THE RELATIONSHIP BETWEEN MENTAL WORKLOAD AND DRIVING PERFORMANCE OF AGEING DRIVERS

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FACULTY OF ENGINEERING
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KUALA LUMPUR

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THESIS SUBMITTED IN FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

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[THE RELATIONSHIP BETWEEN MENTAL WORKLOAD AND DRIVING PERFORMANCE OF AGEING DRIVERS]

ABSTRACT

The population of ageing drivers is increasing rapidly. As ageing happened, they are exposed to disabilities due to degenerative processes, thus affecting their driving performance. For changes in driving method or design to occur, ageing drivers' driving tasks need to be monitored, designed and tested. Comprehensive research needs to be conducted to investigate how to integrate mental workload with driving performance of ageing people. Moreover, there has been no study yet that develop a model to predict overall driving performance in Malaysia. Hence, the main objective of this study is to develop and validate a model which quantifies the mental workload on the driving performance of ageing drivers. In this study, the methodology consisted of database observations, survey and on-the-road experimental tasks. For the experimental tasks, the measurements involved were subjective ratings using NASA Task Load Index (NASA-TLX), physiological measure using electroencephalogram, number of traffic violations (NTVs), speed variability, and reaction time of peripheral detection. The accident database showed that the accident occurrences appear to be much higher among male drivers. From the survey on 182 drivers, about 60% of ageing drivers have been involved in accidents previously; driving experience has significant association with accident involvement. They have driving difficulties during rain (72%), rush hour (57%) and nighttime (59%). From the experimental tasks, the NASA-Task Load Index scores revealed that the ageing drivers' subjective workload ratings increased with higher complexity situation. Their mean physical demand score was the highest compared to others in Moderately Complex Situation (MCS) and Very Complex Situation (VCS); scoring 37.25 and 43.50 respectively. Meanwhile, for Electroencephalogram signals' fluctuation, results showed that situation complexity had significant effects on RPθ and

RPα of channel locations F_ZP_Z and O_1O_2. Both frequencies were lower in VCS compared to MCS. In addition, RPθ and RPα were significantly higher among male drivers compared to female, regardless of the situation complexity and ToT. Findings revealed that the highest mean number of traffic violations was in VCS where it was 35% higher compared to Simple Situation (SS). Furthermore, results showed that the mean speed in SS was significantly higher than MCS (42%) and VCS (38%), while the mean speed variability in MCS was significantly lower than SS (25%) and VCS (35%). The maximum reaction time was in VCS where it was 6% slower than the minimum reaction time obtained in MCS. Regression models were developed to determine Overall Driving Performance Score (ODPS) of each situation complexity based on the strong correlation and linear relationship between mental workload and driving performance elements. The relationship among these variables is significantly linear in SS (R=0.861), MCS (R=0.813) and VCS (R=0.749). All three models have been validated using data from different groups of drivers. The models would be beneficial as a guideline for designers, manufacturers, developers and policy makers in designing better driving environment for ageing drivers. They will be able to integrate safety and transportation to optimize and sustain driving performance while minimizing accident risks for ageing drivers as well as other road users.

Keywords: Ageing drivers, mental workload, driving performance, subjective measure, objective measure

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[PERHUBUNGAN ANTARA BEBAN KERJA MENTAL DAN PRESTASI PEMANDUAN PEMANDU-PEMANDU MENINGKAT TUA]

ABSTRAK

Populasi pemandu meningkat tua semakin bertambah dengan pesat. Dalam proses penuaan, mereka terdedah kepada ketidakupayaan akibat proses degeneratif, sehingga mempengaruhi prestasi pemanduan mereka. Bagi mana-mana peralihan kaedah atau reka bentuk yang dicadangkan, tugas pemandu meningkat tua perlu dipantau, direka dan diuji. Penyelidikan menyeluruh diperlukan untuk menyiasat cara mengintegrasikan beban kerja mental dan prestasi pemanduan pemandu-pemandu meningkat tua. Selain itu, belum terdapat kajian membina model untuk meramalkan keseluruhan prestasi pemanduan di Malaysia. Oleh itu, objektif utama kajian ini adalah untuk membangunkan dan mengesahkan model yang mengambilkira beban kerja mental dan prestasi pemanduan pemandu meningkat tua. Dalam kajian ini, metodologinya terdiri daripada pemerhatian pangkalan data, kaji selidik dan tugas-tugas eksperimen di jalan raya. Untuk tugas-tugas eksperimen, pengukuran yang terlibat adalah penilaian subjektif menggunakan NASA Task Load Index (NASA-TLX), ukuran fisiologi menggunakan electroencephalogram, jumlah pelanggaran lalu lintas, variasi kelajuan, dan masa tindak balas pengesanan periferal. Pangkalan data kemalangan menunjukkan kejadian kemalangan lebih tinggi di kalangan pemandu lelaki. Berdasarkan kaji selidik terhadap 182 pemandu, kira-kira 60% pemandu meningkat tua telah terlibat dalam kemalangan sebelum ini; pengalaman memandu mempunyai perkaitan signifikan dengan penglibatan kemalangan. Mereka mengalami masalah pemanduan semasa hujan (72%), pada waktu sibuk (57%) dan waktu malam (59%). Dari tugas-tugas eksperimen, skor NASA-TLX mendedahkan beban kerja subjektif bagi pemandu-pemadu meningkat tua adalah meningkat dengan kekompleksan situasi lebih tinggi. Purata skor tuntutan fizikal adalah tertinggi berbanding lain dalam situasi sederhana kompleks dan sangat kompleks; masing-masing mencatat 37.25 dan

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43.50. Sementara itu, untuk isyarat Elektroensefalogram, hasil kajian menunjukkan kerumitan keadaan mempunyai kesan signifikan terhadap RPθ dan RPα lokasi F_ZP_Z dan O_1O_2. Kedua-dua frekuensi adalah lebih rendah dalam situasi sangat kompleks berbanding situasi sederhana kompleks. Di samping itu, RPθ dan RPα jauh lebih tinggi di kalangan pemandu lelaki berbanding wanita, tanpa mengira kompleksiti dan masa bagi tugasan. Penemuan menunjukkan jumlah purata pelanggaran lalu lintas tertinggi berada di situasi sangat kompleks di mana ia adalah 35% lebih tinggi berbanding dengan situasi mudah. Selain itu, keputusan menunjukkan purata kelajuan di situasi mudah jauh lebih tinggi daripada situasi sederhana kompleks (42%) dan situasi sangat kompleks (38%), manakala purata variasi kelajuan di situasi sederhana kompleks jauh lebih rendah daripada situasi mudah (25%) dan situasi sangat kompleks (35%). Masa tindak balas maksima diperolehi dalam situasi sangat kompleks di mana ia adalah 6% lebih perlahan daripada masa tindak balas minimum diperolehi dalam situasi sederhana kompleks. Model regresi dibangunkan untuk menentukan skor prestasi pemanduan keseluruhan bagi setiap kekompleksan situasi berdasarkan hubungan korelasi dan linear kuat antara elemen-elemen beban mental dan prestasi pemanduan. Hubungan antara pembolehubah-pembolehubah ini adalah linear ketara dalam situasi mudah ($R = 0.861$), situasi sederhana kompleks ($R = 0.813$) dan situasi sangat kompleks ($R = 0.749$). Ketiga-tiga model ini telah disahkan menggunakan data dari kumpulan pemandu berlainan. Model-model ini akan bermanfaat sebagai panduan perekabentuk, pengilang, pemaju dan pembuat dasar dalam merekabentuk persekitaran memandu yang lebih baik untuk pemandu meningkat tua. Mereka akan dapat mengintegrasikan keselamatan dan pengangkutan untuk mengoptimumkan dan mengekalkan prestasi pemanduan sambil meminimumkan risiko kemalangan untuk pemandu meningkat tua serta pengguna-pengguna jalan raya lain.

Kata kunci: Pemandu meningkat tua, beban kerja mental, prestasi pemanduan, pengukuran subjektif, pengukuran objektif

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LIST OF SYMBOLS AND ABBREVIATIONS

BMI	:	Body mass index
DALI	:	Driving Activity Load Index
DBQ	:	Driver Behaviour Questionnaire
DHQ	:	Driving Habits Questionnaire
EEG	:	Electroencephalogram
EF	:	Effort
EOG	:	Electrooculogram
ERP	:	Event-Related Potentials
FFT	:	Fast Fourier Transform (FFT)
FR	:	Frustration
HMI	:	Human Machine Interface
LED	:	Light Emitting Diode
MCS	:	Moderately Complex Situation
MD	:	Mental Demand
MIROS	:	Malaysian Institute of Road Safety Research
NASA-TLX	:	National Aeronautics and Space Administration task load index
NTV	:	Number of Traffic Violations
ODPS	:	Overall Driving Performance Score
OP	:	Own Performance
PD	:	Physical Demand
PDT	:	Peripheral detection task
PSD	:	Power Spectral Density
RMSE	:	Rating Scale Mental Effort
RPα	:	Alpha relative power

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RPβ	:	Beta relative power
RPθ	:	Theta relative power
RT	:	Reaction Times
SDLP	:	Standard Deviation of Lane Position
SDSTW	:	Steering-Wheel Movements
SEE	:	Standard Error of Estimate
SS	:	Simple Situation
SV	:	Speed Variability
SWAT	:	Subjective Workload Assessment Technique
TD	:	Temporal Demand
VCS	:	Very complex Situation
WHO	:	World Health Organization
WP	:	Workload Profile
WWL	:	Weighted Workload

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CHAPTER 1: INTRODUCTION

1.1 Background

The world's ageing people population is increasing rapidly. This phenomenon is ultimately not only in the European region, but also in regions such as Northern America, Latin America, the Caribbean, Asia and Oceania (Figure 1.1) (United Nations Department of Economic and Social Affairs, 2014). The United States' ageing population is expected to increase from 13% (2010) to 23% by year 2050 (Nurul Shahida et al., 2015). Meanwhile, in 2010, 16% of the United Kingdom (UK) population was over the age of 65 and in 23 years, it is predicted that the older population will constitute almost a quarter of all UK citizens. In the Netherlands, the population of those aged 65 and above is expected to rise from 16% in 2010 to between 23 and 29% in 2040 (Statistics Netherland and Netherlands Environmental Assessment Agency, 2012). This similar episode is also observed in Asian countries, including Malaysia.

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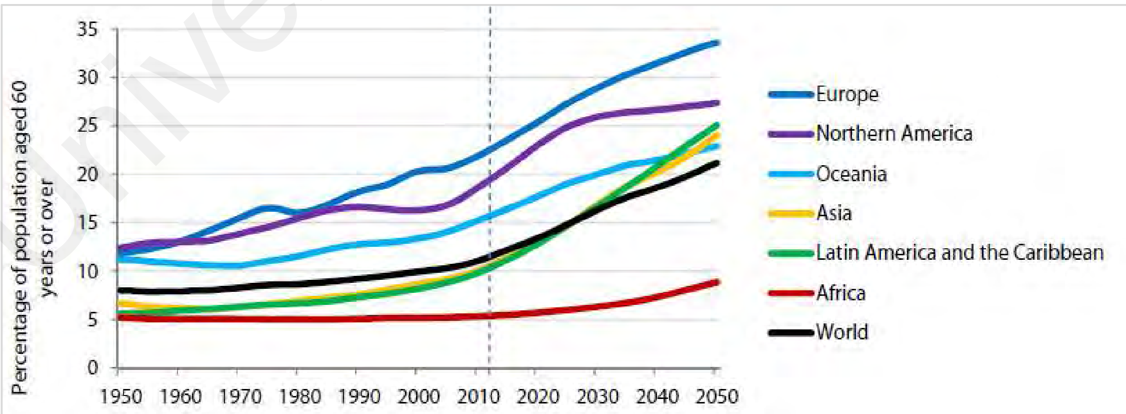

Figure 1.1: Percentage of the population aged 60 years or over, estimated for 1950-2014 and projected to 2050 (Source: Population Facts Report, United Nations Department of Economic and Social Affairs, 2014)

In Malaysia, it is expected that the ageing population (50 years and above) as in Figure 1.2 will be more than double in the next twenty two years (6.2 million in 2018 to 14.2

million in 2040) (Department of Statistics Malaysia, 2018b). According to the Ageing Workforce™ 2006 Report, the Asia Pacific will be central to most of the world's elderly people with 998 million people aged 60 and above by 2050, especially in Asia's most developed countries (Dawal et al., 2015; Rashid et al., 2008). The proportions of people aged 50 years in Singapore, for example, is forecasted to increase from twenty-three percent to fifty percent over the next twenty-five years (Dawal et al., 2015). This is due to longer life expectancy, low fertility rates, outstanding public health policies, improvements in medical technologies and efficient healthcare systems (Onunkwor et al., 2016; World Health Organization., 2014a).

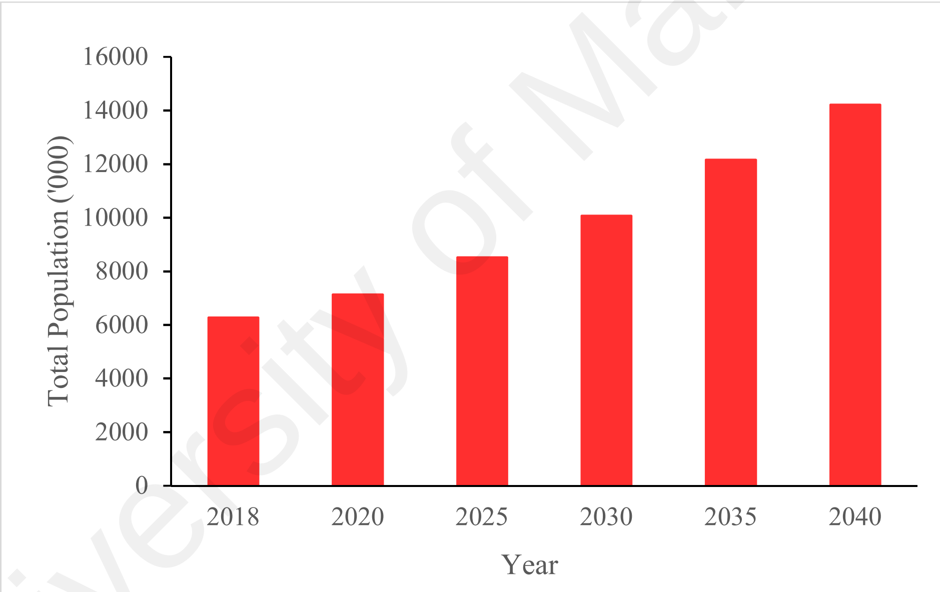

Figure 1.2: The trends of the Malaysian ageing population (Source: Department of Statistics Malaysia, 2018b)

The increase in the ageing population throughout the years has a significant relationship with the statistics of the working population and the employed in Malaysia (Kamil & Dawal, 2015). The working population is increasing rapidly from 2010 (11.9 million) to 2018 (14.7 million) (Department of Statistics Malaysia, 2018a). On the other hand, the Minimum Retirement Age Act 2012 (Law of Malaysia Act 753) was gazetted on 16 August 2012 and was enforced on 1 July 2013. The Act states that the minimum retirement age of an employee is when the employee attaining the age of 60 years

(Ministry of Human Resources, 2016). The employers may set a retirement age for their employees which is higher than 60 years. With raised retirement age, it is expected that the ageing population will still involve in the country's working area and economic development of the country. In 2013, there were more than 1.1 million employees aged 50 years and above (Department of Statistics Malaysia, 2013). It is consequential that most of the ageing employees travel to their workplace by driving their own vehicle. Apart of that, the ageing population is highly dependent on cars to meet their needs such as buying groceries, going to the park, meeting relatives, going to religious classes and so on. Despite the ease of mobility, the effect of ageing can make access to vehicles difficult or impossible over time (Hanson & Hildebrand, 2011; Donaghy et al., 2005).

In countries with effiecient public transportations like Japan, the ageing population might prefer public transportations over self driving. A national survey on Japanese adults aged sixty and above revealed that eighty percent of the drivers within that age range would consider to stop driving when they experienced functional decline or attained a certain age (Ichikawa et al., 2015). However, Malaysia's public transporation is still in the developing phase and improving the convenience level. Putting the Japan's 51 years vast experience as reference in managing the public transporation (Sun Media Corporation, 2016) might be currently preferable by ageing populations in the country. In Malaysia, the physical, social and and health issues related with ageing people (Mafauzy, 2000) contribute to the reason why public transports are not their choices.

