is commonly used as the lateral control parameters. It

represents the variability of lateral position over a journey. The other parameter that has been used for lateral control is centrality index (CI) (Stimpson et al., 1977; Wong, 1989). CI represents the centrality position of a vehicle. It was first formulated by Stimpson et al. (1977) in which CI represents the centrality position of a vehicle.

$$CI = \frac{|\overline{LP_e} - \overline{LP_c}|}{0.1 LW} \quad \text{Equation 2.1}$$

where:

LP_e = mean lateral placement of right vehicle tyre with respect to the right edge of the travelled lane (ft.)

LP_c = mean lateral placement of the left vehicle tyre with respect to the centreline of the travelled lane (ft.)

LW = width of the travelled lane (ft.)

If the value of CI is zero, it means that the centreline of the vehicle is exactly at the centre of the travelled lane. Wong (1989) modified the formula from Stimpson et al (1977) by incorporating vehicle wheel span. The formula is then re-written as:

$$CI = \frac{(2 \times X_1 + VW - TW)}{TW} \quad \text{Equation 2.2}$$

where:

VW = vehicle wheel span

X_1 = distance from outer face of the right wheel to the right boundary (driver's perspective)

TW = width between the right and left reference boundaries

Wong (1989) also defined several boundary values of CI, which can generally describe the position of the vehicle. The boundary values can be described in Figure 2.7. While CI is used to indicate the position of the vehicle within the reference driving lane, boundary values will help to indicate the encroachment of the vehicle onto other lanes. When CI equals to ± 1 , it indicates that the vehicle centreline is exactly on either left or right boundary right. It means that at least half of the vehicle has already encroached onto another lane, or one can say that the vehicle has already changed to another lane once the CI crosses those boundary values of ± 1 .

Figure 2.7 Centrality Index (CI) illustration (source: Wong, 1989)

2.9.2 Hazard perception

Hazard perception is the ability to read road situation and awareness of the hazardous situation (Horswill & McKenna, 2004; Mills et al., 1998). Hazard perception test (HPT) has been used as part of driving licensing test in UK and Australia. It also has been used to assess driving performance in different studies. Hazard perception test has been found to be closely related to crash involvement (Wallis & Horswill, 2007). HPT is believed to involve multi-component cognitive skills that represent the complexity in driving task.

HPT is usually done by asking the subject to watch a driver perspective video footage that contains some hazardous situation. When the subject detects the hazard, he needs to indicate his response by moving the handle, using the touch screen or pressing button. The time between the hazard appearing until the response was registered is measured as reaction time. The average reaction time is used to measure the subject's performance.

Several studies have shown that on-road driving experience has a correlation with hazard perception. Previous studies have found that experienced driver has faster response compared to novice driver (McKenna & Crick, 1991; Wallis & Horswill, 2007). Hazard perception is also influenced by training intervention. Previous studies showed that subject who received hazard perception training prior to the test performed better, indicated by faster response, than the untrained control groups (McKenna & Crick, 1991, 1994; Mills et al., 1998). Hazard perception is also affected by age and driving experience. On-road driving experience also improves driver's perception of risk and his awareness about possible hazardous situation on-road (Borowsky, 2006; Sagberg & Bjornskau, 2006). Borowsky (2006) also found that young-inexperienced drivers are more reactive toward hazards, while experienced drivers are more likely to be preventive towards hazardous situations.

As mentioned before, hazard perception test is mostly based on video footage. In conventional HPT, the participant is only asked to register his response without any need to make a decision to avoid a collision with the hazardous object. With that format, the HPT is mainly a detection task. However, such a format is not really able to portray the complexity of driving task. Previous studies have shown that there are differences in visual behaviour between solely viewing and when combined with other actions (Steinman, 2003), including driving (Mackenzie & Harris, 2014, 2015). Therefore, it is more useful to examine hazard perception in a test environment that properly represents the complexity of driving task. The driving simulator in current research is intended to be a platform to extend the HPT beyond a detection-only task. With the driving simulator, the test subject is given freedom to make a decision and apply it into an action to avoid a collision. Decision-making process and action-taking are interesting aspects of hazard perception and interaction for exploration.

2.10 Summary and gap identification

Safety is an important aspect that needs to be fulfilled in transportation practices. Inadequate safety conditions can lead to a road traffic accident (RTA) that causes either loss of life or disability and also economic loss. Human factors have been identified as the biggest contributing factor of RTA. There are several aspects in human factors that can influence driver capability and risk-taking either in the long-term (e.g. age, experience, disability) or in the short-term (e.g. fatigue, alcohol intoxication, etc.) (Petridou & Moustaki, 2000). Driving is a complex task that requires a certain minimum level of skills and ability. The skills and ability for driving can be improved through training and on-road driving experience.

While many studies have noted that driving experience will help to further develop the driving skill obtained from the training period, from the author's best knowledge, there is no study on the effect of driving inactivity on the driving performance. Similar studies in military and sports found that certain skills that have not been used for some periods of times may be forgotten or degraded over time (Farr, 1987; Wisner et al., 1999). Degraded condition may result in poor driving performance. The high price of the private vehicles in Singapore has resulted in many people not having regular access to a private vehicle after they get their driving licence. From 2011 to 2015, there was a 13.5% increase of number of Classes 3 and 3A licence holders (for licensure to drive a private car), from 1,686,272 to 1,913,161 (Singapore Police Force, 2017b). Meanwhile, the car and light good vehicles population remained steady at 725,484 in 2011 and 724,586 in 2015 (Land Transport Authority, 2017). This situation creates a unique driver population in Singapore with a large pool of inactive drivers, defined herewith as a person who receives driving training but remains inactive of driving for some periods of time. Therefore, it is interesting how driving performance is affected by driving training and inactivity. Therefore, this research aims to address the issue on retention of driving skills in relation to driving inactivity, specifically for the young, freshly-licensed, and hence inexperienced, drivers. Herein, simulated driving can provide a safer and more convenient environment for performance-based assessment, where specific scenarios can be re-created and a similar driving environment can be provided for every subject.

Chapter 3 Methodology

3.1 Overview

This Chapter covers the methodology that was employed in this research, in order to answer the research questions. Two main hypotheses were tested through the series of experiments. Firstly, active drivers will perform the best compared to novice, inactive and no licence groups. Secondly, inactive drivers are expected to have poorer driving performance, being worst off than novice (freshly-trained) drivers but still better than no licence groups who never get any driving training before. The research was divided into two stages: passive mode driving assessment, and active mode driving assessment. Passive mode served as the preliminary stage to assess the effect of training, experience and inactivity on driving performance. In the active mode, driving skills were assessed by two main components namely, vehicle control performance, and interaction with other road users, especially hazard perception and anticipation. The detailed assessment and analysis method are explained in this Chapter, including the experimental design, while the results are covered in the following chapters.

3.2 Data collection framework

To examine the effect of training and duration of inactivity on driving performance, data related to human factors and driving performance are necessary. The required data include driver's demography, driver's conditions, and driving performance. Though driving is a complex activity that involves many sub-activities, this research aims to assess the driving performance on two aspects: driving handling skills and interaction with other road users. A comprehensive driving assessment was conducted to assess the effect of driver's training and duration of driving inactivity on driving performance.

In-lab driving assessment using a driving simulator was chosen for conducting the driving assessment, as it offers a safer and controllable assessment setting compared to real driving. It suits the current research since this current research involved inactive drivers and no licence subjects that would be risky if put on real road setting. A driving simulator was thus developed with valid scenarios that matched the needs of this research. The challenge in the development of driving assessment using a driving simulator was to develop the virtual driving environment and scenarios that can replicate the real environment and relevant with

real driving situations. For the current research, a fixed-base simulator was chosen as it is easier to assemble, move and store. Although there are some limitations of the fixed-base driving simulator, realistic driving experience using this driving simulator can be generated by using suitable hardware and software components.

As mentioned in the first chapter, this research focused on young inexperienced drivers. Young and inexperienced drivers were chosen as they have less mature driving skills since they have less experience. They are expected to be more prone to degradation of skills caused by inactivity compared to experienced drivers. Young and inexperienced drivers are in their transition period between no licence phase to experienced driver phase. They have already obtained the basic skills through driving training, however, they would need on-road practices to maintain as well as further develop those skills.

A preliminary stage was conducted at the beginning of this study, to examine the effect of experience, inactivity and training on driving performance. The preliminary stage focused on the hazard perception test in a passive driving assessment setting. The result from the preliminary passive stage was then used to design and improve the experiment on the subsequent stage: active mode driving assessment. In the active mode driving assessment, driving skills were divided into two main components: vehicle control skills and hazard perception and anticipation. Vehicle control skills represent the ability of the driver to maintain a stable movement of the vehicle. Meanwhile, the hazard perception and anticipation represent how the driver perceives the hazard and how well he anticipates the hazard to avoid a collision. Further details about each stage of research are explained in the following sections.

3.3 Passive mode driving assessment

An experiment to study response time was conducted as a preliminary assessment of the effect of driving training and on-road experience on driving performance. Hazard perception test (HPT) was chosen to examine the driving performance at this stage. HPT has been included in the licensing process in several jurisdictions (e.g. U.K. and four Australian States). Previous studies have shown that hazard perception is closely related to driving experience (Horswill et al., 2008; McKenna & Crick, 1991; Milech et al., 1989; Wallis & Horswill, 2007) and also accident risk (Horswill & McKenna, 2004; Quimby et al., 1986). Hazard perception involves several cognitive skills, such as road environment scanning,

detection of stimuli (Mayhew & Simpson, 1995), interpretation and decision-making process (Milech et al., 1989). Therefore, HPT was chosen to examine driving performance in this research.

The HPT assessed the response performance of participants who faced stimuli of dangerous situations under passive control driving simulator setup. The response time from three groups of participants, active drivers, inactive drivers and no licence group, was compared to examine the effect of driver's training and driving experience on the driving performance. Passive mode serves as a part-task assessment of the hazard perception and anticipation process, in which the focus is mainly on hazard perception. On the passive mode, the participant does not have any control over the vehicle, and he makes his task upon the detection of a hazard.

3.3.1 Test subjects

Participants for the HPT were recruited and classified into three groups based on their possession of driving licence and inactivity from driving. These three groups were active group, inactive (since licensure) group, and no licence group. Table 3.1 shows the detailed description and criteria of each group. In essence, those inactive drivers who did not drive since licensure would be devoid of on-road driving experience. The cut-off period of 3 months was chosen to define inactive give. Previous study has shown that some skill sets start to deteriorate as early as from around 3.5 months' of inactivity (Wisher et al., 1999).

Table 3.1 Description of testing group

Group	Description	Skill level	Sample size (n)
Active	The participant holds a valid Singapore driving licence for more than 1 year and regularly drives	Training; On-road experience	14
Inactive	The participant holds a valid driving licence but has not been driving since obtaining licence more than three months ago	Training; No on-road experience	10
No Licence	The participant does not possess any valid driving licence (including overseas licence)	No Training; No on-road experience	14

A total 38 participants were recruited for this experiment: 14 participants in the active group (12 males, 2 females), 10 participants in inactive since licensure group, referred later as inactive group (6 males, 4 females), and 14 participants in no licence group (4 males, 10

females). Their age ranged from 20 to 30 years old. They were recruited from undergraduate students of Nanyang Technological University (NTU).

3.3.2 Equipment

The experiment was conducted on an in-laboratory video-based simulation setting. The video contained day-time driving scenes around NTU campus as seen from the driver's perspective, which included several hazardous scenes (Yeung & Wong, 2015). The overall video was about 4-minute long and contained four hazards. The videos were shown on a 46-inch LED display while the participant was seated in the driving seat with distance from the participant's eyes to the display at approximately 1.1 metres. The seat was equipped with mock steering wheel, gear stick and pedals. The steering wheel, gear stick and pedals did not affect the control of the video in this experiment. Figure 3.1 shows the equipment set-up of the experiment.

A simple circuit was connected to the pedal brake with two LED bulbs positioned on the top and bottom edges of the LED display. The LED bulbs light up when a participant responds to the hazardous event by hard stepping on the pedal brake. A video recorder was set up to record the participant's reaction that is indicated by the LED lights. The video recorder was positioned on the side of the participant and was arranged such that it can capture the LED display and the LED bulbs.

Figure 3.1 Driving simulator setup

3.3.3 Stimuli

There are four hazards on the 4-minute long video which serve as the stimuli to trigger participant's reaction. The hazards vary in terms of the collision damage potential (property damage only; potential loss of life) and collision avoidance potential. Previous studies have shown that different types of hazard (i.e. object involved, motion) affect the risk perception of drivers which in turn affects their responses (Armsby et al., 1989). Brown and Groeger (1988) explained that there are two main inputs of driver risk perception: information of potential hazard, and information of abilities to prevent those hazards to become actual accidents.

The four hazards involve conflicts with different objects, from unprotected-vulnerable road user that can lead to serious injury or even loss of life to another motorised vehicle that can lead to expensive property damage. The avoidance potential is related to the proximity of the 'driven' test car to the hazard as can be quantified by the time-to-collision (TTC) without braking action, as well as the span of collision zone. TTC is the elapsed time from the instant the hazardous object first appears on the screen to the instant whereby a collision just about to occur with the hazardous object without any braking action. Figure 3.2 illustrates the TTC. The damage potential and avoidance potential jointly contribute to the overall risk of the hazard. Table 3.2 summarises the characteristics of each hazard, while Figure 3.3 illustrates the scenes of the hazards.

Figure 3.2 Illustration of time-to-collision (TTC)

Figure 3.3 Hazards

Table 3.2 Hazard characteristics for passive mode

Hazard (Object)	Avoidance potential	Collision damage potential
A1 (Merging Car)	Somewhat difficult	Severe (property damage, injury)
A2 (Cut-across Bike)	Somewhat difficult	Severe (potential fatality)
A3 (Dropping Object)	Rather difficult	Light property damage
A4 (Roll-across Trolley)	Rather difficult	Light property damage

Hazard detection-response window is defined as the time boundaries whereby the response of the participant is considered as a valid response to the hazard. Responses that were registered outside the hazard detection-response window (i.e. very slow response) would be deemed as an invalid response. Hazard detection-response window starts when the hazardous object first appears on the screen. A rapid response, i.e. braking, is necessary with the appearance of each hazard in order to avoid a collision. The test car is shown to come to a complete stop just outside the merging point whereby a collision could be avoided (i.e. test car stops at the verge of the collision zone), and this juncture is considered as the end of the hazard detection-response window.

A1 (Merging Car): A car suddenly appears, merges and tracks along the path of the test car

A car suddenly appears from a minor road at the left side of the test vehicle. The car then proceeds to converge onto the path of the test car. The hazard detection-response window is about 3.5 s, starting from the time the car first appears on the screen until the test car comes to a complete stop. The intention of this scenario is to examine the response of participant towards a hazard that involves another vehicle in which there is a severe property damage potential. TTC for this hazard is relatively moderate of about 2.8 s, while the potential collision zone is quite long as both vehicles converge and track along the same trajectory.

A2 (Cut-across Bike): A bicycle comes from the left side and then cuts across the street

A cyclist emerges from behind roadside landscape greenery and proceeds to cross the roadway ahead of the test vehicle. The hazard detection-response window is clocked from the time the cyclist clearly appears from behind the roadside greenery until the car comes to a complete stop, which works out to about 3.5 s. The intention of this scenario is to examine the response of participant towards a hazard that involves a vulnerable-unprotected road user, in which there is a potential loss of life or serious injury. This hazard has a moderate TTC of about 2.5 s and a medium collision zone (short lateral stretch across the travelled lane of test car).

A3 (Dropping Object): An object drops suddenly from an overhead pedestrian bridge

The test car drives towards an overhead pedestrian bridge when suddenly a sizable (but apparently light) object contained inside a plastic bag drops from the overhead bridge. The moment the bag is visible until the test car comes to a complete stop is defined as the hazard detection-response window, which lasts for about 2 s. This hazard has a relatively short TTC, about 1.8 s, and a small collision zone (i.e. a small spot). In terms of collision damage potential, this hazard can cause light property damage.

A4 (Roll-across Trolley): An unmanned trolley rolls across the path of test car

The test car drives down-slope into a car park, and a trolley suddenly appears from the left and cuts across the path of the test vehicle. The hazard detection-response window starts from the moment the trolley first appears on the video until the test car completely stops, which is about 2 s. This hazard's intent is to test the response of participants towards an

object hazard that moves across a horizontal trajectory in a very sudden manner. It has a short TTC (about 1.5 s) and a medium collision zone (i.e. short lateral stretch).

3.3.4 Procedures

On the day of the test, the participant reported to Transport and Geospatial Laboratory (TGS Lab) in NTU. Upon his arrival at TGS Lab, the participant was briefed about the experiment and its procedure. The participant was also asked to fill a questionnaire (see Appendix A) about his age, driving licence status and applicable frequency of driving. After that, the participant was asked to sit in the driving seat and the video was played and displayed on the monitor. The participant was instructed to observe and fully step on the brake pedal every time he detected a hazardous situation that he judged to require a braking response; herein, the test car would come to a stop just in front of collision zone in the simulation. The video footage contained several scenes of hazards, as described earlier.

The whole experiment was video-recorded (from the perspective of test subject), including the display of the driving scenes and the status of the LED bulb. The time interval from the abrupt hazard onset to the bulb lighting up (denoting the participant's braking response) is computed as the response latency (RL). Essentially, RL is defined as the time span between the onset of a hazard until participant initiates a response. This RL is used as the performance indicator for this experiment. The applied experimental procedures were pre-approved by the NTU Institutional Review Board on ethics issues before the commencement of the experiment series.

3.3.5 Data analysis

The analysis for this experiment focuses on the detection of hazardous situations. Response latency was chosen as the performance indicator. Response latency (RL) represents the time frame between the first appearance of a hazard on the screen until a response is registered by the participant, by stepping on the brake pedal. As mentioned before, a video camera recorded the whole experiment, including the scene and the LED bulb which indicates the response. From the recorded video, the time stamps when the hazardous object first appears and the response is registered were extracted. The time frame between these two timestamps is the RL. As all the hazards are abrupt hazard and instruction was given to the participant to detect hazards, the RL in this experiment can be considered as an abrupt RL. Figure 3.4 illustrates the response latency.

Figure 3.4 Illustration of abrupt response latency (RL)

3.4 Active mode driving assessment

As mentioned before, driving is a complex activity that involves different sub-activities in it. The passive mode driving assessment has its limitations since it could not fully represent the complexity of driving. The passive mode can only be used to obtain limited driving performance indicators. Therefore, the active mode driving assessment was conducted to better represent the complexity and more sub-activities in driving task. The important components in driving are vehicle control and interaction with other road users. Vehicle control performance, in this research, is referred as the ability of the driver to maintain the vehicle position, be it lateral and longitudinal, on a journey. Another important aspect of driving is to create a safe interaction with other road users. The most critical point in the interaction of road user is when he encounters a hazardous situation. Therefore, the ability to anticipate hazard and making a correct decision in order to avoid a collision caused by the hazard is an important driving performance. Those two components are examined in the active mode driving assessment.

3.4.1 Experimental design for active mode driving assessment

The experiment was divided into two parts: vehicle control assessment and hazard perception and anticipation. This is to represent two components in the practical driving test: circuit test (vehicle handling), and on-road test (road user interaction and road regulations). Therefore, one can assume that when someone has passed the test, he has an adequate vehicle handling skill and can safely interact with other road users. The vehicle control assessment was conducted along a virtual expressway segment, which replicates an actual expressway. The expressway segment consisted of two types of segment: straight segment

and horizontal curve segment. The performance in the overall journey was analysed first, followed by separate analyses for the straight segment and horizontal curve segment. The horizontal curve serves as the more challenging segment which might better discriminate the effect of driving inactivity. The performance components assessed on this part are speed control and lateral control.

In addition to the vehicle control assessment, driving assessment on active mode driving simulator included hazard anticipation and anticipation assessment on the second part of the experiment. This assessment examines the performance of the participant on the critical situation in the interaction with other road users. Hazard perception and anticipation are chosen as they represent the most critical situations of safe interaction with other road users, which form one of the test aspects in Singapore driving training and test. The experiment modified the hazard perception test, which is based on video record, into an active continuous simulated driving scene and with full vehicle control. Therefore, the participants have independent choices in responding to a critical situation. Previous study has shown the feasibility to use driving simulator, with active control, for hazard perception test (Underwood et al., 2011). The active setting of the driving simulator has been found to be better at representing the complexity of driving task and how it affects the visual behaviour compared to the passive setting, which is based on video record (Mackenzie & Harris, 2014, 2015). Table 3.3 shows the experimental design of the vehicle control performance assessment. Detailed explanations on the performance indicators are given on Section 3.4.7

Table 3.3 Experimental designs for the active control driving assessment

		Active driver	Freshly Trained	Inactive driver	No Licence	Performance component
Vehicle control performance	Straight segment situation	(A ₁)	(B ₁)	(B ₁ -)	(C ₁)	Percentage of Variance of lane position (VLP) and lane overrun (PLO)
	Horizontal curve segment	(A ₂)	(B ₂)	(B ₂ -)	(C ₂)	
Hazard perception and anticipation		(A ₃)	(B ₃)	(B ₃ -)	(C ₃)	Response latency (RL): Lag time, Time to fixation, PIEV time

The focus group of participants in this experiment were young drivers. However, as different from the passive stage, in this experiment, there were four groups. In the passive stage, the duration of inactivity on the inactive groups was very wide, from short-range inactivity (1-2 months) to more than six months. Drivers who were recently inactive may not experience the same amount of deterioration as drivers who were inactive for a long period. The level of competency of recently active drivers may be close to the level when they passed the driving test. Therefore, for the active stage, a new category called novice group (which include the freshly trained and recently inactive participants) were added to the categorisation. The cut-off point for novice and inactive groups is explained in subsequent chapters.

3.4.2 Test subjects

For this set of experiments, participants were recruited from Nanyang Technological University (NTU). As this research is mainly focused on young and inexperienced drivers, the age of the participants ranged from 20 – 30 years old. At first, the participants were categorised into two groups of 'Licensed' and 'No Licence'. Further analyses were then conducted to get a cut-off condition to further classify 'Licensed' group, based on their driving inactivity period, into active, novice and inactive groups. Table 3.4 shows the detailed description and criterion of each group.

A total of 132 participants were recruited for this study. One participant who reported experiencing a high level of simulator sickness at the end of the simulation run was excluded from the analysis which reduced the sample to 131 counts. The sample consisted of 96 driving licence holders and 35 non-drivers. They were recruited from among NTU students and staff. The age of the participants ranged from 20 to 30 years old. Participants with driving licence had a range of driving inactivity from 0 months (for active drivers) and up to 72 months (for non-active licensees) (mean = 9.6 months; SD = 17.7). This age group was rather suitable for this study on young drivers with limited on-road experience. The no-licence group consists of participants who do not have any valid driving licence and do not know how to drive. It serves as the baseline of driving performance in the absence of any training in order to examine whether skills level of inactive drivers will deteriorate to be no better than untrained level or not.

Table 3.4 Description of groups

Group	Criteria	Remarks
Licensed	The participant holds a valid Singapore driving licence	Further analysis conducted to sub-classify this group based on the driving experience and inactivity period
No licence	The participant does not possess any valid driving licence in Singapore or elsewhere	

Each participant was required to finish the full driving run and obtained honorarium as a token of appreciation for his participation. The participants' data were anonymised using code according to their group to keep their identity confidential.

3.4.3 Apparatus

This study was conducted using the driving simulator at NTU Transport and Geospatial Laboratory (TGS Lab) (see Figure 3.5). The simulator is a fixed-base driving simulator. It has a simple frame for an adjustable driver seat, steering wheel, and pedals but does not have a motion base.

The earlier generation of the driving simulator, which was used in passive stage, had its limitations such as no control over vehicle movement. Very limited types of experiment could be done and very limited data could be obtained from it. Therefore, a new generation of the driving simulator was developed as an advancement from the earlier generation. The present driving simulator setup allows the participant to have an independent control of the vehicle movement, including direction and speed (active mode). A virtual environment of the test road network was built using *UC-Win/Road version 11.01 Driving Sim*. The surrounding environment is displayed through three 46-inch LED monitors which are placed around the driver seat. Black cloth is used to fence in the driving simulator, to avoid distractions from outside the simulator. Logitech G27 was used as the control input, steering wheel and pedals, of the simulator which was connected to the vehicle control function on the UC-Win/Road. Improvements were also done on the hardware of the driving simulator to support smoother rendering of the virtual environment. Table 3.5 shows the specifications of the driving simulator hardware

Figure 3.5 Driving simulator setup

Table 3.5 Hardware specifications of the driving simulator

Component	Specification
CPU	Intel® Core™ i7-6700 (8MB cache, 3.4 GHz)
Graphics Card	NVIDIA GTX 1080
RAM	16 GB DDR4 2133Mhz (8GB x 2)
SSD	128 GB
HDD	1 TB
OS	Windows 7 64-bit
Display	3 x Samsung 46-inch LED TV
Sound	Logitech Z906 5.1 speaker system
Steering wheel	Logitech G27 Racing Wheel
Driving simulator frame	RSeat RS1 with modified seat

SensoMotoric Instrument (SMI) eye tracking glasses (ETG) was used to collect the eye behaviour data of the participants, such as gaze position, pupil diameter, fixation, and blink duration. SMI-ETG is a portable eye tracking equipment, which is equipped with an eyewear and a mobile phone as the recording device. Snap-on corrective lenses are available for participants with corrected eyesight, from -4.5 to +4.5. Figure 3.6 (a) and (b) show the SMI-ETG with and without corrective lenses.

Figure 3.6 SMI-ETG eyewear: (a) SMI-ETG normal glasses and (b) SMI-ETG with snap-on corrective lenses

Three cameras are attached to the SMI-ETG in which one camera (front camera) captures the forward scene that participant looks at, and the other two capture the eye of the participant (one for each eye). The SMI-ETG uses binocular with automatic parallax compensation and dark pupil tracking as its eye tracking technique. Six infra-red lights are beamed from the eyewear into each participant's cornea which will produce reflection (shown as six white dots) around the pupil, called corneal reflection (CR). Figure 3.7 shows the eye image that is captured by the SMI-ETG with the CR dots around the pupil. The CR and pupil move as the participant's gaze moves. The SMI-ETG system detects the position of the pupil and CR and then uses the information to determine the gaze position. Then, the gaze position will be overlaid into the forward scene that is recorded by the front camera. The SMI-ETG records the data in the form of '.txt' file as well as video record. The video record contains the video of the scene and super-imposed gaze cursor. All the data recorded through the SMI-ETG were extracted using SMI's *BeGaze Qualitative Analysis Software*.

Figure 3.7 Eye image with six CR dots and pupil detection

3.4.4 Questionnaire

To gain a better understanding of the participant's profile, including demography, activities and fatigue level, a questionnaire was administered to each participant before the driving adaptation session in the experiment. The questionnaire was designed with three parts: participant's background information, participant's daily activities and participant's subjective fatigue rating.

In the first part, data related to demography, such as age, gender and driving licensing were asked. To indicate the driver's experience, not only data about years of experience and driving licence possession were asked, but also the frequency of the driving activities. The questions about his daily activities and subjective fatigue rating were aimed at capturing the participant's condition when he participated in the experiment. Fatigue is one factor that can affect a person's driving performance. Therefore, to minimise the effect of fatigue in this experiment, the subjective fatigue ratings were used to pre-check the pre-experiment condition of the participant. It was to make sure that all participants were in the acceptable level of fatigue. USAFSAM and Piper fatigue scales were used as the subjective fatigue ratings in this experiment.

A post-experiment questionnaire was administered to capture the participant's experience during the simulation. It included simulator sickness questionnaire (Bouchard et al., 2007; Kennedy et al., 1993), to assess the level of simulator sickness of the participants. The simulator sickness score may serve as a filter for data analysis, where participant with severe simulator sickness would be excluded from the analysis. The questionnaire also included several questions related to the experience of the driver who encountered various hazards during the driving sessions. The results are used for an in-depth analysis on how the participants think about the hazard and what things might influence their decision-making. The questionnaire also covered the participant's perception of his experience during the experiment on the driving simulator, such as difficulty on adaptation to the simulator setup, simulator sickness experience and whether the simulator sickness affected his driving during the simulation. This set of questions as related to the driving simulator experience was used as a reference in case any anomaly data were found during the analyses. The full set of the questionnaire is attached in Appendix B.

3.4.5 Procedures

The participant reported to Transport and Geospatial Laboratory (TGS Lab) in NTU. Upon participant's arrival, he was given a short briefing about the experiment. The participant needed to read through the consent form and sign on it for an agreement to participate in the experiment. The participant filled the questionnaire which included a subjective fatigue scale. After that, the participant wore the eye tracker. Necessary adjustments and calibration were made after the participant was seated on the driver seat.

Before proceeding to the first session of the driving simulation, the participant went through the adaptation run to familiarise with the driving simulator setup including vehicle control setup and the display. The adaptation session lasted for about 5 - 7 minutes. The participant was given a 5-minute rest period between the end of adaptation and the start of the first session.

After re-checking the eye tracker calibration, the first session was started. As described before, in the first session the participant drove on an expressway environment without any planted hazard. The participant was instructed to keep driving in the middle lane without changing his lane position. A 15-minute rest period was given to the participant after the first session. The second session was commenced after rechecking the eye tracker calibration. For the second session, the participant drove along an urban road network with several planted hazards. The second session was related to the assessment of the other component of driving performance which is safe interaction with other road users, specifically hazard perception and anticipation. More detailed explanation on the scenarios is provided in Section 3.4.6.

For all the driving simulation sessions, including the adaptation, navigational messages were given to guide the participant. The participant was asked to follow the posted speed limit and traffic rule. The participant might choose to withdraw from the experiment at any time without penalty. Upon the completion of the second session, the participant was asked to fill the post-experiment questionnaire and the simulator sickness questionnaire (SSQ). After the participant completed the post-experiment questionnaire, he was asked to stay and rest in the lab for about 30 minutes. This holding period is to make sure that the participant recovered from any effect of simulator sickness before he continued his activities. Figure 3.8 shows the overall procedures of the experiment.

Figure 3.8 Active control driving assessment procedure

3.4.6 Test scenarios

The important factor of the driving assessment is the development of test scenarios. The test scenarios need to be able to objectively assess the component of driving performance. Each test scenario consists of a set of tests in a continuous driving task.

As mentioned before, the main test scenario was laid out on an expressway segment, which included a straight segment and a horizontal curve segment. An adaptation session was conducted before the main test scenario, in order to allow the participants to be familiar with the setup. Using the feature in UC-Win/Road, test scenarios were thus developed to accommodate this set of indicators in the simulated driving.

Driving performance data, such as speed control and lateral control, were measured and recorded during the driving assessment using the data logger function from the driving simulator software.

3.4.6.1 Adaptation to driving simulator

Driving on a driving simulator might give a different feeling from driving a real vehicle, which includes differences in visual experience, motion and vehicle control. Adaptation becomes an important part of an experiment when using a driving simulator. Participants may need some

periods of time to adapt to the driving simulator environment and control. Several studies have been done in relation to driving simulator adaptation.

There are several components of the driving simulator that participants need to adapt with, which include visual and motion sensation as well as vehicle control. Visual and motion sensations relate to the ability to overcome simulator sickness. On the other hand, the adaptation of vehicle control parts affects the ability of the participant to control the vehicle as if he drives on a real vehicle. That can affect the driving performance on a driving simulator. In this research, the adaptation session mainly focused on the vehicle control. There are two main components that were considered: steering wheel handling and pedal control. Sahami and Sayed (2013) also suggested that adaptation session should provide participants with chances to practise driving and steering control since these will affect their driving performance in the driving simulator.

For the two components of steering wheel handling and pedal control, offset of lane position and speed variability were used as the performance indicators that indicate the adaptation level of the participants. Lane position was used as the indicator as it relates to the control of steering wheel to keep the vehicle on the stabilised position. Pedal control was represented by the speed variability.

McGehee et al. (2004) conducted a study to assess the time required for a driver to adapt to a driving simulator. They used steering behaviour as the indicator for the adaptation and they found that the steering behaviour is stabilised within the first 240 seconds. Sahami and Sayed (2010, 2013) used number of practice runs instead of period of time to indicate how long it takes for the participants to adapt in driving simulator. The adapted participants adapted to the task after an average of 8.5 trials.

Sahami and Sayed (2013) suggested that participant's adaptation is largely task-independent, which means that the task in adaptation session may not need to be exactly the same with the main session task. The important consideration in the development of adaptation protocol is to give chance to participants to practise the vehicle control skills: pedals and steering control. The same study also suggested that the residual effect of adaptation session can be brought to the main experiment. It means that when one focuses on one particular control component, the learning for that particular component shall continue into the main session. This might cause bias in the driving performance, since that particular

part may be more adapted than other components. Therefore, the instruction given to participants cannot be too specific to a certain component. A general instruction is preferable to let participants adapt to all relevant control components.

The choice of route of adaptation session also should be a consideration. Ronen and Yair (2012) investigated the effect of different complexity of road and adaptation requirements. They found that roads with different complexity required different periods of adaptation, with more complex road needing a longer adaptation period. Thus, a simple straight highway may not be suitable as the adaptation route if a more complex road is used in the main experiment. It may take an additional time for the participants to adapt to a more complex road environment.

The adaptation scenarios were developed by taking into consideration the findings from previous studies. Therefore, for this research, a route with a similar complexity of road environment was chosen for adaptation with the route that was used in the main experiment. In order to avoid familiarisation effect, a different route was chosen for the adaptation session. The route included a straight segment, curve segment and junction, to allow the participant to adapt to turning manoeuvre and braking. The adaptation lasted for about 5 – 7 minutes for each participant.

3.4.6.2 Vehicle control performance

The main scenario involved driving on an expressway, without any hazard along the test segment. This session also focused on collecting data related to vehicle control performance: speed control and lateral control. In order to capture the participant's performance on lateral control, the participant needed to drive on a road test that allowed him to maintain a speed over quite a long period and with minimum turning manoeuvre. Therefore, an expressway environment was chosen since it provided a road section with constant speed limit without any need for stop-and-go movement or turning manoeuvre.

In this scenario, the participant was asked to drive along the expressway and was informed about the posted speed limit, 80 km/hour, before he started to drive. The speeding warning was turned off for this scenario, to give the participant freedom to control on his speed choice without any guidance from the warning message. It also simulated a more realistic driving condition since in the real life there is no warning when a driver violates the speed limit. There is no leading vehicle positioned in front of the test vehicle, thus allowing the participant

to choose his own speed without influence from a front vehicle. Figure 3.9 shows the starting scene of the assessment of vehicle control performance.