Realizing that car is essential for mobility, there are numerous concerns about the safety of the ageing drivers on the road. Ageing drivers are prone to serious injuries or even death when they involved in accident (Ichikawa et al., 2015; Thompson et al., 2013; Lei & Roetting, 2011; Box et al., 2010). In Malaysia, the number of accidents recorded in 2016 was the highest on record since 10 years ago (Malaysia Road Safety Department, 2016). The Ministry of Transport Malaysia reported that the number of death due to

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accidents are escalating each year with a total 6674 cases in year 2014 to 7,152 in year 2016 which corresponds to 7% increment. However, the more alarming data was that the number of deaths due to accidents in 2015 for road users aged 51 and older reported by the Traffic Statistics Branch of the Royal Malaysia Police was 1875 (28% of the total number of deaths), which had increased by 2% compared to the previous year. Ageing people can be described as having 'a progressive and generalized impairment of function, resulting in an increased vulnerability to environmental challenges' (Vysata et al., 2014). Vulnerability to injury begins around the age of 55 and increases with age (L. Evans, 1993).

Ageing drivers are more likely to experience degenerative effects and suffer from medical disabilities that affect their driving performance. As people age, the visual perception of ability decreases, and so does cognitive and psychomotor functions (Eby, 2009; Anstey et al., 2005). This is due to ageing people has physical, functional and health limitations compared to the younger one. The probability of developing musculoskeletal problems tend to increase with age (Onunkwor et al., 2016; Tajvar et al., 2008). Due to these adverse circumstances, ageing drivers tend to demonstrate inappropriate driving attitudes such as turning against oncoming traffic, intersection yield failure, not maintaining the right speed, not properly staying in a lane and confusing between gas and brake pedals (Song et al., 2015).

Concern over the relationship between these elements started since more than 30 years ago (Silva, 2014). The fact that ninety percent of road accidents are due to human errors (Amditis et al., 2010), leads ergonomist focus their concern on the processes involved, particularly on the mental workload impact on the driving task performance and road safety (Silva, 2014; Kantowitz & Simsek, 2001). Driving is a complex task for ageing drivers, especially in the twenty-first century, where driving mental workload level increase as the driving condition becoming more complex (Baldwin & Coyne, 2003;

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Verwey, 2000). Mental workload in driving was defined by Boer (2005) as the effort required to maintain the driving state within a subjective safety zone. Mental workload level is partly contributed by physical and mental factors. Both contain biological (related to structuring and function), physiological (related to processing in living systems) and behavioral (related to the event and occurrence) components that integrate with each other during a task, especially driving. Ageing drivers should be competent to not only handle high-intensity information outside the vehicle; they must also be able to process and manage new information technologies inside the vehicle that are increasingly advanced. For example, driving support systems nowadays can provide a lot of information in terms of traffic, weather, road layout, the fastest route and so many more. Without appropriate handling, instead of supporting the ageing drivers, these inputs can be dangerous especially when they do not have the capacity to handle them (de Waard, 1996). This situation varies and acts as a prompting factor of drivers' mental workload (Silva, 2014; Baldwin & Coyne, 2003). Moreover, physical and mental human factors such as stress, fatigue, motivation and behavior will limit efficient driving performance based on internal and external information about the vehicle, thus increasing the distribution level in the visual and auditory resources, consequently affecting the mental workload (Makishita & Matsunaga, 2008).

While driving has the potential to be integrated with constructivist-derived strategies, it also places specific demands on ageing drivers to process appropriate methods that facilitate their own driving through the driving activities and interactions with the vehicle. To propose changes of driving method or design, ageing drivers' driving task needs to be monitored, designed and tested. Research is needed to investigate how to integrate drivers, vehicle and environment within a constructivist mode consistent with the objectives of vehicle driving of ageing people, specifically in Malaysia. There is still a gap in research on this topic in the country. Most of the studies on Malaysian drivers

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focus on young drivers and does not highlight mental workload as one of the main contributors to driving performance, especially for the ageing drivers (Ismail, 2015; Sullman et al., 2015; Yii, 2015; Kulanthayan et al., 2004). This is then the intention of this study; to develop a model which quantifies mental workload on the driving performance of ageing drivers. This model can complement and integrate safety and design by monitoring signs of non-optimal levels of mental workload related to the human, vehicle and environment during a driving task.

1.2 Problem Statement

Human populations around the world are ageing rapidly. Promoting healthy ageing and building systems to meet the needs of older adults are valuable, so that older people have the freedom to be and do what they value (World Health Organization, 2018). World Health Organization in consultation with Member States and other partners are developing a comprehensive Global Strategy and Action Plan on Ageing and Health. Several priority areas are improving measurement, monitoring and understanding of the population. Focused research, new metrics and analytical methods are needed for a wide range of ageing issues.

As the fastest-growing segment of the population in most countries all over the world, the number of ageing people contributes a lot to Malaysia's total population every year. In a short time, Malaysia will be categorized as an aged country when the percentage of older people reaches 15% of the total population (Zawawi, 2013). Concurrently, compared to year 2012, the driver's cumulative total in 2016 increased by 1.95 million which is a 14.7% increment (Road Transport Department Malaysia, 2016). The number of drivers recorded is increasing, reflecting that the number is partly by the ageing people who remain as active drivers since the retirement age increment and there is no age limit for a license renewal in this country. Strong concern on ageing drivers is a

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disproportionate threat not only to themselves, but also to the other road users. For example, one of the issues of ageing drivers is signaling during driving. Without this essential communication method between the road users, accident can easily occur. Furthermore, the road accident in Malaysia recorded 25% increment from year 2010 (414421 cases) to 2016 (521466 cases) (Malaysian Institute of Road Safety Research, 2019).

Researchers are consistent with the assumption that accident risks are strongly related to driver mental workload and the impact that it has on driving task performance (Dijksterhuis et al., 2011; Kantowitz & Simsek, 2001). Mental and physical factors that contribute to mental workloads are different in ageing drivers and young drivers. This is due to functional limitations experienced by ageing drivers are greater than the younger one (Onunkwor et al., 2016). All the changes in visual, physical and cognitive ageing drivers must be analyzed, and adapting measures must be developed involving humans, vehicles and the environment for appropriate mental workload, leading to better driving performance among ageing drivers. Identifying at-risk ageing drivers is also an exclusively useful tool to overcome limitations in their driving skills. The presence of a performance model would offer a comprehensive approach in the evaluation of the ageing driver's performance to ensure their safety and other road users.

1.3 Research Objectives

1. To determine the driving mental workload key factors of ageing drivers based on driving task-related factors.

2. To identify the driving performance key elements of ageing drivers based on driving task-related factors.

3. To determine the relationship between the driving mental workload and performance of ageing drivers.

4. To develop and validate an overall driving performance score (ODPS) model which quantifies the driving mental workload on the driving performance of ageing drivers.

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1.4 Significance of the Study

Currently, there are few driving performance models have been developed from previous studies. However, an integrated model of ageing driver's mental workload and performance has yet to be fully developed, especially in Malaysia. Purpose of this study is to address this limitation by developing an integrated model of the ageing driver's performance by using ageing drivers in Malaysia as participants. This model will provide a comprehensive understanding on human performance by incorporating three main domains of human performance: human, activity and context. The study highlights the importance of implementing the driver's mental workload measures into the development, design, and assessment of driving performance elements. The results will be helpful for researchers in the related field to understand how driving task demands influence the mental workload of ageing drivers under various road types and traffic complexity conditions. For designers and developers, this research will influence design considerations for ageing drivers by providing evidence of the effects of mental workload on driving performance elements. As for the policy makers, results from this study will help to improve transportation planning in minimizing the risk of accidents for ageing drivers as well as other road users. Through this study, ageing drivers will be able to gain insights into their vehicle navigation and of the potential to manage and improve their driving mental workload.

1.5 Scope and Context of Research

This study covers the measurement of the driver mental workload and performance in relation to the variations of driving task-related factors among ageing drivers in Malaysia. In this study, ageing people includes subjects with the age of 50 years and older in agreement with WHO's Study on Global AGEing and Adult Health project, thus the terms 'ageing drivers' will be used throughout the research instead of elderly drivers.

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In the initial phase, the observation on the accident databases and survey on drivers in Malaysia was done in providing the literature reviews to design the experimental task. Next, this study focuses on the brain's signals, subjective ratings, number of traffic violations, speed and reaction times of the peripheral detection task during the experimental driving task. The experimental driving tasks are real-time based with different settings and mainly involve the vision, cognition and psychomotor of the ageing drivers. A driving habit and behavior survey was carried out on 182 participants where 100 drivers were ageing drivers of 50 years and above. 40 drivers were involved in the driving task experiment. Factors such as time limitation, cost constraint, and absence of certain equipment resulted in the number of participants recruited for the experiment.

1.6 Structure of the thesis

There are six chapters in this thesis (Figure 1.3). Chapter 1 presents the introduction of this study which includes the background, problem statement, objectives, significance and scope of the study. Chapter 2 explores the various literatures that are relevant to the topic of this study and assist in identifying the research gaps and summarizing the direction of this research. The methodology details applied in this study is presented in Chapter 3. Chapter 4 elaborates the results and analysis performed in the study which consist of accident trends, survey result and experimental task result including mental workload measurements (i.e. NASA-TLX, EEG relative power bands) and driving performance measures (i.e. number of traffic violations, speed and speed variability, reaction time of the peripheral detection task). In Chapter 5, the key findings are highlighted and compared with the result of previous studies, and the implications of the findings are discussed and overall conclusion, contribution to knowledge and recommendations are presented in Chapter 6.

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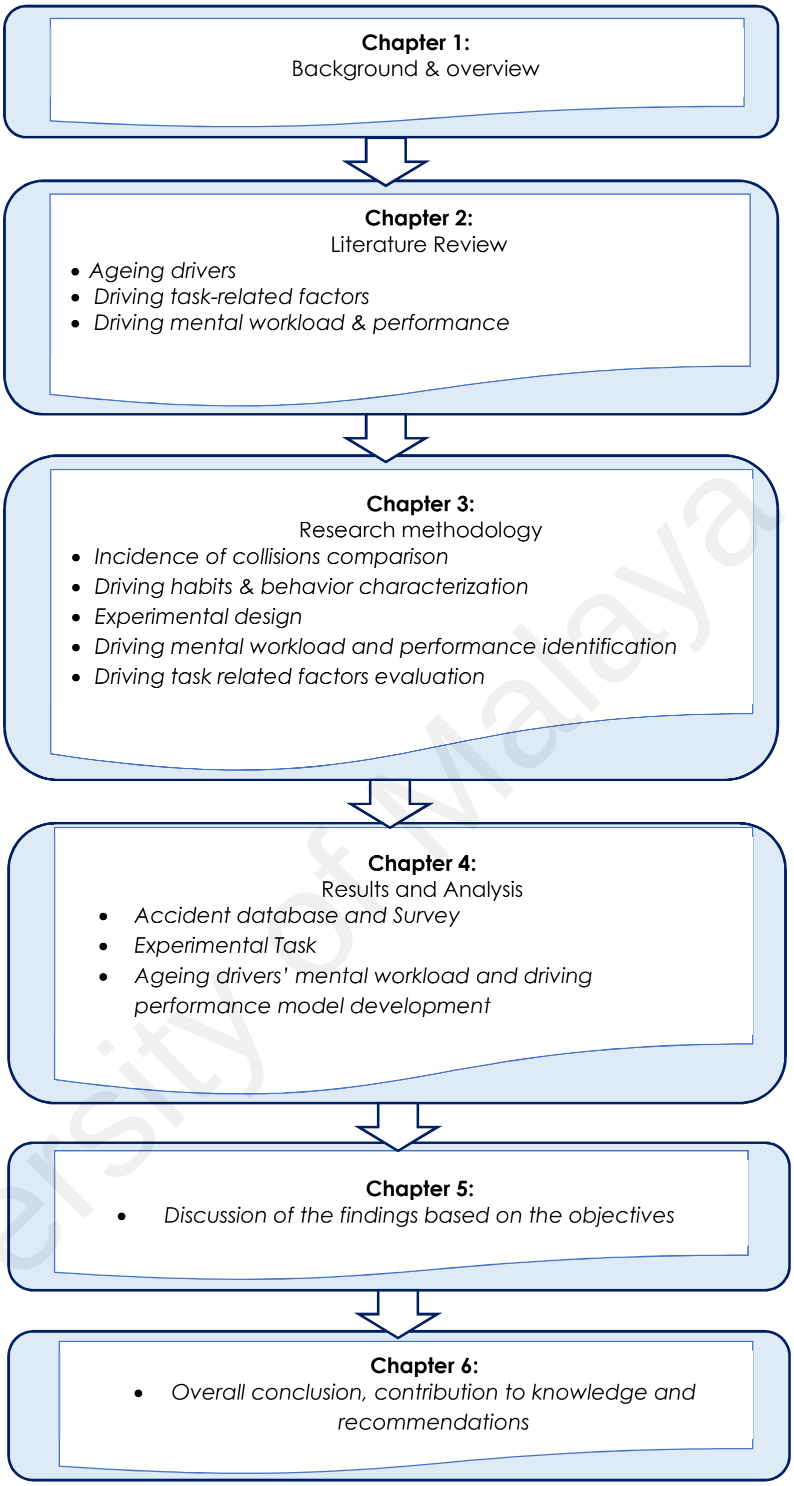

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Figure 1.3: Structure of the thesis 'The Relationship Between Mental Workload and Driving Performance of Ageing Drivers'.

CHAPTER 2: LITERATURE REVIEW

2.1 Overview

This chapter will explore various literatures that are relevant to the topic of this study, identify the research gaps and summarize the direction of this research. It includes overviews on the ageing drivers' issues in Section 2.2, while concepts of driving task related factors in Section 2.3. Meanwhile, the concepts and details of mental workload and driving performance are presented in Section 2.4 while their measures are described thoroughly in Section 2.5. In addition, previous mental workload and driving performance models and frameworks are discussed in Section 2.6. Finally, the overall findings and gaps in the existing body of knowledge are summarized at the end of this chapter.

2.2 Issues and conditions associated with ageing population

Numerous investigators have reported several issues and conditions that should be considered in determining the capacity of ageing drivers on the road. However, it is important to inspect profoundly on the characteristic, context of research and abilities impairments thoroughly. These important elements are reviews in next sub-sections.

2.2.1 Ageing characterization

People around the world are living longer (World Health Organization, 2018). Most of the countries nowadays have a large portion of ageing population and this number is increasing dramatically. In year 2015, there were more than 52% people aged 50 years and above worldwide compared to year 2000; and by year 2100, the number of older people is projected to have more than tripled (Figure 2.1). The advance of this trend can be seen in high-income countries. For example, Japan is home to the world's most aged

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population with 33 per cent were aged 60 years and over in 2015, followed by German (28 percent) (World Health Organization., 2014a).

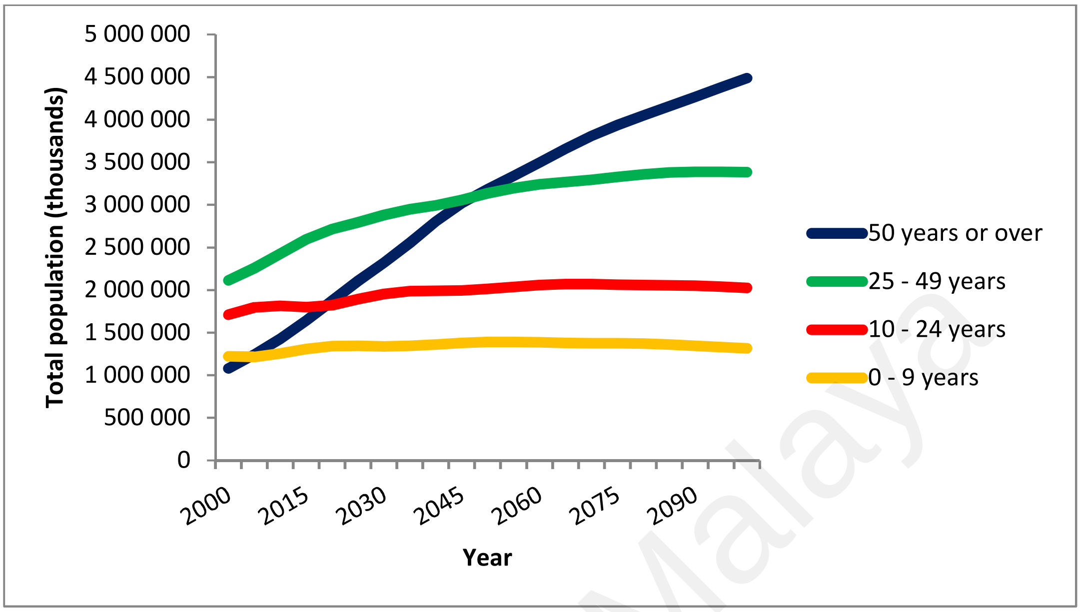

Figure 2.1: Increase in world ageing population from year 2000 to 2100

(*Data source: United Nations (2015). World Population Prospects: The 2015 Revision).*

Ageing can be referred as a biological process which has its own dynamic characteristics. Human wide varieties of molecular and cellular are damaged as lifetime increases. It is beyond human control that the process takes place towards the end of one's life. Physical and mental capacity will encounter a gradual decrease which leads to an increasing risk of diseases and impairments such as musculoskeletal problems, decline in conceptual reasoning ability (Onunkwor et al., 2016), slowed processing speed and decline of immediate memory (Harada et al., 2013).

Apart from biological changes, ageing citizens are often linked with transition phase such as licensing, retirement, relocation of residential and parting with loved ones. In developing technical response to ageing, it is important to not only consider the approaches that can improve the ageing deficiencies, but also those that may reinforce adaptation and recovery (World Health Organization, 2018). There is a very thin line

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between the definition of ageing population and elderly. The elderly has often been referred to those aged 60 and above (United Nations, 2015; World Health Organization, 1995; Department of Statistics Malaysia, 2013). Britain Friendly Societies Act 1875 enacted the definition of old age as ‘any age after 50’. Depending on the setting, the region and the country, ageing people should be reflected by physical and mental conditions (World Health Organization., 2014b), declination in everyday competence and independent daily routine (Anstey et al., 2005), as well as less contribution to the society (Gorman, 1999). The World Health Organization’s Study on Global AGEing and Adult Health (SAGE) 2012 has chosen participants from age 50 years and above involving various countries such as China, India, Ghana, Mexico and Russia to reflect the urgency to study on this age range and the compatibleness for comparison with other large high-income country ageing studies.

There is no definite definition or universal agreement on the age at which a person becomes old, despite there are commonly used definitions of old age (WHO, 2002). On the other hand, ageing was defined as “*a process showing the effects of time; a process of change, usually gradual and spontaneous*” (Mobbs, 2003). Based on the rule of thumb developed by Nathan Shock and his coworkers (Shock, 1979), by the age of 50 years old, human will experience physiologic systems accrue impairments up to 30%. The transformation, from a youthful to a more mature condition, is occurring far more rapidly in Asia than in today’s more industrially advanced countries (National Research Council, 2012). These phenomena are more obvious in some Asian countries like Malaysia which is experiencing rapid economic development, reflecting their incorporation in the world’s economy. In addition, recently Lee et al. (2020) has put chronological onset of old age in their study as 50 years and above in Selangor (state with the highest number of elderly in Malaysia). It is found that this group was considered less likely to use mobile health as a health management strategy due to lack of interest to adopt and learn newer technologies.

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This illustrates that there are differences between those aged 50 years and older compared to younger people in perceptions on latest technologies and social medium.

In this study, ageing people includes subjects with the age of 50 years and above in agreement with WHO's SAGE project instead of only considering people of 60 years and above as a focus group. It was assumed that by using subjects starting with the age of 50 years, this study will be indirectly incorporating chronological, functional and social definitions (Kowal & Dowd, 2001) and considering the impairments development of these age range population in this country. It is believed that these data will be important to assist engineers, designers, policy makers and program planners. The outcome, evidence and resulting information will quantify more accurate facts to determine the action needed in designing approaches for ageing populations.

2.2.2 Ageing drivers in Malaysia

As one of developing countries in the world, Malaysian ageing population is growing. In Malaysia, declining fertility imposed direct and indirect implications over older people and their family members. They are likely to be affected by the consequent demographic changes and other activities operating in the Malaysian society and the economy (Arokiasamy, 1999). It is consequential that a growing number of older individuals will continue to become active drivers (Böcker et al., 2017; Cheung & McCartt, 2011).

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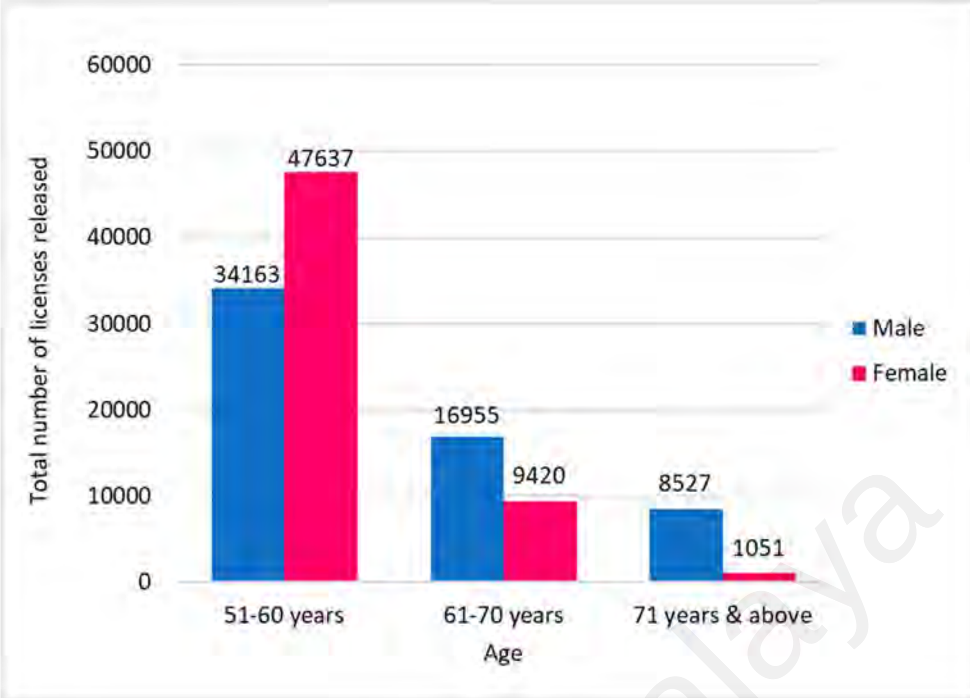

Figure 2.2: Number of licenses released for ageing drivers from year 2010 until 2016 (Source: Road Transport Department of Malaysia, 2017)

Data released by the Road Transport Department of Malaysia showed that the ageing road user were still active in submitting applications for licenses (Figure 2.2). In Malaysia, there is no maximum age limit for a driver to apply for a driving license, as long as he/she is able to fulfil the main requirement which is health eligibility. It is crucial to examine such drivers' relative safety in terms of licensed drivers' rate that clarifies the relationship with the accident's occurrence. Strict licensing policies in many countries have been set nowadays, which involves medical examinations (Kahvedžic, 2013). A driving lesson is compulsory for a 70-year old driver in Japan who wants renew his/her driving license, consisting of a lecture, driver aptitude test, an on-road driving assessment, and a discussion session (Ichikawa et al., 2015).

2.2.3 Safety and driving abilities impairment of ageing drivers

With shifts in demographics, the importance of older drivers' safety continues to increase in importance (Ichikawa et al., 2015; Kohata, 2011; Organisation for Economic

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Co-Operation and Development, 2001). Most older drivers, including rural seniors are highly dependent on their automobile for travel, yet the effects of ageing can make access to their vehicles difficult or impossible over time (Hanson & Hildebrand, 2011; Donaghy et al., 2005). From previous research that examined accident rates, crash involvement per kilometre driven begins to increase after the age of 65 (J. Eberhard, 2008; Li et al., 2003; Dellinger et al., 2002) with the greatest increment in crash rates observed in drivers of 80 years and above. Meanwhile, previous studies also highlighted some findings on the problems and issues faced by older drivers. Table 2.1 summarises the difficulties faced by older drivers in performing driving task compared to younger drivers.

Table 2.1: Difficulties of older drivers in performing driving task

No.	Difficulties of Older Drivers	Previous studies
1	Overtaking another vehicle	(Langford et al., 2006; Mayhew et al., 2006; Oxley et al., 2003; McGwin & Brown, 1999)
2	Violate more traffic controls	(Preusser et al., 1998)
3	Fail to yield the right of way and to heed stop signs or signals	(McGwin & Brown, 1999)
4	More misjudgements about whether there was enough time to proceed (aged 70–79) and search errors (e.g., Looking but not seeing) (aged 80+)	(Braitman et al., 2007)

Although the risky characteristic imposes, keeping the ageing drivers off the road is not the best option as the discontinuance of driving can contribute to social isolation, depression and a variety of other health-related issues (Marottoli et al., 1997). Sufficient functioning of numerous abilities is required for a safe and efficient driving. A driver must have the capability to compute information about the road, other drivers, weather, vehicles and themselves quickly and accurately. Wise decisions and appropriate responses are needed along an ongoing driving task. Decrement in any of these abilities could lead to adverse traffic safety effects. Unfortunately, most of these skills decline

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with increasing age (Eby, 2009). For example, if an accident happens involving an ageing driver, the ageing factors should be highlighted. In the context of ageing process, the driver was experiencing a degenerative process which contributed to certain limitations. An accident that happens due to brake failure of the car may have occurred due to the physical limitation of the driver in handling emergency braking. A different result may befall if a younger driver was facing the exact same situation instead of an ageing driver.

Instead of only highlighting the negligence of ageing drivers, limitation due to ageing drivers' vision should be reflected where age-related change happens in the eye such as that the amount of light scatter increases with age (Eby, 2009). Furthermore, the response rate of an ageing driver may comprise due to ageing factors. Previous research reported that slower reaction time among elderly drivers has a strong relationship with overall driving performance and measures related to vehicle control (T.A. Ranney & Pulling, 1989). These natural age-related changes do occur and is strongly related to impairment during interactions with vehicle and environment in driving. For example, motoric reactions of ageing drivers are slower compared to young people leading to inadequate response rate during an emergency. This disadvantage is due to the physical health problems such as musculoskeletal problems which tend to develop as people age (Onunkwor et al., 2016). Meanwhile, when viewing issues that occur related to the driving environment, ageing people tend to have problem seeing, reading and comprehend while driving especially in glaring situations, at night and inclement conditions due to the reduced vision (Kenneth et al., 2016).

Despite of having declination in visual perception cognitive and psychomotor functions, ageing drivers usually utilize their experience in facing driving obstacles to avoid accidents. They might use a compensation strategy to keep driving skills on an appropriate level and anticipate dangerous conditions rather than relying on quick reflexes to react to them (Karthaus & Falkenstein, 2016). Examples of compensation

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strategies are like avoiding driving during fatigued; at rush hour; in high time pressure; without a fellow passenger; in darkness, in the rain and on complex roads (Karthaus et al., 2014). Nevertheless, not all ageing drivers are exposed to this knowledge and some may not use these strategies well. In complex situations, these strategies may fail. Therefore, the assessment of driving in real traffic in critical situations is very important.

2.3 Driving and the task-related factors

Driving is a complicated task that involves three main factors namely human (i.e.: driver), vehicle and environment. Each of these elements have either positive or negative contribution toward driving workload and performance. Thus, any flaws in one or more of these factors can cause driving impairment and accident occurrence. It is significant to identify and describe the requirements necessary for a safe and efficient conduct of the driving task.

2.3.1 Significant effects of driver factors on driving task

The main cause of incidents on the road is due to the human factor (Seo et al., 2018; Merat et al., 2005). Accidents instigated by humans happen when a driver is incapable of providing and allocating the mental and physical capacity to perform the driving task assigned, which then resulted in the deficiencies and failure of the task. The human factors consist of not only contain personal characteristics such as age, gender, and experience; but also involves the body size (anthropometry), bodily response to internal and external forces (biomechanics), physiology, behavioural response to tasks, information processing and decision-making (skill psychology) and effort perception (Scheer & Mital, 1997). Examining more on personal characteristics, it is clear in previous studies that age, gender and experience have significant effect on the driving task. Comparisons were made on numerous studies between age groups to see the effects on the driving task. For example, it was found by Merat et al. (2005) that older drivers tend to maintain a lower mean speed

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than average drivers. They also demonstrate a specific effect of ageing where it impacts both reaction time and response accuracy (Salvia et al., 2016b; Cantin et al., 2009; Warshawsky-Livne & Shinar, 2002). Davidse et al. (2009) found that while driving on a straight road, old participants had slightly longer reaction times than young participants. In the meantime, some studies highlighted that the task within the driving assignment also showed statistically significant differences between the age groups. Mobile phone usage as a distraction during the driving task was the most popular task assigned to the participants during driving experiments (Papadakaki et al., 2016; Shi et al., 2016; Haque & Washington, 2015; Horsman & Conniss, 2015; Ige et al., 2015; Saifuzzaman et al., 2015; Haque & Washington, 2014; Benedetto et al., 2012; McEvoy et al., 2006). It was found by Perlman et al. (2019) that older participants took longer time to complete the phone usage than younger participants across their methods.

Experience and gender have shown significant effects on driving performance in previous studies. Driving experience, as measured in total or yearly mileage, is strongly dependent on gender (Roidl et al., 2013; Lajunen & Parker, 2001). Research suggests that these factors lead to various driving patterns on speeds and/or speeding (Bjorklund, 2008; de Craen et al., 2008; Mesken et al., 2007; Laapotti & Keskinen, 2004; Dula & Ballard, 2003; Ferguson, 2003). Gemou et al. (2013) consider experience and gender as focus factors in their studies, both on real-time and simulation experiment. It was also found in a study by Paxion et al. (2015) that the lack of experience is part of contributors to the increment of the subjective workload, the avoidance strategies and the reaction times and so on to the number of collisions. Lyu et al. (2017) found in their study on workload and driving performance that there were significant effects regarding the experience and gender on speed and lane deviation. They have highlighted that the driving workload is higher for new drivers than for skilled drivers. The average driving target speed in their experiment of experienced drivers was lower than that of non-professional drivers, while the target speed of male drivers was lower than that of female. Recent study done by Malhotra et al. (2018) highlighted that a driver's experience is a significant predictor of speed choice where more experienced participants were more likely to drive slower. However, there are recent studies which include both genders in their driving experiment (Charlton & Starkey, 2017; Gillath et al., 2017; F. Li et al., 2017; Navon & Kasten, 2015) but did not highlight and discuss further on the gender effects. Some did not find significant effects on gender in driving performance parameters studied (Oviedo-Trespalacios et al., 2017).

In the meantime, Naing et al. (2007) found from their study that 'distraction' and 'inattention' were both found to be frequent contributing factors in the accident analysis work. These factors, which resulted in acute low levels of awareness and alertness, were also found to contribute in many accident data sources. Distraction can be defined as a diversion of attention away from activities critical for safe driving towards a competing activity (World Health Organization, 2011). Drivers' distraction consist of four types, namely visual (e.g., looking away from a non-driving related task), cognitive (e.g., reflecting on a subject of conversations as a result of talking on the phone rather than analysing the road situation), physical (e.g., when drivers hold or operate a device rather than steering the wheel with both hands) and auditory (e.g., when a device is turned up so loud that it masks other sounds such as ambulance sirens) (K. Young & Regan, 2007). However, combined types of distraction may occur at one time which depends on the trigger. Naing et al. (2007) in their further study have selected the 'attention', 'sudden health problems', and 'mobile phone use' factors for analysis. The 'attention' factor was referred to when the driver has declared that they were distracted by undertaking another task that is different from driving and this was thought to have contributed to an accident. Meanwhile, 'sudden health problems' was ascribed to all states concerning 'sudden physical incapability' of the road user which contributes to an accident (sudden failures in health which are not expected at the start of the trip, e.g. heart attack, stroke, epileptic fit, asthma attack). On the other hand, 'mobile phone use' was referred to as all states where the driver speaks on the phone, handling the communication equipment or using a hands-free speaking device; and was thought to have contribute to an accident. Other human factors such as anthropometry, biomechanics and physiology, and effort perception will be discussed in the next sections of this chapter.

2.3.2 The significant vehicle factor in examining driving task

In various research, vehicle was considered as one of the significant factors in investigating performance, safety and crashes among drivers (Thompson et al., 2013; Naing et al., 2007; Wang et al., 2002). Vehicle is a crucial factor since it acts as a machine of a man-machine system in the driving performance concept. Thompson et al. (2013) considered on the vehicle's characteristics in their study on analysing serious and fatal crashes of older rural and urban drivers. The data was subtracted from the year of the accident to calculate the age of the vehicle (in years) at the time of the crash. However, based on their statistical analysis, there was no statistically significant difference between the median age of vehicles driven by older urban drivers and older rural drivers in their crashes. Hence, the age, and presumably the safety of their vehicles did not differ.

In the meantime, speed was also related to the vehicle by previous studies. Naing et al. (2007) assumed speed as vehicle component, even though the speed is determined by road user. In most European databases, 'speed' is part of the human component since it is the human decision who contributes to any value of speed. They reported that the 'speed' factor was found to be a frequent contributing factor to collisions.