Since in this research, the lateral control analyses did not include any lane changing process, each participant was instructed to keep driving within the lane where he started off. The participant was not allowed to change his lane position and he had to maintain his position within the lane where he drove from the beginning until the end. The participant was asked to drive in the middle lane. The middle lane was chosen to avoid other effects such as heavy vehicle movement, merging and diverging traffic from entrance and exit of the expressway on speed and lateral control. Middle lane also gives more freedom in terms of lateral control since there is no restriction from road kerb and median. The traffic was kept on the low end so that the test vehicle would not be following any front vehicle nor be tracking alongside another vehicle on the adjacent lane(s). In this way, the movement of the test vehicle was not hampered by vehicles in the vicinity which could otherwise constrain the pace and manoeuvre of the test vehicle.

As have been mentioned, the scenario was focused on data collection related to vehicle control performance, specifically lateral control. In the calculation, the first 30 seconds of the data were excluded since there would be some re-adaptation at start-up. Lane encroachment and variance of lateral position were used as the performance indicators. Further details about these performance indicators and their analyses are explained in Section 3.4.7. Table 3.6 shows the performance indicators for the normal driving scenario. The further explanations of the performance indicators can be found on Section 3.2.7.

Figure 3.9 Starting scene of the vehicle control assessment scenario

Table 3.6 Performance indicators for vehicle control assessment

Performance component	Performance indicator
Lateral control	Centrality index
	Percentage of Lane Overrun
	Variance of Lateral Position (left and right)

3.4.6.3 Hazard perception and anticipation

The hazard perception and anticipation assessment involved the interaction between test vehicle and several planted hazards along the test route. The test scenario focused more on hazard handling ability of the participants, which is a critical issue on the interaction between road users. Urban road network including local and collector roads was chosen as the test route since it provides more interaction opportunities with other road users thus is possible to create more planted hazards along the road. This scenario adopted the hazard perception test concept continuous driving scene and full vehicle control.

The planted hazards vary from hazard involving vulnerable road user to a merging heavy vehicle. The hazards chosen in this assessment are common events on everyday driving. These planted hazards represent the different severity of hazard for both the test subject himself and the road user involved. The hazards also involved different complexity on the decision-making process. Figure 3.10 shows the planted hazards along the test route and Table 3.7 summarises the characteristics of the hazards. A speed limit warning was implemented for this scenario. It is to make sure that the participant drives within the speed that the planted hazard was designed for so that the hazard appearance is in-step with the vehicle movement. The descriptions of each hazard are provided below.

Hazard 1 (Pedestrian at zebra crossing): A pedestrian crosses the slip road at zebra crossing

When the test vehicle enters a slip road, a pedestrian approaches and crosses the road at the zebra crossing in front of the test vehicle. It represents a situation where the driver is expected to slow down whenever approaching a zebra crossing, thereby easing the abruptness of the hazard situation. The complexity of decision-making is expected to be the lowest since the driver is only left with one clear choice which is to stop the vehicle.

Table 3.7 Hazard characteristics for active mode

Hazard	Avoidance potential components			Avoidance potential	Collision damage potential
	Time to collision	Collision zone	Avoidance option		
Hazard 1 (Pedestrian Crossing)	Long	A stretch (1 lane)	Braking	Moderate	Fatality
Hazard 2 (Pedestrian Jaywalking)	Moderate	A stretch (3 lanes)	Braking, swerving	Moderate	Fatality
Hazard 3 (Merging Lorry)	Short	A stretch (2 lanes)	Braking, Swerving	Difficult	Severe property damage
Hazard 4 (Cut-across Car)	Short	A stretch (3 lanes)	Braking, swerving	Difficult	Severe property damage

Figure 3.10 Different type of planted hazards along the second scenario

Hazard 2 (Pedestrian jaywalks): A pedestrian jaywalks across the road ahead of the test car

As the test vehicle drives through a major road, a child visible at the edge of the pedestrian path starts to jaywalk across the road ahead of the test car. The jaywalking is a more unexpected situation than the first hazard. Since it is a multi-lane road, the participant has more options to avoid the collision with the pedestrian, i.e. braking or swerving. It adds more complexity on the decision-making for this hazardous situation.

Hazard 3 (Merging lorry): A lorry comes from the left and merges with the path of the test car

At the expressway, a lorry comes from a side road at the left of the test car and merges into the path of the test car. It involves a heavy vehicle which is less vulnerable than the first two hazards but might have a more severe impact in case of a collision as compared to the other hazards. The hazardous situation takes place on a two-lane road, which adds-in to the complexity of the decision-making process.

Hazard 4 (Cut-across car): A car comes from the left side and turns right

When the test car approaches a junction at an arterial road, a car comes from the minor road at the left and then makes a right turn crossing the path of the test car. It involves a light vehicle, which bears less severe impact in case of a collision. However, the hazard takes place at a junction of a multi-lane road, which creates a more complex decision-making consideration.

3.4.7 Data analyses

3.4.7.1 Data analysis for vehicle control performance

Lateral control is referred as the ability of the driver to maintain the vehicle lateral position on the road within the specific safe boundary. Lateral control is an important factor in driving as it affects the safe interaction with other adjacent vehicles on the road, especially motorcycles. Inability to control the lateral position of the vehicle can result in greater lane wandering and lane encroachment. That condition could be dangerous as it increases the risk of a side-swipe collision.

The main performance indicator for lateral control in this research is Centrality Index (CI). Centrality Index is a dimensionless measure that describes the central positioning of a vehicle with given a wheel span (VW) across the width between two specified boundaries (TW) (Stimpson et al., 1977; Wong, 1989). Since the participant was asked to maintain his lateral position to be within the lane where he started his journey, the boundaries were defined as the delineation lines of the starting lane. The centreline along the journey was also harmonised to be the centreline of the starting lane. For this research, the CI formula from Wong (1989) (see Equation 2.2) was modified to handle the collected data in this project. Since the test subjects used a same car for the entire experiment, the vehicle wheel

span (VW) is constant for all experiments, which is 1.94 m. The lane width (TW) of the whole journey of the experiment is also constant at 3.70 m

The UC-Win/Road data logger records the data of the offset distance (X) of the vehicle's centreline (CL_{car}) from the centreline of the travelled lane (CL_{lane}). Herein, the lane's centreline is located mid-distant astride the dashed lane delineation lines. The sampling is done at every 0.10-second. Based on available data, the CI equation can be re-written as:

$$CI = -\frac{2X}{TW} \quad \text{Equation 3.1}$$

The X value is referred as the distance from the centreline of the vehicle to the centreline of the starting lane. TW is the width of the driving lane which is uniform throughout the journey. Wong (1989) introduced a pair of boundary values of CI, +1 and -1, which represents the value when the centreline of the vehicle goes beyond the left and right boundaries respectively. In this research, since the width of vehicle and lane was uniform for all of the participants, a pair of intermediate value was introduced. An intermediate value of +0.48 indicates the moment the test vehicle touches the left or right delineation line and starts to encroach the other lane. Figure 3.11 illustrates the centrality index (CI) which shows the boundary and intermediate values of CI.

Figure 3.11 Illustration of the centrality index (CI)

Two other lateral control parameters were derived from the calculated CI. The first parameter is variance of lateral position (VLP) which is related to lane wandering tendency. VLP was calculated based on the variance of CI that was measured at regular points along the journey (see Equation 3.2). A larger variance in the CI means that position of the vehicle had varied greatly along the journey and would denote erratic (unstable) lateral control. The lane wandering tendency is an important factor as it conveys the ability of the driver to control his vehicle to a stable lateral position trajectory within the confines of the lane. An unstable control in the lateral position can lead to the vehicle encroaching into an adjacent lane which would increase the risk of sideswipe with other vehicles, especially motorcycles.

$$VLP = \frac{1}{n} \sum_{i=1}^n (CI_i - \overline{CI})^2 \quad \text{Equation 3.2}$$

The second parameter is percentage of lane overrun (PLO). PLO represents the tendency of the test vehicle to encroach onto the adjacent lane. It was calculated as the time proportion of the journey in which parts of the test vehicle encroached onto the adjacent lane (JT_{encroach}) to the total journey time (JT_{total}) (see Equation 3.3). Lane encroachment is an important parameter in lateral control, as an abrupt and unintentional lane encroachment may disrupt traffic flow movements on the adjacent lane and thus increases the risk of sideswipe with other vehicles on the adjacent lane.

$$PLO = \frac{JT_{\text{encroach}}}{JT_{\text{total}}} \times 100\% \quad \text{Equation 3.3}$$

3.4.7.2 Data analysis for hazard perception and anticipation

The assessment performance indicators for hazard perception are different from those for vehicle control. In this assessment, the main focus was on hazard perception and anticipation ability, and the performance indicators are related to such ability. Response latency was chosen as the performance indicator. Response latency represents the ability of the participant to quickly recognise and respond to a hazard. However, the response latency in this stage would be slightly different from the abrupt response latency on the passive mode driving assessment. The action in passive mode was very straight forward, in which participant only needs to step on the brake pedal upon detection of a hazard. On the active mode, the participants were given full freedom to control the vehicle, and they could employ different actions to avoid collision with the hazard. Therefore, the participants need to decide

by themselves what action to take to avoid a collision. The response latency would be a result from an interactive and dynamic interaction between the participant in the test car and the hazardous object. In order to differentiate the response latency from the one used in the passive mode driving assessment, it will be referred as interactive response latency (IRL) from here on.

Reaction time or response latency has been used as a performance indicator in many previous studies on driving. Response latency (referred in this stage as interactive response latency) is usually calculated as a time interval from the time that the stimulus first appears on the screen to the time the subject reacts to the stimulus. Yeung and Wong (2015) decomposed response latency into two components: time-to-first-fixation (TFF) and reaction time (RT). The present research adopted and modified the components, TFF and RT, to analyse the RL. In this research, the TFF component was further decomposed into two components of lag time (LT) and time to fixation (TF), and categorised as detection components of IRL. LT represents the delay that transpires till the eye starts to move towards the hazard. It is referenced from the time the object first appears on the screen (for abrupt hazard) or the hazardous situation materialises (for gradual hazard) until the fixation point starts to move towards the direction of the object to then fixate on the object and thereafter follows the object's movement. TF is defined as the time needed to move the fixation point to the targeted object. It is referenced from the time the fixation point starts to move towards the direction of the supposedly hazardous object until the eye fixates onto the object and thereafter continues to follow the object. Using eye tracking equipment, the eye movement and fixation can be recorded. The second component of IRL is the reaction components, or also referred as PIEV time. PIEV stands for perception, intellection, emotion and volition. PIEV is a theory that is widely used in highway engineering to describe that perception and reaction process of a driver. It explains that the perception-reaction time can be broken down into these four components. In this research, PIEV time is defined as the period between the first fixation on the hazardous object and the moment the participant steps on the brake which reflects how fast the subject reacts to the stimulus. During the PIEV time, a driver goes through a process that includes looking at the object, understanding the implication, making a decision, and applying the decision into action. The two components of detection and reaction components form the total response time that is called interactive

response latency (IRL). Figure 3.12 shows the breakdown of the response latency components.

Figure 3.12 Components of interactive response latency (IRL)

3.5 Summary

This research aims to examine the effect of duration of driving inactivity on driving skills. The assessment was divided into two parts: passive mode and active mode. In the passive mode, the participant did not have any control over the vehicle. The main objective is to assess the hazard perception of each group of subjects. Meanwhile, for active mode, the participant has a full control over the vehicle. In the active mode, driving performance was assessed using two components: vehicle control performance, and hazard perception and anticipation. Vehicle control performance refers to the ability to safely control the vehicle on the road. Several performance indicators from two performance components, lateral control and speed control, were used to assess this driving component. In the vehicle control assessment, the participants were asked to drive along an expressway while maintaining their speed to not exceed the speed limit as well as maintaining their lateral position. The other component in the assessment is hazard perception and anticipation, which is a critical point in interaction with other road users. In hazard perception and anticipation assessment, response latency is used as the performance indicator. This assessment is a combination of the hazard perception and hazard anticipation since the participant has a full control over the action to avoid collision with hazardous objects.

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Chapter 4 Passive mode driving assessment

4.1 Overview

This Chapter covers the preliminary experiment in this research using the passive mode driving simulator. A hazard perception test was conducted in this setting. The passive mode response time experiment served as the initial and preliminary work on hazard perception components of this study. In the analysis, the response latency (RL) values from the three groups are compared. Then, findings on the effect of training and inactivity are discussed. Lastly, a summary is drawn from it, including the improvement that can be done for the later stage. The raw data from the experiment are attached in Appendix C.

4.2 Results

The time sequence of the video-recorded response was extracted to obtain the RL of all hazards for each participant. As noted earlier, RL was calculated from the time stamp when the hazard first appears abruptly on the screen to the point that the LED bulb lights up, indicating the participant's response. Video processing software, *Avidemux 2.6*, was used to extract the abrupt RL data from the video records to the nearest frame at 0.04s resolution. Table 4.1 shows the summary statistics of the results of the experiment, while Figure 4.1 shows the average values and the associated standard error.

Figure 4.1 Response latency (RL) with standard error

Table 4.1 Summary statistics of the result of experiment (Response Latency)

Hazard	Subject Group	Count	Average RL (s)	Variance
A1	Active	14	0.849	0.102
	Inactive	10	1.367	0.293
	No Licence	14	1.179	0.358
A2	Active	14	1.183	0.072
	Inactive	10	1.336	0.225
	No Licence	14	1.162	0.143
A3	Active	14	1.121	0.096
	Inactive	10	1.113	0.056
	No Licence	14	1.160	0.086
A4	Active	14	0.712	0.058
	Inactive	10	0.829	0.087
	No Licence	14	0.929	0.141

The result shows that active group participants, on the average, performed better (that is, by responding faster) than the inactive group for most hazards. It is indicated by the smaller average RL values of this group of participants which varies between 0.712 to 1.183 seconds (s). Meanwhile, the average RL values straddle between 0.829 - 1.367 s. As for participants without driving licence (no licence group), the average RL values straddle around 0.929 - 1.179 s. Statistical analysis was carried out using *Rstudio 1.0.136* to examine if there are underlying differences between the three groups in each hazard. The results show significant differences at 10% significance level across the three groups for one hazard - A1– but not for other hazards. In Abrupt 1, the RL values of the active group were much shorter than the two other groups, particularly between active and inactive groups which are significant at 10%. Table 4.2 shows the result of the statistical test between groups within each hazard.

Table 4.2 Result of Statistical test between groups within each hazard

Hazard	Homogeneity test	ANOVA		Welch ANOVA ^a		Post-hoc	Games-Howell ^b p-value
	p-value	F value	p-value	F value	p-value		
A1	0.028	3.408	0.044	4.329	0.028	Active<Inactive	0.040
A2	0.466	0.726	0.491				
A3	0.807	0.100	0.905				
A4	0.437	1.719	0.194				

^a only displayed when variances were not equal

^b Games-Howell used when variances were not equal

Besides comparison between groups within each hazard, a statistical analysis was also conducted to examine the underlying differences across hazards within each group. The hazards in this study, as described in Table 3.2, are characterised by collision damage potential, and collision avoidance potential. The results of ANOVA indicate a significant effect of the types (hence characteristics) of hazard particularly for active group and, to some extent, inactive group but not for the no licence group. This suggests that for the trained groups, their response to the hazards is influenced by the characteristics of the hazard, though their effects are more pervasive for the active than inactive groups. Table 4.3 shows the results of the statistical tests between hazards within each group.

Table 4.3 Result of statistical test between types of hazards

Group	Homogeneity test	ANOVA		Welch ANOVA ^a		Post-hoc	Tukey HSD	Games-Howell ^b
	p-value	F value	p-value	F value	p-value		p-value	p-value
Active	0.908	8.481	0.000			A1<A2	0.017	
						A1<A3	0.070	
						A2>A4	0.000	
						A3>A4	0.002	
Inactive	0.082	4.101	0.013	4.1037	0.021	A1>A4	0.016	0.070
						A2>A4	0.030	0.050
No Licence	0.014	1.093	0.360	1.302	0.293			

^a only displayed when variances were not equal

^b Games-Howell used when variances were not equal

The post-hoc test results show those pairs of hazards that have significant differences. Figure 4.2 illustrates the relationship between avoidance likelihood, damage potential and the response latency. The bigger circle indicates more severe collision damage potential. From the illustrations, we can group those into two categories: avoidable-but-severe hazard and unavoidable-but-light hazard.

As can be seen in Figure 4.2 no licence and inactive groups behave in a similar pattern between the two hazard categories. Both groups are able to differentiate their response for hazards within unavoidable-but-light consequences hazard group. One can readily note that RL for hazard A3 is noticeably higher than hazard A4 for all groups. However, the difference

in RL between hazards A3 and A4 is more distinct for the active, follows by the inactive and then the no licence group. In other words, active drivers are able to respond faster to hazard A4 (Roll-across Trolley), which is not an uncommon hazard as compared to hazard A3 (Dropping Object). The faster RL could be partly explained by on-road experience gained for active drivers. Also, the slower response to hazard A3 might due to the fact that a plastic bag is seen as a lighter consequence than that of a trolley as in hazard A4.

Figure 4.2 Comparison of response latency values (in seconds)

On the other hand, both inactive and no licence groups cannot differentiate the response to hazards within avoidable but severe consequence hazards. That is, the RL of hazards A1 (Merging Car) and A2 (Cut-across Bike) for inactive and no licence groups fall into a similar range, however, there is a distinctive difference in RL between these 2 hazards for the active group. With the merging car conflict of A1, it is not unexpected that active drivers would react faster to avoid such a collision as compared to a crossing bicycle conflict of A2. Hazard A1 is a more common incident in everyday driving. In addition, having limited self-damage potential on the test car may have somewhat influenced the RL. The participant may perceive A1 to be higher risk than A2. It is in line with the previous study by Armsby et al. (1989), in which they show that the fast moving vehicle (i.e. car) is perceived to be riskier than vulnerable road user (i.e. pedestrian). It indicates that active group is able to discern the detailed characteristics of a hazard even if it belongs to the same group of hazard characteristics. Some small differences could affect the risk perception thus their RL.

4.3 Discussion

4.3.1 Effect of driving training

Comparison of performance of active/inactive (trained) groups with no licence (untrained) group serves to provide an indication of the effect of training. The active group shows consistently faster response than no licence group; furthermore, the active group is more discriminating in the response celerity against various hazards. This shows the value-add of the training at licensure that is further reinforced through on-road driving. In contrast, the inactive group, though trained-at-licensure to drive, is somewhat better than no licence group for unavoidable-but-light hazards but may be no better or be worse off for avoidable-but-severe hazards.

4.3.2 Effect of driving inactivity

The active group generally has a better performance on hazard detection than the inactive group, particularly for common incidents like hazard A1 (Merging Car). The active group has exposure to real road driving environment, and they are experienced to make a fast and correct decision. These results show the negative effect of driving inactivity (since licensure) or alternatively, the benefit of post-licensure on-road experience on hazard detection. Previous studies - from anti-submarine operator to electrician - surmised that there is a moderate rate of decay due to inactivity after learning the cognitive skills which are related to decision skills (Semb & Ellis, 1994; Wisher et al., 1999). Wisher et al. (1999) pointed out, in the case of military personnel, soldiers who spend more time on active duty have greater opportunities to practice their skills, which leads to the experience of over-learning that enhances resistance against forgetting.

The effect of persistent training may also be applied to driving skills - the more a driver spends his time driving on the road, the stronger is the retention of the driving skills. Therefore, for a common incident like hazard A1 (Merging Car), the active driver can react much faster than the inactive driver, because the active driver experiences it often in everyday driving. Indeed, the active group is able to discern the different risk levels against each hazard. On the other hand, the inactive group has lesser ability to differentiate the hazards, while no licence group is least discriminative. This is in line with the study by Benda and Hoyos (1983) who showed that novice drivers perceive all situations that share certain characteristics as the same risk level, while experienced drivers perceive situations based on

multiple characteristics and consider hazardousness as holistic attributes. This shall apply to drivers who, upon licensure, never have on-road driving experience. Findings from previous research on novice and experienced drivers found that experiences do affect driver's hazard anticipation/identification strategy and perception towards risk (Borowsky, 2006; Sagberg & Bjornskau, 2006). This study shows that such concept can also be applied in the case of inactive and active drivers. Active drivers are able to combine available information in their hazard identification process which leads to the ability to differentiate risk level within same hazard categories, while the inactive group is unable to differentiate them.

4.4 Summary

This research investigated the effect of the training and driving inactivity on the driving performance, specifically on hazard perception. Overall, active drivers indicate better performance on hazard detection by responding faster to the hazards than inactive and no licence subjects. The results also suggest that training contributes to the development of hazard perception and strategy on the decision-making process. Meanwhile, the abrupt response latency (RL) of trained groups (active and inactive groups) are influenced by the characteristics of hazards (i.e. damage potential and avoidance potential), although the influence is different between inactive and active drivers. Active drivers are better able to discern the characteristics across all hazard situations, in perceiving its risk level, and less so for inactive drivers, and least for no licence subjects. The results support the argument that lack of on-road driving experience affects the hazard identification strategy and perception of risk. The results also suggest that post-licensing driving exposure is needed not only to retain but also to improve and enhance the hazard perception. With regular practice, the skills can be strongly retained and shall last longer as well.

The experiment was conducted in passive settings, where the participant did not have any control over the vehicle. It came with some limitations. The main task is solely the hazard detection. It may not fully replicate the complexity of driving task, which may affect the hazard identification and decision-making process. Other than that, with the passive setting, only some information could be obtained. Therefore, for the next stage, an active mode driving simulator is used, so that the complexity of driving task could be better replicated. The results also showed that more discriminative result found for the more common hazards. Therefore, in the subsequent experiment, in order to demonstrate a more discriminative

result of the effect of experience and inactivity, the hazardous situations are carefully chosen to represent the common events of everyday driving.

In this experiment, the participants were divided into three groups: active, inactive and no licence. However, the range of inactivity on the inactive groups is very wide, spanning from recent inactivity (1-2 months) to more than six months. The range of inactivity period could affect their performance which also affects the average value and variability of the response latency. Drivers who are only recently inactive may not experience the same amount of deterioration as drivers who are inactive for a longer period. Recently inactive drivers' level of competency may be close to the level as when they just passed the driving test. Therefore, for the subsequent stage, a finer categorisation will be used which includes an additional category of the novice group which represents the freshly trained drivers. The cut-off point for novice and inactive groups is explained in the following chapter.

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Chapter 5 Active mode driving assessment: Vehicle control skills

5.1 Overview

This Chapter covers the presentation and analysis of the data and results of the experiment on vehicle control performance. For this second phase of the study, an active mode driving assessment was conducted. A part of it is an assessment of vehicle control performance. Vehicle control assessment was conducted on a virtual expressway network which includes straight and horizontal curve segments. First, the result of overall vehicle control performance along the journey was analysed. In the second part, the result was differentiated into two segments namely, straight segment and horizontal curve segment. The compiled raw data of the experiment are attached in Appendix C. After that, the findings on the effect of training, experience and inactivity are discussed and summarised at the end of this Chapter.

5.2 Vehicle control performance on overall journey

Various driving performance data were measured and recorded along the journey on the test route using data logger function of the driving simulator. As mentioned before, the test route was an expressway, for about ± 6 km length, which included straight and horizontal curve segments. Along the journey, each participant was asked to keep on his initial lane and to drive within the speed limit of 80 km/h.

In the assessment of vehicle control performance, the main focus of the analysis is on the lateral control. Centrality index (CI) is used as the parameter that represents the centrality tendency of the test vehicle. The CI indicates the position of the vehicle with reference to the centreline of the test vehicle and the centre of the lane. As mentioned in the previous chapter, based on the lane width of the test road and the width of the test vehicle, a pair of intermediate CI values were calculated. The intermediate values of ± 0.48 represent the state when the side of the vehicle crosses the left or right boundaries. It means that if the CI value is between -0.48 to $+0.48$, the test vehicle is fully within the lane boundaries. The boundaries are set with reference to the delineation line of the test lane.

Data related to the lateral position of the test vehicle relative to the centre of the lane were collected at 0.10 seconds interval. The data were then used to calculate the CI of each point using Equation 3.1. Each participant would produce an average CI value and the associated

variance. Figure 5.1 shows the CI values of all participants with error bars represent the two standard deviations. The orange and green lines represent the right and left boundaries. The average operating speed values of the participants are shown as red dots. Note that the horizontal axis is not numerated, with each vertical intersecting line occupied by a participant's values.

Figure 5.1 Average centrality index (CI) and speed of all of participants

From CI, other parameters can be further derived. The first parameter is variance of lateral position (VLP) which is related to lane wandering tendency. While average CI value will only reveal the tendency of the overall position of the test vehicle, the variance of the lateral position represents whether the tendency of the test vehicle to wandering behaviour along the journey. VLP was calculated based on the CI values that were calculated every 0.10 seconds interval along the journey. The bigger the value of the variance of CI, the more variable the lateral position of the vehicle along the journey which means that the test vehicle was wandering a lot. The lane wandering tendency is an important factor as it shows the ability of the driver to control his vehicle along a stable lateral position. An unstable control of lateral position may cause the vehicle to overrun to another lane and increases the risk of side contact with adjacent vehicles, especially motorcycles which often ride in-between the lanes.

The VLP was calculated from the CI data points collected for each participant that represents the position of the vehicle on the road. Therefore, each participant's data produce one value of VLP. Figure 5.2 shows the average variance of lateral position across the different durations of inactivity. As shown in Figure 5.2, there is a jump of the VLP for the duration of inactivity more than three months. It suggests that beyond three months of inactivity, the skills of lane wandering control start to deteriorate as indicated by higher VLP value along the test route. However, although the skills had deteriorated, it is still much better than the baseline value of the no licence group who have not receive any prior driving training.

Figure 5.2 Average variance of lateral position versus duration of inactivity

As mentioned in the previous chapter, there is an additional group called novice group in-between the active and inactive groups. This novice group include drivers who became inactive for a shorter period than the inactive group. In essence, this group represents the level of competency of freshly trained drivers. A cut-off point is needed to separate novice group and inactive group. Based on above finding, one can set a cut-off point for the inactive group as being more than three months of inactivity. Those participants with inactivity duration not exceeding 3 months are assumed to represent the novice level, who would possess VLP closer to active drivers. Previous study from military field has also shown that

some skill sets start to deteriorate as early as from 14 weeks' of inactivity (Wisher et al., 1999). Herein, the participants were grouped into one of the active group, novice group, inactive group and no licence group. Table 5.1 shows the description of each group.

Table 5.1 Participant grouping description

Group	Description	Sample Size (n)
Active	The participant holds a valid driving licence for more than 2 years and been driving regularly	36
Novice	The participant holds a valid driving licence but has not been driving since obtaining licence (within the last three months)	29
Inactive	The participant holds a valid driving licence but has not been driving since obtaining licence more than three months ago	31
No Licence	The participant does not possess any valid driving licence in Singapore or elsewhere and has not received any prior driving training	35

As regarding the first part of the experiment, an important aspect is the general tendency of the position of the vehicle. During driving training, a person is taught to keep the vehicle around the centre of the lane, to avoid encroachment to the other lanes. However, in real practices, it is very rare that a driver positions the vehicle exactly at the centre of the lane. The driver shall use certain cues as a reference in maintaining his lateral position. Figure 5.3 shows the average offset distance of the vehicle.

The average offset distance shows the tendency of the vehicle to offset to the driver's side (right) or to the front passenger's side (left). The result shows that for the active group, the general tendency is to offset more to the driver side, or in Singapore case, closer to the right delineation lane. During driving training, a person is taught to keep the vehicle around the centre of the lane, to avoid encroachment to the other lanes. However, through on-road driving experience, active drivers would develop their own method to maintain their position using available cues. The delineation lanes serve as useful reference line in maintaining the lateral position. The right delineation line is certainly easier to use as the reference line than an 'imaginary' centreline, as they are physically on the road surface and closer to the driver's position. However, for the no licence group the general tendency is to offset to the front passenger's side. It may be because they never have received any training and are thus inexperienced with vehicle control on a real road. Another point that can be noted is that

novice group and inactive group tend to have bigger offsets than the active group, both for the left and right offsets. It may be because both groups want to be closer to the reference line so that it is easier for them to track their way. However, the greater offsets impose a bigger risk of lane encroachment and side contact with adjacent vehicles.

Figure 5.3 Average left and right offset distance (with standard error)

5.3 Vehicle control performance on straight and horizontal curve segments

The test circuit for vehicle control assessment consisted of both straight segment and horizontal curve segment. Further, a detailed separate analysis for straight and horizontal curve segments are explained in following sections. The detailed separate analysis serves to give greater insights into the performance of vehicle control under different horizontal alignments.

Straight segment and curve segment pose a different challenge in terms of vehicle control, especially for lateral control. Curve segment is expected to be more challenging for the driver to maintain his lateral position, as he is required to turn his vehicle to follow the curve while maintaining his lateral position within a safe boundary. Therefore, horizontal curve segment plays an important part in the analysis.

5.3.1 Vehicle control performance on straight segment

Driving on the straight lane is essentially concerned with maintaining a linear trajectory and is considered less challenging as compared to negotiating a horizontal curve. However, the ability to handle the vehicle is no less important. Along the straight segments, drivers tend to drive faster given the lesser demand for the maintenance of lateral control, and it might thereby result in lesser safety time window available to make a decision in case of any hazard. Therefore, the ability to handle a vehicle along the straight segment is no less important than for horizontal curve even though the situation may not as challenging.

Figure 5.4 shows the average values of (a) VLP, and (b) PLO of each group, with the error bar indicating one standard error. The average VLP value ranges from 0.066 to 0.280. The result shows that VLP for the active group is the lowest which implies that active group has the best lane wandering control compared to the other three groups. As expected, the no-licence group has the worst performance compared to the other groups. The average PLO value for straight segments ranges from 7.5% to 28.4%. The active group has the lowest PLO which indicates the best lane encroachment control among these four groups.

Tables 5.2 and 5.3 show the summary statistics of the VLP and PLO for all the groups along the straight segments. ANOVA and post-hoc tests were conducted on the dependent variables with the participant group as the independent variable. Table 5.4 shows the results. All the statistical tests were performed using *Rstudio 1.0.136*.

Table 5.2 Summary statistics of VLP for straight segment

<i>Groups</i>	<i>Count</i>	<i>Average</i>	<i>Variance</i>
Active	36	0.066	0.004
Novice	29	0.084	0.007
Inactive	31	0.115	0.010
No Licence	35	0.280	0.199

Table 5.3 Summary statistics of PLO for straight segment

<i>Groups</i>	<i>Count</i>	<i>Average</i>	<i>Variance</i>
Active	36	0.075	0.006
Novice	29	0.134	0.034
Inactive	31	0.162	0.024
No Licence	35	0.284	0.042

(a)

(b)

Figure 5.4 Average VLP (a) and average PLO (b) of straight segment (with standard error)

Results of ANOVA indicate a significant effect of participant group for both VLP and PLO. The active group consistently had the lowest average value of VLP and PLO, which indicate the best lateral control among the four groups. On the other hand, as observed in Figure 5.4, the Inactive group consistently performed worse than the novice group on both VLP and PLO variables.

Table 5.4 Result of statistics test of VLP for straight segment

Road segment	Variable	Homogeneity test	ANOVA		Welch ANOVA ^a		Post-hoc	Games-Howell ^b
		p-value	F value	p-value	F value	p-value		p-value
Straight segment	VLP	0.021	F(3, 127) = 5.669	0.001	F(3, 65.565) = 4.041	0.011	Active < Novice	0.781
							Active < Inactive	0.108
							Active < No Licence	0.039
							Novice < Inactive	0.577
							Novice < No Licence	0.07
							Inactive < No Licence	0.161
							Active < Novice	0.382
	PLO	0.008	F(3, 127) = 10.49	3.25E-06	F(3, 61.219) = 12.171	2.40E-06	Active < Inactive	0.032
							Active < No Licence	0.000
							Novice < Inactive	0.923
							Novice < No Licence	0.016
							Inactive < No Licence	0.037

^a only displayed when variances were not equal^b Games-Howell used when variances were not equal

As observed in Figure 5.4, PLO gives more discriminating results compared to VLP, especially between active group and novice group. Lane encroachment control can be considered as a more complex task than lane wandering control. Lane encroachment control entails the skills of controlling lane wandering in relation to estimating the vehicle's position based on lane delineation reference lines.

5.3.2 Vehicle control performance on horizontal curve segment

A similar set of analysis was also conducted for horizontal curve segment. As mentioned before, a horizontal curve segment may pose a more challenging task in driving, especially for lateral control. It may show a more discriminated result as compared to the straight segment. The lane wandering and lane encroachment parameters were measured and calculated solely for the horizontal curve segments. There are three horizontal curve

segments along the left-hand drive test road with test vehicle going from curve 1 to curve 3. Figure 5.5 shows the curve segments.

Figure 5.5 Horizontal curve segments (driving from West to East)

Figures 5.6 and 5.7 show the average VLP and PLO for each curve, respectively. The average VLP value for the active group is consistent for all three horizontal curve segments. It is important to note that, driving from West to East direction, the first and third curves are left-turn while the second curve is a right-turn curve. From both Figures 5.6 and 5.7, it can be seen that majority of the groups showed less stable lateral control on left-turn curves, as indicated by the higher average values of VLP and PLO for curves 1 and 3. It might give some indications that left-turn curve bear more difficulties than right-turn curve. It might be due to the position of the driver being on the right side that makes it difficult to estimate the left reference delineation line when he is turning to the left direction. Therefore, he experiences less stable lateral control and more lane encroachment on a left-turn curve than a right-turn curve.

The length of transition segment might also affect the stability of lateral control on a curve segment. The lateral control on the first curve is expected to be more unstable since the

drivers might still be adapting to the curved geometry. The subsequent curves are expected to have more stable lane wandering and lane encroachment. However, as can be seen from Figures 5.6 and 5.7, although on the second curve the VLP and PLO values are lower, it became higher again on the third curve. It might be due to the different length of the available transition segment. The transition segment between curves 2 and 3 is shorter, as can be seen in Figure 5.5. Thus, the driver may have less time to recover his lateral position before entering the next curve.

Although there are different types of the curve among the curve segment, the result shows that both VLP and PLO values for all the curves are not significantly different. Therefore, in the subsequent analysis, the average values of VLP and PLO from all the curve segments are used.

Figure 5.8 shows the average (a) VLP and (b) PLO of each group for the overall horizontal curve segments. The average value of VLP ranges from 0.061 to 0.221. Consistent with the straight segment, no licence group had the highest VLP compared to the other groups. The lane encroachment control was also analysed through the PLO parameter. The average value of PLO ranges from 12.2% to 32.6%, relatively higher than on straight segment which thus indicates higher difficulty level on the horizontal curve segment.