In exploring vehicle functions and effects on human in a driving task, it is essential to examine the vehicle and driver's relations in terms of human machine interactions. For a

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driver to generate outputs such as controlling the vehicle motions and changing the vehicle's state, it is important for him/her to obtain information from the display inside the vehicle. Thus, controls and displays are part of human machine interface (HMI) which specifies the bidirectional links from the driver to the vehicle (Gáspár et al., 2014). Operating the vehicle's basic functions (i.e. control the movement of the vehicle) consists of primary HMI while the role of the secondary HMI components is to operate and display the comfort and infotainment functions (Gáspár et al., 2014). Examples of the components can be seen in Figure 2.3 below. Basically, both components had both input and output channel that assists the decision-making process of the driver. The input channel of the component is not limited to wheels, lever, buttons, switches, sliders and knobs all around the driver but also the sensors especially in modern vehicles. Meanwhile, the output channel is the feedback about the execution of the desired task and warning of the problems and errors. Designing these components ergonomically is very crucial to ensure that they are well operable and user-friendly, especially to population with limitations such as ageing drivers.

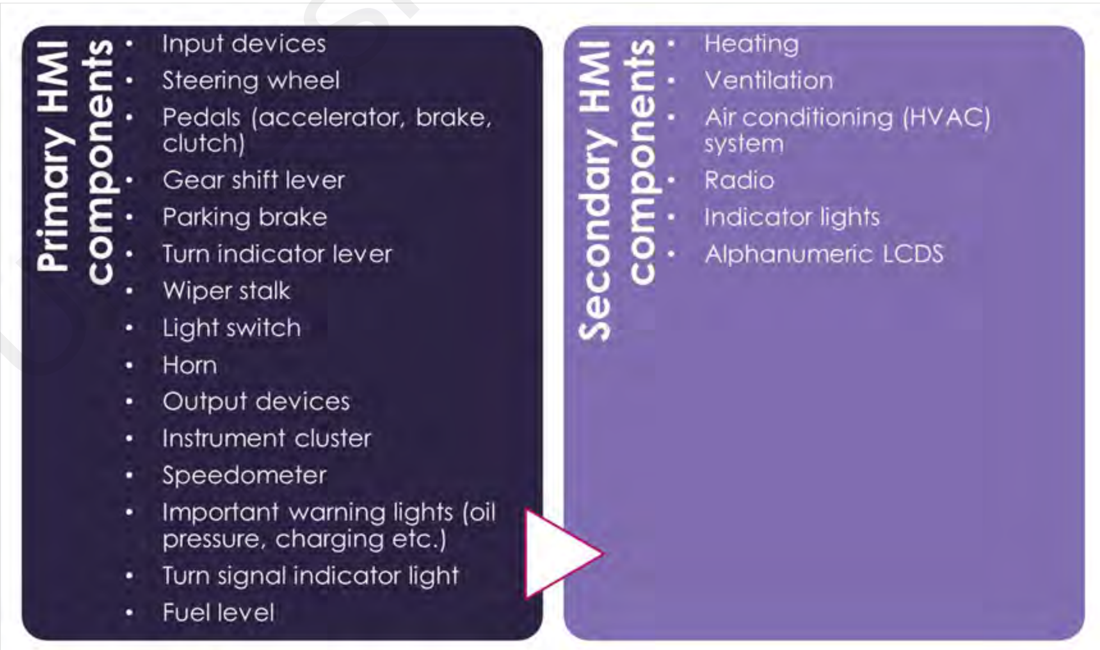

Figure 2.3: HMI components in operating the vehicle's basic functions (Source: Gáspár et al., 2014)

Majority of the primary HMI components involve hand work. It requires dexterity and precision in hand usage especially in the control lever unit. Thus, it is crucial to consider the variable in hand work to examine what influences effectiveness, comfort and efficiency of hand-related work (Sara & Henrik, 2012; S Pheasant & Haselgrave, 2006). In this study, the focus is into the turn signal lever since its function is basic yet so crucial where it is important to be able to communicate with another road user in performing a driving task. Furthermore, ageing drivers recorded difficulty and limitations in changing lanes, interacting with another road user during overtaking and heed the right signal in the driving task (Langford et al., 2006; Mayhew et al., 2006; Oxley et al., 2003; McGwin & Brown, 1999). Examining the reasons behind the difficulty related to the current design is valuable to improve future design of the component. The body posture including the arm position is related to the car seat which is outside of the study scope, thus will not be discussed in depth in this study. As the turn signal lever involves hand functions and characteristics, body dimensions or anthropometry related to the hand is essential in relating the ergonomics concepts with the design. The turn signal lever involves precision grips where objects are held with the tips of fingers and thumb (Sara & Henrik, 2012). Beside the dimensions, turn signal levers also involve visual perceptions, cognitive and psychomotor functions which ageing drivers will usually experience the deterioration in both mechanisms (Eby, 2009; Anstey et al., 2005). Monitoring the signal lever usage will not only confirm the problem acquired by ageing drivers, but also understanding the reasons behind it to strategize countermeasures for future design work.

2.3.3 Driving situation based on driving environment outside the vehicle

Driving environment outside the vehicle is another crucial factor which involves lighting, road and weather conditions, road layout, road surface, horizontal and vertical road alignments and speed limit at the location (Thompson et al., 2013). In terms of

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lighting, various possible lighting conditions appear during driving task is performed, for example dazzling sunshine, dawn, dark and blurry depending on the time and weather during the driving task is performed. Several environment elements during driving do affect the complexity of a driving situation. For example, the type of road designs (i.e.: motorways vs. rural roads vs. city roads), type of road layout (i.e.: straight vs. with curves, even vs. inclined, junction vs. no junction) and the traffic flow (i.e.: high density vs. low density) (Paxion et al., 2014).

Numbers of previous research highlighted the different levels of complexity with different road traffic environments. In the study by Crundall and Underwood (1998), they have highlighted and investigated on the visual search strategies of the participants. They found that drivers with experience choose visual strategies based on the complexity of the road traffic environment. Meanwhile, novice drivers' visual search strategies were inflexible to changes in (visual) demand. On the other hand, years back, Lee and Triggs (1978) found that the increment of driving environmental complexity influenced negatively on the detection of peripheral presented stimuli. Besides, it was reported by previous studies that it was the task's demand that affected the eye movement patterns as well as sensitivity to the stimuli in the drivers' visual periphery instead of the visual complexity (Miura & Shinohara, 2000; Miura, 1986). In the meantime, Chan and Courtney (2000, 1993) revealed that differences in cognitive demand also affect sensitivity in the visual periphery at a constant level of perceptual load in the foveal field. Furthermore, a research on perceptual workload and visual cortical processing indicated, inter alia that increasing foveal target detection. For example, as the visual workload increases, such as driving in an information-rich environment (e.g. a busy high street with delivery trucks, cyclists, pedestrians, children, crossing traffic, etc., all in close proximity to each other), the residual attention capacity available for allocating to parafoveally stimuli will decrease (Handy et al., 2001).

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Numerous previous researches have investigated on the relationship of human factors and situation complexity. Paxion et al. (2015) had considered the driving experience of the human element and situation complexity in the context of driving performance where it was shown that, situation complexity contributed a major determinant of driving workload and performance. Fastenmeier and Gstalter (2007) discussed on the taxonomy of the situation complexity, where they categorised a very complex situation on a city road as having curves or junctions, and a high traffic density. Other researchers stated that higher complexity environment could result in lower driving speed in order to compensate for the high amount of resources allocated in the greater demanding driving state (De Waard, 1996). Again, some researchers explained that rural roads are often described as having fewer curves; moderate traffic density and narrow road were categorised as moderately complex situation (Pavlou et al., 2016; Paxion et al., 2014). While few scholars are of the opinion that for highway roads, the layout are usually straight roads with low density traffic flow (Paxion et al., 2014), and a driver must be able to maintain alertness on a monotonous task which is believed to affect their driving (Perrier et al., 2016; Jongen et al., 2014; Ratcliff & Strayer, 2014; Calhoun et al., 2002; Brouwer & Ponds, 1994; Avolio et al., 1985). Recent study by Tran et al. (2017) distinguished the situation complexity in their driving experiment between three types of conditions (i.e. low, medium, high) based on the environment complexity related to time and weather, vehicular traffic density and behaviour, pedestrian density, change of lanes and stop of a car and driving out of a car on oncoming lane in a city road.

Besides, the effects of situation complexity on mental workload and driving performance elements have been well-documented in the past (Ceci et al., 2010; Baldauf et al., 2009; Brookhuis et al., 2009; Cantin et al., 2009; Guido et al., 2007; Patten et al., 2006; Törnros & Bolling, 2006). There are findings which showed that, situation complexity effect mental workload by consequence, and driving performance are all sensitive to the Time on Task (ToT) (Rahman & Dawal, 2016; E. Wascher et al., 2016; Baldauf et al., 2009; Guido et al., 2007; Otmani, Roge, et al., 2005). Driving duration that is related to environment is also one of the contributors to driving performance variances. The reason for this is because it was revealed that, driving performance decreases with ToT, both in day and night time and not limited only to simulators driving experiments (Edmund Wascher et al., 2016; Akerstedt et al., 2010; Hong Jun Eoh et al., 2005) but also on-the-road driving experiment (Sandberg et al., 2011; Verster et al., 2011; Ramaekers et al., 1992).

2.4 Empirical research on driving mental workload and performance: definition, concept and importance

Attributed to the development and advancement of mechanisation and automation, mental workload is one of the important concerns in the transportation systems. mental workload can be simply pictured as the relationship of the mental capacity and the task in demand. A long as there is any activity involved in one's condition, there is a task demand that occurs in accomplishing the goal of the task. Mental workload can be simplified as the relationship between the mental demand of a task and the worker's being (Leung, 2006; De Waard, 1996). Demand is the effort made to accomplish certain goal. A person that was given a goal will allocate certain amount of mental, physical and emotional effort. Even though the term 'mental workload' will directly give the idea of just mental resources, mental workload is also contributed by physical capacity. Both cannot be fully separated when a subject is performing a task (Fallahi et al., 2016; Lean & Shan, 2012). An appropriate task performance in various fields is highly depended on the main component; human him/herself.

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The concept of mental workload describes it as how the goal is reached and how much resources are required by the task. Thus, the mental workload depends not only on the operator but also on the characteristics of the task. Everyone by nature has different ways, capabilities and nature in living their daily lives. The tasks that must be faced everyday are performed with different amounts of resources and are done differently compared to one person to another. In addition, the individual's resources also depend on his or her experiences and skills owned (HQs Civil Aviation Authority, 2009). Because of these differences, a given task will not induce the same level of workload for all persons. Meanwhile, the characteristics of a task may result in different amounts of resources needed. A task that has high complexity is a task that has a larger number of stages of processing in order to complete it. A high complexity system can provide a heavy mental workload to the human operators (Hwang et al., 2007). Difficulty is also one of the task characteristics which are related to the processing effort that is required by the individual for a task performance (De Waard, 1996).

Having an appropriate level of mental workload is important for each individual human operator. This is because everyone is expected to perform as anticipated when a task is given. For most human operators, the performance indicator will be degraded if the mental workload is either too high or too low (Hwang et al., 2007). High complexity and demanding task require a person to work harder to accomplish the task (Vidulich & Tsang, 1987). In this type of situation, the operator may demonstrate delayed information processing due to high amount of the information that outstrips their capacity which exhibites an increased in mental workload level. Mental workload is considered overload if the task demand exceeds available resources (Dadashi et al., 2013). On the other hand, when human operators' mental workload is lower than the proper level, they will become bored and tend to make mistakes (Ryu & Myung, 2005).

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Several previous studies proved that research on mental workload is very important. Hwang et al. (2007) developed an early warning model that allows the operator or supervisor to monitor the operator's mental workload by a physiological indicator. Meanwhile, Raskin (2000) stated that human-computer interface usability can be strengthened by mental workload measures. In addition, monitoring human operator mental workload also helps in designing appropriate adaptive automation strategies (Kaber & Usher, 2000). The proposed models can also be applied to fields such as aviation, air transportation control, driving and radar vigilance.

Mental workload has an adjacent relationship with human performance as it is the result of task demand and intermediaries' factors related to its adaptive strategies (Parasuraman & Hancock, 2001). In the case of driving mental workload, it is the relationship between the driving task and the driver himself/herself which produces outcome and accomplishments valued by the level of performance as defined in engineering systems (Baron et al., 1990). Performance research particularly can be described as a comprehensive understanding of human performance by incorporating three main domains of human performance; human – activity – context (Bailey, 1996). Thus, driving performance can be defined as the incorporation of drivers (human), driving (activity) and driving conditions particularly performed (context). It is the representation of the driver's capability to complete the driving task safely and efficiently in transporting the vehicle from one place to another. The concept of human performance can be described as a framework for understanding and predicting factors affecting the performance of human, which will contribute positively to the overall success of a complex man-machine system (Pew & Baron, 1983). Previous studies defined driving performance based on their scope of research concerning plenty of affecting factors (McEvoy et al., 2006). For example, Perrier et al (2016) stated highway driving performance as the abilities of drivers to stay vigilant for longer periods of time especially

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under monotonous circumstances (Perrier et al., 2016; Jongen et al., 2014; Ratcliff & Strayer, 2014; Calhoun et al., 2002; Brouwer & Ponds, 1994; Avolio et al., 1985). On the other hand, Papadakaki et al. (2016) described on the driving performance as the link of drivers and driving tasks in the context of mobile usage. Paxion et al. (2015) considered the driving experience as a human element and situation complexity as the context of the driving performance. On the other hand, Pavlou et al. (2016) described driving performance in drivers with cognitive impairments (as the human domain element) driving (as the activity) in rural and urban road (as the context) in their study.

Ergonomists are concerned about the drivers' mental workload since an overload of information may lead to distraction while the driving task is performed (Verwey, 2000). De Waard (1996) stated a few factors that can affect drivers' workload as in Figure 2.4. These factors were reported to have the capability to increase or decrease the mental workload. For example, instead of reducing demands, feedback on the environments (e.g. information on road and traffic condition demands during the driving task) may become an additional information that has to be processed which can lead to an increase of workload.

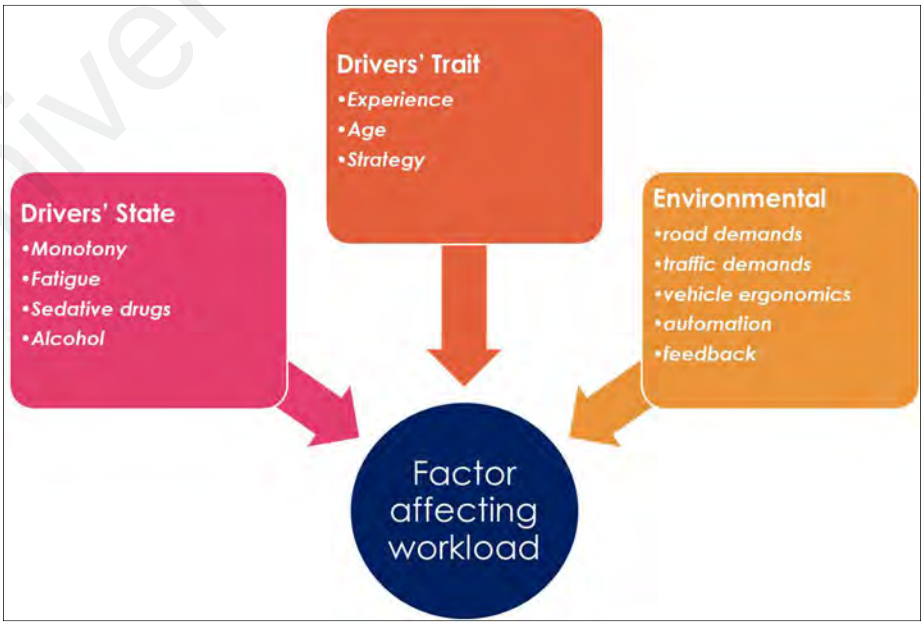

Figure 2.4: Factors that affect driver's workload (Source: De Waard, 1996)

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In the last decades, there are lots of research on the driving performance concerning plenty of affecting factors (McEvoy et al., 2006). Recently, Papadakaki et al. (2016) investigated on the driving performance while using a mobile phone. They highlighted that there was an increased variation in steering and lateral lane position were evident during mobile phone use. In addition, following distance and acceleration decrement was shown during mobile phone use. On the other hand, Paxion et al. (2015) investigated on the effect of driving experience and situation complexity on the driving performance. It was emphasized in their study that the situation complexity and lack of experience increase the subjective workload. Moreover, the avoidance strategies and reaction times influenced the number of collisions depending on the situation complexity and driving experience.

The list shown in Table 2.2 summarises the distribution of interest among researchers on which factors were discussed the most and general overview of human performance study involving drivers around the world. From this comparison table, there is still a lacking on studies related to mental workload of ageing drivers in recent years especially in Malaysia. Most of the studies done measure on the young drivers with the focus on drivers' factors other than their mental workload during the driving task.

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Table 2.2: Recent studies on factors relating to driving performance.

Authors/ Variables	Country	Young drivers	Ageing drivers	Cognitive	Mental WL	Physical WL	Alertness	Distractions	Fatigue	Behavior	Environment	Sleep	Safety /safety culture	Driving performance	Driving simulation	Real driving task
Papadakaki et al. (2016)	Greece	x		x				x						x	x	
Paxion et al. (2015)	France	x			x									x	x	
Saifuzzaman et al. (2015)	Australia	x				x									x	
Herman et al. (2014)	New Zealand	x							x			x	x			
Ahmed et al. (2015)	Qatar	x								x			x			
Aidman et al. (2015)	Australia	x					x							x		x
Ismail et al. (2015)	Malaysia	x				x			x		x			x	x	
Thompson et al. (2013)	Australia		x							x	x		x	x		
Lei et al. (2011)	Germany			x	x										x	
Maglione et al. (2014)	Italy	x			x							x		x	x	
Borghini et al. (2012)	Italy	x							x			x		x	x	
Wascher et al. (2016)	Germany	x							x						x	
Zhao et al. (2015)	China	x		x											x	
Li et al. (2017)	China	x		x												x

**WL = Workload*

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Ideally, drivers are required to perform all driving task activity to achieve driving goals. However, not all activity can be fulfilled due to differences in vehicle control ability and situational awareness (Wong & Huang, 2010). Situational awareness can be pictured as how an individual change their perception on environmental elements that diverged in terms of time and space thus undertake different strategies to face the altered situation (Borghini et al., 2014a). The basis of the situation awareness concept is that an individual is being alert of the surroundings and understanding what the information means both in current and the later situation. Several studies have presented on the relationship between mental workload, situation awareness and driving performance (Nählinder, 2009; Ma & Kaber, 2005). Borghini and his research team (2014) developed a model mapping between the three elements where that they indicated that "*An increase in mental workload (a more demanding task) leads to a decrease in situation awareness, which, in turn, leads to lower performance*" as in Figure 2.5. The individual's performance might be biased and subjects to changes due to circumstances beyond controls. It is important to maximize the control in terms of the variances along a real time driving experiment especially involving risky participants. The more suitable setting to test on the situation awareness with different characteristics on the driving environment is more suitable to be applied for simulation studies.

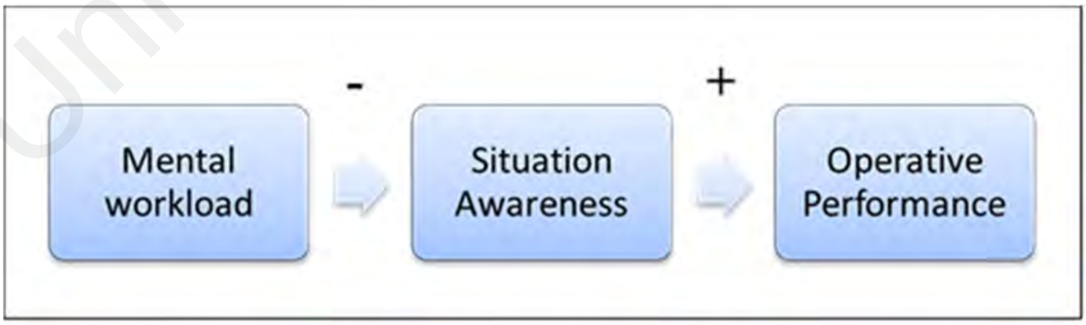

Figure 2.5: The association of mental workload, situation awareness and operative performance (Source: Borghini et al., 2014)

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2.5 Measures of driving mental workload and performance

Previously, researchers were inspired to study mental workload after realising the importance of this human factor. There were three types of measurements that have generally been used to measure mental workload, particularly for drivers namely subjective, physiological, and performance measures of driving tasks (HQs Civil Aviation Authority, 2009; Hwang et al., 2007; Lei & Roetting, 2011; Ryu & Myung, 2005).

2.5.1 Subjective measure as a reliable method in measuring mental workload

Self-reported measurements, usually known as subjective measure is one of the reliable methods used by previous studies on mental workload (Abd Rahman et al., 2020; Silva, 2014). There are seven questionnaire criteria identified to assess the subjective level of workload (Paxion et al., 2014; Rubio et al., 2004) as shown in Figure 2.6.

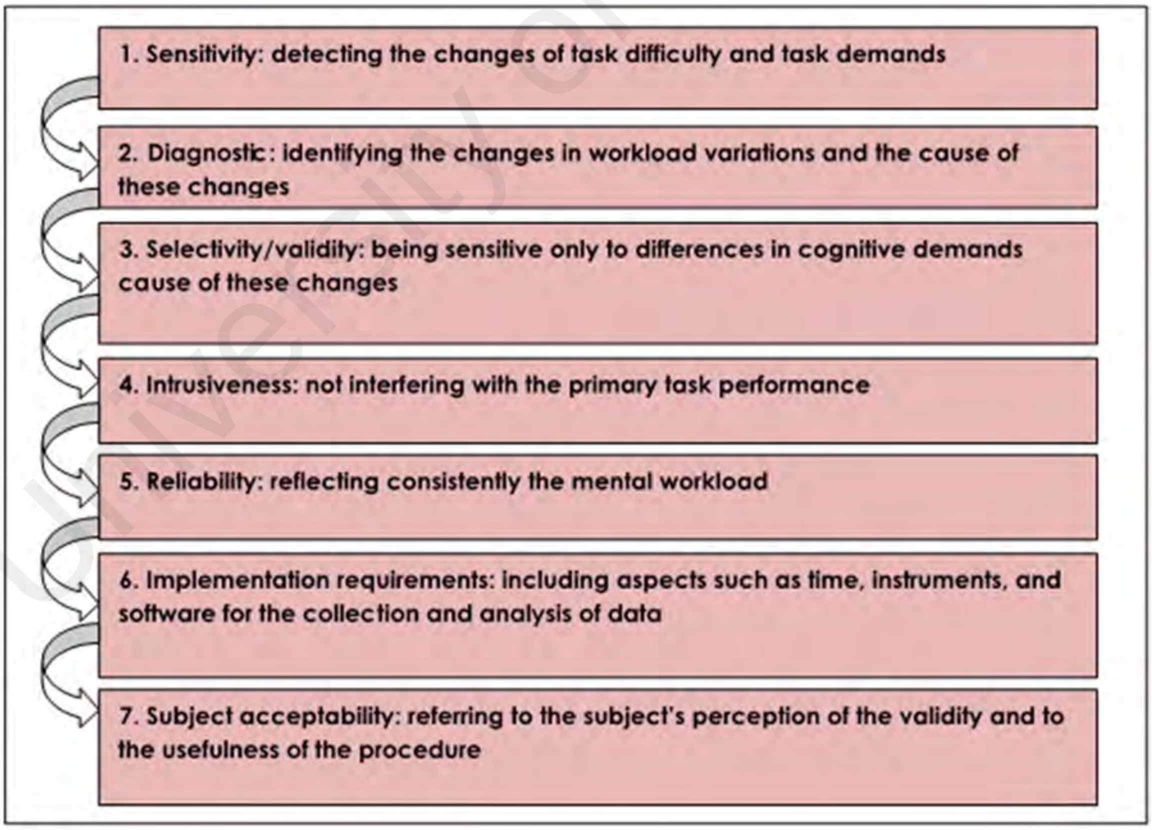

Figure 2.6: Questionnaire criteria identified to assess the subjective level of workload

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There were three questionnaires that are usually used in driving study; Subjective Workload Assessment Technique (SWAT; (Reid & Nygren, 1988)); workload profile (WP; (Tsang & Velazquez, 1996)); National Aeronautics and Space Administration task load index (NASA-TLX; (Hart & Staveland, 1988)). SWAT consists of scales assessing different workload components. For example, time load, mental effort load, and psychological stress load. There were three levels of subjective workload proposed for each scale in the questionnaire which are low, medium, and high. Meanwhile, WP questionnaire was developed based on a study by Wickens (1987) on multiple resources model. The proportions of attention resources used by the participants in a study need to be estimated immediately after having experienced a particular task. The workload is based on eight dimensions: 1) perceptual/central processing; 2) response selection and execution; 3) spatial processing; 4) verbal processing; 5) visual processing; 6) auditory processing; 7) manual output; and 8) speech output (Rubio et al., 2004). The participants will be provided with numbers between 0 (no demand) and 1 (maximum demand) that represents the proportion of attentional resources used in each of the eight workload dimensions for each task. Another scale that measure the driving mental workload is Driving Activity Load Index (DALI). Pauzié (2008) has developed the index based on NASA-TLX which consist of six scales each that going from low to high demanding.

2.5.1.1 Measurements of Perceived mental workload using NASA-TLX

On the other hand, the NASA-TLX questionnaire consist of six combinations of relevant factors characterising the subjective workload. The factors are presented in Table 2.3 as follows.

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Table 2.3: Six combinations of relevant factors characterizing the subjective workload in NASA-TLX (Paxion et al., 2014).

No.	Factor	Descriptions
1.	Mental demands	Amount of mental and perceptual activity required
2.	Physical demands	Amount of physical activity required
3.	Temporal demands	Amount of pressure felt due to the rate at which the task elements occurred
4.	Own performance	Successful assessment in doing the task required and satisfaction assessment in accomplishing it
5.	Effort	Difficulty assessment in having to mentally and physically work to accomplish the level of performance
6.	Frustration	Assessment of different feelings: insecure, discouraged, irritated, stressed and annoyed vs. Secure, gratified, content, relaxed and complacent during the task

The NASA-TLX has more advantages compared to the WP, the SWAT and DALI in terms of dimensions, task performance predictions, applicable on real complex tasks, sensitivity, diagnosticity, selectivity/validity and intrusiveness (Paxion et al., 2014). Nevertheless, researchers need to select a questionnaire based on the specific desired outcome and their own research focus. In this study, NASA TLX was selected for its suitability criteria in fulfilling the objectives, fit the study's goal and capability to assess the mental workload of the experimental design. It is projected to analyse the influence of situation complexity on the subjective mental workload level and on driving performance.

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2.5.2 Evaluation of mental workload by physiological measures

Another method that has been very effective in the evaluation of mental workload is by physiological measurement (Lei & Roetting, 2011; Hwang et al., 2007; Ryu & Myung, 2005). Each person's physiological response to mental tasks are different from one another and the result patterns would also be different from task to task (Hwang et al., 2007; Miyake, 2001; Xie & Salvendy, 2000). There are many physiological parameters but those that are widely used by experts are brain signal activity measurement using Electroencephalogram (EEG), Heart Rate, Eye blinking and Heart Rate Variability. Among these advanced measurements, EEG tool is more acceptable and accurate in providing a quantitative measurement of human performance (Ryu & Myung, 2005; Chen & Vertegaal, 2004).

2.5.2.1 Measurements of mental workload through Electroencephalogram

Brain signal monitors (Rahman & Dawal, 2016; Zhang et al., 2015; Vysata et al., 2014; Liao et al., 2012) are commonly used to estimate brain activities in field studies. These devices capture neural activity such as information on brain structures and functions. It is known that mental workload is part of the brain functions reflection. Extensive monitoring of brain signal frequency to varying workload is based on the premise that the submaximal frequency is linearly related to the level of mental workload (H.-S. Kim et al., 2014; Borghini et al., 2012). EEG efficiently records and monitor signals which are bands of frequencies and event-related potentials (ERPs).

Sinusoidal brain waves are measured from peak to peak in a range from 0.5 to 100μV in amplitude. The EEG signals are derived using Fourier transform leads to visibility of different bands of frequencies on the graph. The brain state of an individual may make certain frequencies more dominant although the spectrum is continuous. The waves have been classified into five basic groups based on the individual peak to peak property namely delta (0.5 to 3.99 Hz), theta (4-7.99 Hz), alpha (8-12.99 Hz), beta (13-30 Hz) and gamma (31-100Hz). Figure shows different characteristic of the waves with amplitudes within one seconds of time.

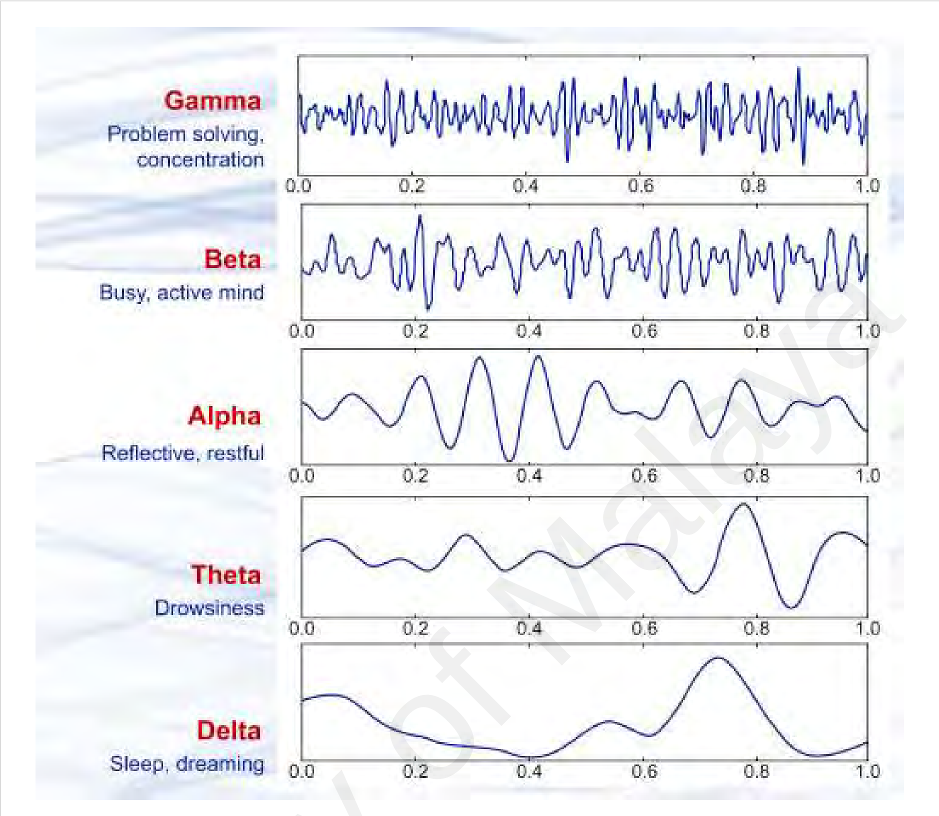

Figure 2.7: Example of brain wave with dominant frequencies relevant to gamma, beta, alpha, theta, and delta band (Picture source: Abhang et al., 2016).

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Meanwhile, ERP present time-based measurement of mental in various type of situations. Variations of mental workload can be characterised by several long-latency ERP components. Long latency of auditory-evoked potential consists of wave components which are used to estimate the function of human hearing system and other mental activities. Positive or negative potentials can be observed after 100, 200, or 300 ms of stimulus presentation and they were labelled as P1 (Positive 1), N1 (Negative 1), P2 (Positive 2), N2 (Negative 2), P3 (Positive 3) and so on. Ying et al. (2011) recorded in their experiments that some latencies (N1, P2, N2, P3) increased significantly after their mental tasks were adopted. On the other hand, Miller et al. (2011) revealed a variation of mental workload in their findings on onset latencies component amplitudes that were inversely related to task-difficulty. ERP has numbers of advantages such as high diagnosticity to perceptual and cognitive processing, and some disadvantages such as insensitive to response factors and poor signal-to-noise ratio as they are influenced by other electrical signals (e.g., heart, eyes, muscles, and external sources) (De Waard, 1996). In this study, bands of frequencies from the EEG signals will be monitored and used as a measure of mental workload of ageing drivers. The output of the bands reflects the increasing of mental workload with the decreasing of alpha band of 8 to 13 Hz and increasing of theta band of 4Hz to 8Hz (Borghini et al., 2014a; Kramer, 1991).

Lots of previous studies used EEG bands frequencies analysis to evaluate the driver's performance. However, there is still a lack on research that evaluates the ageing drivers' performance that focuses on the mental workload and relates it to the driving task-related factors and driving performance. Studies on the driving task and EEG bands frequencies measurements are summarised in Table 2.4.

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Table 2.4: Summary of studies on the driver's performance and EEG bands frequencies measurements.