Figure 5.6 Average variance of lateral position (with standard error)

Figure 5.7 Average percentage of lane overrun (with standard error)

Tables 5.5 and 5.6 show the summary statistics of VLP and PLO on horizontal curve segments, respectively. Univariate ANOVA and post-hoc tests were also conducted for the dependent variables, VLP and PLO, with participant groups as the independent variable. Table 5.7 shows the summary results.

Table 5.5 Summary statistics of VLP at horizontal curve segment

Groups	Count	Average	Variance
Active	36	0.060	0.002
Novice	29	0.086	0.006
Inactive	31	0.105	0.004
No Licence	35	0.221	0.075

Table 5.6 Summary statistics of PLO at horizontal curve segment

Groups	Count	Average	Variance
Active	36	0.122	0.012
Novice	29	0.190	0.017
Inactive	31	0.238	0.036
No Licence	35	0.326	0.042

(a)

(b)

Figure 5.8 Average VLP (a) and average PLO (b) of overall horizontal curve segment (with standard error)

Table 5.7 Result of statistical test for VLP at horizontal curve segment

Road segment	Variable	Homogeneity test	ANOVA		Welch ANOVA ^a		Post-hoc	Games-Howell ^b
		p-value	F value	p-value	F value	p-value		p-value
Curve Segment	VLP	0.008	F(3,127) = 7.661	9.54E-05	F(3, 63.34) = 7.0143	3.80E-04	Active < Novice	0.347
							Active < Inactive	0.01
							Active < No Licence	0.008
							Novice < Inactive	0.739
							Novice < No Licence	0.039
							Inactive < No Licence	0.088
	PLO	0.042	F(3,127) = 9.601	9.27E-06	F(3, 67.154) = 10.05	1.48E-05	Active < Novice	0.12
							Active < Inactive	0.022
							Active < No Licence	0.000
							Novice < Inactive	0.661
							Novice < No Licence	0.011
							Inactive < No Licence	0.284

^a only displayed when variances were not equal^b Games-Howell used when variances were not equal

ANOVA also found a significant effect of participant group on both VLP and PLO for the horizontal curve segment. The VLP of the inactive group is higher than active and novice groups, although it is still lower than no licence group. The same trend as on the straight segment was also observed on curve segment for PLO. The active drivers performed the best compared to the other three groups, as indicated by the lowest PLO. Lowest PLO indicates that the active group ran over the delineation line and encroached on the other lane the least compared to the other groups. It means that the active driver is more able to control the position of the car within the lane boundaries and can incur the least risk of contact with the vehicles in adjacent lanes. As observed in Figure 5.8, similar to straight segment, PLO also gives more discriminating results, especially among the participants with driving licences. It strengthens the argument that more complex task or skills are more affected by having on-road driving experience and not being inactive.

5.4 Discussion

5.4.1 Effects of driving training and on-road driving experience

As can be observed from Figures 5.4 and 5.8, the no licence group performed the worst among the four test groups. The statistical test found that the no licence group has significantly higher VLP and PLO value than the other three groups who have driving licence, except for PLO on the horizontal curve segment. On horizontal curve segment, the result shows that the PLO of the inactive group is not significantly different from no licence group.

The no licence group has less stable control on the lateral position and lack of ability to maintain the vehicle position within the safe boundary, on both straight and horizontal curve segments. The no licence group never receive any training and never have any experiences on controlling a vehicle, thus they do not possess the feeling of controlling a vehicle. Meanwhile, the other three groups have gone through driving training and passed driving test to get a driving licence. Therefore, they know at least the basic skills for driving and how to control the vehicle, through the driving training. It shows the evidence of the effect of driving training in the development of driving skills.

In general, the results also found that active group, who regularly drive for more than two years, performed the best compared to other three groups. The active group is not only better on maintaining a stable lateral position, they are also better at positioning the vehicle within the safe driving lane. It shows the effect of on-road driving experience on vehicle control performance. Significant differences are especially found between active group and inactive group. It might due to that while the inactive licence holders have received driving training, which makes them perform better than no licence group, the inactivity may to some extent affect the performance in handling the vehicle due to lack of practice after getting their licence. Meanwhile, active drivers not only have received driving training, they also have more opportunity to practise and improve their skills. Therefore, their skills are significantly developed.

The differences are more evident particularly for the more complex task, i.e. PLO, and on more complex road condition, i.e. horizontal curve segment. A marginal difference was also found between active group and novice group on lane encroachment parameter, PLO, for the horizontal curve segment. It shows that on-road driving experiences further develop one's driving skills, especially for the more complex task and road condition. Familiarity with

real road situations is needed for better handling vehicles on more difficult road setting, i.e. horizontal curve segment. With more on-road driving experience, a driver will be more familiar with the road condition and able to use available cue or reference to estimate his lateral position thus ensuring better lateral control.

5.4.2 Effects of driving inactivity

During driving training, a person is prepared with necessary driving skills to reach a certain required level of driving skills. As he passed the driving licencing test, one can assume that he has attained acceptable driving skills. However, as some previous studies in other areas have pointed out, some human knowledge and skills may deteriorate if left inactive for some prolonged periods of time. The results from the current research suggest that a similar trend also applies to on-road driving exposure as affecting driving skills.

In general, the results of VLP and PLO indicate that driving licence holders who went through inactivity period will likely deteriorate on their driving skills, especially in controlling the lateral position of the vehicle. Even on the less difficult segment, i.e. straight segment, the result indicates that inactive group performs worse than the novice group. Inactive licence holders wander in wider lateral range compared to both groups: novice and active drivers. They also tend to encroach on other lanes more often. The result indicates the deterioration of ability of the inactive licence holders to maintain a stable lateral position of the vehicle. Meanwhile, active drivers have more on-road experience that helps not only to retain the trained skills but also to improve on it. It is reflected by the better results on the VLP and PLO.

As mentioned before, the statistical tests found that inactive drivers performed significantly worse than active drivers. It might be due to the combination of more driving experience from the active group and the driving inactivity for the inactive group that result in the bigger difference between these two groups. On the other hand, no significant effect has been found between novice group and inactive group. Nevertheless, the results can still be an indication that there is a tendency that a driver may lose his driving skills due to inactivity. No significant effect can be found for PLO between inactive and no licence group on the horizontal curve segment. It implies that on more difficult task and more difficult road condition, the driving skills of the inactive driver may deteriorate to the level of the unlicensed level.

Between two parameters, VLP and PLO, different tendency can also be observed. For VLP, the result of the inactive group leans closer to the active group and novice group than no licence. On the other hand, the average PLO of the inactive group, especially on horizontal curve segment, is closer to no licence group. It may due to different level of complexity between lane wandering control and lane encroachment control, in which lane encroachment is considered to be more complex. Lane wandering is considered less complex than lane encroachment control, and it is part of basic driving skills of driving that is learned during the early stage of driving training. During the training period, the driver will learn how to handle the vehicle and get used to it. Ability to maintain the stability of the vehicle is also part of it, with familiarisation to the steering wheel control. The result suggests that this skill can be retained longer even after some periods of inactivity. The results also suggest that the improvement through on-road experience after training period may not be as much as during training period.

While the lane wandering performance deals with the ability to maintain the stability of the vehicle lateral position, the lane encroachment combines the ability to maintain the stable position and the ability to estimate the position of the vehicle on the driving lane. This aspect is a more complex task compared to lane wandering, especially on horizontal curve segment. The results indicate that it is more prone to deteriorate resulting from inactivity. Upon completion of his training, if a person never drives again for a while he may easily lose the sense to estimate his position within the driving lane. He is also not familiar in using available cue on the road to help him estimate his position. It results in more encroachment on other lanes. The ability to estimate the position using available reference, although is also part of training, may also need to be further improved and retained through a period of on-road experience.

5.5 Summary

Two main parameters were analysed for vehicle control assessment: VLP for lane wandering and PLO for lane encroachment. The average VLP and PLO values were compared across different groups of participants: active group, novice group, inactive group, and no licence group. The analysis was done in two different settings: straight segment and curve segment. A consistent trend was found for both settings for both parameters. In general, for lateral control performance, active group perform the best among these four groups. On the other

hand, the novice and inactive groups always fall between active and no licence groups, for both VLP and PLO.

Driving training helps a person to learn basic required skills that are needed to be able to drive on road. After getting the driving licence, driving regularly gives the opportunity for the driver to practise and enhance the skills that have been obtained through training. The results indicate that without further on-road practices, some driving skills, i.e. lane wandering control and lane encroachment control, may deteriorate after some periods of inactivity. The deterioration rate may vary for different sets of skills, with more complex, i.e. lane wandering tasks, experiencing faster deterioration rate. For more complex driving skills, the deterioration can cause the level of competency to degrade to untrained level. The deterioration of driving skills is especially more sensitive for the young-inexperienced driving licence holders, as the skills that they gained may not be 'deeply planted' yet.

ANOVA found that there are significant differences between participant groups for both parameters on the straight and horizontal curve segments. Pairwise test then found that there is significant difference between no licence group and other licence holder groups, especially with the active group. It suggests the effectiveness of driving training programme in preparing a person to be able to drive a vehicle. However, in some cases, i.e. PLO for horizontal curve-segment, no licence group is not significantly different from the inactive group. It suggests that in some context, the driving skills of inactive licence holders may deteriorate almost to the same level as an untrained person.

A version of this chapter has been submitted to Transportation Research Part F: Transportation Psychology and Behaviour (submitted on 8th March 2017, under review since 1st July 2017). The submitted version can be found in Appendix D.

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Chapter 6 Active mode driving assessment: Hazard perception and anticipation

6.1 Overview

This Chapter covers the presentation and analysis of the result of the experiments on hazard perception and anticipation. The active mode driving assessment was conducted. In the active mode response time experiment, participants were given the control of the vehicle. Interactive response latency (IRL) and its component served as the performance indicators. The last part of this Chapter discusses and summarises the findings from this experiment. The raw data of the hazard perception and anticipation experiments are attached in Appendix C.

6.2 Result on interactive response latency (IRL) and its component

Active mode hazard perception test is a modified version of the conventional hazard perception test (HPT). In conventional HPT, the participants are asked to watch a video which contains a series of hazard. The participant is asked to register his response once he detects any hazard on the video. For the current modified HPT, the participant was asked to drive along the determined route. Along the route, several hazards were planted and would come on upon a trigger from test vehicle's position and timing. There are four hazards planted along the test route. In this setting, participants needed to not only detect the hazard but also made a decision to avoid collision with the hazards. The participants were given freedom to control the vehicle, i.e. decelerate, accelerate, lane changing, etc.

All the data and video related to eye movement and fixation were extracted using SMI's *BeGaze Qualitative Analysis Software*. Video processing software, *Avidemux 2.6*, was used to playback of the video and to control it frame by frame. Therefore, the exact time frame to start timing is easily determined, and likewise the exact time of each eye gaze movement. The reaction from the participant towards the hazards, i.e. braking or swerving, is indicated by changes in the reading of the brake pedal and steering wheel indicators. All the readings are recorded onto the log file in the *UC-Win/Road* data logger, including the timestamps. Each action that is indicated on the log file is linked to the exact timestamp as the exact time of response.

The same participants who went through vehicle control assessment participated in the hazard perception assessment. However, some data were excluded from the analysis, due to error on the eye tracking device, which thus reduced the sample to 91 subjects. Table 6.1 shows the detailed sample size of each group.

Table 6.1 Sample size of each group

Group	Description	Sample size (n)
Active	The participant holds a valid driving licence for more than two years and has been driving regularly	24
Novice	The participant holds a valid driving licence but has not been driving since obtaining licence within the last three months	24
Inactive	The participant holds a valid driving licence but has not been driving since obtaining licence more than three months ago	19
No Licence	The participant does not possess any valid driving licence in Singapore or elsewhere	24

6.2.1 Interactive Response latency (IRL)

The interactive response latency (IRL) of each participant was measured based on eye tracking video and the driving log file. The eye tracking video recorded the eye gaze position from time to time; thus, by using the video, the detection process of the hazard can be obtained. As mentioned in Chapter 3, the IRL would be broken down into three components: Lag time (LT), Time-to-fixation (TF), and Perception-Intellection-Emotion-Volition (PIEV) time. Univariate ANOVA was conducted on the IRL and its components, for all hazards, with participant groups as the independent variables. All the statistical tests were performed using *Rstudio 1.0.136*. Table 6.2 summarises the result of the statistical test.

Through data extraction from the recorded video and the driving log file, all components of interactive response latency (IRL) were obtained. IRL values were obtained from the summation of lag time (LT), time-to-fixation (TF) and PIEV time. Figure 6.1 shows the average value and the standard error of IRL, while Table 6.3 shows the summary statistic of IRL for all hazards. ANOVA found significant differences for all the hazards (see Table 6.2).

Table 6.2 Result of statistical test for IRL, LT, TF and PIEV time

Hazard	Variable	Homogeneity test	ANOVA		Welch ANOVA ^a		Post-hoc	Tukey HSD	Games-Howell ^b
		p-value	F value	p-value	F value	p-value		p-value	p-value
Hazard 1	RL	0.005	6.414	0.001	10.627	0.000	Active< Novice		0.020
							Active< Inactive		0.000
							Active< No Licence		0.000
	LT	0.062	2.442	0.070	2.999	0.040	Active< No Licence		0.060
	TF	0.450	1.582	0.200					
Hazard 2	PIEV	0.217	2.899	0.040			Active< Inactive	0.056	
							Active< No Licence	0.075	
	RL	0.011	3.751	0.014	3.877	0.015	Active< No Licence		0.02
	LT	0.374	0.946	0.422					
	TF	0.706	0.552	0.648					
Hazard 3	PIEV	0.045	4.071	0.009	0.580	0.631			
	RL	0.165	3.097	0.031			Active< Inactive	0.061	
	LT	0.561	1.623	0.190					
	TF	0.467	1.174	0.324					
	PIEV	0.257	2.456	0.068			Active< Inactive	0.089	
Hazard 4	RL	0.920	7.267	0.000			Active< Inactive	0.009	
							Active< No Licence	0.000	
	LT	0.862	1.177	0.323					
	TF	0.055	2.420	0.071	2.185	0.102			
	PIEV	0.476	4.041	0.010			Active< No Licence	0.005	

^a only displayed when variances were not equal

^b Games-Howell used when variances were not equal

Figure 6.1 Interactive response latency (IRL) with standard error

Table 6.3 Summary statistics of interactive response latency (IRL)

<i>Hazard</i>	<i>Groups</i>	<i>Count</i>	<i>Average</i>	<i>Variance</i>
Hazard 1	Active	24	1.502	0.200
	Novice	24	2.140	0.800
	Inactive	19	2.325	0.570
	No Licence	24	2.412	0.974
Hazard 2	Active	24	1.589	0.241
	Novice	24	2.058	0.879
	Inactive	19	1.751	0.476
	No Licence	24	2.359	1.320
Hazard 3	Active	24	1.552	0.244
	Novice	24	1.679	0.386
	Inactive	19	2.114	1.110
	No Licence	24	2.025	0.513
Hazard 4	Active	24	1.564	0.482
	Novice	24	1.844	0.261
	Inactive	19	2.140	0.273
	No Licence	24	2.288	0.323

Compared to abrupt IRL from the passive mode, the IRL from this experiment is much longer. The longer IRL is expected, as participants in active mode engage in more complex activities, where they have to look out for hazards while controlling the movement of the vehicle. In comparison, for passive mode, they only engage their focus on detecting the hazards. Previous studies have shown a similar pattern, where reaction time in non-driving (passive) hazard perception is shorter than during driving (active) hazard perception (Mackenzie & Harris, 2014, 2015). With more complex task, drivers had to divide their attention to more area. Therefore, it caused them more time to detect any hazard and decide on the action to do.

As shown in Figure 6.1, the active group generally performed best among the four groups of participants. The average IRL values of active group range between 1.502 – 1.589 seconds. Meanwhile, the average IRL values of novice and inactive groups range between 1.679 – 2.140 and 1.751 – 2.325 seconds, respectively. As for no licence group, the average IRL values straddle around 2.025 – 2.412 seconds. Active drivers may learn from their experience on responding to various situations on the road, therefore they are able to make a faster response to hazards. It is particularly noticeable on H1 (Crossing Pedestrian), which involve pedestrian with the right-of-way. It indicates that with road experience, drivers are

more used to the priority on road users interaction and a better understanding of it. They give an immediate response to give way to the pedestrian, while the other group waited until the hazardous situation was more developed.

Meanwhile, the result also shows that among the trained groups, the inactive group generally performed worst, slightly slower in responding to hazardous situations than the novice group. It shows the effect of inactivity. Inactivity can cause deterioration in vehicle control, and it may also affect the ability of drivers to estimate the situation and make the necessary response. The no licence group took a longer time to respond than trained groups, especially when compared with active and novice groups. However, the effect of training is not as significant as experience. In terms of hazard perception and anticipation, experiences help to improve the ability to respond to the hazardous situation more than just driving training. During on-road driving, a driver encounters many events including some hazardous situations. Therefore, he builds up his ability and knowledge on how to handle those situations better. Meanwhile, driving training mainly focuses on the basic handling of vehicle. There is less focus on responding to hazardous situations. With the benefit from eye tracking device, the IRL was broken down into three components which represent the detection process and decision-making process.

6.2.2 Lag time (LT)

Lag time (LT) represents the delay that transpires before a person starts to move his fixation point in the detection of an object or hazardous situation on the road. LT is timed from the point at the onset of a hazard on the screen to the time the eye starts to shift towards the direction of the supposedly hazardous object. Figure 6.2 shows the average value (with standard error) of LT for each group and hazard, while Table 6.4 shows the summary statistics of LT for all hazards.

As shown in Figure 6.2, the active group had the fastest LT among the four groups across all hazards, ranging between 0.436 – 0.506 seconds. As for novice group, the average LT values ranging between 0.597 – 0.777 seconds. The inactive group has average LT values ranging between 0.479 – 0.734 seconds, while no licence group has its average LT values range between 0.642 – 0.899 seconds. It indicates that delay in detection is affected by the experience of drivers. With more on-road experience, active drivers may be more sensitive to

the change in the surrounding road environment. Therefore, their responses are triggered faster by the appearance of hazardous object.

Table 6.4 Summary statistics of lag time (LT)

<i>Hazard</i>	<i>Groups</i>	<i>Count</i>	<i>Average</i>	<i>Variance</i>
Hazard 1	Active	24	0.468	0.168
	Novice	24	0.777	0.367
	Inactive	19	0.718	0.290
	No Licence	24	0.899	0.501
Hazard 2	Active	24	0.436	0.162
	Novice	24	0.597	0.349
	Inactive	19	0.479	0.335
	No Licence	24	0.687	0.465
Hazard 3	Active	24	0.498	0.143
	Novice	24	0.714	0.272
	Inactive	19	0.698	0.355
	No Licence	24	0.797	0.230
Hazard 4	Active	24	0.506	0.157
	Novice	24	0.637	0.240
	Inactive	19	0.734	0.136
	No Licence	24	0.642	0.129

Figure 6.2 Lag time (in seconds) with standard error

Previous studies have shown that experienced drivers tend to direct their eye gaze on a wider area than novice drivers (Konstantopoulos et al., 2010; Mourant & Rockwell, 1972; Underwood et al., 2002). It may explain the present study results. Wider scanning area of experienced drivers helps them to detect any hazard potential that may come from any direction in a faster time. Meanwhile, the novice drivers who focus more only on the road ahead may miss the sight of the hazardous object and only notice it when it gets closer to them.

Meanwhile, no distinct difference or pattern is observed between novice and inactive groups. It may due to the fact both groups are on the inexperienced side, although they are different in terms of the inactivity period. Although they have been trained to lookout-for-hazard, due to their lack of experience they are not used to do that and not sensitive to the change in on-road driving situations. A study by Wallis and Horswill (2007) found that novice drivers are less sensitive to hazards, and they need a higher threshold of hazard in order to notice it. It may also apply in the case of novice and inactive drivers in this experiment. Both groups need more developed hazards before they can notice them. As the hazard becomes more developed and close enough to the novice and inactive groups they would then take notice. Therefore, both groups have a longer lag to notice the hazards.

There is no noticeable difference found between no licence and novice groups indicating the less effect of driving training on the awareness of hazardous situations. It shows that driving training alone may not enough to prepare driver to face and detect any hazardous situations. Driving training mainly focuses on vehicle control skills, thus on-road driving practice/experience is needed to develop the visual skills for safe driving.

6.2.3 Time-to-fixation (TF)

Time to fixation (TF) is the period from the time the participant starts to move his fixation point until the participant fixates onto the hazard. This is a mechanistic process of the movement of the eye fixation point. TF is the shortest component of RL. Figure 6.3 shows the average value of TF (with standard error) of each group in every type of hazard, while Table 6.5 shows the summary statistics of the TF for all hazards.

Table 6.5 Summary statistics of time-to-fixation (TF)

<i>Hazard</i>	<i>Groups</i>	<i>Count</i>	<i>Average</i>	<i>Variance</i>
Hazard 1	Active	24	0.262	0.026
	Novice	24	0.356	0.063
	Inactive	19	0.398	0.045
	No Licence	24	0.351	0.057
Hazard 2	Active	24	0.380	0.051
	Novice	24	0.351	0.037
	Inactive	19	0.301	0.032
	No Licence	24	0.331	0.051
Hazard 3	Active	24	0.381	0.054
	Novice	24	0.283	0.022
	Inactive	19	0.357	0.042
	No Licence	24	0.367	0.040
Hazard 4	Active	24	0.258	0.019
	Novice	24	0.257	0.025
	Inactive	19	0.328	0.018
	No Licence	24	0.361	0.043

Figure 6.3 Time-to-fixation (in seconds) with standard error

As shown in Figure 6.3, no significant effect was found on TF values. TF is closely related to a physiological mechanism of the eye. Therefore, driving experience and training have no significant effect on the TF results. Considering that all participants are all in the similar age range (young adult), it is expected that their physiological conditions would be somewhat

similar, which thus results in a similar range of TF. The average TF values range between 0.257 – 0.398 seconds.

6.2.4 PIEV time

Perception-Intellection-Emotion-Volition (PIEV) time represents the time that is needed by the participant to perceive the hazard he sees, making a decision and implements the decision into an action. Compared to the other components, i.e. LT and TF, PIEV time has a longer average value. This indicates that decision-making process takes more time on the hazard anticipation process. Figure 6.4 shows the average value of PIEV with standard error for each group, while Table 6.6 shows the summary statistics of PIEV time.

Generally, the active group has faster PIEV time than the other three groups. The average PIEV time values of active group range between 0.673 – 0.773 seconds. Meanwhile, the average PIEV time values of novice group straddle between 0.683 – 1.110 seconds. It indicates better performance on decision-making component due to on-road experiences of active drivers. They are able to make a necessary decision faster since they experience 'extra learning' phase through on-road experiences after licensing. During on-road driving, a driver interacts with many other road users. He may develop some strategies on how to handle various situations on-road through past experiences. It may help him to process the situations faster when he encounters similar situations again. He also has more experience, therefore being more 'trained', on dividing his attention into several driving task components which include responding to hazardous situations. The results also show that inactive drivers took a longer time to decide and apply their action compared to active and novice drivers, indicating the effect of inactivity on the decision-making process. As shown in previous chapters, inactivity causes deterioration on vehicle control performance and this condition combined with inexperienced reduces the ability to estimate the hazardous situation and make a timely decision accordingly.

Table 6.6 Summary statistics of PIEV time

<i>Hazard</i>	<i>Groups</i>	<i>Count</i>	<i>Average</i>	<i>Variance</i>
Hazard 1	Active	24	0.772	0.122
	Novice	24	1.006	0.380
	Inactive	19	1.208	0.380
	No Licence	24	1.162	0.377
Hazard 2	Active	24	0.773	0.142
	Novice	24	1.110	0.262
	Inactive	19	0.971	0.306
	No Licence	24	1.341	0.650
Hazard 3	Active	24	0.673	0.097
	Novice	24	0.683	0.112
	Inactive	19	1.058	0.918
	No Licence	24	0.862	0.156
Hazard 4	Active	24	0.761	0.197
	Novice	24	0.921	0.226
	Inactive	19	0.993	0.319
	No Licence	24	1.258	0.308

ANOVA found significant differences for H3 (Merging Lorry), specifically between active-inactive, and H4 (Cut-across Car) between active-no licence. It indicates the effect of both experience and inactivity on the ability to respond to hazards. H3 and H4 specifically have shorter time-to-collision (TTC), which requires a faster response to avoid a collision. It shows that when there is acute time pressure, experience and inactivity show more dominant effect. Experiences help drivers to learn to quickly make their decisions. Meanwhile, inactive drivers are not familiar with the real road driving condition hence they may not be able to make a quick decision under such pressure. Inactive drivers are also considered as inexperienced drivers. A previous study shows that an inexperienced driver needs a higher threshold of the hazard before he will notice it and then respond to it (Wallis & Horswill, 2007). It also applies in the current case in that inactive driver waits for a longer time until hazard gets closer and be fully developed before he considers that he needs to take an action to avoid a collision. It results in a longer PIEV time.

Figure 6.4 PIEV Time (in seconds) with standard error

Significant differences are also found on H1 (Crossing pedestrian). As different from the other hazards, in this hazard, the priority is on the other road user (pedestrian) and the option available is only braking/slow down. The situation is quite straight forward for response. The result shows that active group is particularly significantly faster than inactive and no licence groups, thereby showing the effect of experience, inactivity and training. With their experiences, active drivers are more aware of the priority on road interaction. Therefore, they immediately give the priority to the pedestrian. Meanwhile, others may not be as aware of the priority concept of road user interaction, therefore they await until the situation becomes more hazardous (closer to the pedestrian) to consider it as a hazard and respond to it.

6.3 Discussion

6.3.1 Effects of driving training

Comparison of performance of trained (active/novice/inactive) groups with no licence (untrained) group serves to provide an indication of the effect of training. Interactive response latency (IRL) parameter shows that trained groups, especially active and novice groups, respond faster than no licence group. It shows the effect of training on the ability of drivers to handle the vehicle in response to hazardous situations.

However, the differences between novice and no licence groups in most of the cases are not significant. It indicates that training alone does not affect the hazard anticipation performance significantly. Driving training programme, in Singapore, does not include intensive or specific training on hazard perception or vehicle handling under hazardous situation. Although training of safety procedure (such as look out for hazard) and emergency brake exists, it is never done intentionally in the real hazardous situation since it impossible to do it on the real road. Therefore, such skills may not be really well developed from training alone. Defensive driving course, which deals with vehicle handling on hazardous situation, usually comes as an optional programme after licensing rather than as an inclusive programme of driving training. Therefore, to sharpen their skills in responding to the hazard, drivers may need some amount of on-road experience. Alternatively, including hazardous situation response training (in driving simulation) to driving training, may help to train driver in responding to hazards. Some studies have suggested PC-based training, that directly covers issues related to visual scanning and risk awareness, can help to improve the visual scanning strategy that is necessary for safe driving (Chapman et al., 2002; Fisher et al., 2004).

6.3.2 Effects of driving experience and inactivity

The active group generally has a better overall performance in responding to hazardous situations, indicated by a shorter interactive response latency (IRL) than the three other groups. Active group also has shorter average values for both LT and PIEV time, indicating better performance in both detection and decision-making process. As mentioned before, the result shows that driving training alone gives a less significant contribution to hazard perception and anticipation. Meanwhile, experiences may give active drivers more familiarity with real road driving situations. They may also have experienced some hazardous situations before and have learnt from those situations on how to safely avoid collision/accident, so the response can be triggered faster. They have greater sensitivity to change of situation in surrounding compared to novice and inactive. The results also show that experience gives a better understanding of the priority of road users' interaction and how to behave accordingly. On the other hand, novice driver may be less familiar with the road situations. Underwood et al. (2002) argued that novice drivers may have less understanding of road situations which affect their visual scanning strategies. The novice drivers tend to scan on a narrower area. This visual behaviour may then affect their hazard detection.

Previous studies have shown the higher involvement of young-inexperienced and elderly drivers as compared to middle-aged experienced drivers (Massie et al., 1995; McGwin & Brown, 1999). Young drivers involvements in road traffic accident (RTA) are usually attributed to inexperience, overconfidence and fatigue (Cooper, 1990; Doherty et al., 1998; Hakamies-Blomqvist, 1993; Macdonald, 1994). While driving training has prepared drivers to safely handle a vehicle, driving training may be lacking on the aspect of responding to hazardous situations. The lack of experience on handling hazardous situation makes it harder for them to make a timely and correct response, and such condition may lead to an accident.

In learning some new skills, a person will go through a learning phase until he reaches mastery level. In term on driving, mastery level would be similar to passing the practical driving licence test. After that, when someone continues to practise his skills beyond learning period, he will experience what it called 'over learning' phase. This 'over learning' phase strengthens the level of skills gained on the original learning phase (Farr, 1987; Wisher et al., 1999). This would be similar to driver's practice with subsequent gain in real road experience after he has gotten the driving licence. This phase helps drivers to strengthen their driving skills and enhances their resistance against forgetting.

Meanwhile, the overall result of IRL shows that generally, novice drivers respond slightly faster than the inactive drivers, indicating that novice drivers are, in general, slightly better in responding to hazards compared to inactive drivers. Results from the previous chapter have shown that inactive drivers experience deterioration of vehicle control skills. The deterioration of vehicle control skills may also affect their ability to respond to the hazardous situations. They may have less confidence on controlling the vehicle to avoid a collision as compared to novice drivers. However, the differences are not noticeable. It might due to both groups, in terms of their experiences, are on the same inexperienced level. They do not have as much experiences as the active group. Therefore, they lack 'practice' on the safe interaction with other road users in real road driving settings. It shows that in driving skills that are related to hazard perception and anticipation, experiences play more dominant effects. Furthermore, a longer period of inactivity from driving negates drivers to gain real on-road experience on interaction with other road users, in order to build and sharpen their skills in responding to hazards.

6.4 Summary

Hazard Perception Test (HPT) has been conducted to assess the effect of training, experience and inactivity on driving performance in terms of interaction with other road users, specifically hazard perception and anticipation. Consistent with passive mode, the result suggests that driving experience affects performance in both detections of hazard and also the response towards hazards. It is indicated by faster detection and response time of active drivers as compared to other groups of participants. Drivers who rarely use their driving skills may lose the opportunity to practise their skills and familiarise with driving conditions, therefore they may possess less experience in interacting with other road users. It would affect the familiarity to make a correct and timely response to the hazardous situation. No significant differences are found between novice and inactive drivers. It may be due to lack of experience on on-road driving of both groups. Therefore, they fall into the similar situation which is lack of experience in on-road driving.

Driving training, especially in Singapore, never really cover any exposure to hazardous situations. Therefore, the ability of to safely respond to hazards could be developed only as the drivers experience on-road driving rather than through training. However, many young drivers may not have the opportunity to drive a vehicle regularly after they obtain their driving licence. This inactivity prevents drivers to strengthen their skills on hazard anticipation. Defensive driving course, which is usually offered after licensing, may help to train drivers to respond to hazardous situations. Authority may also include a lesson on hazard response training in driving simulation to prepare 'students' on hazard anticipation prior to getting their driving licence instead of after getting their licence.

A version of this chapter has been submitted to Transportation Research Part F: Transportation Psychology and Behaviour (submitted on September 2017). The submitted version can be found in Appendix E.

Chapter 7 Conclusion

7.1 Overview

This Chapter contains the summary of the current results, recommendations as well as areas for potential future research. A series of experiments have been done to examine the effect of driving training, experience as well as driving inactivity on driving performance. The summary of research methodology and main findings are presented in this Chapter. In the last part, the recommendations and potential future work are explained.

7.2 Motivation for this research study

Overall on-road driving skill is a cumulated acquisition of driving skills learned during the training period and furthered tempered with post-licensing on-road driving exposure. Inactivity from on-road driving can result in deterioration of driving skills. With the extremely high cost of car ownership, there are many people in Singapore who hold a valid driving licence but yet have a very limited chance to drive regularly since many do not have access to a personal vehicle. These inactive licence holders are allowed to take up on-road driving again anytime. This situation may result in serious safety issues on the road, as the driving skills may have deteriorated due to driving inactivity. Therefore, there is a need for further study to examine the level of deterioration and then propose necessary recommendation on this issue, such as the necessity of driving refresher course. This research addresses the issue on skills deterioration of learned driving skills as a result of driving inactivity, specifically for young-inexperienced drivers.

7.3 Research methodology

This study is divided into two stages: passive mode driving assessment and active mode driving assessment. The study was conducted using driving simulator at Transport and Geospatial Laboratory in NTU. Driving simulator was chosen among other options, e.g. on-road driving test, as it offers safer and more controllable driving environment where specific scenarios can be created and tested without introducing risk to other road users and the participant. The first stage, passive mode driving assessment, served as a preliminary stage to examine the relationship between driving training, experience as well as inactivity with driving performance. A Hazard Perception Test (HPT) was conducted using a passive mode driving simulator. HPT was chosen as previous studies have shown that it has a close

relationship with accident rate and involves several driving-related cognitive skills. The passive mode driving simulator is equipped with a 46-inch LED TV and a simple frame to resemble a driving seat, mock steering wheel, and pedals. However, the steering wheel and pedals do not have any control function. A video containing four types of hazards was played through the LED TV monitor while the participant sat on the driving seat. The hazards vary in terms of the collision damage potential (property damage only; potential loss of life) and collision avoidance potential. The participant was asked to press the brake pedals every time he detected any hazard in the video. The brake pedal was connected to a light bulb which served as an indicator of participant's response. The time between the first appearance of the hazard and the time when participant registered his response was recorded as the response latency (RL). The results and limitations found in the passive stage, such as realism of the driving simulator setting and limited information on the hazard response process, served as inputs in designing the second stage.

The second stage involves active mode driving assessment. Considering the results and also limitations of the passive mode driving assessment, the second stage moved to an active mode driving simulator where the participant was given a full control over the movement of the vehicle. A virtual environment, including road network, was developed to replicate the real on-road driving environment in a more interactive setting. Several improvements were made to the driving simulator system in order to facilitate those functions, for both software and hardware aspects. Three 46-inch LED monitors were used to display the surrounding driving environment and vehicle cockpit. Meanwhile, Logitech G27 controller was used as the steering wheel and pedals which were connected to the vehicle control function of the driving simulator software. An eye tracking device was used in the experiment to enable the data collection on the visual behaviour (e.g. eye movement) of the participant during driving activity. The eye tracker is useful to obtain more detailed information on the process of hazard detection. With the detailed information of the eye movement, the hazard response process can be broken down and the exact detection and decision-making phases can be separated for further analysis.