Researcher(s)	Objective(s)	Methodology	No. of Subjects & (Age in years)	Equipment	Main Findings
Li et al. (2017)	- Correlation degree between driver's reaction time and the physiological signal	- on the road experiments - Reaction time test systems - The power spectrum densities (PSD) of α, β, δ, and EEG wave are calculated	15 males, 5 females (24 - 51)	Biopac System	- Two mathematical models are used to establish the functional relation of α/β-the reaction time. -The α wave increased when the driver was sleepy, while β wave appeared if driver was alert. Hence, the value of α/β increased if the driver was in fatigue.
Wascher et al. (2016)	- Actual states of fatigue in a monotonous driving situation	- driving simulation - compensating crosswind of different strength. -The mean power was extracted for the Theta (4–8 Hz) and the Alpha band (8–12 Hz) for anterior (FCz) and posterior (POz) electrode sites	14 (21-28)	Active two, BioSemi, NL	**Theta power:** - increased with time on task - decreased with stronger crosswind - the increment is related to an increased effort to keep the performance high **Alpha power:** -The variation with time on task and task complexity reflects a concept of boredom or attentional withdrawal. - related to the amount of information processing - assumed to be high when the processing system is running in an idle state. - increased has been related to mental states of **reduced performance**. - the decrement reflects increasing complexity

Lei et al. (2016)	- Feasibility of using a method based on EEG for deriving a driver's mental workload index.	- Simulated experiment combining a lane-change task and n-back task -the task load: **driving task load** and **working memory load**, with each containing three task load conditions.	19 males, 7 females (21 – 33)	ActiCap, Brain Products, Germany	-The frontal **theta** activity showed significant increases in the working memory load dimension. - Significant decreases in parietal **alpha** activity were found when the task load was increased in both dimensions. -The driving task load contributed more to the changes in **alpha** power, whereas the working memory load contributed more to the changes in **theta** power.
Maglione et al. (2014)	- Increment of cerebral workload and the insurgence of drowsiness during car driving in a simulated environment by	- Simulated drive tasks with five levels of increasing difficulty - The workload index = the ratio between the EEG power spectral density in theta band over the central frontal area (Fz) and the EEG power spectral density in alpha band over the central parietal area(Pz)	9 females,11 male (24-30)	Brain Products GmbH, Germany	- the derived workload index is sensitive to the mental efforts of the driver during the different drive tasks performed -workload index was based on the estimation the variation of EEG power spectra in the theta band over prefrontal cortical areas and the variation of the EEG power spectra over the parietal cortical areas in alpha band. -drowsiness could be indexed by the appearance on the EEG traces of the alpha spindles

Eoh et al. (2005)	- observe EEG changes as time proceeds - compare the EEGs of the driver on straight/curved roads - observe the EEG difference between pre-accident and post-accident - analyze EEG alpha and theta burst and its relationship to microsleep	-Simulated continuous driving, car movements and 8 **(Fp1, Fp2, T3, T4, P3, P4, O1, O2)** channels of EEG were recorded -Three basic indices, three ratio indices, and two burst indices were calculated from preprocessed EEG signals.	8 males (mid-20s)	LXE1008C (Laxtha, 2002). Acknowledge 3.5.7 (BIOPAC System Inc., 1998	- EEG alpha, beta, beta/alpha and (alpha+theta)/beta indices showed significant differences between driving periods - Beta and (alpha + theta)/beta were related to the mental alertness level - In the comparison of road type indices of the straight section of the driving task were significantly different from those of the curved section - Theta burst activity was significantly different between driving sessions; Theta waves mainly occur at sleep state - Alpha and beta waves showed a significant change while driving in a drowsy state in this study - Alpha waves occur during relaxed conditions, at decreased attention levels and in a drowsy but wakeful state - Beta waves are associated with increased alertness and arousal

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2.5.3 Performance measures of driving tasks

In a driving task, performance is measured based on the capability of the driver in performing the driving task at a level considered acceptable and safe, particularly on maintaining the vehicle without colliding with another road user (Silva, 2014). A driver's perception of safety in driving environment is an important influence on driving behaviour and task performance (Wang et al., 2002). In previous research, there are a lot of methods and techniques in measuring driving performance. All of them were done based on general rules related to the nature of the task tested and specifically focused on research questions (Yannis et al., 2017). The quantification of performance contains essential components namely efficiency and accuracy (Cai & Lin, 2011). The literature review indicated that the main measure of driving performance can be categorised into two types, namely direct and indirect measurements as in Figure 2.7.

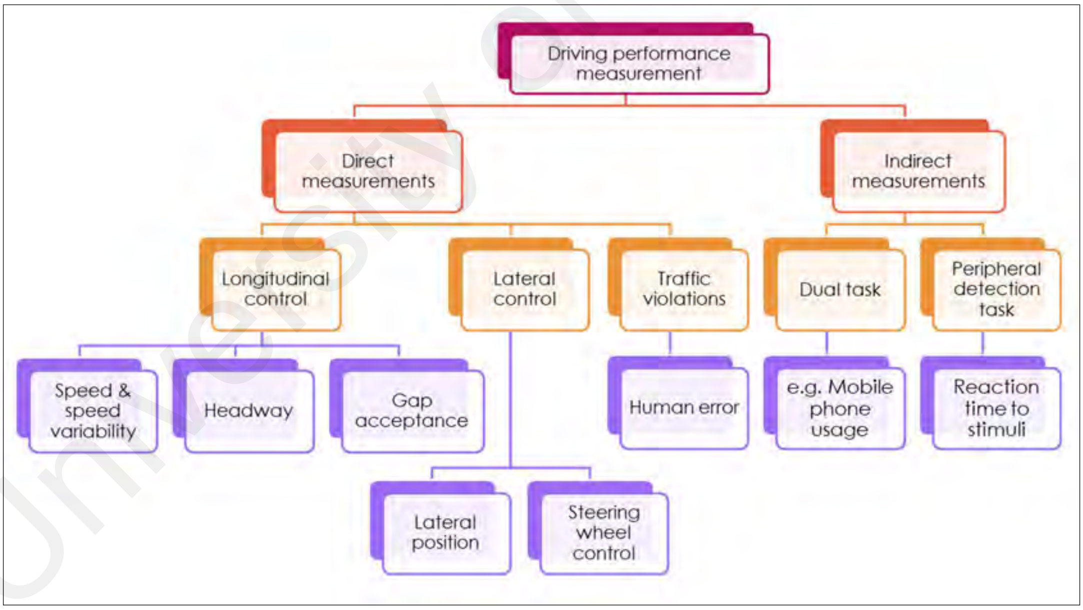

Figure 2.8: Measure of driving performance based on previous studies and analysis.

2.5.3.1 Direct measurements on the driving task - Primary task

The direct measure of driving performance is basically focusing on the primary driving task involving lateral and longitudinal control of the vehicle. Lateral control principally focuses on how well drivers maintain vehicle position within a lane which is usually represented by the lateral position measures (Gemou, 2013; Liang & Lee, 2010; Caird et al., 2008; Horrey & Wickens, 2006; Green et al., 2004; Greenberg et al., 2003) and steering wheel control evaluation (Regan, 2008; Brooks et al., 2005; T. A. Ranney et al., 2005; McGehee et al., 2004). This control involves psychomotor activity to maintain the vehicle within the lane limits which involves the driver's eye-hand coordination (Silva, 2014).

Meanwhile, longitudinal control corresponds to driver's controls on the longitudinal motion of the vehicle which also contributes to the safety of the vehicle. Three of the most common measures involved in longitudinal controls are speed measures (F. Li et al., 2017; Hoogendoorn et al., 2010; Yannis et al., 2010; Baldauf et al., 2009; Manser & Hancock, 2007; Rakauskas et al., 2004; Haigney et al., 2000), headway measures (Aidman et al., 2015; Hoogendoorn et al., 2010; Regan, 2008; T. A. Ranney et al., 2005; Strayer & Drews, 2004) and gap acceptance (sometimes known as safety margin) (Farah et al., 2007; Brown & Hummer, 2000; Polus et al., 2000). Among these, the most significant and wide relation to accidents or crash in previous driving experimental studies (real-time and simulation) is the speed measurement which usually includes speed variability (or speed variation), speed adoption and maximum speed (Malhotra et al., 2018; Oviedo-Trespalacios et al., 2017; Ebnali et al., 2016; Manser & Hancock, 2007).

The main aims of speed control are for safekeeping especially for preventing vehicle collisions with other vehicles that are in the same direction, maintaining a steady flow of traffic and allowing the driver to keep control even when faced with normal traffic events (Silva, 2014). In previous studies, inability to control the speed has been related to distractions such as mobile phone usage and navigation device usage (Seo et al., 2018; Saifuzzaman et al., 2015). The speed variability either under influence of distracters or not has been used as an indicator to determine the driver ability to control the driving speed (Ebnali et al., 2016; Pavlou et al., 2016; Navon & Kasten, 2015). Horberry et al. (2006) highlighted that speed variability has been shown to increase as drivers engage in concurrent tasks reflecting higher mental workload.

On the other hand, driving performance can also be measured by traffic violation where it indicates accuracy of the driving task (Tran et al., 2017; Cai & Lin, 2011; Bouchner et al., 2006; Ma & Kaber, 2005; Brookhuis & De Waard, 2001). The number of traffic violations can be measured by human errors such as misperception, information processing errors, and slow decision-making where they are frequently identified as major reasons that can cause the accidents (Tran et al., 2017). In previous studies, human errors comprised driving out of the lane, missing stop signs, exceeding the speed limit, causing collisions, driving on the red light and no turn signal when changing lanes (Tran et al., 2017; Cai & Lin, 2011). However, there should be a clear difference between human error measurement of driving task in a real-time study and in simulator driving experiment. This is because a real-time driving experiment must prioritise safety during the experimental duration and some errors that are done in simulators (i.e. collisions, distracting task ahead, and obstacles) cannot be applied in the study.

2.5.3.2 Indirect measurements on the driving tasks - Secondary task association to primary task

The indirect measure focused on the relationship of the secondary task and the primary task. The measurement is mainly on monitoring the capacity to handle the mental workload and quantifying the performance of the driving task with another important event happening within the task. The secondary task frequently acquires memory, mental calculation, attention, etc. (Silva, 2014) such as mobile phone usage, car-following task and mirror checking task (De Waard, 1996). Usually, in previous simulation studies, mobile phone usage has been used as the dual task that needs to be performed by the driver (Papadakaki et al., 2016; Haque & Washington, 2015, 2014; Benedetto et al., 2012). In a real-time experimental study, testing the mobile phone usage on the driving performance is not suitable and can be dangerous.

In the meantime, one of the well-known measurements of driving performance is by Peripheral detection task (PDT). PDT is a method used to measure reaction time to detect stimuli (visual or auditory) and the percentage on missed PDT signals as a measure of mental workload (Brookhuis et al., 2009; Makishita & Matsunaga, 2008; Jahn et al., 2005; Patten et al., 2004; Verwey, 2000; Van Winsum et al., 1999). The PDT system has one red high-intensity light emitting diode (LED), which is placed in the left part of the participant's visual field using a head mounted device (Ceci et al., 2010). Meanwhile, Patten et al. (2006) stated in their study that a visual stimulus was in the form of a LED, placed in the peripheral area of the driver's line of forward sight. During the measurement, the drivers respond to visual stimuli presented off centre of their forward view by pressing a micro switch placed on the left index finger (Törnros & Bolling, 2006) with eccentricities ranging between 5° and 25° left of the drivers' normal line of sight (Jahn et al., 2005).

PDT not only has been used in real-time and environment studies; it was widely used in simulator studies and shown itself to be a sensitive measure of cognitive workload, especially where visual demand is high such as in driving (Patten et al., 2004; Harms & Patten, 2003; Olsson & Burns, 2000; Van Winsum et al., 1999; Crundall & Underwood, 1998). There are numbers of advantages of PDT such as its continuousness; available in the background throughout the entire experiment; large quantities of data can be collected; baseline or reference data (within subject design) are easily included in the

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experimental design and provides a more valid reflection of the driving task and its demands on the driver.

2.6 Mental workload and performance model in previous study

The mental workload and driving performance model proposed in previous studies involving factors related to demographics, characteristic, work-related factors (i.e. human, machine and environment), mental workload and performance are first reviewed to identify the suitability of each model for application in driving tasks model. Mental workload model can be defined as schemas of dynamic systems or scenarios that include the understanding of system components, as well as their interaction and time-dependent changes (Höger et al., 2005). There are five significant models identified. These models provide valuable insights into the form of driving performance concepts model for driving tasks.

2.6.1 Model of de Waard (1996)

Dick de Waard (1996) has developed a model in his research which it represents key concepts of mental workload. It shows and maps variables pattern and described the relationship between workload, performance and demand. The outcome was presented in terms of regions of performance and measure's sensitivity to the workload. The model consisted of three type of measures which is task-performance measure, subjective measure and physiological measures. For the primary task performance measures, the study used standard deviation of lane position (SDLP) and steering-wheel movements (SDSTW). On the other hand, de Waard also assigned the car-following and mirror checking task to their experimental participants as both measures represent the secondary task performance of the drivers. Meanwhile, the self-rated measure used was Rating Scale Mental Effort (RMSE) by Zijlstra & Meijman (1989). Activation scale by Bartenwerfer

(1969) was used in the car-phone study and in their driving simulation test. On the other hand, heart rate measure was also used in the different load driving task of the experiment.

The model depicts changes in workload and mental performance measures in their individual bars (Figure 2.8). The areas highlighted in the bar are based on six regions in the graph that represent the sensitivity of the workload measures. The state-related effort was presented in region A1 while task-related effort in region A3. The optimal performance with low mental workload is obtained in region A2. The RSME can reflect the driver's mental effort when the performance is in region A1 and A3/B while the activation scale is in region D, B and C. Meanwhile, the sensitivity of the SDLP and SDSTW is highest in the B and D regions. However, it was stated in their study that improvement can be made on their primary task performance measures. The car-following measure sensitivity was expected in the D/A1 and A3/B regions of performance while the mirror checking was in A3/B regions. In a more complex driving environment, task-related effort was indicated by the heart rate measure. It was highlighted that the heart rate was more sensitive in D and B region while heart rate variability (0.10 Hz component) is most sensitive in the A3 region.

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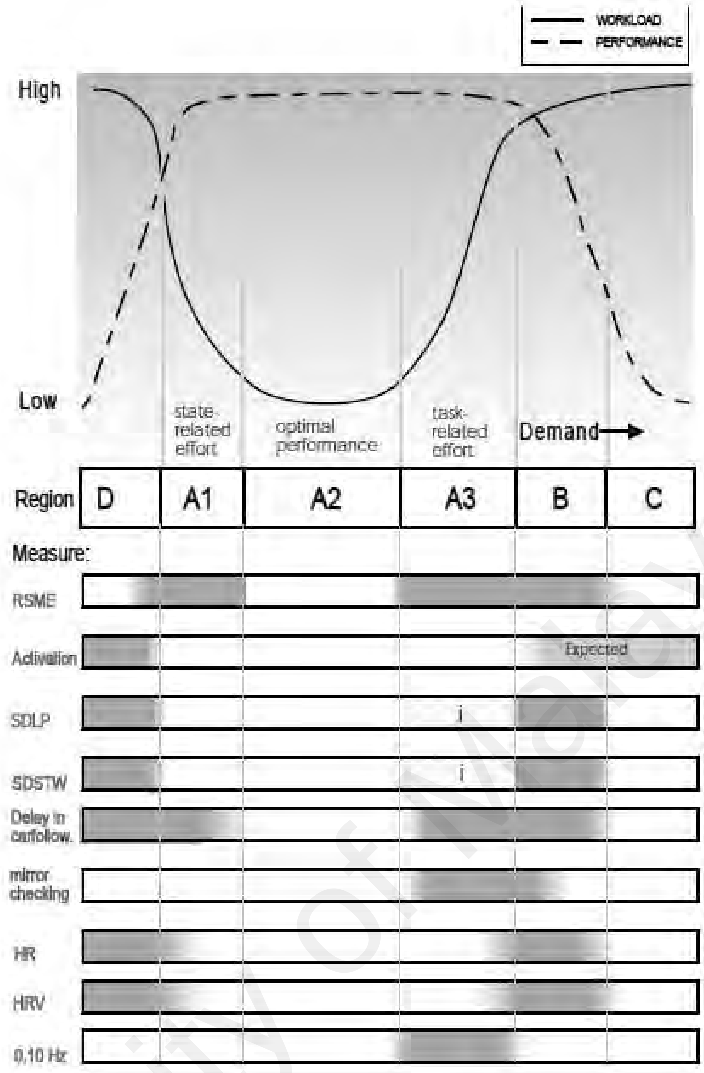

Figure 2.9: Workload in six regions and sensitivity of different measures to driver mental workload (Source: Dick de Waard, 1996)

2.6.2 Model of Wong & Huang (2010)

Wong and Huang (2010) proposed a conceptual model which illustrates a framework for driving mental process in their study on developing a model of driver mental workload for accident causation and prevention. As shown in Figure 2.9, the model described the factors that affect the driving mental workload and the relationship among the factors. It can be observed that the task activity perceived will contribute to the task perception and would be performed by drivers to achieve their goals. The model suggested that the task activity and demand alone cannot exhibit the characteristics of mental workload; drivers'

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motivated capability must also be taken into account. In their model, mental workload is tempted by the interaction between motivated capability and task demand. Wong and Huang also expanded their model by mapping the sources of motivated capability (consists of driver's capacity and psychology condition) and task demand (consists of primary task and secondary task).

The model's concept can be referred to investigate further on the driving mental workload of ageing drivers and the factors that contribute to the capability and demand of the driving task. The model also highlighted the importance of the task demand's characteristics in designing experimental study so that different levels of mental workload experienced by drivers can be evaluated and analysed, thus contributing to various levels of driving performance.

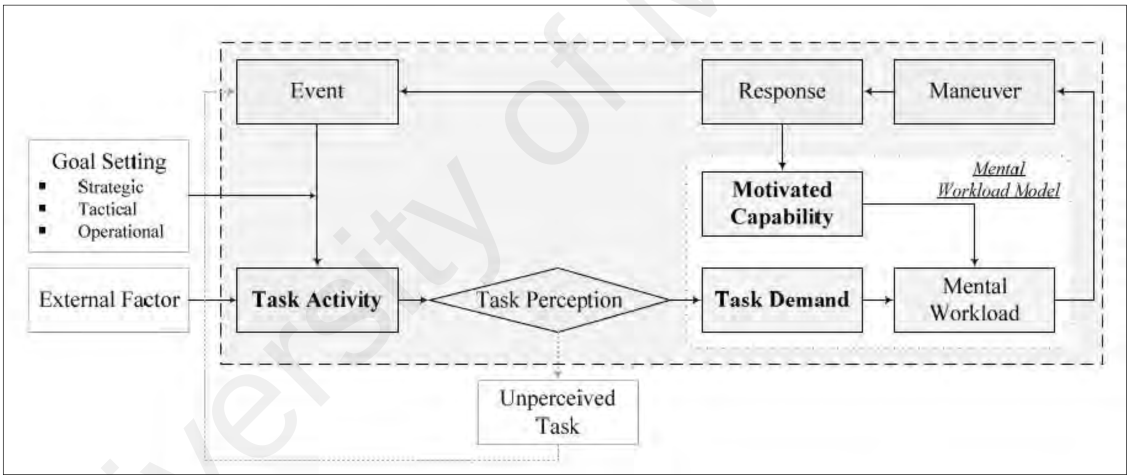

Figure 2.10: Conceptual model of driving mental process within the context of mental workload-related factors (Wong & Huang, 2010)

2.6.3 Model of Tran (2017)

The model of Tran et al. (2017) predicted drivers' work performance by integrating six physiological indices, including pupil dilation, blink rate, blink duration, fixation duration, heart rate and standard deviation of normal mean inter-beat intervals (Figure 2.10). The group method of data handling (GMDH) was used to establish the model on different workload levels by integrating the six indices into a synthesized index. Each variable selected in this study was normalised to a range of 0 to 1 before the computation process was done. In the final model, pupil dilation, blink rate and heart rate index were the best significant predictor factors in the performance by the subject. The model was expressed in the form of an equation with variables namely Y (Performance of the subject); X_1 (pupil dilation); X_2 (blink rate) and X_5 (heart rate). The mean square error was small (1.03) and R squared of the model was 78.1 % which is it represent a high variance in the dependent variables can be explained by the model.

The model concept can be adopted to study driving performance of ageing drivers considering the mental workload measures. The model shows physiological indices such as cardiac responses (i.e. heart rate) which was also previously sensitive and used as a mental workload measures (Heine et al., 2017; Brookhuis & De Waard, 2001).

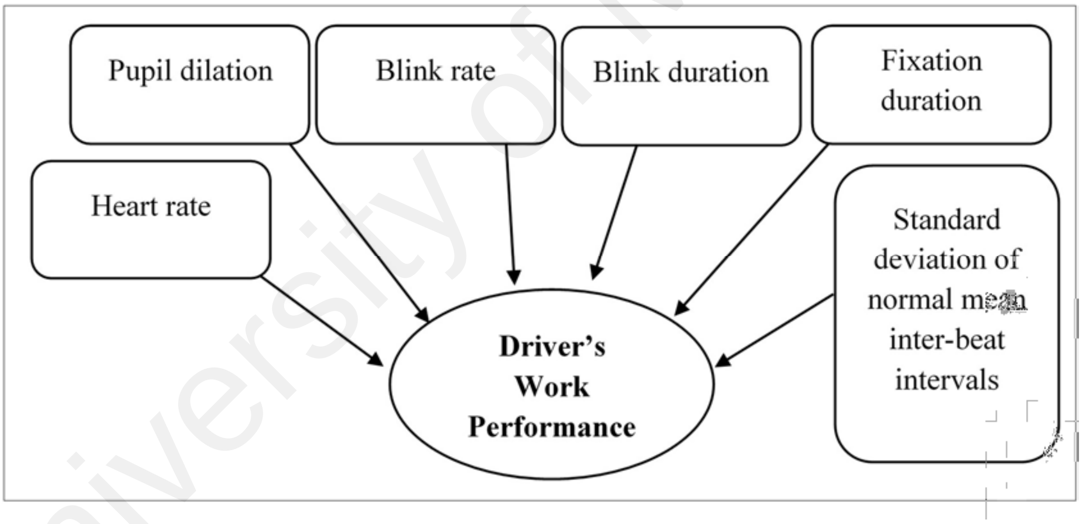

Figure 2.11: Driver's work performance prediction model based on physiological indices (Tran et al., 2017)

2.6.4 Model of Paxion et al. (2015)

The mental workload and performance relationship plotting (Figure 2.11) was developed by Paxion et al. (2015) where three levels of environment complexity were used in their experimental study. In their study, four levels of driving experience were manipulated in their simulation experiment. The performance was measured in terms of strategies to avoid pedestrians (braking, swerving, combination of both braking and

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swerving, and anticipating), the Reaction Times (RT) of the first action realised after the pedestrian's appearance in the driver's vision field, and the number of collisions with pedestrians.

This study highlighted that the subjective workload was depending on driving experience and situation complexity and determined reaction times for drivers. On the other hand, the number of collisions was significantly depending on subjective workload, avoidance strategies and reaction times. This link was modulated by situation complexity as a function of driving experience. This study can be referred to establish an experimental setup design that considers the experience of drivers as a human profile and situation complexity as the environment's characteristics in designing a real-time experiment which evaluates mental workload and performance of the ageing drivers.

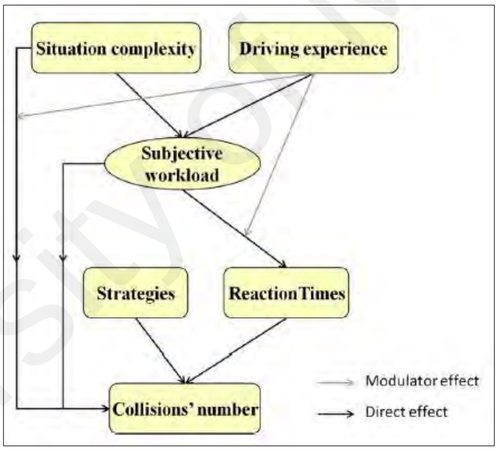

Figure 2.13: Predictors of the collisions' number model in a study of situation complexity and driving experience on subjective workload and driving performance (Paxion et al., 2015).

2.6.5 Model of Rouse et al. (1993)

Rouse et al. (1993) highlighted a topic which described the relationship between subjective workload and human behaviours. They have developed a model of the dynamics of this relationship as shown in Figure 2.12. The result in their experimental simulation shows that simple linear identification algorithms are surprisingly robust in on-line identification of noisy, nonlinear versions of the model. The variables within the model included four vectors; x(t) (system state at time t), u(t) (human activity at time t),

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p(t) (system performance at time t) and s(t) (subjective experience of workload at time t). As indicated in their model, subjective experience(s) is related to what people do, how the system responds, and perhaps how well performance objectives are achieved. However, performance measure in this study was only related to subjective experience indirectly via two transformations. Thus, more comprehensive and multiple measures within different categories should be used for mental workload and performance evaluations.

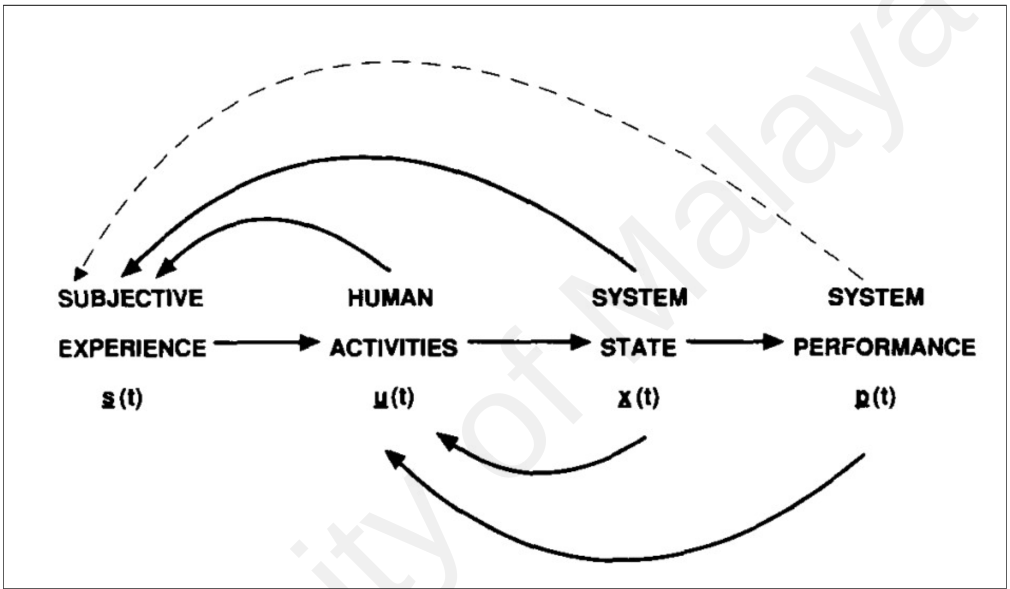

Figure 2.13: A model on the Dynamics of Mental Workload and Human Performance in Complex Systems (Rouse et al., 1993)

2.6.6 Summary of Significant Factors from Reviewed Models

Most of the existing models developed by previous studies were based on comprehensive relevant literature reviews. Most of the relevant model were clearly testing the relationship of capability and demand characteristics. The difference of each study is the type of measures done for each condition of the studies. The factors used in the driving mental workload and performance models developed by previous researchers are summarised in Table 2.5. Based on the findings, these are the most important factors up to now. It is evident that there are no model that specifically establishes which correlates the psychology and physiological response of ageing drivers and task demand in real-time driving in determining the driving mental workload and performance. Therefore, these factors were particularly considered and adopted in designing the methodology, thus evaluating the driving mental workload and performance of ageing drivers.

Table 2.5: Summary of the factors involved in the existing driving mental workload and performance models

Factor	**Model**	**de Waard (1996)**	**Wong & Huang (2010)**	**Tran (2017)**	**Paxion et al., 2015**	**Rouse et al., 1993**
Capability condition	Psychology conditions	x	x		x	x
	Physiological conditions	x	x	x		
Specific task demand characteristics	Primary task	x	x	x	x	x
	Secondary task	x	x	x	x	

Note: ‘x’ indicates that the factors are investigated by the respective researcher(s)

2.7 Summary of the Literature Review

Grounded on a broad review of relevant literature, it can be summarized that driving mental workload is an important factor in the driving performance (particularly for ageing drivers in Malaysia). Previous studies have shown that there is a definite link between different levels of mental workload and driving performance. This indicates that ageing drivers will be exposed to a higher task demand and consequently, higher mental workload levels involving certain driving task-related factors. Besides the adoption of the relevant parameters involved in earlier studies, previous mental workload models are

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reviewed to identify the significant factors in relation to driving mental workload and driving performance. The significant factors related to driving task and driving mental workload of the reviewed models are adopted to derive ageing drivers' driving performance model in this study.

In this study, a robust systematic review of the driving mental workload and performance and concept and models was conducted for this study where current literature, its limitations, quality and potential has been identified. The search words and strings with interest over time worldwide from year 2016 to 2020 (full score is 100) based on analytic data are presented in Table 2.6. Majority of the selected literature were from the current year to fifteen years back of publication and limited to English language. Meanwhile, databases searched was on the number of ageing population all over the world; accident involvement worldwide and Malaysian active drivers.

Table 2.6: Search words and strings with interest over time (from year 2016 to 2020)

Search words and strings	Interest over time worldwide (Number of hits score)
Mental workload	66
Driving performance	100
Driving difficulties	33
Driving factors	56
Ageing	45

It shall be highlighted that few attempts have been made to investigate the relationship between mental workload and driving performance with different driver's capability and levels of driving task demand by means of objective measurements. The gap that can be identified from the literature review is that there is no study yet on Malaysian ageing drivers focusing on the real-time on the road; with psychological and physiological measurements on their driving mental workload and performance. Thus, this study is

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aimed to fulfil the gap (Figure 2.14) and extend the existing body of knowledge by providing insight on the relationship between driving task-related factors and mental workload responses in relation to the driving performance. It is believed that it is very important to produce a driving performance model that can support the government's efforts to improve road safety in terms of drivers, vehicles and driving environments.

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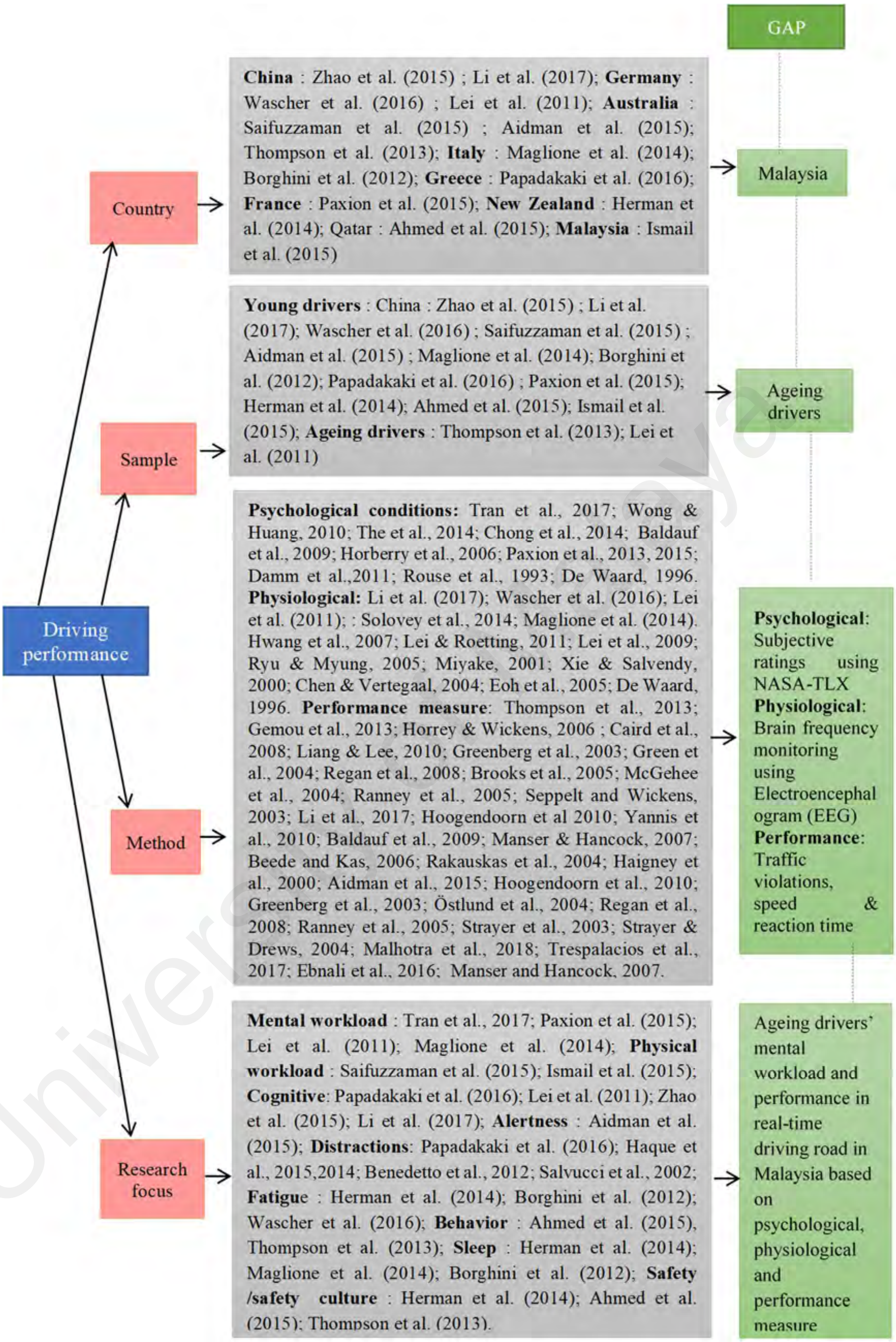

Figure 2.14: Research gap

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Overview

The methodology applied in this study is presented in this chapter. This chapter is divided into six major sections. The methodological framework which serves as a guideline on the techniques to achieve the objectives is described in Section 3.2. The methodology implemented consists of observation on the official accident occurrence database, administration of a survey to the participants and experimental tasks. The flowchart outlining the guideline on the techniques being used, as well as the steps taken to achieve the objectives of the study are described in Section 3.3. Details on the accident database's observation and drivers' survey are presented in Section 3.4 which includes the subjects and the survey instruments. Experimental task details are described in Section 3.5; which include types, duration, variables which are the research focus, equipment and tools used for the measurements, participants and procedures. The data analysis and the statistical analysis method used in this study are presented in Section 3.6. The summary is given at the end of this chapter

3.2 Methodological framework on mental workload and driving performance

A methodological framework was developed to validate the following proposed hypotheses on the mental workload and driving performance:

1. Hypothesis 1

Null hypothesis:

Ho: There is no statistically significant difference in mental workload and driving performance of ageing drivers on different driving task-related factors.