A total of 132 participants were involved in the experiment, with age ranging between 20 to 30 years. One participant was excluded due to simulator sickness, so the final number of participants was 131 participants. At first, the participants were categorised into two groups of 'Licensed' and 'No Licence'. Further analyses were then conducted to get a cut-off

condition to further classify 'Licensed' group, into active, novice and inactive groups. There are two aspects of driving skills that were tested in this active stage: vehicle control skills and hazard perception and anticipation. Vehicle control skills represent the ability of drivers on basic control of vehicle movement, while hazard perception and anticipation represent the critical point on safe interaction with other road users. Two types of questionnaire were administered on the second stage. The first questionnaire was pre-experiment questionnaire which was administered before the start of the experiments. Pre-experiment questionnaire was done to collect demographic data of the participant as well as his fatigue condition. The fatigue condition rating served as a pre-check of participant's fatigue condition prior to the experiment. It was to make sure that the condition of the participant is within acceptable fatigue level. The second questionnaire was post-experiment questionnaire which included simulator experience questionnaire and simulator sickness questionnaire. The purpose of the post-experiment questionnaire was as a cross-check tools during analysis about participant's experience in the driving simulator, especially related to hazard response, as well as his simulator sickness level. Participant with a high level of simulator sickness was excluded from analysis. An adaptation session was conducted before the main experiment sessions. The adaptation session was aimed to give participant ample time to get used with the driving simulator environment and the control setup, i.e. steering wheel and pedals. In adaptation session, the participant was asked to drive on a predetermined route for about 5-7 mins. After adaptation session, the participant was asked to rest before continuing to next session.

For the vehicle control assessment, the participant drove through a stretch of virtual expressway under free-flow conditions with speed limit 80 km/h. He was instructed to keep to the designated test (middle lane) lane for the complete circuit, i.e. there was no lane changing involved. The traffic was kept on the low end so that the movement of test vehicle was not hampered by vehicles in the vicinity. The speed and lateral position of the vehicle were recorded every 0.10 seconds in a log file for each participant. Centrality Index (CI) was calculated to indicate the vehicle position at every sampling point in time. Two parameters were then calculated as the performance indicators: variance of lateral position (VLP) for lane wandering control and percentage of lane overrun (PLO) for lane encroachment control. After this session end, the participant was given a break for 15 minutes to give him a time to recover from any effect of simulator sickness before continuing to the next session.

The next session was a hazard perception and anticipation test. This part was modified from conventional hazard perception test (HPT). In this experiment, instead of watching hazard contained in a video, the participant drove a car along a specified virtual route in which several hazards had been planted. Participant was asked to obey road regulations and to avoid collision with other road users. Navigational messages would appear to help participant navigate the vehicle. The hazards vary in terms of road user involved, avoidance potential and damage potential to examine the response of participant on different types of hazards. The hazards were chosen from common event in everyday driving situations. Eye tracker was used in this experiment to examine the eye behaviour when participant identifies the hazards. The eye tracker recorded all the driving scenes including the eye gaze position during the driving activity, while the driving simulator log file recorded all the vehicle parameters (i.e. braking, steering wheel position). Those records were used to calculate the time span between the first appearance of hazard to the action from the participant which is referred as interactive response latency (IRL). The interactive response latency was further refined into three sub-components: lag time (LT), time-to-fixation (TF) and PIEV (Perception-Intellection-Emotion-Volition) time.

7.4 Summary of main findings

7.4.1 Passive mode driving assessment

A total of 38 participants were involved in the experiment. They were divided into three groups: active (14 participants), inactive (10 participants) and no licence (14 participants) groups. Overall results show that active group has faster response latency (RL), ranging between 0.712 to 1.183 seconds, than inactive and no licence groups. It indicates the effect of on-road driving experience and constant practices on the ability of the drivers to detect and respond to hazards. It is interesting to note that the differences between active and inactive groups are more prominent when it comes to response to common hazard in everyday driving, i.e. A1 (Merging Car). It indicates that experience helps to prepare drivers for similar situations, therefore the more common the type of hazard, the faster are the response of active drivers, since they have more experience of it. Therefore, to show a more discriminating result for the second stage experiment, a series of common on-road hazards were chosen as the stimuli.

The differences between active and inactive groups can also be seen from how they differentiate their response to different characteristics of hazards. The untrained group is not much affected by damage potential and avoidance potential. Meanwhile, response latency (RL) of trained groups are influenced by the characteristics of hazards (i.e. damage potential and avoidance potential). Inactivity affects the way drivers incorporate available cue on responding to hazards. Active drivers are able to discern the characteristics across all hazard situations, in perceiving its risk level. The results support the argument that lack of on-road driving experience affects the hazard identification strategy and perception of risk.

Limitations

The series of experiments were conducted on a driving simulator instead of real-road driving. Therefore, the results may not be directly transferable to real-road driving condition. The experiment was conducted in a passive setting, where the participant did not have any control over the vehicle movement. Only limited data could be obtained from the passive mode driving simulator. The main task is hazard detection without controlling the vehicle. It shall not fully replicate the complexity of driving task, which thus affects the hazard identification and decision-making process. Notwithstanding, the results should still be acceptable for relative comparison among the groups since all participants went through the same setting. Only limited information related to hazard response process can be obtained since no eye movement data were recorded. Therefore, it is difficult to identify the exact detection and decision-making phase to further analyse the detailed process.

In this first stage experiment, the participants have been divided into three groups: active, inactive and no licence. However, the duration of inactivity for the inactive groups is very wide, spanning from recent inactivity (1-2 months) to more than six months. Drivers who are only recently inactive may not experience the same amount of deterioration as drivers who are inactive for a longer period. Recently inactive drivers' level of competency may be close to the level as when they just passed the driving test. Therefore, for the second stage, a finer categorisation was used which includes an additional category of the novice group who represents the freshly trained drivers.

7.4.2 Active mode driving assessment

Vehicle control skills

A comparison of variance of lateral position (VLP) values across different periods of inactivity was done. A jump of VLP values was observed after three months of inactivity. It suggests that beyond three months of inactivity, the skills of lane wandering control start to deteriorate as indicated by higher VLP value along the test route. Based on above finding, one can set a cut-off point to separate inactive group from novice group as being more than three months of inactivity. Then, the participants, on the second stage, were divided into four groups: active (36 participants), novice (29 participants), inactive (31 participants), and no licence groups (35 participants).

The results show different strategies employed by different groups of drivers on positioning their vehicles on the road. The general tendency for the active group is to offset more to the driver's side, or in Singapore's case, closer to the right delineation lane. The active drivers would develop their own method to maintain their position using available cues. The delineation lanes serve as useful reference line in maintaining the lateral position, as they are physically on road surface and closer to the driver's side. However, for the no licence group the general tendency is to offset to the front passenger's side. It may be because they never have received any training and are thus inexperienced with vehicle control on a real road. On the other hand, novice group and inactive group tend to have bigger offsets than the active group, both for the left and right offsets. It may be because both groups want to be closer to a reference line so that it is easier for them to track their trajectory, although it may pose a bigger risk of side-collision with adjacent vehicles. The novice and inactive groups have not well developed their ability to estimate their lateral position and safer separation distance with adjacent vehicles.

The average values of VLP and PLO for no licence are noticeably higher than the three licensed groups (active, novice and inactive). Without any prior training, a person will not have a stable lateral position control of vehicle. It shows that driving training does help to prepare drivers with basic vehicle control skills, i.e. lateral control. Among the three trained groups, the active group performed the best. It is indicated by lower average VLP and PLO values for both straight and horizontal curve segments. It shows that on-road driving experience helps drivers to improve their driving skills, i.e. lateral control. After reaching

mastery level through training, drivers experience an over-learning phase through on-road driving exposure. Over-learning helps to improve the skills and enhances their resistance against forgetting. Meanwhile, the result also shows that inactive group has bigger average values of VLP and PLO on both straight and horizontal curve segments. It suggests that inactivity from on-road driving upon licensure may result in deterioration of the driving skills that have been learned before. Inactive drivers experience deterioration of ability on estimating vehicle position and may lose the 'feeling' of controlling the vehicle. The differences are even more noticeable for PLO on horizontal curve segment, in which PLO of inactive drivers is not significantly different from those without a licence. It might be due to a more complex task of lane encroachment control, especially on horizontal curve segment, compared to lane wandering control, causing faster deterioration rate.

In conclusion, driving training helps a person to learn basic skills needed to drive on the road, i.e. vehicle control. After getting the driving licence, on-road driving gives the opportunity for the driver to practise and enhance the skills that have been learned through training. The results indicate that without any on-road exposure, some vehicle control skills, i.e. lane wandering control and lane encroachment control, may deteriorate after some periods of inactivity. The deterioration may vary for different set of skills, with more complex (e.g. lane encroachment control) tasks having faster deterioration rate. For more complex driving skills, the deterioration can result in the level of competency being relegated close to untrained level. The deterioration of driving skills is especially more sensitive for young-inexperienced driving licence holders, as the skills that they have gained may not be 'deeply rooted' yet.

Hazard perception and anticipation

Other driving related skills that are examined in the active stage is safe interaction with other road users, especially in hazardous situations. A modified hazard perception test format was used involving active control over the movement of the test vehicle. A total 131 participants, who were also involved in vehicle control assessment, participated in the experiment. However, only 91 sets of eye tracking data were usable for data analysis: 24 for active groups, 24 for novice groups, 19 for inactive groups, and 24 for no licence groups.

Interactive response latency (IRL) parameter, as well as lag time (LT) and PIEV time, shows that trained groups, especially active and novice groups, detect and respond faster than no

licence group. It shows the effect of training on the ability of drivers to handle the vehicle in response to hazardous situations. However, the differences between novice and no licence groups in most of the cases are not significant. It indicates that training alone does not affect the hazard anticipation performance significantly. Driving training programme, in Singapore, does not include intensive or specific training on hazard perception or vehicle handling under hazardous situations. Therefore, drivers may need some amount of on-road experience to sharpen their skills in responding to the hazard.

The results also suggest that driving experience and inactivity affect the ability in detecting and responding to the hazardous situations. Active drivers had shorter IRL, as well as LT and PIEV time, than the other trained groups (novice and inactive) and those who do not have a driving licence. It can be attributed to the combination of the driving training that they received and the experience that is gained by active drivers through on-road driving. As drivers gain more experience on the road, they become more familiar with driving conditions and possible hazardous situations that may occur while they are driving on the road. It helps them to strengthen their driving skills and respond faster when they encounter similar situations again, which result in the shorter decision-making process (PIEV time). Previous studies also showed that experience affects visual behaviour, in which experienced drivers scan a wider area. It helps them in detecting upcoming potential hazard faster (shorter LT). On the other hand, drivers who are inexperienced (both novice and inactive), have not gained those experiences, therefore they are less aware of the possible hazards that may occur. They are also less sensitive to the changes in the surrounding environment, since they tend to focus their eye gaze mainly on the road ahead. The inactive drivers also lose the opportunity to gain driving exposure to sharpen their hazard perception and anticipation skills. They experience deterioration of driving skills that they learn from the driving course, due to less driving exposure compared to the active drivers. It may result in less confidence in handling the vehicle and deciding what action to take when facing dangerous situations.

However, not all components of IRL are affected by experience, training and inactivity. The results for time-to-fixation (TF) show that there is no pattern or noticeable differences found among the groups. TF is related to the physiological mechanism of the movement of the eye. It is more affected by the physiological conditions of the driver/subject. Considering that all participants are in the similar age range, it is expected that their physiological conditions shall be somewhat similar, which thus results in a similar range of TF.

Limitations

Nevertheless, there are certain limitations of these experiments. The series of experiments were conducted on a driving simulator instead of real-road instrumented driving. Therefore, the simulator results would not be fully transferable to real-road driving conditions. In terms of the simulator system, it was a fixed-base system with a sports car steering wheel which, being smaller and more sensitive than a normal car steering wheel, would engender greater variability in the VLP and PLO values. It is noted that all participants went through the same setup, including an adaptation session to be familiarised with the simulator system before commencing the main experiment. The results are therefore suitable for relative comparison among the groups who underwent the simulation experiments.

7.5 Concluding remarks and recommendations

This research was started with the motivation to address the issue on driving skills retention of inactive driving licence holders, especially the young-inexperienced group, which is a common situation in Singapore due to the high cost of vehicle ownership. While many studies on skills retention have been done in field of sports and military, to the author's best knowledge, there is no study specifically addressing the issue on driving skills retention after some periods of driving inactivity. This research is aimed at finding out how on-road experience and driving inactivity would affect the driving performance and give recommendations to address the related issue.

The results from both vehicle control and hazard perception aspects suggest that post-licensing driving exposure is needed not only to retain but also to improve the driving skills. With regular practice, the skills can be strongly retained and shall last longer as well. Exposure to real road driving experience also helps to familiarise with road conditions and thus further improves and enhances the driving skills, especially for hazard perception and anticipation. For some skills that are not well covered on driving training, e.g. hazard perception and anticipation, on-road driving experience has an important role to sharpen the skills in those aspects. Meanwhile, inactivity not only prevents drivers to practise and improve their driving skills but also can cause deterioration of their driving skills. Skills that have never been used for some periods are prone to deterioration and be forgotten. The deterioration rate of every skill can be different, in which more complex skills may have faster deterioration rate. Deterioration of driving skills will then affect the driving performance and safety.

Hereby, in looking at Singapore driving populations and driving inactivity in general, authorities may consider a mandatory refresher course for driving licence holders who have been inactive for a long-term period, especially for young licensed subjects who have never ever progressed to on-road driving. It will help the drivers to refresh the skills that they have learned during licensure as well as familiarise them to the real road situations. It is to make sure that the drivers will be at least back to the level when they passed the driving licence test.

A more targeted course can be designed to deal with the most critical aspects of driving skills. The findings from this study suggests that hazard perception and anticipation is a more critical part of the driving skills, as the performance of inactive driver in this aspect can be no better than the no licence group in some cases. Therefore, the intervention for inactive drivers should be focused on this aspect. With more targeted intervention, a more cost-effective strategy can be applied to deal with the problem of inactivity. Such a refresher course can be done on driving simulator, especially when dealing with hazardous scenarios, to make sure that the drivers recover their skills before going back on-road.

The result, especially from hazard perception and anticipation aspect, also suggest that experiences have a more dominant effect on hazard perception and anticipation than driving training. It suggests the lack of content on hazard perception and anticipation in the driving training programme. Defensive driving course, which deals with driving in dangerous situations, commonly comes after licensing process and not as a mandatory component of training. Therefore, the authorities may consider to include hazard perception and anticipation course, i.e. using driving simulators, on the driving training curriculum to help in preparing the drivers on responding to hazardous situations.

This study also contributes on advancing methodology of hazard perception test by using a driving simulator. With the driving simulator, an active hazard perception test can be conducted where the participants can control the direction and speed of the vehicle during the test. This setup will better replicate the complexity and realism of driving task as compared to conventional hazard perception test where the participant only needs to watch a video without controlling the vehicle. This study also introduces a new way to analyse response latency by using eye tracker to trace the hazard response process. With this new methodology, the response latency can be further broken down into components which

represent detection and decision-making process when responding to a hazard. With this decomposition, a better understanding of the response process is obtained.

7.6 Future works

This study has focused on young driver groups who have shorter driving experience by virtue of licensure being at 18 years of age (in Singapore). The active group's driving experience ranged between two to five years, which is more restrictive than what is normally used to define an experienced driver (≥ 10 years). Although the driving skills might not further improve greatly from prolonged years of driving, it may be assumed that the effect of experience found in this research could be somewhat greater for even more experienced drivers. It is pertinent to note that this study did not include very experienced drivers (> 10 years of experience) who have stopped driving for some period. This group may have a different rate of deterioration than young-inactive drivers. In this regard, further studies can also look into the issues of an experienced driver who have stopped driving for some period.

Regarding the choice of hazardous situations for testing in this research, a set of specific scenarios involving several aspects of road safety was applied. These hazards covered various types of road users as well as different road settings. Given the versatility of simulation, driving performance can be evaluated on all manner of situations and interactions, according to types of locations (e.g. at junctions, tight turns, etc.), potential damage (e.g. severe safety of life, property damage, etc.), interaction of different user types (e.g. drivers versus cyclists, drivers versus pedestrians, etc.) and indeed, any combinations of situations and features that can be generated in the virtual reality landscape rendered to the test subjects. An important scenario for future study is that of interactions at signalised junctions where drivers' hazard perception and anticipation can be studied, given that junctions are accident hot spots in the road network.

Future research can also look into different aspects of driving task. As driving is a complex task consisting of many different sub-tasks, each task or skills may have different resistance toward deterioration caused by driving inactivity. More detailed study may help to identify the skill components that are more prone to deterioration due to driving inactivity. It can be used to design an effective driving refresher course.

The other possible future research is in the field of autonomous vehicles. With the advancement in the development of the autonomous vehicle, sometimes in the near future,

more and more autonomous vehicles shall be deployed on the roads. It shall attract more people to own and handle autonomous vehicle, including inactive drivers or maybe non-licence holders. Autonomy also leads to less active driving control, in which drivers may not use their driving skills as much as before. Although the autonomous vehicle is designed to be able to move without direct control from a human, some emergency situations may occur that may need someone to take over for human control. As found in this research, inactivity affects the ability of drivers to handle the vehicle and make the response towards hazardous situations. Future research on how driving experience, training and inactivity would affect the ability to take over the control of the autonomous vehicle, in the case of any emergency situations, might be useful for the development of safety for autonomous vehicle systems.

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BEFORE FATIGUE INDUCTION SESSION

USAFSAM MENTAL FATIGUE SCALE

Circle the number that is your best estimate of your current average mental fatigue. Use this scale:

1	2	3	4	5	6	7
Fully Alert. Wide Awake	Very lively. Responsive, but not at peak	Okay. Somewhat fresh	A Little tired. Less than fresh	Moderately tired. Let down	Extremely tired. Difficult to concentrate	Completely exhausted.

VISUAL ANALOG SCALE

Mark below on the scale from 0 to 100 your level of mental fatigue with 0 being none and 100 being extremely fatigue

MODIFIED PIPER FATIGUE SCALE

1. To what degree are you now feeling:

Strong 0 1 2 3 4 5 6 7 8 9 Weak 10

2. To what degree are you now feeling:

Awake 0 1 2 3 4 5 6 7 8 9 Sleepy 10

3. To what degree are you now feeling:

Lively 0 1 2 3 4 5 6 7 8 9 Listless 10

4. To what degree are you now feeling:

Refreshed 0 1 2 3 4 5 6 7 8 9 Tired 10

5. To what degree are you now feeling:

Energetic 0 1 2 3 4 5 6 7 8 9 Unenergetic 10

6. To what degree are you now feeling:

Patient 0 1 2 3 4 5 6 7 8 9 Impatient 10

7. To what degree are you now feeling:

Relaxed 0 1 2 3 4 5 6 7 8 9 A Great Deal 10

8. To what degree are you now feeling:

Exhilarated 0 1 2 3 4 5 6 7 8 9 Depressed 10

9. To what degree are you now feeling:

Able to Concentrate 0 1 2 3 4 5 6 7 8 9 Unable to Concentrate 10

10. To what degree are you now feeling:

Able to Remember 0 1 2 3 4 5 6 7 8 9 Unable to Remember 10

11. To what degree are you now feeling:

Able to Think Clearly 0 1 2 3 4 5 6 7 8 9 Unable to Think Clearly 10

AFTER FATIGUE INDUCTION SESSION

USAFSAM MENTAL FATIGUE SCALE

Circle the number that is your best estimate of your current average mental fatigue. Use this scale:

1	2	3	4	5	6	7
Fully Alert. Wide Awake	Very lively. Responsive, but not at peak	Okay. Somewhat fresh	A Little tired. Less than fresh	Moderately tired. Let down	Extremely tired. Difficult to concentrate	Completely exhausted.

VISUAL ANALOG SCALE

Mark below on the scale from 0 to 100 your level of mental fatigue with 0 being none and 100 being extremely fatigue

MODIFIED PIPER FATIGUE SCALE

1. To what degree are you now feeling:

Strong
0 1 2 3 4 5 6 7 8 9 Weak
10

2. To what degree are you now feeling:

Awake
0 1 2 3 4 5 6 7 8 9 Sleepy
10

3. To what degree are you now feeling:

Lively
0 1 2 3 4 5 6 7 8 9 Listless
10

4. To what degree are you now feeling:

Refreshed
0 1 2 3 4 5 6 7 8 9 Tired
10

5. To what degree are you now feeling:

Energetic
0 1 2 3 4 5 6 7 8 9 Unenergetic
10

6. To what degree are you now feeling:

Patient
0 1 2 3 4 5 6 7 8 9 Impatient
10

7. To what degree are you now feeling:

Relaxed
0 1 2 3 4 5 6 7 8 9 A Great Deal
10

8. To what degree are you now feeling:

Exhilarated
0 1 2 3 4 5 6 7 8 9 Depressed
10

9. To what degree are you now feeling:

Able to
Concentrate
0 1 2 3 4 5 6 7 8 9 Unable to
Concentrate
10

10. To what degree are you now feeling:

Able to
Remember
0 1 2 3 4 5 6 7 8 9 Unable to
Remember
10

11. To what degree are you now feeling:

Able to
Think Clearly
0 1 2 3 4 5 6 7 8 9 Unable to
Think Clearly
10

APPENDIX B: Questionnaire for active control driving assessment

**NANYANG
TECHNOLOGICAL
UNIVERSITY**

Questionnaire on Driving Frequency

+

Age: _____ Gender: F/M Citizenship: ☐ Singaporean ☐ PR ☐ Others: _____

Do you have any Singapore valid driving licence? ☐ Yes, class: _____ ☐ No

How long have you hold your Singapore driving licence? _____ years

Do you have any other country valid driving licence? ☐ Yes, where: _____ ☐ No

How long have you hold you're the other country licence? _____ years

How long it takes from the time you got your driving licence until your first driving?

☐ Few days ☐ Few weeks ☐ _____ months ☐ _____ years ☐ Never drive

How long have you actively driving?

☐ Few days ☐ Few weeks ☐ _____ months ☐ _____ years ☐ Never drive

When is the last time you drive?

☐ Today ☐ ____ days ago ☐ ____ weeks ago ☐ ____ months ago ☐ ____ years ago ☐ Never

In past 5 years, how often do you drive a car or other motor vehicle?

☐ Almost everyday ☐ A few days a week ☐ A few days a month ☐ A few days a year ☐ Never

In past 5 years, how many kilometres do you drive every year, in average?

☐ <5,000 ☐ 5,001 – 10,000 ☐ 10,001 – 15,000 ☐ 15,001 – 20,000 ☐ 20,001 – 25,000 ☐ >25,000

In your opinion, do you think it is an issue/problem if someone who have not driven for long period back to drive again?

☐ Very serious problem ☐ major problem ☐ problem ☐ minor problem ☐ Not a problem at all

In your opinion, which component will degraded the most when someone not driving for long period?

☐ Steering skills ☐ Pedal control ☐ Familiarity with road situation ☐ Road hazard recognition ☐ Others: _____

In your opinion, how important is refresher course for someone who did not drive for a long period?

☐ Extremely important ☐ Very important ☐ Moderately important ☐ Slightly important ☐ Not important at all

How many hours did you sleep last night? _____ hours

Did you drink any caffeine (e.g. tea, coffee) in 24 hours? ☐ No ☐ Yes, at _____ hours before

Did you drink any energy drink on the last 24 hours? ☐ No ☐ Yes, at _____ hours before

Please indicate the activities that you have been done today, from the time you wake up until now. ☐

Time	Activity Description

USAFSAM FATIGUE SCALE

Circle the number that is your best estimate of your current general fatigue condition, on 1-7 scale.

1	2	3	4	5	6	7
Fully Alert. Wide Awake	Very lively. Responsive, but not at peak	Okay. Somewhat fresh	A Little tired. Less than fresh	Moderately tired. Let down	Extremely tired. Difficult to concentrate	Completely exhausted

MODIFIED PIPER FATIGUE SCALE

For each of the following questions, fill in the circle indicating the number that best describes the fatigue you are experiencing now, on 0 – 10 scales. If you are not experiencing fatigue now, fill in the circle indicating '0' for your response.

1. To what degree are you now feeling:

Strong
☒ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 Weak

2. To what degree are you now feeling:

Awake
☒ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 Sleepy

3. To what degree are you now feeling:

Lively
☒ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 Listless

4. To what degree are you now feeling:

Refreshed
☒ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 Tired

5. To what degree are you now feeling:

Energetic
☒ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 Unenergetic

6. To what degree are you now feeling:

Patient
☒ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 Impatient

7. To what degree are you now feeling:

Relaxed
☒ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 A Great Deal

8. To what degree are you now feeling:

Exhilarated
☒ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 Depressed

9. To what degree are you now feeling:

Able to Concentrate
☒ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 Unable to Concentrate

10. To what degree are you now feeling:

Able to Remember
☒ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 Unable to Remember

11. To what degree are you now feeling:

Able to Think Clearly
☒ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 Unable to Think Clearly

Post-Experiment Questionnaire

Are you prone to motion sickness?

☐ Carsickness ☐ Airsickness ☐ Seasickness ☐ No

Do you feel uncomfortable/ sick after taken the driver assessment test?

☐ Yes ☐ No

If yes, does it affect your driving? ☐ Yes ☐ No

How realistic do you feel is this driving simulator compared to real road driving?

Not Realistic at all Very Realistic
1 2 3 4 5

How hard do you find the simulator to get adapt with?

Very Easy Very Hard
1 2 3 4 5

Please rank these parts in driving simulation, from the one do you think is the easiest to get adapt with to the hardest, 1 for the easiest, 3 for the hardest.

☐ Steering wheels ☐ Pedals ☐ Vision

Please rank these parts real life driving, from the one do you think is the easiest to deal with to the hardest, 1 for the easiest, 3 for the hardest.

☐ Steering control ☐ Pedals control ☐ interacting with other road users

In which aspect do you think that this simulator can be further improve in order to feel more realistic?

Hazardous Scenario

Scenario 1

Did you experience this scenario during the experiment? ☐ Yes ☐ No (Go to Scenario 2)

☐ How dangerous do you find this scenario?

Not dangerous

Very dangerous

1

2

3

4

5

How expected do you find this scenario to happen?

Unexpected at all

Very expected

1

2

3

4

5

How mentally demanding was this hazard?

Very Low

Very High

1

2

3

4

5

How physically demanding was the hazard?

Very Low

Very High

1

2

3

4

5

How hurried or rushed was the pace of the hazard?

Very Low

Very High

1

2

3

4

5

How successful were you in accomplishing the task (avoiding the hazard)?

Perfect

Failure

1

2

3

4

5

How hard did you have to work to accomplish your level of performance (in avoiding the hazard)?

Very Low

Very High

1

2

3

4

5

How insecure, discouraged, irritated, stressed and annoyed were you?

Very Low

Very High

1

2

3

4

5

Do you have any other comments on this hazard?

Scenario 2

Did you experience this scenario during the experiment? ☐ Yes ☐ No (Go to Scenario 3)

How dangerous do you find this scenario?

Not dangerous

1

2

3

4

Very dangerous

5

How expected do you find this scenario to happen?

Unexpected at all

1

2

3

4

Very expected

5

How mentally demanding was this hazard?

Very Low

1

2

3

4

Very High

5

How physically demanding was the hazard?

Very Low

1

2

3

4

Very High

5

How hurried or rushed was the pace of the hazard?

Very Low

1

2

3

4

Very High

5

How successful were you in accomplishing the task (avoiding the hazard)?

Perfect

1

2

3

4

Failure

5

How hard did you have to work to accomplish your level of performance (in avoiding the hazard)?

Very Low

1

2

3

4

Very High

5

How insecure, discouraged, irritated, stressed and annoyed were you?

Very Low

1

2

3

4

Very High

5

Do you have any other comments on this hazard?

Scenario 3

Did you experience this scenario during the experiment? ☐ Yes ☐ No (Go to Scenario 4)

How dangerous do you find this scenario?

Not dangerous

Very dangerous

1

2

3

4

5

How expected do you find this scenario to happen?

Unexpected at all

Very expected

1

2

3

4

5

How mentally demanding was this hazard?

Very Low

Very High

1

2

3

4

5

How physically demanding was the hazard?

Very Low

Very High

1

2

3

4

5

How hurried or rushed was the pace of the hazard?

Very Low

Very High

1

2

3

4

5

How successful were you in accomplishing the task (avoiding the hazard)?

Perfect

Failure

1

2

3

4

5

How hard did you have to work to accomplish your level of performance (in avoiding the hazard)?

Very Low

Very High

1

2

3

4

5

How insecure, discouraged, irritated, stressed and annoyed were you?

Very Low

Very High

1

2

3

4

5

Do you have any other comments on this hazard?

Scenario 4

Did you experience this scenario during the experiment? ☐ Yes ☐ No

How dangerous do you find this scenario?

Not dangerous

1

2

3

4

5

Very dangerous

How expected do you find this scenario to happen?

Unexpected at all

1

2

3

4

5

Very expected

How mentally demanding was this hazard?

Very Low

1

2

3

4

5

Very High

How physically demanding was the hazard?

Very Low

1

2

3

4

5

Very High

How hurried or rushed was the pace of the hazard?

Very Low

1

2

3

4

5

Very High

How successful were you in accomplishing the task (avoiding the hazard)?

Perfect

1

2

3

4

5

Failure

How hard did you have to work to accomplish your level of performance (in avoiding the hazard)?

Very Low

1

2

3

4

5

Very High

How insecure, discouraged, irritated, stressed and annoyed were you?

Very Low

1

2

3

4

5

Very High

Do you have any other comments on this hazard?

Simulator Sickness Questionnaires

Please rate the symptoms of sickness that you experienced during the simulation. Tick in the corresponding boxes

Symptoms of sickness	<i>None</i>	<i>Mild</i>	<i>Moderate</i>	<i>Severe</i>
General Discomfort				
Fatigue				
Headache				
Eyestrain				
Difficulty Focusing				
Increased Salivation				
Sweating				
Nausea				
Difficulty Concentrating				
Fullness of Head				
Blurred Vision				
Dizzy with eyes open				
Dizzy with eyes closed				
Vertigo (spinning head)				
Stomach Awareness				

APPENDIX C: Raw data of experiments

C.1 Response latency RL passive mode hazard perception test

	A1	A2	A3	A4
No License (n= 14)	01.83	01.73	01.16	01.47
	01.83	01.50	01.43	00.93
	01.07	01.47	01.53	01.63
	00.90	01.17	01.33	00.80
	01.36	01.13	01.16	01.37
	02.13	01.20	01.20	01.00
	01.80	01.53	01.16	01.13
	01.01	01.60	01.74	00.93
	01.80	00.90	00.91	00.70
	00.70	00.60	00.70	00.47
	00.44	01.23	00.66	00.47
	00.50	00.70	01.10	00.87
	00.60	00.57	01.06	00.37
	00.54	00.94	01.10	00.87
Inactive (n = 10)	02.13	01.13	01.17	01.00
	01.97	02.43	01.11	01.47
	00.77	01.43	00.97	00.93
	01.33	01.47	00.90	00.80
	01.87	01.47	01.47	00.93
	01.13	01.43	01.40	00.87
	01.10	01.33	01.27	00.73
	00.60	00.60	00.67	00.40
	00.96	00.97	01.06	00.56
	01.81	01.10	01.11	00.60
Active (n=14)	00.77	01.43	01.10	00.90
	01.30	01.47	00.90	00.80
	00.70	01.10	01.33	00.83
	01.13	01.43	01.43	00.97
	00.85	01.40	01.77	01.10
	00.87	01.13	01.33	00.80
	00.77	01.07	01.33	00.80
	00.43	00.64	01.12	00.44
	00.85	01.24	01.06	00.84
	00.74	01.18	01.07	00.53
	01.54	00.91	00.97	00.80
	00.61	01.18	00.50	00.43
	00.33	01.57	00.77	00.30
	01.00	00.81	01.01	00.43

C.2 Vehicle control performance on overall journey

No	Group	Year_In	Month_In	Speed Variability	stdev	Speed Violation	Average speed	Lateral variability	Average offset to Left	Average offset to right	Average lateral position	Exceeding safety band	CI	Var CI	2SD	R bound	L Bound
2	A	0	0	8.69	2.95	0.02	76.17	0.09	-0.22	0.28	0.13	0.01	-0.07	0.03	0.32	0.00	0.00
6	A	0	0	45.66	6.76	0.00	68.26	0.38	-0.38	0.67	0.35	0.23	-0.19	0.11	0.66	0.19	0.03
9	A	0	0	8.26	2.87	0.00	72.32	0.48	-0.47	0.57	0.07	0.17	-0.04	0.14	0.75	0.11	0.05
18	A	0	0	24.50	4.95	0.18	76.27	0.41	-0.61	0.30	-0.38	0.11	-0.02	0.12	0.69	0.00	0.13
25	A	0	0	9.76	3.12	0.07	74.10	0.11	-0.24	0.38	0.24	0.02	-0.13	0.03	0.18	0.02	0.00
27	A	0	0	37.01	6.08	0.06	75.73	0.30	-0.47	0.35	-0.08	0.06	0.04	0.09	0.29	0.03	0.07
29	A	0	0	11.03	3.32	0.08	76.25	0.49	-0.59	0.57	0.03	0.21	-0.03	0.17	0.41	0.10	0.11
30	A	0	0	106.48	10.32	0.23	71.43	0.21	-0.29	0.47	0.24	0.08	-0.13	0.06	0.25	0.61	0.02
31	A	0	0	7.11	2.67	0.24	78.38	0.25	-0.43	0.38	-0.05	0.06	0.03	0.07	0.27	0.03	0.03
33	A	0	0	48.41	6.96	0.41	80.23	0.24	-0.39	0.40	0.09	0.07	-0.05	0.07	0.27	0.04	0.04
41	A	0	0	7.16	2.68	0.33	79.53	0.11	-0.29	0.18	-0.10	0.02	0.05	0.31	0.56	0.00	0.02
42	A	0	0	5.34	2.31	0.09	77.73	0.10	-0.32	0.20	-0.18	0.01	0.10	0.03	0.17	0.00	0.01
45	A	0	0	37.08	6.09	0.34	78.44	0.24	-0.42	0.38	-0.19	0.09	0.10	0.07	0.27	0.02	0.07
49	A	0	0	8.61	2.93	0.00	72.01	0.11	-0.44	0.20	-0.35	0.04	0.19	0.03	0.18	0.00	0.04
50	A	0	0	3.79	1.95	0.03	77.29	0.23	-0.34	0.43	0.08	0.05	-0.05	0.07	0.26	0.04	0.01
51	A	0	0	12.97	3.60	0.00	72.82	0.18	-0.38	0.32	-0.21	0.05	0.11	0.05	0.23	0.01	0.04
55	A	0	0	1.88	1.37	0.02	77.91	0.05	-0.16	0.18	0.05	0.00	-0.03	0.01	0.12	0.00	0.00
56	A	0	0	30.74	5.54	0.08	72.03	0.23	-0.44	0.32	-0.15	0.09	0.08	0.07	0.26	0.01	0.07
67	A	0	0	12.72	3.57	0.28	77.20	0.21	-0.28	0.47	0.22	0.05	-0.12	0.06	0.25	0.04	0.01
68	A	0	0	2.56	1.60	0.23	78.72	0.18	-0.27	0.48	0.35	0.07	-0.19	0.05	0.23	0.06	0.00
71	A	0	0	10.81	3.29	0.15	75.81	0.26	-0.34	0.49	0.11	0.07	-0.06	0.08	0.28	0.06	0.01
73	A	0	0	9.52	3.09	0.45	78.52	1.01	-0.25	0.75	0.48	0.15	-0.16	0.30	0.54	0.14	0.01

No	Group	Year_In	Month_In	Speed Variability	stdev	Speed Violation	Average speed	Lateral variability	Average offset to Left	Average offset to right	Average lateral position	Exceeding safety band	CI	Var CI	2SD	R bound	L Bound
81	A	0	0	21.28	4.61	0.09	71.45	0.59	-0.67	0.54	-0.31	0.27	0.28	0.16	0.40	0.01	0.25
111	A	0	0	4.07	2.02	0.12	78.22	0.05	-0.19	0.19	-0.04	0.00	0.02	0.02	0.13	0.00	0.00
112	A	0	0	37.01	6.08	0.06	75.73	0.29	-0.48	0.34	-0.09	0.10	0.05	0.09	0.29	0.03	0.07
113	A	0	0	26.48	5.15	0.22	76.93	0.11	-0.29	0.50	0.41	0.04	-0.22	0.03	0.18	0.41	0.00
114	A	0	0	22.84	4.78	0.33	77.87	0.07	-0.11	0.44	0.41	0.03	-0.22	0.02	0.14	0.03	0.00
115	A	0	0	8.04	2.84	0.09	76.94	0.26	-0.48	0.35	-0.19	0.08	0.10	0.08	0.28	0.01	0.07
116	A	0	0	13.09	3.62	0.28	77.93	0.18	-0.41	0.26	-0.14	0.05	0.08	0.05	0.23	0.01	0.04
117	A	0	0	34.81	5.90	0.26	76.12	0.29	-0.56	0.35	-0.32	0.18	0.17	0.08	0.29	0.02	0.16
118	A	0	0	16.59	4.07	0.59	79.93	0.15	-0.24	0.32	0.14	0.03	-0.08	0.04	0.21	0.02	0.01
119	A	0	0	8.95	2.99	0.65	80.76	0.21	-0.38	0.34	0.01	0.06	-0.01	0.06	0.25	0.04	0.02
120	A	0	0	1.78	1.33	0.00	76.43	0.05	-0.15	0.51	0.49	0.05	-0.26	0.02	0.15	0.05	0.00
121	A	0	0	9.81	3.13	0.28	78.16	0.26	-0.44	0.42	-0.04	0.06	0.02	0.08	0.28	0.03	0.04
122	A	0	0	20.34	4.51	0.04	72.20	0.33	-0.35	0.69	0.48	0.27	-0.26	0.10	0.31	0.26	0.02
123	A	0	0	3.81	1.95	0.00	74.25	0.23	-0.37	0.60	0.48	0.18	-0.26	0.07	0.26	0.18	0.01
15	B	0.25	3	29.44	5.43	0.02	74.51	0.08	-0.21	0.25	0.03	0.00	0.22	0.02	0.31	0.00	0.00
17	B	0.166667	2	15.40	3.92	0.17	75.99	0.25	-0.36	0.61	0.46	0.19	0.11	0.07	0.54	0.18	0.01
19	B	0.25	3	8.95	2.99	0.17	77.68	0.21	-0.43	0.32	-0.20	0.05	0.01	0.06	0.49	0.01	0.04
23	B	0.083333	1	16.22	4.03	0.07	74.45	0.29	-0.69	0.23	-0.58	0.23	0.21	0.09	0.58	0.00	0.22
24	B	0	0	25.75	5.07	0.50	78.98	0.20	-0.34	0.37	0.06	0.05	-0.25	0.06	0.48	0.03	0.13
28	B	0	0	33.32	5.77	0.00	73.36	0.33	-0.39	0.52	0.14	0.14	-0.07	0.10	0.31	0.08	0.05
35	B	0	0	9.80	3.13	0.00	71.95	0.17	-0.49	0.23	-0.27	0.05	0.15	0.05	0.22	0.00	0.05
39	B	0.166667	2	53.38	7.31	0.10	68.74	0.23	-0.46	0.30	-0.13	0.08	0.07	0.07	0.26	0.02	0.06
46	B	0	0	4.73	2.17	0.01	75.32	0.16	-0.20	0.46	0.28	0.07	-0.15	0.05	0.22	0.06	0.00

No	Group	Year_In	Month_In	Speed Variability	stdev	Speed Violation	Average speed	Lateral variability	Average offset to Left	Average offset to right	Average lateral position	Exceeding safety band	CI	Var CI	2SD	R bound	L Bound
62	B	0.25	3	25.17	5.02	0.00	69.37	0.61	-0.65	0.50	-0.14	0.21	0.07	0.18	0.42	0.08	0.13
66	B	0	0	24.92	4.99	0.18	76.30	0.20	-0.31	0.38	0.15	0.04	-0.08	0.06	0.24	0.02	0.02
70	B	0.083333	1	3.19	1.79	0.09	77.89	0.15	-0.24	0.37	0.11	0.03	-0.06	0.04	0.21	0.03	0.00
74	B	0	0	37.95	6.16	0.02	70.85	0.20	-0.51	0.32	-0.34	0.09	0.19	0.06	0.24	0.01	0.08
75	B	0	0	25.20	5.02	0.04	71.28	0.27	-0.51	0.36	-0.30	0.14	0.16	0.08	0.28	0.02	0.12
77	B	0.166667	2	24.59	4.96	0.00	69.48	0.17	-0.22	0.58	0.47	0.12	-0.25	0.05	0.22	0.11	0.00
83	B	0.25	3	18.45	4.30	0.40	79.96	0.40	-0.44	0.50	0.00	0.15	0.00	0.12	0.34	0.08	0.07
86	B	0.25	3	89.74	9.47	0.33	75.76	0.57	-0.75	0.53	-0.36	0.31	0.19	0.17	0.41	0.06	0.24
93	B	0.25	3	18.79	4.34	0.01	71.64	0.56	-0.59	0.64	-0.01	0.25	0.01	0.16	0.40	0.13	0.12
102	B	0	0	35.58	5.97	0.10	72.19	0.08	-0.20	0.32	0.22	0.01	-0.12	0.02	0.16	0.01	0.00
104	B	0.167	2	7.40	2.72	0.14	77.14	0.16	-0.33	0.65	0.62	0.15	-0.33	0.05	0.22	0.15	0.00
106	B	0	0	26.04	5.10	0.02	70.68	0.50	-0.44	0.71	0.35	0.27	-0.19	0.15	0.38	0.23	0.04
107	B	0	0	24.59	4.96	0.02	72.03	0.18	-0.46	0.25	-0.19	0.09	0.16	0.05	0.23	0.00	0.09
108	B	0	0	9.09	3.01	0.11	75.80	0.19	-0.37	0.31	-0.10	0.06	0.06	0.06	0.24	0.02	0.04
109	B	0	0	47.60	6.90	0.00	67.46	0.30	-0.43	0.49	0.05	0.09	-0.02	0.09	0.30	0.06	0.03
125	B	0.083333	1	10.49	3.24	0.21	77.05	0.20	-0.41	0.30	-0.11	0.04	0.06	0.06	0.24	0.01	0.03
126	B	0	0	5.74	2.40	0.18	74.36	0.42	-0.47	0.50	0.06	0.18	-0.03	0.12	0.35	0.10	0.08
127	B	0	0	52.10	7.22	0.00	63.95	0.12	-0.32	0.21	-0.16	0.48	0.36	0.60	0.77	0.11	0.38
129	B	0.083333	1	34.72	5.89	0.00	67.44	0.22	-0.57	0.25	-0.40	0.14	0.22	0.06	0.25	0.00	0.14
130	B	0.166667	2	41.35	6.43	0.19	74.26	0.36	-0.59	0.38	-0.24	0.18	0.13	0.10	0.32	0.01	0.17
1	B-	0.5	6	10.36	3.22	0.31	79.04	0.23	-0.54	0.44	-0.40	0.11	0.41	0.07	0.52	0.02	0.09
5	B-	1	12	20.95	4.58	0.00	61.99	0.29	-0.42	0.52	-0.02	0.14	-0.04	0.10	0.64	0.11	0.04

No	Group	Year_In	Month_In	Speed Variability	stdev	Speed Violation	Average speed	Lateral variability	Average offset to Left	Average offset to right	Average lateral position	Exceeding safety band	CI	Var CI	2SD	R bound	L Bound
7	B-	0.5	6	16.72	4.09	0.44	78.37	0.59	-0.88	0.18	-0.75	0.31	0.09	0.17	0.83	0.00	0.31
8	B-	6	72	29.01	5.39	0.00	70.58	0.49	-0.64	0.51	-0.17	0.24	0.17	0.14	0.76	0.06	0.17
10	B-	0.583333	7	20.55	4.53	0.25	77.38	0.36	-0.49	0.45	-0.14	0.12	-0.50	0.10	0.65	0.05	0.07
12	B-	1	12	82.60	9.09	0.92	93.71	1.24	-0.90	0.93	0.34	0.43	0.08	0.36	1.20	0.31	0.11
13	B-	0.5	6	10.18	3.19	0.05	74.33	2.15	-1.14	1.52	0.93	0.68	0.07	0.63	1.59	0.58	0.10
14	B-	3	36	105.90	10.29	0.07	64.69	0.37	-0.46	0.52	0.08	0.14	0.07	0.11	0.66	0.08	0.06
20	B-	0.5	6	5.46	2.34	0.05	76.41	0.17	-0.41	0.26	-0.14	0.04	-0.18	0.05	0.45	0.00	0.03
26	B-	2	24	100.82	10.04	0.07	66.60	0.12	-0.30	0.22	-0.03	0.01	0.02	0.03	0.18	0.00	0.01
34	B-	0.5	6	7.51	2.74	0.09	76.92	0.12	-0.24	0.33	0.14	0.02	-0.07	0.04	0.19	0.02	0.00
36	B-	0.666667	8	70.92	8.42	0.66	82.60	0.52	-0.43	0.79	0.52	0.34	-0.28	0.15	0.39	0.32	0.02
43	B-	0.5	6	10.22	3.20	0.14	76.42	0.19	-0.47	0.27	-0.26	0.06	0.14	0.05	0.23	0.00	0.06
47	B-	1	12	10.53	3.24	0.06	75.09	0.22	-0.37	0.34	-0.07	0.06	0.04	0.06	0.25	0.02	0.04
48	B-	1	12	6.33	2.52	0.03	74.89	0.50	-0.70	0.45	0.50	0.23	0.14	0.15	0.38	0.05	0.18
52	B-	0.5	6	21.43	4.63	1.00	88.41	0.22	-0.44	0.35	0.12	0.08	-0.07	0.06	0.25	0.03	0.05
63	B-	1	12	20.20	4.49	0.16	77.25	0.35	-0.39	0.65	0.42	0.26	-0.23	0.10	0.32	0.24	0.02
64	B-	0.5	6	2.92	1.71	0.09	77.71	0.15	0.23	0.38	0.20	0.04	-0.11	0.04	0.21	0.04	0.00
65	B-	1	12	19.45	4.41	0.48	78.72	0.30	-0.35	0.52	0.24	0.12	-0.13	0.09	0.30	0.11	0.01
79	B-	1.5	18	26.70	5.17	0.00	64.60	0.43	-0.52	0.52	-0.05	0.17	0.03	0.13	0.36	0.07	0.11
82	B-	2	24	9.54	3.09	0.00	71.51	0.25	-0.36	0.56	0.37	0.14	-0.20	0.07	0.27	0.11	0.02
85	B-	0.5	6	54.75	7.40	0.03	68.57	0.47	-0.60	0.51	-0.07	0.23	0.04	0.14	0.37	0.08	0.15
88	B-	1	12	21.35	4.62	0.00	62.76	0.18	-0.30	0.34	0.00	0.04	0.00	0.05	0.23	0.02	0.02
98	B-	1	12	3.83	1.96	0.06	77.34	0.73	-0.62	0.83	0.30	0.36	-0.16	0.21	0.46	0.26	0.10
99	B-	0.5	6	40.07	6.33	0.01	71.02	0.21	-0.38	0.40	0.16	0.06	-0.09	0.06	0.25	0.04	0.02

No	Group	Year_In	Month_In	Speed Variability	stdev	Speed Violation	Average speed	Lateral variability	Average offset to Left	Average offset to right	Average lateral position	Exceeding safety band	CI	Var CI	2SD	R bound	L Bound
105	B-	1	12	10.81	3.29	0.63	81.13	0.40	-0.85	0.32	-0.76	0.40	0.41	0.12	0.34	0.00	0.39
110	B-	0.833	10	18.99	4.36	0.12	73.59	0.15	-0.36	0.29	-0.08	0.03	0.04	0.04	0.21	0.00	0.03
124	B-	1.5	18	36.72	6.06	0.15	74.20	0.39	-0.46	0.59	0.09	0.18	-0.05	0.11	0.34	0.13	0.05
128	B-	0.5	6	36.73	6.06	0.38	78.43	0.58	-0.70	0.51	-0.17	0.26	0.09	0.17	0.41	0.07	0.19
131	B-	1	12	21.76	4.66	0.02	72.48	0.17	-0.36	0.29	-0.10	0.03	-0.05	0.05	0.22	0.01	0.02
132	B-	1	12	14.38	3.79	0.41	78.03	0.52	-0.61	0.61	0.61	0.23	0.03	0.15	0.39	0.13	0.11
3	C	-	-	39.37	6.27	0.20	72.21	0.37	-0.53	0.50	-0.13	0.17	0.03	0.11	0.33	0.04	0.11
4	C	-	-	73.26	8.56	0.00	62.01	0.50	-0.69	0.52	-0.32	0.29	1.20	0.14	0.38	0.05	0.22
11	C	-	-	7.56	2.75	0.02	73.99	0.58	-0.67	0.56	-0.05	0.24	0.01	0.16	0.40	0.10	0.14
16	C	-	-	15.46	3.93	0.06	73.39	5.73	-3.17	1.00	-2.21	0.45	0.23	1.67	1.29	0.10	0.65
21	C	-	-	16.79	4.10	0.78	80.13	0.19	-0.35	0.31	-0.02	0.06	0.31	0.06	0.24	0.03	0.03
22	C	-	-	8.24	2.87	0.05	76.04	0.71	-0.76	0.70	-0.42	0.32	-0.03	0.21	0.46	0.06	0.27
32	C	-	-	17.16	4.14	0.14	76.46	0.55	-0.62	0.58	0.05	0.21	-0.03	0.16	0.40	0.09	0.12
37	C	-	-	2.82	1.68	0.04	76.40	0.35	-0.62	0.29	-0.32	0.17	0.17	0.10	0.32	0.00	0.16
38	C	-	-	3.84	1.96	0.02	76.26	0.28	-0.50	0.38	-0.13	0.08	0.07	0.08	0.29	0.03	0.06
40	C	-	-	22.70	4.76	0.69	80.60	1.09	-0.92	0.66	-0.51	0.34	0.27	0.32	0.56	0.06	0.28
44	C	-	-	55.37	7.44	0.31	76.37	1.98	-0.95	1.26	0.05	0.48	-0.03	0.58	0.76	0.25	0.23
53	C	-	-	16.10	4.01	0.17	76.75	1.18	-1.08	0.68	-0.42	0.46	0.23	0.35	0.59	0.12	0.35
54	C	-	-	27.34	5.23	0.05	73.47	0.19	-0.62	0.19	-0.53	0.18	0.29	0.06	0.24	0.00	0.18
57	C	-	-	67.37	8.21	0.06	69.03	0.32	-0.55	0.35	-0.25	0.16	0.14	0.09	0.31	0.02	0.14
58	C	-	-	70.86	8.42	0.00	65.40	1.93	-1.24	0.79	-0.46	0.49	0.25	0.56	0.75	0.14	0.35
59	C	-	-	24.95	4.99	0.10	73.18	0.41	-0.67	0.37	-0.35	0.26	0.19	0.12	0.35	0.03	0.24
60	C	-	-	2.97	1.72	0.00	73.07	0.35	-0.48	0.50	0.01	0.13	0.00	0.10	0.32	0.07	0.06
61	C	-	-	3.40	1.84	0.08	78.27	0.17	-0.31	0.41	0.20	0.04	-0.11	0.05	0.22	0.03	0.01

No	Group	Year_In	Month_In	Speed Variability	stdev	Speed Violation	Average speed	Lateral variability	Average offset to Left	Average offset to right	Average lateral position	Exceeding safety band	CI	Var CI	2SD	R bound	L Bound
69	C	-	-	3.36	1.83	0.05	76.87	0.41	-0.52	0.43	-0.04	0.12	0.02	0.12	0.34	0.04	0.08
76	C	-	-	111.69	10.57	0.09	63.30	1.55	-0.94	0.98	0.15	0.41	-0.08	0.45	0.67	0.24	0.17
78	C	-	-	44.30	6.66	0.40	77.62	1.82	-0.87	1.14	-0.28	0.38	0.15	0.53	0.73	0.07	0.31
80	C	-	-	46.00	6.78	0.02	71.74	0.22	-0.33	0.41	0.07	0.02	-0.04	0.06	0.25	0.00	0.02
84	C	-	-	49.93	7.07	0.26	76.32	0.62	-0.57	0.76	0.29	0.33	-0.16	0.18	0.43	0.26	0.08
87	C	-	-	7.37	2.72	0.03	76.80	0.71	-0.69	0.70	0.06	0.32	-0.03	0.21	0.46	0.18	0.14
89	C	-	-	6.40	2.53	0.00	69.85	0.94	-0.78	0.85	0.34	0.38	-0.18	0.27	0.52	0.26	0.12
90	C	-	-	3.48	1.87	0.03	76.25	0.67	-0.71	0.59	0.00	0.28	0.00	0.20	0.44	0.13	0.15
91	C	-	-	13.00	3.61	0.05	75.55	0.37	-0.56	0.40	-0.13	0.14	0.68	0.11	0.33	0.03	0.11
92	C	-	-	13.86	3.72	0.02	73.00	0.51	-0.57	0.53	0.05	0.22	-0.03	0.15	0.39	0.12	0.10
94	C	-	-	56.54	7.52	0.01	66.38	0.37	-0.50	0.46	-0.05	0.14	0.02	0.11	0.33	0.06	0.07
95	C	-	-	25.36	5.04	0.00	69.71	0.62	-0.61	0.61	0.03	0.23	-0.02	0.18	0.43	0.13	0.09
96	C	-	-	45.96	6.78	0.23	74.65	0.81	-0.69	0.75	-0.10	0.29	0.05	0.24	0.49	0.10	0.19
97	C	-	-	34.91	5.91	0.05	71.43	0.51	-0.35	0.72	0.37	0.23	-0.20	0.15	0.38	0.21	0.02
100	C	-	-	45.98	6.78	0.14	76.67	9.38	-2.98	1.86	-0.76	0.76	0.41	2.74	1.66	0.33	0.44
101	C	-	-	98.62	9.93	0.16	75.17	0.65	-0.71	0.59	-0.05	0.28	0.03	0.19	0.44	0.11	0.17
103	C	-	-	11.23	3.35	0.09	75.92	0.96	-0.89	0.81	0.24	0.41	-0.13	0.28	0.53	0.27	0.14

C.3 Vehicle control performance on straight segment

No	Group	Year of inactivity	Month of Inactivity	Speed Variability	stdev	Speed Violation	Average speed	Lateral variability	Average offset to Left	Average offset to right	Average lateral position	Exceeding safety band	CI	Var CI	2SD	R bound	L Bound
6	A	0	0	11.51	3.39	0.10	74.76	0.10	-0.20	0.38	0.26	0.02	-0.14	0.03	0.34	0.02	0.00
7	A	0	0	11.79	3.43	0.04	76.11	0.21	-0.37	0.35	0.04	0.06	-0.02	0.06	0.49	0.04	0.03
9	A	0	0	9.25	3.04	0.07	76.70	0.38	-0.48	0.54	0.05	0.14	-0.03	0.11	0.67	0.07	0.07
12	A	0	0	51.27	7.16	0.46	81.93	0.23	-0.42	0.38	0.07	0.07	-0.04	0.07	0.52	0.03	0.04
17	A	0	0	3.59	1.89	0.36	79.19	0.07	-0.23	0.16	-0.06	0.01	0.03	0.02	0.29	0.00	0.01
20	A	0	0	38.68	6.22	0.44	79.86	0.21	-0.37	0.35	-0.14	0.07	0.07	0.06	0.49	0.01	0.06
26	A	0	0	17.95	4.24	0.27	76.82	0.49	-0.63	0.28	-0.41	0.13	0.22	0.14	0.76	0.00	0.13
27	A	0	0	4.37	2.09	0.11	77.97	0.10	-0.33	0.18	-0.18	0.02	0.10	0.03	0.34	0.00	0.01
28	A	0	0	4.41	2.10	0.17	78.48	0.18	-0.40	0.33	-0.09	0.03	0.05	0.05	0.46	0.01	0.02
30	A	0	0	7.65	2.77	0.00	71.78	0.10	-0.44	0.21	-0.35	0.03	0.19	0.03	0.35	0.00	0.03
37	A	0	0	2.45	1.56	0.00	77.68	0.18	-0.24	0.44	0.21	0.06	-0.11	0.05	0.46	0.06	0.00
38	A	0	0	8.60	2.93	0.00	72.19	0.31	-0.41	0.50	0.07	0.12	-0.04	0.09	0.60	0.09	0.03
43	A	0	0	8.29	2.88	0.00	74.11	0.12	-0.35	0.32	0.23	0.03	0.12	0.04	0.38	0.00	0.03
44	A	0	0	9.13	3.02	0.04	76.83	0.07	-0.19	0.29	0.17	0.00	-0.09	0.02	0.29	0.00	0.00
47	A	0	0	95.26	9.76	0.23	72.28	0.17	-0.25	0.48	0.30	0.05	-0.16	0.05	0.44	0.05	0.00
49	A	0	0	18.99	4.36	0.00	68.70	0.36	-0.37	0.62	0.27	0.19	-0.15	0.11	0.65	0.16	0.03
55	A	0	0	1.97	1.40	0.27	77.92	0.03	-0.12	0.16	0.08	0.00	-0.04	0.01	0.19	0.00	0.00
56	A	0	0	23.54	4.85	0.11	73.77	0.19	-0.37	0.29	-0.08	0.06	0.04	0.06	0.47	0.01	0.42
67	A	0	0	11.49	3.39	0.20	77.36	0.17	-0.28	0.44	0.20	0.03	-0.11	0.05	0.45	0.03	0.01
68	A	0	0	2.85	1.69	0.25	78.65	0.15	-0.30	0.48	0.40	0.07	-0.22	0.04	0.42	0.07	0.00
71	A	0	0	8.57	2.93	0.17	76.58	0.23	-0.35	0.45	0.12	0.05	-0.06	0.07	0.52	0.04	0.01
73	A	0	0	9.05	3.01	0.53	78.66	1.30	-0.16	0.86	0.63	0.18	-0.34	0.38	1.23	0.18	0.00

No	Group	Year of inactivity	Month of Inactivity	Speed Variability	stdev	Speed Violation	Average speed	Lateral variability	Average offset to Left	Average offset to right	Average lateral position	Exceeding safety band	CI	Var CI	2SD	R bound	L Bound
81	A	0	0	23.94	4.89	0.13	72.02	0.62	-0.88	0.31	-0.65	0.32	0.35	0.18	0.85	0.00	0.32
111	A	0	0	3.59	1.89	0.11	77.78	0.05	-0.19	0.19	-0.04	0.00	0.02	0.02	0.25	0.00	0.00
112	A	0	0	11.79	3.43	0.04	76.11	0.21	-0.37	0.35	0.04	0.06	-0.02	0.06	0.49	0.00	0.00
113	A	0	0	12.64	3.55	0.28	77.75	0.10	-0.31	0.51	0.43	0.03	-0.23	0.03	0.35	0.03	0.00
114	A	0	0	23.60	4.86	0.23	76.61	0.06	-0.03	0.46	0.45	0.02	-0.25	0.02	0.26	0.02	0.00
115	A	0	0	6.75	2.60	0.06	75.84	0.18	-0.40	0.36	-0.09	0.03	0.05	0.05	0.46	0.01	0.03
116	A	0	0	10.53	3.25	0.27	77.81	0.16	-0.39	0.24	-0.12	0.04	0.07	0.05	0.44	0.01	0.03
117	A	0	0	25.56	5.06	0.08	75.41	0.22	-0.54	0.24	-0.35	0.15	0.19	0.06	0.51	0.00	0.15
118	A	0	0	15.75	3.97	0.72	80.81	0.11	-0.21	0.28	0.12	0.01	-0.06	0.03	0.35	0.00	0.01
119	A	0	0	9.27	3.04	0.79	81.31	0.21	-0.39	0.33	0.00	0.05	0.00	0.06	0.50	0.03	0.02
120	A	0	0	1.68	1.30	0.00	76.53	0.08	-0.18	0.53	0.50	0.07	-0.27	0.02	0.31	0.07	0.00
121	A	0	0	10.70	3.27	0.23	77.70	0.25	-0.39	0.45	0.04	0.05	-0.02	0.07	0.54	0.04	0.01
122	A	0	0	9.60	3.10	0.03	73.49	0.31	-0.39	0.64	0.42	0.24	-0.22	0.09	0.61	0.22	0.02
123	A	0	0	3.79	1.95	0.00	73.96	0.23	-0.41	0.61	0.50	0.20	-0.27	0.07	0.52	0.19	0.01
1	B	0.16667	2	47.15	6.87	0.15	71.17	0.20	-0.47	0.25	-0.17	0.00	0.09	0.06	0.48	0.00	0.00
8	B	0	0	24.12	4.91	0.00	74.44	0.29	-0.40	0.48	0.09	0.11	-0.05	0.09	0.59	0.05	0.06
18	B	0	0	10.62	3.26	0.00	72.45	0.19	-0.49	0.24	-0.22	0.05	0.12	0.06	0.48	0.00	0.05
19	B	0	0	17.04	4.13	0.66	80.73	0.16	-0.31	0.32	0.04	0.02	-0.02	0.05	0.43	0.01	0.01
21	B	0	0	4.64	2.15	0.00	75.22	0.14	-0.18	0.46	0.32	0.06	-0.17	0.04	0.41	0.06	0.00
36	B	0.083333	1	12.75	3.57	0.06	75.14	0.15	-0.63	0.23	-0.58	0.20	0.32	0.04	0.42	0.00	0.20
42	B	0.25	3	90.50	9.51	0.27	73.29	0.13	-0.35	0.21	-0.17	0.02	0.09	0.04	0.39	0.00	0.02
48	B	0.25	3	22.06	4.70	0.00	75.33	0.08	-0.21	0.25	0.06	0.00	-0.03	0.02	0.31	0.00	0.00
51	B	0.166667	2	11.75	3.43	0.20	76.45	0.19	-0.37	0.61	0.50	0.19	-0.27	0.06	0.48	0.18	0.01

No	Group	Year of inactivity	Month of Inactivity	Speed Variability	stdev	Speed Violation	Average speed	Lateral variability	Average offset to Left	Average offset to right	Average lateral position	Exceeding safety band	CI	Var CI	2SD	R bound	L Bound
62	B	0.25	3	19.56	4.42	0.00	71.44	0.49	-0.60	0.35	-0.20	0.15	0.11	0.14	0.76	0.03	0.12
66	B	0	0	12.31	3.51	0.23	77.29	0.15	-0.28	0.36	0.16	0.02	-0.09	0.04	0.42	0.01	0.01
70	B	0.083333	1	2.94	1.71	0.05	77.73	0.15	-0.24	0.39	0.13	0.04	-0.07	0.04	0.42	0.04	0.00
74	B	0	0	39.51	6.29	0.03	72.03	0.15	-0.46	0.26	-0.33	0.04	0.18	0.04	0.42	0.00	0.03
75	B	0	0	13.96	3.74	0.05	73.28	0.21	-0.46	0.30	-0.27	0.07	0.15	0.06	0.50	0.01	0.07
77	B	0.166667	2	20.92	4.57	0.00	71.30	0.14	-0.19	0.61	0.51	0.11	-0.28	0.04	0.40	0.10	0.00
83	B	0.25	3	23.83	4.88	0.40	80.33	0.41	-0.40	0.54	0.06	0.14	-0.03	0.12	0.69	0.09	0.05
86	B	0.25	3	55.61	7.46	0.37	77.14	0.51	-0.74	0.49	-0.38	0.94	0.26	0.15	0.77	0.69	0.26
93	B	0.25	3	17.47	4.18	0.00	72.31	0.61	-0.64	0.65	-0.10	0.29	0.06	0.18	0.85	0.13	0.16
102	B	0	0	27.06	5.20	0.13	73.94	0.06	-0.14	0.31	0.25	0.01	-0.14	0.02	0.27	0.01	0.00
104	B	0.167	2	7.15	2.67	0.13	76.78	0.12	-0.08	0.65	0.64	0.11	-0.34	0.04	0.38	0.11	0.00
106	B	0	0	9.00	3.00	0.01	73.02	0.48	-0.46	0.70	0.30	0.27	-0.16	0.14	0.75	0.22	0.05
107	B	0	0	23.76	4.87	0.02	72.70	0.14	-0.38	0.24	-0.21	0.05	0.11	0.04	0.40	0.01	0.05
108	B	0	0	7.72	2.78	0.12	76.36	0.18	-0.35	0.32	-0.07	0.04	0.04	0.05	0.46	0.02	0.02
109	B	0	0	56.80	7.54	0.00	68.56	0.27	-0.39	0.48	0.04	0.07	-0.02	0.08	0.56	0.05	0.02
125	B	0.083	1	9.32	3.05	0.23	77.51	0.21	-0.44	0.29	-0.12	0.05	0.07	0.06	0.50	0.01	0.04
126	B	0	0	4.91	2.22	0.00	74.03	0.43	-0.48	0.47	0.05	0.17	-0.03	0.12	0.71	0.09	0.08
127	B	0	0	29.29	5.41	0.00	65.98	0.10	-0.28	0.21	-0.12	0.45	0.26	0.46	1.36	0.11	0.34
129	B	0.083	1	36.39	6.03	0.00	67.75	0.23	-0.56	0.28	-0.36	0.11	0.19	0.07	0.52	0.00	0.11
130	B	0.167	2	36.74	6.06	0.26	76.10	0.27	-0.48	0.35	-0.17	0.11	0.09	0.08	0.56	0.01	0.10
4	B-	0.666667	8	45.34	6.73	0.83	86.01	0.54	-0.43	0.79	0.51	0.35	-0.28	0.16	0.80	0.32	0.03
5	B-	2	24	52.82	7.27	0.66	69.59	0.07	-0.21	0.22	0.04	0.00	-0.02	0.02	0.28	0.00	0.00
10	B-	0.5	6	3.77	1.94	0.12	77.89	0.09	-0.19	0.31	0.17	0.01	-0.09	0.03	0.32	0.01	0.00
11	B-	0.5	6	20.59	4.54	1.00	88.72	0.24	-0.48	0.35	0.11	0.08	-0.06	0.07	0.53	0.03	0.06

No	Group	Year of inactivity	Month of Inactivity	Speed Variability	stdev	Speed Violation	Average speed	Lateral variability	Average offset to Left	Average offset to right	Average lateral position	Exceeding safety band	CI	Var CI	2SD	R bound	L Bound
14	B-	0.5	6	12.26	3.50	0.09	74.73	1.49	-0.72	1.56	1.11	0.69	-0.60	0.44	1.32	0.62	0.07
15	B-	0.5	6	9.81	3.13	0.46	79.82	0.17	-0.49	0.48	-0.41	0.07	0.22	0.05	0.45	0.01	0.06
16	B-	3	36	90.88	9.53	0.12	68.18	0.40	-0.49	0.56	0.12	0.17	-0.07	0.12	0.68	0.09	0.08
22	B-	0.5	6	14.27	3.78	0.35	77.92	0.26	-0.61	0.18	-0.50	0.16	0.27	0.08	0.55	0.00	0.16
23	B-	1	12	9.86	3.14	0.06	75.42	0.16	-0.33	0.31	-0.06	0.03	0.03	0.05	0.43	0.01	0.02
29	B-	1	12	4.39	2.10	0.00	75.29	0.38	-0.59	0.40	-0.18	0.14	0.10	0.11	0.67	0.04	0.10
31	B-	6	72	23.62	4.86	0.00	72.04	0.46	-0.59	0.48	-0.10	0.21	0.05	0.13	0.73	0.06	0.14
33	B-	0.5	6	11.56	3.40	0.15	76.29	0.20	-0.47	0.28	-0.23	0.06	0.12	0.06	0.48	0.00	0.06
34	B-	0.58333	7	20.95	4.58	0.31	77.60	0.27	-0.41	0.41	-0.14	0.08	0.08	0.08	0.56	0.04	0.04
40	B-	1	12	18.23	4.27	0.00	67.10	0.17	-0.23	0.51	0.38	0.12	-0.21	0.05	0.44	0.12	0.00
41	B-	1	12	98.81	9.94	0.89	91.91	0.76	-0.56	0.94	0.54	0.39	-0.29	0.22	0.94	0.35	0.05
46	B-	0.5	6	2.84	1.69	0.00	76.05	0.15	-0.37	0.25	-0.10	0.01	0.05	0.04	0.41	0.00	0.01
63	B-	1	12	16.26	4.03	0.19	77.70	0.40	-0.40	0.65	0.37	0.28	-0.20	0.12	0.69	0.25	0.03
64	B-	0.5	6	2.67	1.63	0.10	77.92	0.14	-0.19	0.38	0.23	0.04	-0.13	0.04	0.40	0.04	0.00
65	B-	1	12	14.68	3.83	0.33	78.15	0.35	-0.39	0.55	0.28	0.15	-0.15	0.10	0.64	0.14	0.01
79	B-	1.5	18	25.19	5.02	0.00	65.78	0.42	-0.53	0.51	-0.49	0.15	0.03	0.12	0.70	0.05	0.10
82	B-	2	24	8.79	2.97	0.00	72.28	0.19	-0.28	0.56	0.44	0.13	-0.24	0.05	0.47	0.12	0.01
85	B-	0.5	6	47.30	6.88	0.05	71.16	0.52	-0.66	0.56	-0.07	0.28	0.04	0.15	0.78	0.10	0.18
88	B-	1	12	19.39	4.40	0.00	62.91	0.13	-0.25	0.31	0.01	0.01	-0.01	0.04	0.39	0.00	0.01
98	B-	1	12	3.57	1.89	0.02	77.28	0.65	-0.53	0.80	0.26	0.32	-0.14	0.19	0.87	0.23	0.09
99	B-	0.5	6	14.01	3.74	0.00	72.00	0.17	-0.38	0.36	0.14	0.02	-0.07	0.05	0.45	0.00	0.02
105	B-	1	12	9.87	3.14	0.76	82.04	0.37	-0.84	0.26	-0.75	0.39	0.41	0.11	0.66	0.00	0.39
110	B-	0.833	10	21.78	4.67	0.14	73.55	0.13	-0.33	0.26	-0.09	0.02	0.05	0.04	0.39	0.00	0.02

No	Group	Year of inactivity	Month of Inactivity	Speed Variability	stdev	Speed Violation	Average speed	Lateral variability	Average offset to Left	Average offset to right	Average lateral position	Exceeding safety band	CI	Var CI	2SD	R bound	L Bound
124	B-	1.5	18	41.81	6.47	0.08	73.14	0.33	-0.38	0.61	0.12	0.15	-0.07	0.10	0.63	0.12	0.02
128	B-	0.5	6	39.24	6.26	0.53	80.21	0.59	-0.73	0.48	-0.26	0.28	0.14	0.17	0.83	0.06	0.22
131	B-	1	12	15.84	3.98	0.00	71.50	0.15	-0.35	0.27	-0.10	0.02	-0.05	0.43	1.32	0.01	0.01
132	B-	1	12	13.21	3.63	0.59	79.39	0.49	-0.60	0.59	-0.06	0.21	0.03	0.14	0.76	0.12	0.08
2	C	-	-	13.54	3.68	0.08	75.50	0.50	-0.61	0.58	0.03	0.20	-0.01	0.15	0.76	0.08	0.12
3	C	-	-	7.76	2.78	0.04	75.36	0.67	-0.74	0.76	-0.47	0.32	0.25	0.20	0.89	0.04	0.28
13	C	-	-	29.81	5.46	0.63	80.27	0.97	-0.90	0.43	-0.57	0.29	0.31	0.28	1.06	0.03	0.26
24	C	-	-	41.74	6.46	0.34	72.56	0.32	-0.49	0.48	-0.10	0.13	0.55	0.09	0.62	0.05	0.08
25	C	-	-	5.77	2.40	0.00	73.45	0.63	-0.67	0.59	0.01	0.25	-0.02	0.17	0.82	0.12	0.12
32	C	-	-	87.03	9.33	0.00	61.72	0.47	-0.73	0.50	-0.40	0.29	0.22	0.14	0.74	0.03	0.25
35	C	-	-	74.45	8.63	0.35	76.67	1.50	1.18	-0.78	0.20	0.44	-0.11	0.44	1.32	0.27	0.16
39	C	-	-	2.50	1.58	0.00	76.58	0.27	-0.52	0.37	-0.16	0.07	0.08	0.08	0.56	0.02	0.05
45	C	-	-	2.19	1.48	0.00	76.34	0.32	-0.60	0.25	-0.34	0.15	0.18	0.09	0.61	0.00	0.15
50	C	-	-	18.58	4.31	0.08	73.22	4.60	-2.72	0.73	-1.80	0.68	0.97	1.34	2.32	0.10	0.58
52	C	-	-	7.97	2.82	0.78	80.67	0.15	-0.28	0.32	0.07	0.04	-0.04	0.05	0.42	0.03	0.01
53	C	-	-	14.18	3.77	0.15	76.28	0.95	-0.94	0.71	-0.33	0.88	0.18	0.28	1.06	0.56	0.32
54	C	-	-	25.00	5.00	0.06	73.69	0.18	-0.63	0.16	-0.54	0.16	0.29	0.05	0.46	0.00	0.16
57	C	-	-	52.84	7.27	0.03	68.16	0.28	-0.53	0.33	-0.26	0.16	0.14	0.08	0.58	0.02	0.14
58	C	-	-	46.54	6.82	0.00	67.90	1.76	-1.19	0.81	-0.35	0.48	0.19	0.52	1.44	0.16	0.31
59	C	-	-	24.34	4.93	0.11	73.88	0.39	-0.65	0.37	-0.37	0.27	0.20	0.11	0.68	0.03	0.24
60	C	-	-	3.64	1.91	0.00	73.19	0.35	-0.50	0.47	-0.01	0.13	0.01	0.10	0.64	0.06	0.07
61	C	-	-	2.92	1.71	0.02	78.05	0.13	-0.25	0.39	0.23	0.02	-0.12	0.04	0.39	0.02	0.00
69	C	-	-	3.11	1.76	0.05	76.91	0.34	-0.49	0.37	-0.04	0.08	0.02	0.10	0.63	0.02	0.06
76	C	-	-	85.95	9.27	0.08	64.82	1.34	-0.97	0.84	0.02	0.39	-0.01	0.39	1.25	0.21	0.18

No	Group	Year of inactivity	Month of Inactivity	Speed Variability	stdev	Speed Violation	Average speed	Lateral variability	Average offset to Left	Average offset to right	Average lateral position	Exceeding safety band	CI	Var CI	2SD	R bound	L Bound
78	C	-	-	55.38	7.44	0.45	77.58	2.23	-0.84	1.39	-0.13	0.39	0.07	0.65	1.62	0.10	0.29
80	C	-	-	39.93	6.32	0.00	71.38	0.21	-0.33	0.41	0.06	0.01	-0.03	0.06	0.49	0.00	0.14
84	C	-	-	36.14	6.01	0.28	77.26	0.58	-0.53	0.77	0.32	0.33	-0.17	0.17	0.83	0.26	0.07
87	C	-	-	4.56	2.13	0.02	76.89	0.74	-0.73	0.72	0.09	0.34	-0.05	0.22	0.93	0.21	0.14
89	C	-	-	5.49	2.34	0.00	69.98	0.78	-0.79	0.83	0.39	0.39	-0.21	0.23	0.95	0.28	0.11
90	C	-	-	2.38	1.54	0.00	75.82	0.55	-0.58	0.60	0.16	0.23	-0.09	0.16	0.80	0.14	0.09
91	C	-	-	8.07	2.84	0.03	76.39	0.34	-0.54	0.42	-0.18	0.15	0.10	0.10	0.63	0.03	0.12
92	C	-	-	9.23	3.04	0.00	72.63	0.35	-0.47	0.47	0.10	0.55	-0.05	0.10	0.64	0.09	0.46
94	C	-	-	50.31	7.09	0.00	66.03	0.29	-0.45	0.43	0.04	0.09	-0.02	0.08	0.58	0.06	0.04
95	C	-	-	31.25	5.59	0.00	69.41	0.58	-0.62	0.53	-0.06	0.19	0.03	0.17	0.83	0.10	0.10
96	C	-	-	58.39	7.64	0.26	74.49	0.58	-0.67	0.60	-0.15	0.25	0.08	0.17	0.83	0.07	0.19
97	C	-	-	24.03	4.90	0.05	71.60	0.42	-0.37	0.57	0.18	0.16	-0.10	0.12	0.70	0.13	0.03
100	C	-	-	50.67	7.12	0.13	76.95	8.35	-2.74	1.71	-0.83	0.75	0.45	2.44	3.12	0.30	0.45
101	C	-	-	6.39	2.53	0.22	78.41	0.47	-0.66	0.47	-0.12	0.19	0.06	0.14	0.74	0.04	0.15
103	C	-	-	12.55	3.54	0.12	76.38	0.95	-0.86	0.91	0.37	0.47	-0.20	0.28	1.05	0.34	0.12

C.4 Vehicle control performance on curve segment

No	Group	Year of inactivity	Month of Inactivity	Speed Variability	stdev	Speed Violation	Average speed	Lateral variability	Average offset to Left	Average offset to right	Average lateral position	Exceeding safety band	CI	Var CI	2SD	R bound	L Bound
6	A	0	0	2.12	1.24	0.02	72.89	0.12	-0.18	0.39	0.23	0.04	-0.12	0.04	0.35	0.03	0.00
7	A	0	0	3.01	1.11	0.15	79.22	0.41	-0.63	0.38	-0.44	0.30	0.24	0.09	0.55	0.03	0.26
9	A	0	0	5.75	2.34	0.08	75.41	0.60	-0.54	0.71	-0.03	0.36	0.01	0.17	0.74	0.15	0.21
12	A	0	0	1.49	1.21	0.61	78.08	0.17	-0.32	0.38	0.04	0.07	-0.02	0.04	0.35	0.03	0.04
17	A	0	0	2.55	0.96	0.36	81.28	0.12	-0.36	0.27	-0.15	0.05	0.08	0.04	0.36	0.00	0.05
20	A	0	0	4.89	1.79	0.15	76.74	0.10	-0.53	0.16	-0.46	0.11	0.25	0.03	0.34	0.00	0.11
26	A	0	0	3.98	1.37	0.14	77.18	0.20	-0.52	0.26	-0.24	0.10	0.13	0.06	0.47	0.00	0.09
27	A	0	0	3.02	1.10	0.15	77.58	0.06	-0.32	0.13	-0.22	0.00	0.12	0.02	0.24	0.00	0.00
28	A	0	0	2.83	1.27	0.24	79.03	0.23	-0.40	0.37	-0.10	0.15	0.05	0.07	0.49	0.05	0.10
30	A	0	0	2.63	1.60	0.02	73.31	0.06	-0.41	0.10	-0.19	0.06	0.18	0.02	0.26	0.00	0.06
37	A	0	0	0.74	0.79	0.12	76.76	0.12	-0.35	0.27	-0.17	0.03	0.09	0.03	0.36	0.00	0.03
38	A	0	0	3.46	1.42	0.00	73.59	0.69	-0.67	0.53	-0.10	0.34	0.05	0.20	0.85	0.17	0.17
43	A	0	0	1.72	1.25	0.00	70.04	0.12	-0.38	0.18	-0.19	0.06	0.10	0.03	0.36	0.00	0.06
44	A	0	0	2.03	0.95	0.00	74.97	0.13	-0.30	0.34	0.02	0.02	-0.01	0.04	0.38	0.00	0.02
47	A	0	0	7.83	2.50	0.12	74.36	0.25	-0.45	0.33	0.08	0.12	-0.04	0.07	0.53	0.05	0.07
49	A	0	0	4.91	1.76	0.00	71.33	0.36	-0.32	0.72	0.46	0.34	-0.26	0.10	0.62	0.29	0.04
55	A	0	0	0.60	0.70	0.00	77.75	0.06	-0.20	0.22	-0.01	0.00	0.01	0.02	0.26	0.00	0.00
56	A	0	0	1.29	0.81	0.03	70.48	0.22	-0.56	0.30	-0.26	0.09	0.15	0.07	0.51	0.00	0.09
67	A	0	0	5.38	1.94	0.26	77.23	0.24	-0.26	0.49	0.23	0.08	-0.12	0.07	0.49	0.06	0.02
68	A	0	0	0.68	0.69	0.25	79.05	0.23	-0.27	0.49	0.23	0.08	-0.13	0.07	0.50	0.05	0.03
71	A	0	0	0.34	0.44	0.20	77.23	0.08	-0.27	0.22	-0.08	0.00	0.04	0.02	0.31	0.00	0.00
73	A	0	0	4.27	1.27	0.17	76.37	0.18	-0.29	0.49	0.14	0.12	-0.08	0.05	0.43	0.12	0.00

No	Group	Year of inactivity	Month of Inactivity	Speed Variability	stdev	Speed Violation	Average speed	Lateral variability	Average offset to Left	Average offset to right	Average lateral position	Exceeding safety band	CI	Var CI	2SD	R bound	L Bound
81	A	0	0	6.57	1.94	0.00	71.31	0.34	-0.59	0.39	-0.18	0.18	0.10	0.10	0.60	0.06	0.30
111	A	0	0	1.51	0.83	0.21	79.79	0.04	-0.19	0.15	-0.05	0.00	0.03	0.01	0.22	0.00	0.00
112	A	0	0	3.01	1.11	0.15	79.22	0.21	-0.65	0.20	-0.52	0.30	0.28	0.06	0.47	0.01	0.28
113	A	0	0	2.02	0.93	0.12	77.91	0.10	-0.19	0.42	0.26	0.03	-0.14	0.03	0.32	0.03	0.00
114	A	0	0	5.36	1.79	0.55	81.34	0.10	-0.09	0.44	0.35	0.06	-0.19	0.03	0.32	0.06	0.00
115	A	0	0	1.68	1.22	0.19	76.91	0.40	-0.79	0.25	-0.57	0.27	0.31	0.12	0.63	0.00	0.27
116	A	0	0	0.96	0.65	0.34	79.31	0.20	-0.44	0.37	-0.18	0.08	0.10	0.06	0.46	0.03	0.05
117	A	0	0	5.99	1.80	0.66	79.51	0.49	-0.62	0.35	-0.25	0.19	0.14	0.09	0.57	0.03	0.16
118	A	0	0	2.62	1.08	0.53	79.59	0.22	-0.35	0.48	0.13	0.05	-0.07	0.06	0.49	0.03	0.02
119	A	0	0	1.41	1.04	0.28	78.89	0.12	-0.35	0.24	-0.14	0.04	0.08	0.04	0.37	0.00	0.04
120	A	0	0	0.12	0.32	0.00	76.25	0.07	-0.07	0.42	0.37	0.01	-0.20	0.02	0.28	0.01	0.00
121	A	0	0	5.81	1.56	0.43	79.18	0.20	-0.53	0.26	-0.29	0.15	0.16	0.06	0.48	0.00	0.15
122	A	0	0	14.32	3.45	0.06	69.86	0.20	-0.11	0.67	0.58	0.27	-0.31	0.06	0.48	0.27	0.00
123	A	0	0	1.67	1.14	0.00	75.26	0.27	-0.28	0.62	0.43	0.22	-0.23	0.08	0.54	0.22	0.01
1	B	0.16667	2	5.83	2.27	0.00	65.33	0.12	-0.23	0.15	-0.04	0.13	0.02	0.04	0.37	0.07	0.06
8	B	0	0	3.88	1.35	0.00	73.62	0.39	-0.41	0.58	0.17	0.21	-0.09	0.11	0.64	0.15	0.06
18	B	0	0	0.28	0.43	0.00	72.22	0.09	-0.50	0.14	-0.37	0.06	0.20	0.03	0.32	0.00	0.06
19	B	0	0	1.74	0.96	0.25	76.31	0.31	-0.42	0.57	0.26	0.16	-0.14	0.09	0.57	0.13	0.03
21	B	0	0	1.43	1.12	0.04	75.28	0.12	-0.16	0.43	0.27	0.09	-0.14	0.03	0.37	0.09	0.00
36	B	0.08333 3	1	2.62	1.53	0.11	74.74	0.34	-0.65	0.22	-0.39	0.20	0.21	0.10	0.57	0.00	0.20
42	B	0.25	3	4.30	1.91	0.16	76.88	0.43	-0.59	0.50	-0.16	0.18	0.08	0.12	0.69	0.04	0.13
48	B	0.25	3	6.42	2.19	0.07	74.89	0.07	-0.20	0.24	0.01	0.00	0.00	0.02	0.29	0.00	0.00
51	B	0.16666 7	2	8.10	2.59	0.19	76.59	0.17	-0.21	0.56	0.35	0.22	-0.19	0.05	0.43	0.21	0.01

No	Group	Year of inactivity	Month of Inactivity	Speed Variability	stdev	Speed Violation	Average speed	Lateral variability	Average offset to Left	Average offset to right	Average lateral position	Exceeding safety band	CI	Var CI	2SD	R bound	L Bound
62	B	0.25	3	6.43	1.72	0.00	64.22	0.42	-0.75	0.52	-0.11	0.43	0.06	0.12	0.69	0.21	0.22
66	B	0	0	2.78	1.22	0.11	76.50	0.17	-0.30	0.37	0.04	0.02	-0.02	0.05	0.44	0.02	0.00
70	B	0.083333	1	4.46	1.33	0.11	78.03	0.19	-0.27	0.43	0.18	0.09	-0.10	0.06	0.45	0.06	0.03
74	B	0	0	8.01	1.93	0.01	69.41	0.38	-0.65	0.47	-0.27	0.19	0.14	0.11	0.65	0.04	0.15
75	B	0	0	9.52	2.18	0.00	64.90	0.24	-0.57	0.34	-0.26	0.45	0.14	0.07	0.40	0.16	0.29
77	B	0.166667	2	4.65	2.01	0.00	66.00	0.18	-0.14	0.57	0.39	0.21	-0.25	0.05	0.45	0.21	0.00
83	B	0.25	3	2.51	1.22	0.43	79.86	0.21	-0.59	0.17	-0.35	0.20	0.19	0.06	0.49	0.00	0.20
86	B	0.25	3	7.38	1.58	0.39	79.42	0.28	-0.48	0.43	-0.13	0.28	0.07	0.08	0.53	0.11	0.17
93	B	0.25	3	4.11	1.38	0.04	72.00	0.36	-0.44	0.62	0.13	0.25	-0.07	0.11	0.65	0.20	0.05
102	B	0	0	10.18	3.18	0.00	70.23	0.11	-0.23	0.33	0.13	0.04	-0.07	0.03	0.36	0.04	0.00
104	B	0.167	2	0.76	0.68	0.21	78.62	0.21	-0.22	0.58	0.44	0.19	-0.24	0.06	0.47	0.17	0.01
106	B	0	0	3.89	1.60	0.06	66.24	0.31	-0.33	0.63	0.36	0.25	-0.20	0.09	0.59	0.21	0.04
107	B	0	0	16.24	3.75	0.04	70.33	0.20	-0.58	0.23	-0.41	0.13	0.22	0.15	0.70	0.00	0.13
108	B	0	0	2.10	0.96	0.10	75.41	0.21	-0.44	0.23	-0.22	0.09	0.12	0.06	0.43	0.02	0.07
109	B	0	0	4.12	1.82	0.00	64.67	0.41	-0.55	0.55	0.07	0.17	-0.04	0.12	0.68	0.10	0.08
125	B	0.083	1	2.84	1.45	0.20	75.84	0.12	-0.31	0.26	-0.04	0.00	0.02	0.03	0.37	0.00	0.00
126	B	0	0	0.57	0.59	0.00	75.97	0.28	-0.33	0.56	0.20	0.20	-0.11	0.08	0.53	0.17	0.03
127	B	0	0	5.92	2.28	0.00	65.88	0.10	-0.32	0.21	-0.16	0.55	0.35	0.43	1.23	0.12	0.44
129	B	0.083	1	5.09	1.82	0.00	68.14	0.18	-0.62	0.13	-0.52	0.23	0.28	0.05	0.43	0.00	0.23
130	B	0.167	2	4.78	2.12	0.04	71.47	0.25	-0.69	0.31	-0.47	0.30	0.26	0.07	0.54	0.01	0.29
4	B-	0.666667	8	10.06	2.29	0.55	79.79	0.47	-0.25	0.78	0.54	0.27	-0.29	0.14	0.67	0.26	0.01
5	B-	2	24	5.98	1.96	0.00	65.76	0.07	-0.35	0.13	-0.25	0.00	0.13	0.02	0.28	0.00	0.00
10	B-	0.5	6	3.68	1.63	0.06	75.51	0.14	-0.30	0.34	0.01	0.03	-0.01	0.04	0.40	0.03	0.00

No	Group	Year of inactivity	Month of Inactivity	Speed Variability	stdev	Speed Violation	Average speed	Lateral variability	Average offset to Left	Average offset to right	Average lateral position	Exceeding safety band	CI	Var CI	2SD	R bound	L Bound
11	B-	0.5	6	2.59	1.48	1.00	88.12	0.45	-0.62	0.69	-0.25	0.24	0.14	0.23	0.87	0.04	0.21
14	B-	0.5	6	1.67	0.96	0.00	73.56	0.86	-0.52	1.35	0.72	0.58	-0.53	0.27	0.99	0.53	0.05
15	B-	0.5	6	1.88	0.92	0.00	78.22	0.27	-0.49	0.22	-0.45	0.24	0.24	0.08	0.56	0.00	0.24
16	B-	3	36	14.45	3.68	0.00	56.20	0.24	-0.27	0.54	0.20	0.12	-0.11	0.13	0.69	0.12	0.00
22	B-	0.5	6	5.09	1.72	0.74	80.65	0.50	-1.61	0.06	-1.58	0.72	0.85	0.15	0.73	0.00	0.72
23	B-	1	12	3.74	1.91	0.01	72.92	0.31	-0.45	0.47	0.06	0.15	-0.03	0.09	0.56	0.09	0.06
29	B-	1	12	2.54	1.06	0.10	74.08	0.23	-0.50	-0.01	-0.51	0.53	0.28	0.07	0.50	0.09	0.44
31	B-	6	72	6.52	2.40	0.00	66.76	0.39	-0.64	0.88	-0.31	0.31	0.17	0.11	0.66	0.06	0.25
33	B-	0.5	6	4.88	1.33	0.12	76.72	0.13	-0.47	0.15	-0.29	0.12	0.16	0.04	0.38	0.00	0.12
34	B-	0.583333	7	5.54	1.65	0.19	78.01	0.35	-0.57	0.39	-0.08	0.19	0.05	0.09	0.58	0.03	0.15
40	B-	1	12	6.34	2.22	0.00	64.00	0.41	-0.48	0.58	-0.01	0.19	0.01	0.12	0.67	0.08	0.11
41	B-	1	12	3.61	1.31	1.00	98.29	0.98	-1.31	0.74	0.24	0.66	0.18	0.29	1.06	0.12	0.54
46	B-	0.5	6	5.71	1.97	0.24	77.77	0.24	-0.52	0.26	-0.22	0.10	0.12	0.07	0.51	0.00	0.10
63	B-	1	12	4.45	1.38	0.11	77.46	0.33	-0.28	0.73	0.52	0.29	-0.28	0.10	0.60	0.29	0.00
64	B-	0.5	6	1.32	1.04	0.06	76.80	0.19	-0.26	0.43	0.12	0.07	-0.07	0.06	0.46	0.06	0.01
65	B-	1	12	3.03	1.15	0.78	80.49	0.08	-0.21	0.31	0.14	0.05	-0.07	0.02	0.30	0.05	0.00
79	B-	1.5	18	8.59	2.62	0.00	62.43	0.53	-0.63	0.67	0.00	0.32	0.00	0.15	0.77	0.15	0.17
82	B-	2	24	3.07	1.51	0.00	70.23	0.28	-0.42	0.53	0.06	0.15	-0.04	0.08	0.57	0.09	0.06
85	B-	0.5	6	6.01	2.04	0.00	66.32	0.42	-0.61	0.48	-0.09	0.27	0.05	0.12	0.67	0.10	0.16
88	B-	1	12	9.71	1.90	0.00	62.79	0.22	-0.48	0.28	-0.15	0.08	0.08	0.06	0.48	0.00	0.08
98	B-	1	12	0.47	0.46	0.20	77.89	0.38	-0.33	0.78	0.42	0.44	-0.23	0.11	0.62	0.32	0.13
99	B-	0.5	6	4.12	1.26	0.04	74.28	0.12	-0.24	0.42	0.18	0.15	-0.10	0.03	0.34	0.10	0.05
105	B-	1	12	3.46	1.27	0.20	78.52	0.51	-0.90	0.37	-0.76	0.40	0.41	0.15	0.75	0.00	0.40

No	Group	Year of inactivity	Month of Inactivity	Speed Variability	stdev	Speed Violation	Average speed	Lateral variability	Average offset to Left	Average offset to right	Average lateral position	Exceeding safety band	CI	Var CI	2SD	R bound	L Bound
110	B-	0.833	10	4.29	1.14	0.07	74.97	0.13	-0.38	0.31	-0.08	0.03	0.04	0.04	0.39	0.00	0.03
124	B-	1.5	18	6.15	1.77	0.13	75.43	0.34	-0.59	0.39	-0.12	0.04	0.06	0.10	0.62	0.04	0.00
128	B-	0.5	6	7.21	1.70	0.00	74.12	0.33	-0.54	0.44	-0.12	0.22	0.06	0.10	0.58	0.04	0.18
131	B-	1	12	6.76	1.85	0.03	75.38	0.19	-0.39	0.35	-0.16	0.07	-0.09	0.06	0.44	0.02	0.05
132	B-	1	12	4.36	1.19	0.07	75.58	0.43	-0.52	0.62	0.00	0.33	0.00	0.13	0.68	0.16	0.18
2	C	-	-	5.17	1.96	0.27	78.66	0.35	-0.47	0.54	0.08	0.20	-0.04	0.10	0.60	0.11	0.09
3	C	-	-	1.84	0.83	0.15	78.61	0.70	-0.92	0.38	-0.57	0.39	0.31	0.20	0.84	0.06	0.33
13	C	-	-	5.19	1.51	0.89	81.26	0.73	-0.81	0.67	-0.12	0.38	0.07	0.21	0.87	0.14	0.24
24	C	-	-	8.46	2.02	0.00	72.76	0.25	-0.60	0.30	-0.27	0.18	0.15	0.07	0.53	0.01	0.17
25	C	-	-	4.16	1.61	0.10	74.74	0.40	-0.67	0.41	-0.13	0.24	0.13	0.31	0.99	0.03	0.21
32	C	-	-	3.87	1.65	0.00	63.79	0.27	-0.50	0.44	-0.15	0.23	0.08	0.08	0.56	0.08	0.15
35	C	-	-	3.84	1.50	0.12	75.43	0.91	-1.09	0.33	-0.58	0.56	0.31	0.27	0.95	0.14	0.42
39	C	-	-	3.01	1.31	0.00	75.69	0.18	-0.35	0.35	0.03	0.05	-0.01	0.05	0.45	0.03	0.02
45	C	-	-	0.51	0.61	0.15	76.72	0.29	-0.49	0.40	-0.20	0.18	0.11	0.08	0.53	0.02	0.16
50	C	-	-	4.46	1.54	0.06	74.57	1.92	-3.64	0.54	-3.13	0.93	1.69	0.56	1.43	0.13	0.80
52	C	-	-	3.32	1.24	0.84	80.58	0.17	-0.35	0.34	0.09	0.07	0.04	0.14	0.67	0.05	0.02
53	C	-	-	5.02	1.44	0.29	78.70	1.19	-1.37	0.49	-0.77	0.59	0.41	0.35	1.12	0.13	0.47
54	C	-	-	4.20	1.33	0.04	75.42	0.19	-0.64	0.09	-0.51	0.25	0.27	0.06	0.45	0.00	0.25
57	C	-	-	8.90	1.90	0.15	74.14	0.43	-0.69	0.37	-0.39	0.22	0.21	0.13	0.67	0.02	0.20
58	C	-	-	6.59	2.13	-0.13	63.94	3.08	-1.37	0.79	-0.77	0.52	0.42	0.90	1.56	0.11	0.41
59	C	-	-	7.79	1.82	0.11	72.01	0.39	-0.73	0.35	-0.36	0.28	0.19	0.11	0.66	0.00	0.28
60	C	-	-	0.29	0.52	0.00	72.89	0.39	-0.47	0.55	0.05	0.16	-0.03	0.11	0.64	0.13	0.03
61	C	-	-	1.94	0.89	0.28	79.17	0.34	-0.47	0.53	0.18	0.12	-0.09	0.06	0.41	0.02	0.05
69	C	-	-	0.98	0.85	0.05	76.77	0.61	-0.57	0.75	-0.04	0.21	0.02	0.18	0.83	0.11	0.10

No	Group	Year of inactivity	Month of Inactivity	Speed Variability	stdev	Speed Violation	Average speed	Lateral variability	Average offset to Left	Average offset to right	Average lateral position	Exceeding safety band	CI	Var CI	2SD	R bound	L Bound
76	C	-	-	8.53	2.63	0.20	65.65	1.80	-1.02	0.73	0.22	0.62	-0.12	0.53	1.36	0.33	0.28
78	C	-	-	12.28	3.36	0.32	78.54	0.49	-0.93	0.19	-0.79	0.43	0.43	0.14	0.74	0.00	0.43
80	C	-	-	2.61	1.03	0.08	75.80	0.18	-0.27	0.42	0.15	0.04	-0.08	0.13	0.66	0.00	0.04
84	C	-	-	4.36	1.23	0.33	78.48	0.27	-0.41	0.40	0.04	0.33	-0.02	0.08	0.55	0.17	0.16
87	C	-	-	1.57	1.01	0.05	77.87	0.56	-0.58	0.67	0.05	0.27	-0.03	0.17	0.78	0.16	0.10
89	C	-	-	5.64	1.71	0.00	69.24	0.47	-0.52	0.69	0.10	0.38	-0.05	0.14	0.70	0.23	0.15
90	C	-	-	1.78	0.92	0.15	77.19	0.33	-0.75	0.30	-0.45	0.32	0.24	0.10	0.57	0.03	0.29
91	C	-	-	4.69	1.37	0.11	75.28	0.29	-0.49	0.33	-0.09	0.13	0.05	0.08	0.53	0.03	0.10
92	C	-	-	6.11	1.44	0.10	75.12	0.25	-0.51	0.24	-0.25	0.24	0.14	0.07	0.49	0.04	0.20
94	C	-	-	3.08	1.13	0.06	71.26	0.57	-0.71	0.53	-0.32	0.34	0.18	0.17	0.80	0.09	0.25
95	C	-	-	4.00	1.45	0.00	71.87	0.44	-0.35	0.68	0.31	0.25	-0.16	0.13	0.66	0.19	0.06
96	C	-	-	0.52	0.59	0.25	77.20	0.69	-0.49	0.76	0.17	0.28	-0.09	0.20	0.86	0.16	0.12
97	C	-	-	4.10	1.09	0.06	74.52	0.28	-0.13	0.86	0.74	0.40	-0.40	0.08	0.51	0.40	0.00
100	C	-	-	6.64	1.66	0.23	77.41	4.95	-2.41	1.75	-0.48	0.86	0.26	1.45	2.27	0.43	0.43
101	C	-	-	2.44	1.27	0.11	77.38	0.67	-0.79	0.67	0.01	0.53	0.00	0.20	0.86	0.28	0.25
103	C	-	-	1.23	0.98	0.00	74.29	0.26	-0.23	0.44	0.06	0.22	-0.03	0.08	0.53	0.11	0.12

C.5 Response latency RL active mode hazard perception test

S/N	Group	H4			H2			H3			H1		
		LT	TF	PIEV	LT	TF	PIEV	LT	TF	PIEV	LT	TF	PIEV
2	A	0.10	0.30	0.70	0.42	0.46	0.92	0.40	0.30	1.20	0.48	0.25	0.86
3	A	0.10	0.30	0.81	1.30	0.40	0.41	0.30	0.30	0.98	1.00	0.17	0.14
10	A	0.68	0.07	0.47	0.05	0.92	1.82	0.57	0.37	0.25	0.30	0.32	0.50
14	A	0.10	0.30	1.90	0.40	1.70	2.92	0.80	0.50	0.40	0.60	0.40	2.00
17	A	0.30	0.40	0.91	0.42	0.46	0.92	0.60	0.60	0.75	0.48	0.25	0.86
19	A	1.50	0.20	1.51	0.80	0.30	0.80	0.30	1.40	0.72	0.20	0.60	1.13
21	A	0.80	0.80	2.52	0.42	0.46	0.92	0.47	0.41	0.67	0.48	0.25	0.86
24	A	0.21	0.58	0.41	0.90	0.42	0.28	0.10	0.40	0.29	0.76	0.38	1.04
28	A	0.20	0.20	0.38	0.10	0.20	0.99	0.70	0.30	0.59	1.10	0.20	0.39
34	A	1.28	0.30	0.75	0.47	0.50	1.02	0.27	0.40	0.78	0.48	0.25	0.86
39	A	0.77	0.29	0.53	0.63	0.88	0.44	0.08	0.42	0.57	1.58	0.09	0.48
41	A	0.93	0.21	1.77	0.42	0.46	0.92	0.41	0.82	0.20	0.48	0.25	0.86
71	A	0.21	0.40	0.67	0.42	0.46	0.92	0.40	0.20	1.30	0.48	0.25	0.86
72	A	0.30	0.50	0.42	0.42	0.46	0.92	0.10	0.90	0.21	0.48	0.25	0.86
73	A	0.90	0.10	0.81	0.60	0.10	0.70	0.80	0.50	0.50	0.30	0.30	1.50
74	A	0.30	0.20	0.87	1.60	0.30	0.71	0.00	0.20	1.11	0.40	0.40	0.59
75	A	0.80	0.20	0.19	0.20	0.10	1.00	0.60	0.50	0.81	0.20	0.50	0.60
76	A	0.25	0.12	0.51	0.04	0.17	1.13	0.67	0.12	0.81	0.00	0.00	0.31
77	A	0.64	0.23	0.91	0.02	0.50	0.85	0.37	0.42	0.75	0.25	0.42	1.08
78	A	1.00	0.20	0.68	0.00	0.80	0.27	1.70	0.10	0.75	1.30	0.20	0.65
79	A	0.70	0.40	0.50	0.10	0.50	0.27	0.60	0.30	0.54	0.00	0.00	0.48
80	A	0.50	0.08	0.51	0.12	0.33	1.58	0.38	0.12	0.51	0.00	0.25	1.37
81	A	0.08	0.42	0.83	0.00	0.00	0.80	1.04	0.08	1.20	0.04	0.17	1.38
82	A	0.42	0.08	0.46	0.17	0.17	0.56	0.17	0.50	0.53	0.00	0.00	1.17
83	A	0.08	0.08	1.33	0.46	0.42	0.86	0.00	0.00	0.40	0.58	0.12	0.71
1	B	1.25	0.08	1.43	1.67	0.42	3.04	0.40	0.52	0.63	0.68	0.45	1.22
5	B	0.70	0.20	0.31	0.10	0.20	0.52	1.00	0.20	0.45	0.40	0.80	0.63
7	B	0.40	0.40	0.90	0.60	0.40	2.91	0.74	0.27	0.70	0.10	0.30	0.45
9	B	0.20	0.07	2.79	0.28	0.42	0.26	1.67	0.40	0.43	0.35	0.13	0.64
12	B	0.62	0.30	2.31	2.00	0.50	0.91	0.74	0.27	0.70	0.70	1.30	2.50
13	B	0.80	0.30	0.50	0.20	0.30	1.93	0.40	0.30	0.57	0.20	0.20	2.81
15	B	0.60	0.20	1.30	2.40	0.50	2.00	0.80	0.30	0.72	1.90	0.30	1.90
31	B	1.30	0.20	0.70	1.30	0.40	0.89	0.80	0.30	0.72	0.60	0.30	2.43
32	B	1.10	0.40	0.60	1.00	0.60	0.30	0.10	0.60	0.52	0.00	0.00	1.21
35	B	0.62	0.25	0.53	0.17	0.33	1.61	1.08	0.12	0.75	0.21	0.42	0.57
36	B	0.30	0.54	1.41	0.87	0.63	0.91	0.08	0.08	0.18	0.08	0.21	1.17
38	B	0.18	0.17	1.33	0.38	0.33	0.67	0.62	0.22	0.90	0.72	0.73	1.44
44	B	1.18	0.12	0.53	0.63	0.67	1.73	1.60	0.13	0.71	0.52	0.82	0.31

S/N	Group	H4			H2			H3			H1		
		LT	TF	PIEV	LT	TF	PIEV	LT	TF	PIEV	LT	TF	PIEV
47	B	0.95	0.07	1.13	0.58	0.53	1.72	0.54	0.38	0.45	1.92	0.84	0.56
54	B	0.10	0.55	1.88	0.85	0.55	0.46	0.23	0.30	0.52	0.77	1.32	0.27
59	B	0.77	0.22	0.40	1.43	0.13	0.97	0.32	0.23	0.36	1.10	0.03	0.20
66	B	0.08	0.33	0.51	0.68	0.50	0.38	0.17	0.12	0.83	1.21	0.67	3.08
67	B	0.65	0.13	0.70	0.33	0.48	0.97	0.74	0.27	0.70	0.68	0.45	1.22
68	B	0.29	0.42	1.25	0.04	0.42	0.91	0.92	0.17	0.25	0.17	0.37	0.89
69	B	0.25	0.54	1.42	0.00	0.25	0.99	1.13	0.42	0.63	1.21	0.33	0.51
85	B	2.29	0.04	0.21	0.29	0.24	1.23	2.08	0.13	0.95	0.83	0.17	1.19
86	B	0.63	0.21	0.77	0.12	0.08	1.02	0.62	0.25	1.58	0.00	0.00	0.80
87	B	0.70	0.42	0.46	0.00	0.00	0.66	0.21	0.50	1.57	0.58	0.42	1.98
89	B	0.50	0.08	1.33	0.00	0.00	1.48	0.83	0.08	0.93	1.29	0.12	1.39
4	B-	0.60	0.40	1.13	0.10	0.30	0.60	0.40	0.40	1.12	0.80	0.50	1.21
6	B-	0.10	0.30	1.50	0.80	0.20	0.70	0.46	1.10	0.42	1.10	0.70	2.30
16	B-	0.80	0.40	1.82	1.90	0.20	1.13	0.68	0.37	1.11	0.30	1.70	0.94
18	B-	1.50	0.40	0.59	0.20	0.30	0.60	0.68	0.37	1.11	1.00	0.70	0.38
25	B-	1.29	0.31	0.50	0.30	0.40	1.80	0.80	0.30	0.70	0.90	0.10	1.50
29	B-	1.00	0.30	0.20	0.10	0.00	2.61	1.00	0.50	0.40	0.90	0.20	2.40
30	B-	1.10	0.30	0.20	0.10	0.50	0.60	0.10	0.20	0.80	2.60	0.70	1.02
40	B-	1.09	0.51	0.82	0.48	0.30	0.97	0.31	0.28	0.29	0.75	0.49	1.20
43	B-	0.65	0.60	1.15	0.03	0.60	0.78	0.32	0.05	0.56	0.65	0.63	0.76
46	B-	0.62	0.47	1.98	0.20	0.13	0.50	0.23	0.26	0.75	0.28	0.15	1.39
49	B-	0.75	0.35	1.43	0.03	0.68	0.66	0.18	0.36	4.78	0.75	0.49	1.20
65	B-	0.70	0.40	0.33	1.10	0.30	0.40	0.10	0.50	0.80	1.00	0.40	0.22
70	B-	0.58	0.17	1.30	0.08	0.33	0.83	1.83	0.39	1.39	0.30	0.37	0.95
84	B-	1.08	0.21	1.08	0.04	0.29	1.33	1.17	0.17	1.05	0.58	0.21	0.31
88	B-	0.54	0.17	0.79	1.67	0.21	0.50	2.40	0.10	0.46	0.21	0.33	0.90
90	B-	0.17	0.04	1.97	0.00	0.00	1.28	0.54	0.29	2.38	0.00	0.00	2.31
91	B-	0.62	0.21	0.62	1.17	0.17	1.57	0.58	0.12	0.57	0.75	0.49	1.20
92	B-	0.29	0.25	0.52	0.32	0.33	0.62	0.55	0.60	1.21	0.65	0.68	1.36
93	B-	0.47	0.45	0.93	0.48	0.48	0.96	0.60	0.60	1.10	0.75	0.49	1.20
8	C	0.10	0.30	1.10	0.30	0.30	0.74	1.20	0.40	0.80	0.60	0.30	1.00
11	C	0.63	0.07	0.52	0.30	0.70	2.72	0.55	0.85	0.68	0.05	0.15	0.93
20	C	0.70	0.40	1.02	2.40	0.20	0.91	0.70	0.50	0.50	1.50	0.40	1.01
22	C	0.35	0.60	0.72	1.56	0.30	2.86	0.20	0.40	0.96	1.00	0.10	1.70
23	C	0.10	0.30	2.61	1.90	0.50	2.79	0.50	0.30	0.69	2.16	0.30	0.60
26	C	0.77	0.12	2.65	0.12	0.10	2.77	0.68	0.27	0.57	0.02	0.53	1.65
27	C	0.40	0.90	0.40	0.20	0.10	0.92	0.75	0.41	0.86	0.50	0.20	0.61
33	C	1.20	0.30	0.80	1.20	0.30	2.20	0.90	0.80	1.70	2.10	0.10	2.01
37	C	0.08	0.71	0.79	0.04	0.13	0.80	0.13	0.50	0.37	0.58	0.12	2.72
42	C	0.45	0.39	1.54	0.18	0.05	1.08	0.80	0.42	0.78	0.67	0.22	0.53

S/N	Group	H4			H2			H3			H1		
		LT	TF	PIEV	LT	TF	PIEV	LT	TF	PIEV	LT	TF	PIEV
45	C	0.57	0.60	1.23	0.25	0.60	0.70	0.35	0.33	1.42	1.77	0.23	0.72
48	C	0.68	0.70	1.43	0.31	0.34	0.68	0.75	0.70	1.29	0.27	0.30	0.62
50	C	0.48	0.60	1.22	0.04	0.70	0.78	1.27	0.07	0.64	0.38	0.57	0.82
51	C	1.20	0.20	1.00	0.00	0.00	1.25	0.80	1.20	1.46	0.20	0.40	2.39
52	C	0.67	0.08	2.02	0.52	0.72	1.15	0.98	0.18	0.95	0.90	0.38	1.13
53	C	0.37	0.48	0.75	0.57	0.17	0.96	0.02	0.42	0.53	2.67	1.29	0.43
55	C	0.63	1.32	0.30	0.42	0.22	1.48	1.58	0.10	0.28	0.98	0.18	1.22
56	C	1.07	0.53	1.11	0.15	0.47	1.21	0.85	0.25	1.35	0.23	0.32	0.54
57	C	1.42	0.10	0.60	1.45	0.12	0.06	0.32	0.37	0.74	1.17	1.20	1.94
58	C	0.64	0.44	1.18	0.69	0.33	1.34	0.50	0.20	0.60	0.10	0.50	0.90
60	C	0.53	0.18	1.57	0.48	0.41	2.23	1.27	0.35	0.45	0.90	0.38	1.13
61	C	1.02	0.88	0.70	1.90	0.18	0.53	1.70	0.35	1.54	0.90	0.38	1.13
62	C	0.36	0.19	1.82	0.78	0.72	1.22	0.47	0.10	0.66	1.03	0.17	0.34
63	C	0.98	0.08	1.22	0.73	0.28	0.80	0.75	0.41	0.86	0.90	0.38	1.13

APPENDIX D: Submitted manuscript 1

Effect of driving inactivity on driver's lateral control: A driving simulator study

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Highlight(s):

- Driving simulator was used to evaluate the retention of driving skills after a period of on-road driving inactivity;
- Inactivity from driving is associated with deterioration in lane wandering and lane encroachment controls;
- The deterioration varied for different set of skills, with more complex tasks having faster deterioration rate;
- On-road driving experience following licensure is important towards retaining trained skills as well as further improving lateral control skills.

1 Abstract

Overall on-road driving skill is a cumulated acquisition of driving skills learned during training period and furthered tempered with post-licensing driving exposure on the roads. Training serves to develop a person's basic driving skills to survive safely on the roads at first, while subsequent on-road driving hones the driving skills further. Inactivity from on-road driving can result in deterioration of driving skills. Particularly for the case of inactivity immediately following licensure, which is not uncommon in Singapore, the learned skills can degrade rapidly. This research addresses the issue on skills degradation of learned driving skills as a result of driving inactivity, specifically for young-inexperienced drivers. A series of experiments were conducted on a driving simulator for different subject groups involving active driver, novice driver (freshly licensed driver), inactive driver (never ever drive upon licensure), and no licence subjects. The participants drove through a stretch of expressway under free-flow conditions, and lane positioning control was monitored. It is found that without on-road driving exposure, driving skills like maintenance of lane positioning control in terms of lane wandering and lane encroachment may deteriorate after some periods of inactivity. The deterioration varies at different rate, with faster deterioration for more complex tasks. In complex driving tasks, the skills level can regress close to un-trained level. The findings also suggest that on-road driving exposure is needed to not only retain but also to improve the lane control skills.

Keywords: driving licence, lateral control, skills retention, driving simulator

2 Introduction

Driving a vehicle is a complex task that combines many sub-tasks such as control, guidance, and navigation (AASHTO, 2010). Vehicle handling skills hold an important aspect of driving skills to safely navigate and control the vehicle. Key driving skills include, among others, speed control, lateral control and hazard anticipation. Driving training serves to develop basic driving skills of a person and familiarise him (both genders) with the driving task in relation to the road environment, in order to prepare him to drive on the public roads. On-road driving further develops the driver's skills as well as familiarisation with real-world driving conditions. Regular on-road driving is needed to maintain the driving competency. Several studies have examined the effect of driving exposure on selected aspects of driving, such as eye scanning (Borowsky, 2006; Konstantopoulos, Chapman, & Crundall, 2010), visual attention (Crundall, Underwood, & Chapman, 1999), and risk perception (Sagberg & Bjornskau, 2006; Wu, Yan, & Radwan, 2016). Findings from these studies show that regular on-road driving does affect the driver on his driving strategy and perception towards risk.

While on-road driving exposure strengthens one's driving skills, inactivity from on-road driving for a novice driver (freshly licensed driver) may result in deterioration in the skills learned from training. Previous studies in the fields of sports (Garcia-Pallares, Carrasco, Diaz, & Sanchez-Medina, 2009; Neuffer, Costill, Fielding, Flynn, & Kirwan, 1987) and military (Ammons, Farr, Bloch, Neumann, Dey, Marion et al., 1958; Farr, 1987; Fleishman & Jr., 1962; Wisher, Sabol, Ellis, & Ellis, 1999) have shown that periods of inactivity may cause deterioration in skills and performance. In effect, skills gained in the training process and subsequently reinforced with regular application may 'decay' upon disruptions in applying these skills. Furthermore, the deterioration rate may vary for different types of skills. The concept of regular practice to maintain skills proficiency can be exemplified in the example of a recreational aircraft pilot having to chalk up certain quantum of flying hours as a condition of licence renewal. It shows the general premise of maintaining skills through regular exposure to real world practices and experiences. Whereas several studies have pointed out that on-road driving serves to further develop the driving skills after initial training period (to gain licence), to the authors' best knowledge, there is yet any study on the effect of driving inactivity on the driving skills upon getting a licence by young drivers. Certain driving skills learned in the licensing process but never put to practice shall, after some length of time, deteriorate over time. Herein, it is rationalised that driving inactivity for

novice subjects shall result in deteriorated driving performance. In particular, young-inexperienced drivers who never put their driving skills to practice are expected to be particularly prone to driving skills deterioration from inactivity. This situation of young-inexperienced drivers is rather prevalent in Singapore, which has thus provided a strong motivation and a well-fitting setting to undertake the present study.

In Singapore, the high ownership and operating costs of a private vehicle make it difficult for the general population to have regular access to a vehicle, even though many people continue to get a driving licence once they reach licensure age (at 18 years old). Indeed, the number of classes 3 and 3A driving licence holders, for licensure to drive a private car, continues to increase from 1,686,272 in 2011 to 1,913,161 in 2015 (13.5% increase) (Singapore Police Force, 2017), which commensurate with the growing population base. On the other hand, the car population remains relatively stable at 606,180 in 2011 and 604,722 in 2015 (Land Transport Authority, 2017). This situation creates a unique drivers' population in Singapore with a large pool of inactive drivers, many of whom have never driven or rarely ever drive since getting a licence.

Driver licensing, including fitness-to-drive assessment, is a way to distinguish fit drivers from the unfit ones. However, there is no standardised protocol to regularly control and assess a driver in the post-licensing period. Every jurisdiction has its own regulations related to drivers re-licensing or refresher courses. Denmark, Italy, the United Kingdom, the Netherlands, and Portugal require the drivers to undergo regular assessment when they reach a certain age, while in other countries, e.g. Belgium, France and Sweden, there is no renewal required once the drivers got their licences (OECD, 2001). The type of assessment also varies across the jurisdictions. Several jurisdictions have regulations related to fitness-to-drive assessment and re-licensing protocols for elderly driver, traffic offender and person with health concern. However, to the authors' best knowledge, there are no jurisdictions that have regulations that deal with inactive drivers or include a certain minimum quantum of driving hours/frequency in renewal regulations. There are yet any studies addressing this problem of how driving inactivity could impair the driving skills. Therefore, this research aims to address the issue on retention of driving skills in relation to driving inactivity, specifically for the young, freshly-licensed, and hence inexperienced, drivers.

3 Methodology

3.1 Participant sample

A total of 132 participants drawn from student population at the Nanyang Technological University (NTU) were recruited for this study. Before any experimental work, these subjects had to sign pre-approved ethics review protocols which ensure that test subjects voluntarily participate in the project's experiments, and they can stop the experimental run at any time. The sample consisted of 97 driving licence holders (33 females and 64 males) and 35 non-drivers (25 females and 10 males). One participant who reported experiencing a high level of simulator sickness at the end of the simulation run was excluded from the analysis which reduced the total sample to 131 subjects. The age of the participants ranged from 20 to 30 years old. Participants with a driving licence had a range of driving inactivity from 0 month (for active drivers) and up to 72 months (for non-active licensees) (mean = 9.6 months; Std. Dev. = 17.7 months). This age group was rather suitable for this study on young drivers with limited on-road experiences. The no licence group serves as the baseline of driving performance in the absence of any training.

Each participant was required to complete a familiarisation run by taking a short drive on the driving simulator before embarking on the main experiment. Upon completion of the experiment, the participant would receive a monetary honorarium for his participation. After taking a short rest, he shall then leave the laboratory.

3.2 Equipment

This study was conducted using a driving simulator (see Figure 1) installed in NTU's Transport and Geospatial Laboratory (TGS-Lab). It is a fixed-base driving simulator which has a simple frame for driver seat and steering wheel. The simulator is equipped with three 46-inch LED panels which are placed around the driver seat to display the surrounding environment of the test vehicle. A Logitech G27 system comprising control input, steering wheel, and pedals is used in the simulator. A virtual road network was built using *UC-Win/Road version 11.01 Driving Sim* for rendition on this driving simulator.

Figure 1 Driving simulator setup

Driving simulator is chosen for the platform of driving performance evaluation as it offers a safer and more controllable driving environment. Certainly, it would be very risky to conduct the experiment on real road environment, particularly for no licence participants who are never trained in driving. A driving simulator also offers a controllable environment in which one can easily create a required scenario of the driving condition and thence repeat it for all participants to obtain better consistency of scenario among the participants.

Eye tracking glasses (ETG) supplied by SensoMotoric Instruments (SMI) were applied for tracking the eye gaze of each participant during the experimental run on the driving simulator. The SMI-ETG is a mobile head-mounted eye tracking device equipped with three cameras: one camera to record the eye movement on each eye, and one camera to record the forward scene. The ETG records eye gaze data, i.e. gaze position, fixation duration, etc., and also the video of the forward scene overlaid with eye gaze movements. All the data were extracted using SMI's *BeGaze Qualitative Analysis Software*.

3.3 Experimental Procedure

Upon the participant's arrival at TGS-Lab, a research assistant briefed the participant about the experiment. Then, the participant read through and signed an informed consent form to indicate his agreement to participate in the experiment. He also completed a questionnaire regarding his demographic data and his recent activities and current fatigue level; any

participant should be in a relatively fresh state otherwise he come back on another occasion. Following which, the participant settled onto the simulator seat which he can adjust to fit his preference. The participant then put on the SMI-ETG and the research assistant would calibrate the SMI-ETG to maximise the precision of the eye gaze tracking record. Once the calibration was completed, the driving simulation commenced.

Before the participant embarked on the main session, he first undertook an adaptation session. The purpose of the adaptation session is to give the participant sufficient 'play' to get familiar with the driving simulator system so as to prepare the participant for the main driving session. The participant was instructed to drive as he would normally do in a real driving situation, and to follow the traffic rules and navigational message. Once the participant completed the adaptation run, he would take a rest for 15 minutes before starting the main driving session.

During the main driving session, the participant 'drove' on an expressway environment with speed limit at 80 km/hour. The test circuit included straight segments as well as horizontal-curve segments. This combination of straight and curved segments serves to provide different levels of difficulty in vehicle handling along the driving route.

The participant was instructed to maintain his driving speed and not to exceed the stipulated road speed limit. The participant was also instructed to keep to the designated lane for the complete circuit, i.e. there was no lane changing involved. The traffic was kept on the low end so that the test vehicle would not be following any front vehicle nor be tracking alongside another vehicle on the adjacent lane(s). In this way, the movement of the test vehicle was not hampered by vehicles in the vicinity which could otherwise constrain the pace and manoeuvre of the test vehicle. The performance of the participant was monitored during the experiment and he could elect to quit the experiment at any time (for example, due to induced motion sickness). Upon completion of the main driving session, the participant completed a post-experiment questionnaire which included questions about experiencing any degree of simulator sickness. After taking some rest so as to recover from simulator-induced discomfort, the participant was then released from TGS-Lab. All experimental procedures were ethically pre-approved by NTU Institutional Review Board (NTU IRB reference IRB-2015-11-008) before the commencement of the driving simulator experiment.

3.4 Data Analyses

Data were recorded directly by the UC-Win/Road version 10 Driving Sim data logger. Log data from UC-Win/Road module comprises information on driving performance as well as vehicle placement data relative to lane geometry. From UC-Win/Road data logger, offset distance (X) of vehicle's centreline (CL_{car}) from travelled (test) lane's centreline (CL_{lane}) was obtained, with sampling done at every 0.10-secondth point along the journey. Herein, the lane's centreline is located mid-distant astride the dashed lane delineation lines. The lateral position of a vehicle can be expressed by a lateral placement parameter called centrality index (CI). The CI, as defined in Equation (1), is a dimensionless measure that describes the positioning of a vehicle of a given wheel span (VW) across the width between two specified boundaries (TW) (Stimpson, McGee, Kittelson, & Ruddy, 1977; Wong, 1989), with the meaning of the variables illustrated in Figure 2.

$$CI = \frac{(2X_s + VW - TW)}{TW} \quad \text{Equation (1)}$$

Furthermore, Equation (1) can be modified as:

$$CI = -\frac{2X}{TW} \quad \text{Equation (2)}$$

A CI value of zero refers to a situation that the vehicle's CL_{car} coincides with the lane's CL_{lane} , while a CI value of +1 or -1 represents the case when CL_{car} is atop the left or right boundary, respectively. In this study, TW is treated as uniform for the whole journey, set at TW = 3.70 m, while vehicle width is set at VW = 1.94 m since a same car was used throughout the experiment. For the TW and VW values, the left or right wheel of the vehicle is straddling on the left or right delineation line when CI is at ± 0.48 , and the wheel encroaching onto adjacent lane when beyond ± 0.48 .

Figure 2 Illustration of centrality index (CI)

Two additional lateral control parameters were derived from the calculated CI values. The first parameter is the variance of lateral position (VLP) which is related to lane wandering tendency. VLP was calculated based on the variance of CI that was measured at regular points along the journey (see Equation 3). A larger variance in the CI means that the lateral position of the vehicle had varied greater along the journey and would denote erratic (unstable) lateral position control. Such lane wandering tendency is an important factor as it conveys the ability of the driver to control his vehicle to a stable lateral position trajectory within the confines of the lane. An unstable control in the lateral position can lead to the vehicle encroaching onto an adjacent lane which increases the risk of side swipe with other vehicles, especially motorcycles.

$$VLP = \frac{1}{n} \sum_{i=1}^n (CI_i - \bar{CI})^2 \quad \text{Equation 3}$$

The second parameter is percentage of lane over-run (PLO). PLO represents the tendency of the test vehicle to encroach onto the adjacent lane. It was calculated as the time proportion of the journey in which part of the test vehicle encroached onto the adjacent lane (JT_{encroach}) to the total journey time (JT_{total}) (see Equation 4). Lane encroachment is an important parameter in lateral control, as an abrupt and unintentional lane encroachment may disrupt traffic flow

movements on the adjacent lane and thus increases the risk of side swipe with vehicles on the adjacent lane.

$$PLO = \frac{J_{encroach}}{J_{total}} \times 100\% \quad \text{Equation 4}$$

4 Results

Lateral control is related to the ability of a driver to maintain a smooth trajectory while positioning the vehicle safely within the driving lane along the journey. It is closely related to proficient steering control which is one of the basic driving skills being taught during the early phase of driving training. Steady steering control is related to safe interaction with other vehicles on adjacent lanes. In this study, the lateral control performance of the drivers is indicated by two parameters namely, lane wandering, VLP, and lane encroachment, PLO. Several previous studies on driving performance have used lane wandering as an indicator to represent the stability of lateral position control of the vehicle. Meanwhile, the lane encroachment represents the ability of the driver to position the vehicle within the driving lane, so that the vehicle will not interfere with traffic on other lanes which may otherwise lead to risky interaction with other vehicles.

Figure 3 shows the graph of VLP over duration of driving inactivity, for licensed subjects who did not progress to any on-road driving exposure upon licensure (as shown in solid line). The dashed line represents the baseline, which shows the average VLP value of no licence subjects who have never received any driving training. The dotted line represents the upper benchmark, which is the average VLP value of licensed subjects who regularly drive for more than two years. Expectedly, no licence subjects had much larger VLP compared to the licensed group. There is a jump of the VLP beyond three months of inactivity, with generally larger VLP. This suggests that after a couple of months of inactivity, a driver may start to experience deterioration in lateral control ability as revealed by a greater degree of lateral wandering along the lane. It appears that a driver, who upon training (for licensure) and does not progress to on-road driving, may experience a notable deterioration in control of lane wandering, after three or more months of driving inactivity. Nevertheless, even though the skills had deteriorated, they still had much better on lane wandering control than the untrained, no licence group.

Figure 3 Average variance of lateral position (VLP) versus duration of inactivity

Based on this finding, one can set a cut-off point duration of more than three months of driving inactivity in order to characterise the licensed but inactive group. Those participants with inactivity duration not exceeding three months can be taken to represent the novice level, which possesses comparable VLP as active drivers. Herein, participants can be grouped into active group, novice group, inactive group, and no licence group, as shown in Table 1. With this classification, the VLP and PLO were accordingly calculated for each group.

Table 1 Participant grouping description

Group	Description	Sample Size (n)
Active	The participant holds a valid driving licence for more than 2 years and has been driving regularly	36
Novice	The participant holds a valid driving licence but has not been driving since obtaining licence within the last three months	29
Inactive	The participant holds a valid driving licence but has not been driving since obtaining licence more than three months ago	31
No Licence	The participant does not possess any valid driving licence in Singapore or elsewhere	35

The test circuit for vehicle handling assessment consisted of both straight segments and horizontal-curve segments. The influence of straight versus curved alignments was examined given their different demands in terms of vehicle handling. It is rationalised that a curved segment could be more challenging for a driver to maintain a centrally-aligned lateral position, as often times a driver tends to 'cut' corner for a flatter trajectory across a curve. Herein, separate analyses were performed on the curved segments and compared against corresponding performance on the straight segments.

4.1 Straight segments

Driving on a straight lane is essentially concerned with maintaining a linear trajectory and is considerably less challenging as compared to negotiating a horizontal-curve. However, the ability to handle the vehicle is no less important. Along the straight segments, drivers tend to drive faster given the lesser demand in lateral control, and this results in lesser safety time window available to make a decision in response to hazard. Therefore, the ability to handle a vehicle along the straight segments is just as important as on a horizontal-curve.

Figure 4 shows the average values of (a) VLP, and (b) PLO of each group, with the error bar indicating one standard error. The average VLP value ranges from 0.066 to 0.280. The result shows that VLP for the active group is the lowest which implies that active group has the best lane wandering control compared to the other three groups. As expected, the no licence group has the worst performance compared to the other groups. The average PLO value for straight segments ranges from 7.5% to 28.4%. The active group has the lowest PLO which indicates the best lane encroachment control among these four groups.

(a)

(b)

Figure 4 Average VLP (a) and average PLO (b) of straight segments

Tables 2 and 3 show the summary statistics of the VLP and PLO for all the groups on the straight segments. ANOVA and post-hoc test were conducted on the dependent variables with the participant's group as the independent variables. Table 4 shows the summary of the results. All the statistical tests were performed using *Rstudio 1.0.136*.

Table 2 Summary statistics of VLP of straight segments

Groups	Count	Sum	Average	Variance
Active	36	2.386	0.066	0.004
Novice	29	2.441	0.084	0.007
Inactive	31	3.556	0.115	0.010
No Licence	35	9.794	0.280	0.199

Table 3 Summary statistics of PLO of straight segments

Groups	Count	Sum	Average	Variance
Active	36	2.698	0.075	0.006
Novice	29	3.889	0.134	0.034
Inactive	31	5.013	0.162	0.024
No Licence	35	9.934	0.284	0.042

Table 4 Result of statistical tests of VLP and PLO of straight segments

Road segment	Variable	Homogeneity test	ANOVA		Welch ANOVA ^a		Post-hoc	Games-Howell ^b
			p-value	F value	p-value	F value	p-value	p-value
Straight segments	VLP	0.021	F(3, 127) = 5.669	0.001	F(3, 65.565) = 4.041	0.011	Active < Novice	0.781
							Active < Inactive	0.108
							Active < No Licence	0.039
							Novice < Inactive	0.577
							Novice < No Licence	0.070
							Inactive < No Licence	0.161
	PLO	0.008	F(3, 127) = 10.49	3.25E-06	F(3, 61.219) = 12.171	2.40E-06	Active < Novice	0.382
							Active < Inactive	0.032
							Active < No Licence	0.000
							Novice < Inactive	0.923
							Novice < No Licence	0.016
							Inactive < No Licence	0.037

^a Only displayed when variances are not equal^b Games-Howell used when variances are not equal

Results of ANOVA indicate significant effect of participant group for both VLP and PLO. Active group consistently had the lowest average values of VLP and PLO, which indicate the best lateral control among the four groups. On the other hand, as observed in Figure 4, inactive group consistently performed worse than novice group on both VLP and PLO variables.

As observed in Figure 4, PLO gives a more discriminating result compared to VLP, especially between active group and novice group. Lane encroachment control can be considered as being a more complex task than lane wandering control. Lane encroachment control entails the skills of controlling lane wandering in relation to estimating the vehicle's position based on lane delineation reference lines.

4.2 Horizontal-curve segment

A separate analysis was conducted for horizontal-curve segment. As mentioned before, horizontal-curve segment would be a more challenging part in driving, especially for lateral control. The lane wandering and lane encroachment parameters were measured and calculated solely for the horizontal-curve segments. There are three horizontal-curve segments along the left-hand drive road with test vehicle going from curve 1 to curve 3 (see Figure 5).

Figure 5 Horizontal-curve segments

Figures 6 and 7 show the average VLP and PLO for each curve, respectively. The average VLP value for active group is consistent for all three horizontal-curve segments. It is important to note that the first and third curve are left turn while the second curve is right turn orientation. From both Figures 6 and 7, it can be seen most groups showed less stable lateral control on left-turn curve, indicated by higher average value of VLP and PLO for curves 1 and 3. It might give some indications that left-turn curve bear more difficulties than the right-turn curve. It might due to the position of the driver being on the right side of vehicle that makes it difficult to estimate the left reference when the driver turns towards the left direction. Therefore, drivers experience more unstable lateral control and lane encroachment on turn-left curves than turn-right curves.

The length of transition might also affect the stability of lateral control on a curve segment. The lateral control on the first curve is expected to be more unstable since drivers might still be adapting to the curve. Subsequent curves are expected to have more stable lane wandering and lane encroachment controls. However, as can be seen from Figures 6 and 7, although on the second curve the VLP and PLO value are lower, it became higher on the third (turn-left) curve. It might due to the different length of the available transition. The transition between curves 2 and 3 is shorter, as can be seen in Figure 5. Thus, the test subjects would have less time to recover their lateral position before entering the next curve.

Although there are different types of curve among the curve segment, the result shows that both VLP and PLO values for all the curves is not significantly different at 0.10 level of significance (see Table 5). Therefore, in subsequent analysis, the combined average values of VLP and PLO for all three curve segments were used.

Table 5 Result of statistical test for VLP and PLO of horizontal-curve segments

Group	Variable	Homogeneity test	ANOVA	
		p-value	F value	p-value
Active	VLP	0.939	0.810	0.448
	PLO	0.498	1.046	0.355
Novice	VLP	0.706	0.104	0.902
	PLO	0.583	0.061	0.940
Inactive	VLP	0.388	1.655	0.197
	PLO	0.856	0.495	0.611
No Licence	VLP	0.533	1.150	0.321
	PLO	0.797	0.078	0.924

Figure 6 Average variance of lateral position (VLP) of horizontal-curve segments

Figure 7 Average percentage of lane overrun (PLO) of horizontal-curve segments

Figure 8 shows the overall average values of (a) VLP and (b) PLO of each group for the horizontal-curve segments. The average value of VLP ranges from 0.061 to 0.221. Consistent with the straight segments, no licence group had the highest VLP compared to the other groups. The lane encroachment control was also analysed through the PLO parameter. The

average value of PLO ranges from 12.2% to 32.6%, being relatively higher than on straight segments, thus indicating a greater difficulty level on horizontal-curve segments.

(a)

(b)

Figure 8 Average VLP (a) and average PLO (b) of overall horizontal-curve segments

Tables 6 and 7 show the summary statistics of VLP and PLO on horizontal-curve segments, respectively. Univariate ANOVA and post-hoc test were also conducted for the dependent

variables, VLP and PLO, with participants groups as the independent variables. Table 8 shows the summary results.

Table 6 Summary statistics of VLP of overall horizontal-curve segments

Groups	Count	Sum	Average	Variance
Active	36	2.170	0.060	0.002
Novice	29	2.499	0.086	0.006
Inactive	31	3.244	0.105	0.004
No Licence	35	7.722	0.221	0.075

Table 7 Summary statistics of PLO of overall horizontal-curve segments

Groups	Count	Sum	Average	Variance
Active	36	4.383	0.122	0.012
Novice	29	5.508	0.190	0.017
Inactive	31	7.377	0.238	0.036
No Licence	35	11.394	0.326	0.042

Table 8 Result of statistical test for VLP and PLO of overall horizontal-curve segments

Road segment	Variable	Homogeneity test	ANOVA		Welch ANOVA ^a		Post-hoc	Games-Howell ^b
		p-value	F value	P-value	F value	P-value		p-value
Curve Segment	VLP	0.008	F(3,127) = 7.661	9.54E-05	F(3, 63.34) = 7.0143	3.80E-04	Active < Novice	0.347
							Active < Inactive	0.010
							Active < No Licence	0.008
							Novice < Inactive	0.739
							Novice < No Licence	0.039
							Inactive < No Licence	0.088
							Active < Novice	0.120
							Active < Inactive	0.022
							Active < No Licence	0.000
							Novice < Inactive	0.661
PLO	PLO	0.042	F(3,127) = 9.601	9.27E-06	F(3, 67.154) = 10.05	1.48E-05	Novice < No Licence	0.011
							Inactive < No Licence	0.284
							Active < Novice	0.120
							Active < Inactive	0.022
							Active < No Licence	0.000
							Novice < Inactive	0.661
							Novice < No Licence	0.011
							Inactive < No Licence	0.284
							Active < Novice	0.120
							Active < Inactive	0.022

^a only displayed when variances were not equal

^b Games-Howell used when variances were not equal

ANOVA also revealed significant effect of participant's group on both VLP and PLO for horizontal-curve segments at 0.05 level of significance. The VLP of inactive group is higher than active and novice groups, although it is still lower than no licence group. The same trend as prevailed on the straight segments was likewise observed on curved segments for PLO. Active drivers performed the best compared to the other three groups, as indicated by the lowest PLO. The lowest PLO suggests that active group drove over the delineation line and encroach on the other lane in the least compared to the other groups. It means that active driver is more able to control the position of the car within the lane boundaries and with the least risk of contact with vehicles in the adjacent lane. As observed in Figure 8, similar with the straight segments, PLO also gives more discriminating results, especially among the participants with driving licence. It strengthens the argument that task or skill that is more complex is more affected by on-road driving experience and inactivity.

5 Discussions

5.1 Effects of driving training and experiences

As can be observed from Figures 4 and 8, the no licence group performed the worst among the four subject groups. The statistical tests found that the no licence group had significantly higher VLP and PLO values than even the novice group, indicating better driving performance after driving training. The no licence group never receive any training and never has any experience on controlling a vehicle, thus they do not have experiential feeling of on-road vehicle control. On the other hand, the novice group has (recently) gone through driving training and passed the driving test to get their driving licence, which thus equipped them with basic skills for driving. This shows the effectiveness of driving training in preparing a driver with the necessary driving skills.

In general, the results also show that active group, as covering those who regularly drive for more than two years, performed better than novice group and the best among all subject groups. Active drivers are not only better in maintaining a stable lateral position, they are also better in positioning the vehicle within the driving lane. The novice drivers may have been trained on the necessary driving skills; however, they lack real on-road driving experience. Active drivers not only have received driving training, they also have more opportunity to practise and improve their skills. Therefore, their skills are well developed compared to the

novice drivers. Familiarity with real road situations is needed for better handling the vehicles on more difficult road setting, i.e. horizontal-curve segments. With more on-road driving exposure, drivers will be more familiar with the road conditions and be able to use available cue or reference to estimate their lateral positions thus resulting in better lateral control.

Significant differences are found between active group and inactive group. It might be that while inactive driving licence holders had received driving training, which would make them better than those who have never received any training (no licence group), inactivity may affect vehicle handling performance from lack of practice. The combination of lack of on-road driving coupled with inactivity thus creates the big gap in driving skills between these two groups.

The differences are more evident particularly for the more complex task, i.e. PLO, and on more complex road conditions, i.e. horizontal-curve segments. A marginal difference was also found between active group and novice group on lane encroachment parameter, PLO, on horizontal-curve segments. It shows that on-road driving exposure further develops one's driving skills, especially for the more complex task and difficult road condition.

5.2 Effects of driving inactivity

During driving training, a person is prepared with necessary driving skills to reach a certain required level of driving skills. As he passed the driving licencing test, one can assume that he has attained acceptable driving skills. However, as some previous studies in other areas have pointed out that some human knowledge and skills may deteriorate if left inactive for a prolong period of time. The results from the current research suggest that a similar trend also applies to driving exposure as affecting driving skills.

In general, the results of VLP and PLO indicate that inexperienced driving licence holders who do not proceed to on-road driving upon licensure (inactive group) would likely experience deterioration in driving skills, such as in controlling the lateral position of the vehicle. Even on a less difficult segment, i.e. straight segments, the result indicates that inactive group performs worse than the novice group, who recently got their licences. Inactive driving licence holders tend to wander over greater lateral range than active or novice drivers. They also tend to encroach on other lanes more often.

Meanwhile, active drivers who have on-road experience not only retain the trained skills but also improve on it. It is evident by the better results on VLP and PLO performance. The

statistical tests show that inactive driving licence holders performed significantly worse than active drivers, which results from lack of driving exposure and driving inactivity. On the other hand, no significant effect is found for PLO between inactive and no licence group on horizontal-curve segments. It implies that for more difficult task and more difficult road conditions, the driving skills of inactive driver has deteriorated to the level of the untrained level.

Between the two parameters, VLP and PLO, different tendency are observed. For VLP, the result of inactive group leans much closer to active and novice groups than to no licence group. On the other hand, the average PLO of inactive group is closer to no licence group. Lane wandering control is part of basic driving skills of driving that is learned during the early stage of driving training leading to functional ability to maintain the stability of the vehicle, with familiarisation to steering wheel control. This skill is seen to be retained longer even after some period of inactivity. The results also suggest that on-road driving exposure would not result in much further improvement.

While the lane wandering controls deals with the ability to maintain the stability of the vehicle's lateral position, lane encroachment control combines the ability to maintain the stable position and the ability to estimate the position of the vehicle on the driving lane which is the more complex task. The results indicate that lane encroachment control is more prone to deterioration with inactivity. After completion of his training, if a person does not progress into on-road driving, he may easily lose the sense to estimate the position within the driving lane. He is also not familiar in using available cue on the roads to estimate his position. It results in more encroachment into adjacent lane. It shows that the ability to estimate the position using available reference, though being a part of the training, shall require on-driving experience to retain and strengthen this ability

5.3 Limitations of this study

The series of experiments were conducted on a driving simulator instead of real-road driving. Therefore, the results may not be directly transferable to real-road driving condition. Furthermore, the steering wheel that was used was smaller in circumference than that for a normal car, and be relatively more sensitive than a standard steering wheel. Therefore, the general value of VLP and PLO might be over-estimated. Nevertheless, the results are still acceptable for relative comparison between groups since all the participants went through the

same settings. On top of that, they were given an adaptation session to be familiarised with the setup before commencing the main experiment.

The experiment only focused on young driver groups, who have limited driving exposure. The active group's driving experiences ranged between two to five years, which is less than what is normally used to define experienced driver (≥ 10 years). Although their driving skills might not be improved significantly after several years of continuous driving, it can be assumed that the effect of experiences found in this research could well be greater for more experienced drivers. Herein, this study did not include experienced drivers (> 10 years of experience) who have stopped driving for some periods. This group may have different rate of deterioration than young-inactive drivers. Further studies can look into the issues of experienced drivers who have stopped driving for some period.

6 Conclusions

Driving training helps a person to learn basic skills needed to drive on the road. After getting the driving licence, on-road driving gives the opportunity for the driver to practise and enhance the skills that have been learned through training. The results indicate that without any on-road exposure, some driving skills, i.e. lane wandering control and lane encroachment control, may deteriorate after some periods of inactivity. The deterioration may vary for different set of skills, with more complex (e.g. lane encroachment control) tasks having faster deterioration rate. For more complex driving skills, the deterioration can result in the level of competency being relegated close to un-trained level. The deterioration of driving skills is especially more sensitive for young-inexperienced driving licence holders, as the skills that they have gained may not be 'deeply rooted' yet.

Hereby, authorities may consider a mandatory refresher course for driving licence holders who have been inactive for long-term period, especially for young licenced subjects who have never ever progressed to on-road driving. It will help the drivers to refresh the competencies that they have learned during licensure as well as familiarise them to the real road situation. It is to make sure that the drivers will be at least back to the level when they passed the driving licence test.

The results also suggest that post-licensing driving exposure is needed not only to retain but also to improve the lateral control skills. With regular practice, the skills can be strongly

retained and lasted longer as well. Exposure to real road driving experiences also helps to familiarise with road conditions and thus further improve and enhance the driving skills.

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APPENDIX E: Submitted Manuscript 2

Effect of driving experience and driving inactivity on young driver's hazard perception and accident avoidance skills

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Effect of driving experience and driving inactivity on young driver's hazard perception and accident avoidance skills

Highlight(s)

- Hazard perception test was conducted under active simulated driving setting;
- Licensed drivers without on-road driving experiences, either newly licensed (novice driver) or was inactive ever since licensure (dormant driver), are relatively slower in responding to hazards;
- Active drivers with regular on-road driving experiences generally respond the quickest to hazards;
- Licensure training seems to play only a small part in preparing drivers for hazard response;
- On-road driving experience plays an important role to strengthen skills in responding to hazards;
- Defensive driving course should be useful in preparing drivers to face hazardous situations after a sustained long period of inactivity.

Abstract

Driving skills is an accumulation of driving skills learned from training which are further developed through post-licensure on-road driving. A key driving skill is handling interaction with other road users, of which a critical component is on anticipating hazards in order to avoid a crash. Driving skills learned through training during licensure degrade over time if the driver never progresses onto on-road driving (i.e. case of inactive driver). Inactive drivers are quite common in Singapore due to high car ownership cost resulting in many people in the population holding a valid driving licence, but yet having limited opportunity to drive. This research investigated the effect of on-road driving experience as well as driving inactivity on driving performance in terms of hazard perception and anticipation. A sample of 91 participants with a range of driving exposure drove on simulated driving environment in the laboratory. Response latency and its constituent components (lag time, time to fixation and perception-response time) in responding to hazards were used as driving performance indicators. Participants who are active drivers responded faster than inactive (novice and dormant) drivers. Driving training (during licensure) seemed to play only a small role in preparing drivers for hazard response. On-road driving exposure played an important role to

strengthen skills in responding to hazards. Defensive driving course may help drivers to strengthen their driving competencies especially towards responding to hazardous situations.

Keyword(s): Driving Simulator, Hazard Perception, Response Latency, Driving Experience, Driving Inactivity

1 Introduction

Driving a vehicle is a complex task that combines many sub-tasks such as control, guidance, and navigation (AASHTO, 2010). Vehicle handling skills constitutes an important aspect of driving activities to safely navigate and control the vehicle. Familiarity with the driving process that is developed through training (during licensure) and post-licensure on-road driving affects the driving skills of a driver. Key driving skills include speed control, lateral placement control, hazard anticipation etc. In essence, a person's driving skill is a combination of driving skills that are learned during driving training, and further driving skills that are acquired through on-road driving exposure. Driving training serves to develop basic driving skills of a person and familiarise him (both genders) with the driving task and road rules, in order to prepare him to drive on public roads. On-road driving exposure further develops the driver's skills as well as familiarisation with real-world driving conditions.

Previous studies showed that driving experience can influence the visual behaviour of drivers (Borowsky, 2006; Konstantopoulos et al., 2010). While novice drivers tend to focus their eye gaze on a narrower area of the visual field, more experienced drivers scan a wider area which thus affects hazard identification. Crundall et al. (1999) pointed out that an experienced driver is better at detecting peripheral object than a novice driver and a non-driver. Their findings suggested that experience can develop perceptual skills and strategy that lead to a more efficient functional field of view. On-road driving exposure also improves driver's perception of risk and his awareness about possible on-road hazardous situations (Borowsky, 2006; Sagberg & Bjornskau, 2006). Borowsky (2006) found that young-inexperienced drivers are more reactive toward hazards, while experienced drivers are more proactive and preventive towards hazardous situations.

In Singapore, the cost of having a private car is extremely high (amortised capital and operating cost for a small saloon car is of the order of US\$ 800~1,200 a month). Therein, there are many people in the population who hold a valid driving licence, but with limited opportunity to drive due to limited access to a private car. The population of Classes 3 and 3A driving licence holders (to drive a private car) increased from 1,686,272 in 2011 to

1,913,161 in 2015, or 13.5% increase in five years (Singapore Police Force, 2017). However, private car population remained fairly static over the same period, at 725,484 units in 2011 and 724,586 units in 2015 (Land Transport Authority, 2017). This is a rather unique characteristic in Singapore of the driving licence holders' population. In effect, many licence holders have never driven or rarely ever drive since getting their licences.

For the driving course (for licensure), the driver is trained on vehicle handling skills and the driving rules, which include safety procedures (look-out for hazards) and emergency stop. Safety procedure lesson is meant to teach drivers the proper procedure to avoid any hazardous situation that can occur on the road. Emergency stop lesson is meant to prepare driver to react properly when involved in hazardous situation to avoid accidents.

The driving licensing process distinguishes fit-to-drive drivers from the unfit-to-drive ones. This is one of the ways to improve safety by not letting an unfit-to-drive person to be driving on the road. While previous studies have shown that driving experience indeed improves one's driving skills, on the opposite, the skills and familiarity with the driving task and on-road situations may degrade over the time, if a driver never have opportunity to drive regularly. Several studies in the fields of sports (Garcia-Pallares et al., 2009; Neuffer et al., 1987) and in the military (Ammons et al., 1958; Farr, 1987; Fleishman & Jr., 1962; Wisher et al., 1999) have shown that some periods of inactivity may cause deterioration in skills and performance, with different deterioration rates for different skills. This situation could also inflict on driving skills retention. To our best knowledge, there is yet any study on the effects of driving inactivity on driving skills, specifically on hazard perception and accident avoidance. Therefore, this research aims to investigate the effect of driving inactivity as well as on-road driving exposure on driving performance, in particular on hazard perception and anticipation.

2 Methodology

2.1 Test Subjects

Participants were drawn from the student population at the Nanyang Technological University (NTU) for which a sample of nearly 100 participants were recruited. The age of the participants ranged from 20 to 30 years old. Before any experimental work, these subjects had to sign pre-approved ethics review protocols which ensure that test subjects voluntarily participated in the experiments. The subject can stop experimental run at any time, if he feels

unwell at any stage of the experiment. Some data were excluded from the analysis, due to error on the eye tracking device, which thus reduced the sample to 91 subjects.

Participants were grouped into four groups based on their possession of driving licences and their driving activities. These four groups are active group, novice group, inactive group and no licence group. Table 1 shows the detailed description of each group.

Table 1 Description of test groups

Group	Description	Sample size (n)
Active	The participant holds a valid driving licence for more than 2 years and has been driving regularly	24
Novice	The participant holds a valid driving licence but has not been driving since obtaining licence within the last three months	24
Inactive (dormant)	The participant holds a valid driving licence but has not been driving since obtaining licence more than three months ago	19
No Licence	The participant does not possess any valid driving licence in Singapore or elsewhere	24

For the driving simulation run, the participant first went through an adaptation session to familiarise with the virtual environment and the driving simulator setup. After a brief rest, the main experiment commenced which entailed the participant navigating through the road circuit rendered on the virtual environment. Upon completing the experiment, the participant received a monetary honorarium. The participant was required to take a short rest before leaving the laboratory to make sure that he has recovered from any effect of simulator sickness.

2.2 Apparatus

A driving simulator, located in NTU's Transport and Geospatial Laboratory (TGS-Lab), was used to conduct the experiment (see Figure 1). The driving simulator is equipped with a simple frame for driver seat and steering wheel. Three 46-inch LED panels are used to display the driving route and its surrounding environment. A Logitech G27 that consists of a steering wheel and pedals is used as the control input of the driving simulator. With this control input, the participant has complete freedom to control and navigate the vehicle. The virtual environment of the test network was built using *UC-Win.Road version 11.01 Driving Sim*.

Figure 1 Driving simulator set up

Eye tracking glasses (ETG) supplied by SensorMotoric Instruments (SMI) were applied for tracking the eye gaze of each participant during the driving run. The SMI-ETG is a mobile head-mounted eye tracking device equipped with three cameras: one camera to record the eye movement on each eye and one camera to record the forward scene. The ETG records eye gaze data, i.e. gaze position, fixation duration, etc., and also the video of the forward scene overlaid with eye gaze movements. All the data were extracted using SMI's *BeGaze Qualitative Analysis Software*.

2.3 Stimuli

The hazard anticipation and avoidance assessments involved interactions between test vehicle and several planted hazards along the test route. The test scenarios focused principally on hazard handling ability of the participants who had full vehicle control. The test route was an urban road network consisting of local, collector and arterial roads which thus provided interaction opportunities with various levels of road usage. A previous study has demonstrated the feasibility to use a driving simulator, with active control, for hazard perception test (Underwood et al., 2011). The active setting of the driving simulator has been found to be better at representing the complexity of driving task and studying the effect of visual behaviour as compared to passive, video-based hazard perception test (Mackenzie & Harris, 2014, 2015).

The planted hazards varied from hazard involving vulnerable road user dashing across the road to a heavy vehicle merging onto the main flow. These planted hazards represented

different avoidance potential and complexity of the situation. A previous study has shown that risk perception is affected by two main factors namely, information of potential hazard, and information of abilities to prevent those hazards to become actual accidents (Brown & Groeger, 1988). Figure 2 shows the planted hazards along the test route, while Table 2 summarises the characteristics of the hazards. All the hazards chosen for the experiment are situations that would commonly occur on-road. A speed limit warning was applied for the driving experiment. It is to make sure that the participant drives within the speed range that the planted hazards are designed for so that the hazard appearance is in-step with the progression of the vehicle's movement. The descriptions of each hazard are summarised in Table 2.

Table 2 Characteristics of hazards

Hazard	Avoidance likelihood components		
	Time to collision	Collision zone	Avoidance option
Hazard 1	Long	A stretch (1 lane)	Braking
Hazard 2	Moderate	A stretch (3 lanes)	Braking, swerving
Hazard 3	Moderate	A stretch (2 lanes)	Braking, Swerving
Hazard 4	Short	A stretch (3 lanes)	Braking, swerving

Hazard 1: A pedestrian crosses at a zebra crossing

As the test vehicle enters a slip road, a pedestrian approaches and crosses the road at the zebra crossing ahead of the test vehicle. It represents a situation where the driver is expected to slow down whenever approaching a zebra crossing, and be prepared to stop for priority crossing pedestrians. The complexity of decision-making is expected to be the lowest since the driver has only one choice which is to stop his vehicle for pedestrians.

Hazard 2: A child pedestrian jaywalks across the road ahead of the test car

As the test vehicle drives along a major road, a child visible at the edge of the pedestrian footway starts to jaywalk across the road ahead of the test car. This is a more unexpected situation than the first hazard. Since it is a multi-lane road, the participant has options to avoid the collision with the pedestrian, by braking or swerving. It adds more complexity on the decision-making for this hazardous situation.

Hazard 3: A lorry comes from the left and merges onto the path of the test car

At the expressway, a lorry comes from an entry slip road at the left of the test car and merges into the path of the test car. It involves a heavy vehicle which is less vulnerable than the first two hazards but would have a severe impact in case of a collision as compared to the other hazards. The hazardous situation takes place on a two-lane road, which compounds some complexity on the decision-making process.

Hazard 4: A car comes from the left side and turns right

When the test car approaches a junction at an arterial road, a car comes from the minor road on the left and then makes a right turn crossing the path trajectory of the test car. It involves a light vehicle, which bears less severe impact in case of a collision. However, the hazard takes place at a junction of a multi-lane road, which creates more complex decision-making consideration.

Figure 2 Different types of planted hazards along test route

2.4 Experimental procedure

The participant would report to Transport and Geospatial Laboratory (TGS Lab) in NTU. Upon his arrival at the TGS Lab, the participant was briefed about the experiment and asked to sign an informed consent form as an agreement to participate in the experiment. The participant was also asked to complete a questionnaire regarding his demographic particulars, status of driving licensure, prevailing driving activities and current fatigue level. After that,

the participant was asked to sit in the driving seat and to adjust the seating into his preferred position. Note that subjects who are not in a fatigued shall proceed with the experiment.

The participant was asked to drive along a determined route. There were navigational messages to guide the participant. If participant went to the wrong direction, he would restart from the nearest checkpoint. Along the route, four hazards had been planted and each would come out with a trigger from test vehicle's position and timing. In this setting, the participant needed to not only detect the hazard but also made a decision to avoid collision involving the respective hazard. He was given full control of the vehicle, i.e. decelerate, accelerate, lane changing, etc. The participant's eye movements were tracked and recorded using the SMI-ETG, while all vehicle control and movement data were recorded on the UC-Win/Road data logger.

A post-experiment questionnaire related to hazard anticipation assessment was administered after the end of the experiment, together with simulator sickness questionnaire (Bouchard et al., 2007; Kennedy et al., 1993) and driving simulator experience questionnaire. The questionnaire included several questions related to the experience of the driver who encountered various hazards during the driving sessions. The results were used for in-depth analysis on how the participants thought about the hazard and what things might influence their decision-making. After taking some rest so as to recover from simulator-induced discomfort, the participant was then released from TGS Lab. All experimental procedures were ethically pre-approved by NTU Institutional Review Board (NTU IRB reference IRB-2015-11-008) before the commencement of the driving simulator experiment.

2.5 Data Analysis

Response latency is a measure that represents the ability of the participant to quickly recognise and respond to a hazard. The other aspect in the driver's performance concerns hazard-avoiding action. Since the participants were given full freedom to control the vehicle, they could employ different actions to avoid a collision with the hazard. Some may choose to slow down while others may choose to swerve to avoid a collision. This avoidance strategy is an indication of the driver's hazard handling strategy.

Response latency (RL), sometimes referred as reaction time, has been used as a performance indicator in many studies on driving. RL is usually calculated as a time interval from the time that the stimulus first appears on the screen to the time the subject reacts to the stimulus, in conventional HPT (Hazard Perception Test) as indicated by pressing a button. Yeung and

Wong (2015) decomposed response latency into two components: time-to-first-fixation (TFF) and reaction time (RT). The present research adopted and further modified the TFF and RT components to analyse the response time. For this research, the TFF component was further decomposed into two components of lag time (LT) and time-to-fixation (TF), and categorised them as detection components of the response time (see Figure 3). LT represents the delay that transpires till the eye starts to move towards the hazard. It is referenced from the time the object first appears on the driver's perspective until the fixation point starts to move towards the direction of the target object. TF is defined as the time needed to move the eye from the preceding fixation point till reaching the target object. It is referenced from the time the preceding fixation point starts to move towards the direction of the target hazardous object until the eye fixates onto the target object and thereafter continues to follow the object. Using SMI-ETG eye tracker equipment, the eye movement and fixation can be recorded. The second component of response time is the decision-making components, referred as PIEV time. PIEV stands for perception (P), intellection (I), emotion (E) and volition (V). PIEV is a construct that is widely used in highway engineering to describe that perception and reaction process of a driver. It explains that the perception-response time can be broken down into these four components. In this research, PIEV time is defined as the period between the first fixation on the target hazardous object and the moment the participant applied his response action, i.e. by stepping on the brake, which reflects how fast the subject reacts to the stimulus. During the PIEV time, a driver goes through a process that includes looking at the object, understanding the implication, making a decision, and applying the decision into action. These two components, detection and decision-making, form the total response time that is called response latency (RL). Figure 3 shows the breakdown of the response time components.

Figure 3 Response latency (RL) components

All the data and video related to eye movement and fixation were extracted using SMI's *BeGaze Qualitative Analysis Software*. Video processing software, Avidemux 2.6, was used to play back the video and to control it frame by frame. Therefore, the exact time frame to start timing is easily determined, and likewise the exact time of each eye gaze movement. The reaction from the participant towards the hazards, i.e. braking or swerving, is indicated by changes in the reading of the brake pedal and steering wheel indicators. All the readings are recorded onto the log file in the *UC-Win/Road* data logger, including the timestamps. Each action that is indicated on the log file is linked to the exact timestamp as the exact time of response. These parameters are examined in the following analysis.

3 Results

Univariate ANOVA is conducted on the response latency (RL) and its components, for all hazards, with participant groups as the independent variables. Table 3 summarises the result of the statistical test, which shows difference in the various parameters among the participant groups. Notably, the active group generally had the fastest response. All the statistical tests were performed using *Rstudio 1.0.136*

3.1 Response latency (RL)

Through data extraction from the recorded video and the driving log file, all components of response latency (RL) were obtained. RL values were obtained from the summation of lag time (LT), time-to-fixation (TF) and PIEV time. Figure 4 shows the average value and the standard error of RL.

Table 3 Result of statistical test for RL, LT, TF and PIEV time

Hazard	Variable	Homogeneity test	ANOVA		Welch ANOVA		Post-hoc	Tukey HSD	Games-Howell
		p-value	F value	p-value	F value	p-value		p-value	p-value
Hazard 1	RL	0.005	6.414	0.001	10.627	0.000	Active< Novice		0.020
							Active< Inactive		0.000
							Active< No Licence		0.000
	LT	0.062	2.442	0.070	2.999	0.040	Active< No Licence		0.060
	TF	0.450	1.582	0.200					
Hazard 2	PIEV	0.217	2.899	0.040			Active< Inactive	0.056	
							Active< No Licence	0.075	
	RL	0.011	3.751	0.014	3.877	0.015	Active< No Licence		0.02
	LT	0.374	0.946	0.422					
	TF	0.706	0.552	0.648					
Hazard 3	PIEV	0.045	4.071	0.009	0.580	0.631			
	RL	0.165	3.097	0.031			Active< Inactive	0.061	
	LT	0.561	1.623	0.190					
	TF	0.467	1.174	0.324					
Hazard 4	PIEV	0.257	2.456	0.068			Active< Inactive	0.089	
	RL	0.920	7.267	0.000			Active< Inactive	0.009	
							Active< No Licence	0.000	
	LT	0.862	1.177	0.323					
	TF	0.055	2.420	0.071	2.185	0.102			
	PIEV	0.476	4.041	0.010			Active< No Licence	0.005

Figure 4 Response latency (RL) with standard error

As shown in Figure 4, the active group generally performed the best among the four groups of participants. Active drivers may learn from regular on-road experience in responding to various situations, therefore they are able to make a faster response to the hazards. The RL of active group is distinctly faster than the other groups on hazard H1, which involves stopping for a pedestrian with priority right-of-way. It indicates that with on-road driving experiences, drivers are more accustomed to interaction with priority road users. They give a fast response by giving way to the pedestrian, while the other groups await until the hazardous situation is more developed.

Meanwhile, the result also shows that among the trained groups, the inactive group generally performed the worst, and was slightly slower in responding to the hazardous situations than the novice group. It shows the effect of inactivity. Inactivity can result in deterioration in vehicle control, and it may also affect the ability of drivers to estimate the situation and make a necessary response. As expected, the no licence group took a longer time to respond than the trained groups. However, the effect of training is not as significant as on-road driving exposure in terms of hazard perception and anticipation. Certainly, the group with on-road driving exposure had the best ability in responding to the hazardous situation than the novice and inactive groups who have driving training only. With the benefit of eye tracking device, the RL is further broken down into three constituent components which are discussed in the following.

3.2 Lag time (LT)

Lag time (LT) represents the delay that transpires before a person starts to move his fixation point in the detection of an object or hazardous situation on the road. In the present study, the LT is timed from onset of a hazard on the screen to the time the eye starts to move towards the direction of the target hazardous object. Figure 5 shows the average value (with standard error) of LT.

Figure 5 Lag time (LT) with standard error

As shown in Figure 5, the active group had fastest LT among the four groups across all hazards. It indicates that celerity in detection is enhanced by on-road driving exposure of drivers. With more on-road experiences, active drivers may be more sensitive to the change in the surrounding environment. Therefore, eye movements of active drivers are triggered faster by the appearance of hazardous object. Meanwhile, there is no noticeable difference or pattern in LT between novice and inactive groups. It may due to the fact both groups are on the inexperienced side, although they differed in terms of inactivity duration. Although they were trained to look out for hazards, due to lack of on-road experience they would not be sensitive to changes in on-road driving situations. A study by Wallis and Horswill (2007) found that novice drivers are less sensitive to hazards, and they need a higher threshold of hazard in order to notice it. It may also apply to the case of novice and inactive drivers in this experiment. Both groups need more developed hazards before they can notice them, resulting in a longer delay to notice the hazards.

There is no noticeable difference found between no licence and novice groups indicating the lesser effect of driving training on the awareness of hazardous situations. It shows that driving training alone may not enough to prepare driver to face and detect any hazardous situations. Driving training mainly focuses on vehicle control skills, thus on-road driving practice/experience is needed to further develop the visual skills for safe driving.

3.3 Time-to-fixation (TF)

Time-to-fixation (TF) is the duration from the time the participant starts to move his fixation point until the participant fixates onto the target hazard. This is a mechanistic process in the movement of the eye's fixation point. TF is the shortest component of RL. Figure 6 shows the average value of TF (with standard error) of each group in each type of hazard.

Figure 6 Time-to-fixation (TF) with standard error

As shown in **Error! Reference source not found.**, no significant effect was found on TF values. TF is closely related to a physiological mechanism of the eye. Therefore, driving experience and training have limited discriminating effect on the TF. Considering that all participants were all in the similar age range (young adults), it is expected that their physiological condition shall be somewhat similar which thus results in a similar quantum of the TF.

3.4 PIEV time

Perception-Intellection-Emotion-Volition (PIEV) time represents the time interval that is needed by the participant to perceive the hazard he sees, makes a decision and implements the decision into an action. Compared to the other components, i.e. LT and TF, PIEV has a longer average value, which indicates that decision-making process takes more time on the hazard anticipation process. Generally, the active group had faster PIEV time than the other three groups, which suggests that on-road exposure (of the active driver) enhances a better

performance on decision-making. Herein, the active drivers were able to make faster decision since they had 'extra learning' phase through on-road experiences.

ANOVA found significant differences for H3 (merging lorry), specifically between active-inactive groups, and H4 (cut-across car) between active-no licence groups. It indicates the effect of both on-road experience and inactivity on the ability to respond to hazards. H3 and H4 specifically entail shorter time-to-collision (TTC), which requires a faster response to avoid a collision. It shows that under tight time pressure, on-road exposure as well as driving inactivity both imposes certain effect. On-road exposure enhances drivers to make quicker decision. Meanwhile, inactivity without on-road exposure results in the inactive drivers being unfamiliar with the real road driving condition, thus inactive drivers could not make as quick a decision as active drivers. Inactive drivers are essentially inexperienced drivers. Previous study shows that an inexperienced driver needs a higher threshold of the hazard before he shall notice the hazard and then respond to it (Wallis & Horswill, 2007). It also applies in the current case whereby the inactive group awaits a longer time until hazard comes closer and is fully developed before he takes an avoidance action, thereby leading to a longer PIEV time.

Figure 7 PIEV time with standard error

Significant differences were also found on H1 (crossing pedestrian). As different from the other hazards, the priority in H1 is on the other road user (pedestrian) and the option available is only braking/slow down. The situation is quite straight for a clear response. The result

shows that active group is particularly faster than inactive and no licence groups, thus showing the effect of on-road experience, driving inactivity and training. With on-road exposure, active drivers are more aware of the priority in road interactions and hence can immediately accord priority to pedestrian on the zebra crossing. Meanwhile, others may not be as aware of the priority concept of road user interaction, therefore they await until the situation become more hazardous (closer to the pedestrian) before responding to it.

4 Discussions

4.1 Effects of training

Comparison of performance of trained (active/novice/inactive) groups with no licence (untrained) group serves to provide an indication of the effect of training. Response latency (RL) parameter shows that trained groups, particularly the active group, respond faster than no licence group. It shows the effect of on-road driving experience and driving training on the ability of drivers to handle the vehicle in response to hazardous situations.

However, the differences between novice and inactive groups in some cases are not greatly different than no licence group. It indicates that training alone does not substantially affect the hazard anticipation performance. Driving training regime, in Singapore, does not include intensive or specific training on hazard perception or vehicle handling under hazardous situation. Although training of safety procedure (such as look out for hazard) and emergency braking exist, they are never done intentionally under real hazardous situation since it is impossible to generate real hazards on the road. Therefore, such skills may not be adequately developed from training alone. Defensive driving course, which focuses on vehicle handling under hazardous situations, usually comes as an optional programme after licensing rather than as an inclusive programme of driving training. Therefore, to sharpen driving skills in responding to the hazard, drivers may need some amount of on-road exposure. Including hazardous situation response training (in driving simulation) into driving training may help to train driver in responding to hazards. Some studies have suggested PC-based training that directly covers issues related to visual scanning and risk awareness can help to improve the visual scanning strategy that is necessary for safe driving (Chapman et al., 2002; Fisher et al., 2004).

4.2 Effects of on-road driving experience and inactivity

The active group had a distinctly better overall performance in responding to hazardous situations, as indicated by shorter response latency (RL) than the three other groups. Active

group also had shorter average values for both LT and PIEV time, indicating better performance in both detection and decision-making process. These results show that driving training alone gives a less tangible contribution to hazard perception and anticipation. Meanwhile, on-road experiences give active drivers more familiarity with real road driving situations. They may also have experienced certain hazardous situations before and have thus learnt from those situations on how to safely avoid collision/accident, so the responses are triggered faster. They thus possess greater sensitivity to change of situations in surrounding environment as compared to novice and inactive drivers. The results also show that on-road experiences give better understanding of the priority of road users' interaction and how to behave accordingly. On the other hand, novice driver may be less familiar with the road situations. Underwood et al. (2002) argued that novice drivers may have less understanding of road situations which affect their visual scanning strategies. The novice drivers tend to scan on a narrower area. This visual behaviour may then affect their hazard detection.

Previous studies have shown the higher involvement of young-inexperienced and elderly drivers as compared to middle-aged experienced drivers (Massie et al., 1995; McGwin & Brown, 1999). Young drivers involvement in road traffic accident (RTA) are usually attributed to inexperience, overconfidence and fatigue (Cooper, 1990; Doherty et al., 1998; Hakamies-Blomqvist, 1993; Macdonald, 1994). No discriminating differences were found between novice and no licence groups. It suggests the lack of effect of driving training to prepare drivers for hazardous situations. While driving training has prepared drivers to safely handle a vehicle, driving training may be lacking on the aspect of responding to hazardous situations. The lack of experience on handling hazardous situation makes it harder for them to make a timely and correct response, a condition that may lead to a road traffic accident.

In learning new skills, the trainee will go through a learning phase until he reaches mastery level. In terms on driving, mastery level would be similar to passing the practical driving licence test. After that, when someone continues to practise his skills beyond the learning period, he will experiences what is called 'over learning' phase. This 'over learning' phase strengthens the level of skills that is gained over and above the original learning phase (Farr, 1987; Wisher et al., 1999). This is similar to gaining subsequent real road experience after the trainee gets the driving licence. This phase helps drivers to strengthen their driving skills and enhances their resistance against forgetting.

Meanwhile, the overall result of RL shows that generally, novice drivers respond slightly faster than the inactive drivers. This indicates that novice drivers are, in general, slightly

better in responding to hazards compared to inactive drivers. However, the differences are not substantive. It might be due to both groups, in terms of their experiences, being on the same inexperience side. They do not have as much experience as the active group. Therefore, they lack 'practice' on the safe interaction with other road users in real road driving settings. It shows that in driving skills that are related to hazard perception and anticipation, experience plays a more dominant effect. Furthermore, a longer period of inactivity from driving prevents drivers from gaining experience on interaction with other road users.

4.3 Limitations of study

The experiment was conducted in a virtual environment. The driver's emotion and perception towards the hazard might be affected by the virtual environment, which can affect his decision-making. The participant may underestimate the effect of the hazards under such simulated experiment. Notwithstanding, the participants were duly reminded to drive as if they are on real roads and to avoid any collision with other road users.

The present experiment focused only on young driver groups, most of whom had limited driving exposure and with limited experiences of on-road hazards. The active group's driving experiences ranged between two to five years, which is less than what is normally used to define an experienced driver (≥ 10 years). Although their driving skills might not further improve significantly after additional years of continuous driving, it can be assumed that the effect of on-road experiences found in this research could well be even greater for more experienced drivers. Herein, this study did not include experienced drivers (> 10 years of experience) who have stopped driving for some periods. This group may have a different rate of deterioration than young-inactive drivers. Further studies can thus look into the issues of well-experienced drivers who have stopped driving for some periods.

5 Conclusions

This research investigated the effects of on-road driving exposure and driving inactivity of young-adult drivers on hazard perception and anticipation. The result of this study suggests that on-road driving experience affects performance in both detection of hazard and also response towards hazards. Active drivers were found to have faster detection and response time than other groups. Drivers who rarely use their driving skills may lose the opportunity to practise their skills and familiarise with driving conditions, therefore they may be less accustomed in interacting with other road users. It shall affect the skill to make a correct and timely response to the hazardous situation. No significant differences were found between

novice and inactive drivers. It may be due to lack of experience on on-road driving of both groups. Therefore, they fall into the similar side which is inexperience to on-road driving.

The results also suggest the effect of driving training alone on the ability to respond to hazardous situations. Driving training, especially in Singapore, does not touch on hazardous situations during learning and licensing test. Therefore, the ability to safely respond to hazards shall be developed as drivers experience them in on-road driving rather than through training. However, many young drivers may not have the opportunity to drive a vehicle regularly in Singapore. This inactivity coupled with the lack of on-road exposure prevent drivers to enhance their skills on hazard anticipation. Defensive driving course may thus be useful in training drivers to respond to hazardous situation. Herein, the Authority may also include a lesson on hazard response training in driving simulation to prepare 'trainee' on hazard anticipation prior to getting his driving licence, or before a dormant licensee takes up regular driving.

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