Alternative hypothesis:

Hi: There is a statistically significant difference in mental workload and driving performance of ageing drivers on different driving task-related factors.

2. Hypothesis 2

Null hypothesis:

Ho: There is no statistically significant relationship between mental workload and driving performance of ageing drivers at different levels of situation complexity.

Alternative hypothesis:

Hi: There is a statistically significant relationship between mental workload and driving performance of ageing drivers at different levels of situation complexity.

The research hypotheses were tested using data obtained from the experimental tasks as well as statistical analysis. The methodological framework developed as in Figure 3.1 functions as a basis for the methods used to achieve the objectives in this study.

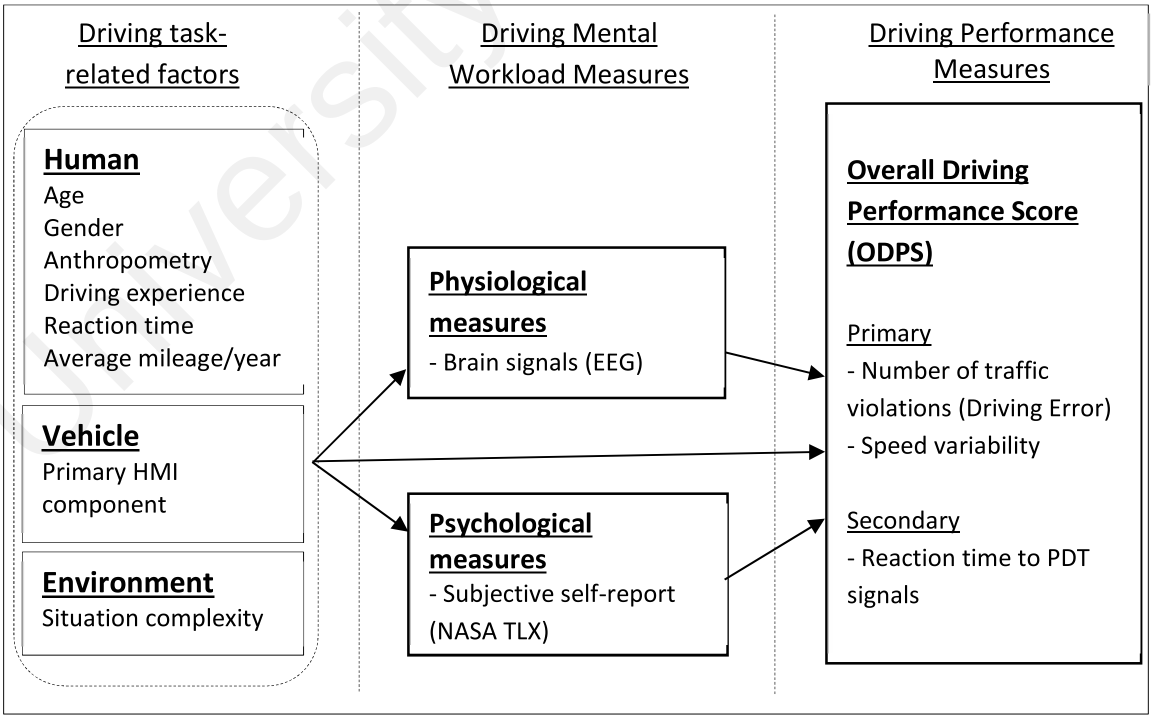

Figure 3.1: Proposed methodological framework to determine the Overall Driving Performance Score

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Several elements involved in the analysis of mental workload and driving performance are proposed based on previous studies (Tran et al., 2017; Paxion et al., 2015; J. Y. Kim et al., 2013; Cai & Lin, 2011; Cantin et al., 2009; De Waard, 1996). The framework shows the relationship between the elements, which provides an understanding on how these elements are used to fulfil the objectives thus determine the driving performance of ageing drivers. In this model, the mental workload is centered based on three driving task-related factors, namely human, vehicle and environment. In this study, factors under the main components were selected as the focus measure and scope of the research. The human factor, in this case the driver, included characteristics such as age, gender, anthropometry, driving experience, reaction time (at the station) and average mileage per year. For the vehicle factor, mechanical and visual were chosen as the main issues of ageing drivers are visual perception ability, cognitive functions and psychomotor functions (Eby, 2009; Anstey et al., 2005). Thus, this study has focused on one of the primary HMI components particularly on the turn signal lever of the experimental car. On the other hand, the environmental factors consisting of driving situations such as traffic and road characteristics are to be emphasized more as they are crucial factors in a driving task (Thompson et al., 2013) thus forming the complexity of the situation. Interaction between these factors will surely determine the pattern of the mental workload responses that could affect driving performance.

It is known that interaction of the three-driving task-related factors contributes to physiological and psychological responses. The brain signal monitoring using Electroencephalogram (EEG) and NASA-TLX ratings represent the mental workload measures during the performed task based on findings of relevant previous studies (Rahman & Dawal, 2016; Paxion et al., 2015; Zhang et al., 2015; Borghini et al., 2014a; H.-S. Kim et al., 2014). The ODPS consists of elements from direct measurements of the primary and indirect measurements of the secondary driving task. From the primary task,

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driving errors will be considered which leads to the Number of Traffic Violations (NTV) based on findings of relevant previous studies (Cai & Lin, 2011).

Besides, speed variability which represents the mental workload level is likewise part of the primary task as measured in studies of other researchers (Ebnali et al., 2016; Pavlou et al., 2016; Navon & Kasten, 2015). Apart from that, Reaction Time (RT) of the Peripheral Detection Task (PDT) will also contribute to the Overall Driving Performance Score (ODPS) for each of the ageing drivers (Zhang et al., 2015; Chong et al., 2014; Ceci et al., 2010). Familiarization of these variables' correlation is crucial to obtain a systematic evaluation of the ageing drivers' performance thus minimizing the risk of inappropriate mental workload that can lead to accident occurrences (Silva, 2014).

3.3 The flowchart of methodology of the study

The flowchart of the methodology that serves as a guideline on the techniques being used, as well as the steps taken to achieve the objectives of the study is described in Figure 3.2. Phase 1 involved defining the goal and objectives of the study while reviewing all the relevant literatures from the previous studies. Next, observation on the accident trends in Malaysia were done based on the accident database from the Malaysia Institute of Road Safety Research (MIROS).

Identification of validated survey questions was done from the literature review and selected questions were prepared, then pilot survey was done to observe the data acceptability. Next, the main survey was conducted on the identified sample group. The outcome from literature review, accident trends and survey were used to design the experiment model of the study.

Phase 2 of the study consists of experimental tasks that measure real-time mental workload and driving performance during road driving. The preliminary experiment was conducted to observe the acceptability of the data and methodology. After that, the main experiment was conducted to obtain relevant data for the study. In phase 3, driving performance model was developed and validated before the final report was written in Phase 4 of the study.

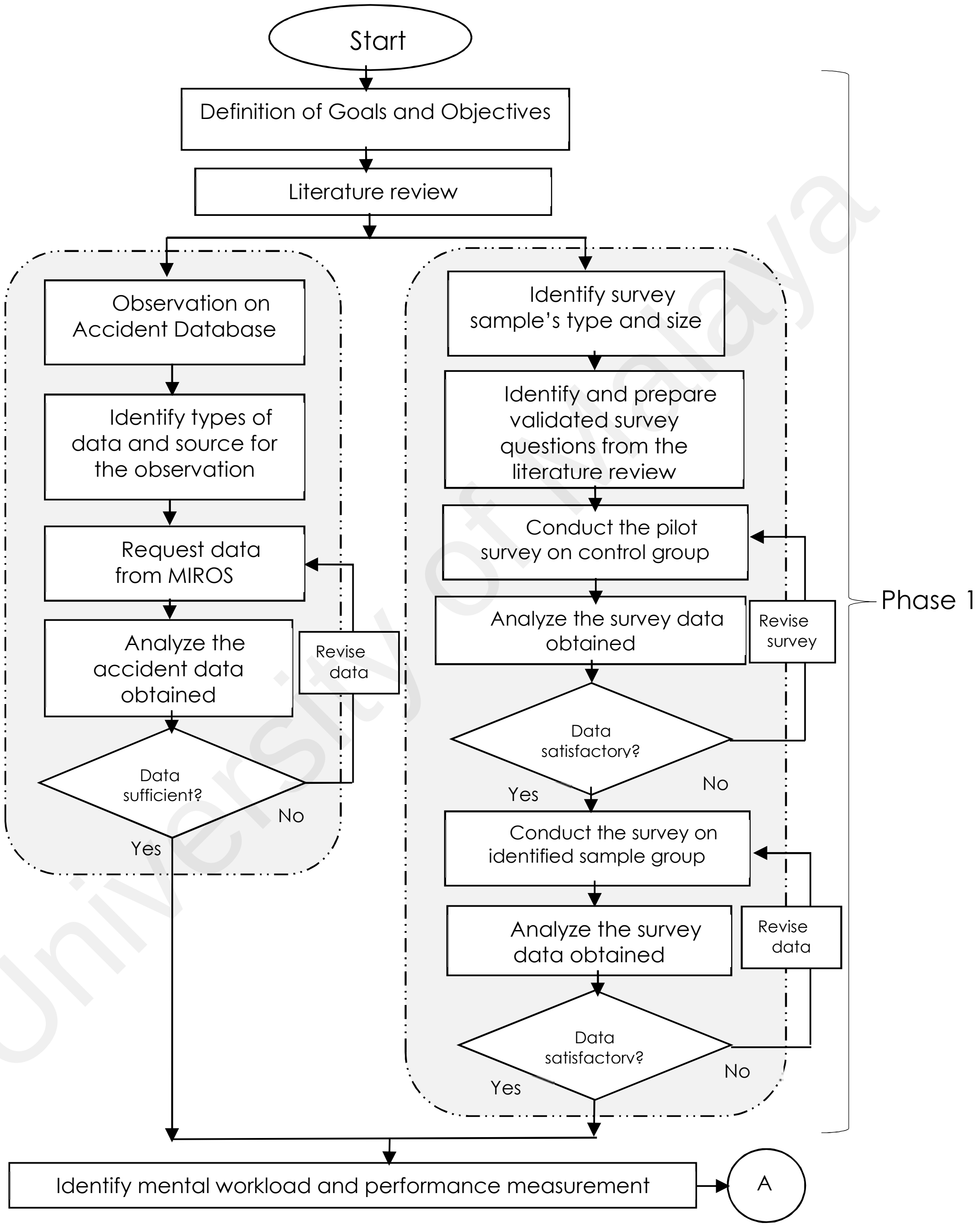

Figure 3.2: Methodological framework

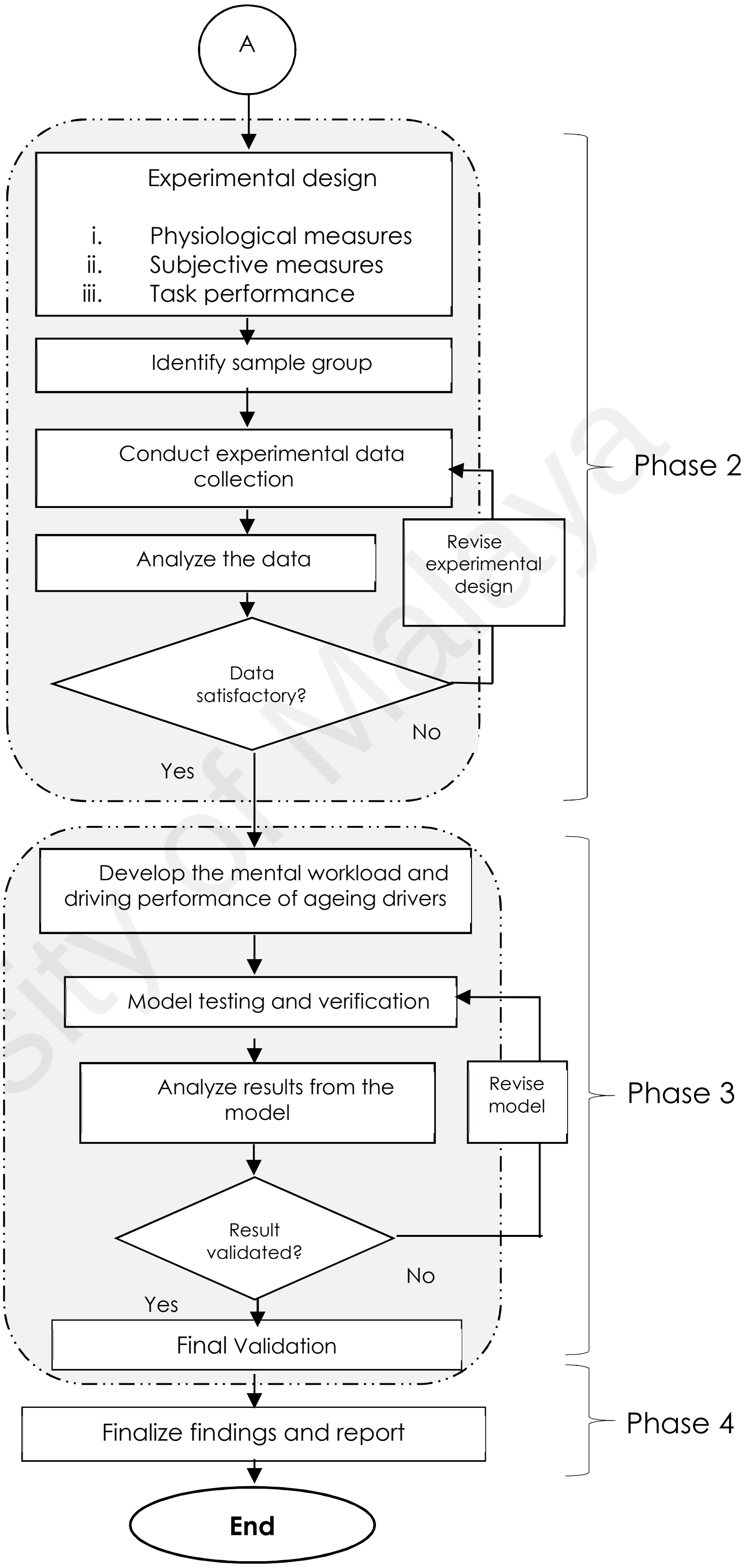

Figure 3.2: Methodological framework (*continued*)

3.4 Accident database observation

The details on the accident database's observation is presented in this section which includes the resources, the characteristics of the subjects and the survey instruments. The observation on the accident databases in Malaysia was done in providing the literature reviews to design the experimental task.

3.4.1 Accident Database – Road Accident Statistics Report of the Royal Malaysia Police

The accident data for years 2013 and 2014 were obtained from Malaysia Institute of Road Safety Research (MIROS) where all accidents reported to the Royal Malaysia Police are compiled. The aim was to investigate the relative safety of older drivers compared to other age groups by examining the incidence of collisions and the morbidity of injuries. Standardized format was used for data collection throughout Malaysia which include the characteristics of the accidents.

The data obtained was on the number of accidents (based on classification of fatality) that drivers/riders involved in while driving or riding various type vehicles for example car, motorcycles, different type of lorry and bus and van for both commercial and non-commercial purposes. In the police data, fatal injuries or deaths are defined as killed while other types are classified as severe and light accident type. The overall data were separated into the age and gender of the driver/riders. Percentage change of type of accidents based on year 2013 and 2014 were computed to analyze the pattern in terms of involvement of young and ageing drivers; gender, different first collision type and type of vehicles involved.

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3.5 Drivers' Survey

Survey on drivers in Malaysia was conducted in providing the literature reviews to design the experimental task. It was done to characterize the driving habits of older people and to examine how driving status relates to quality of life. This study was also aimed at investigating the cross-age groups in terms of distractions, violations, errors and lapses on the road, comparing the driving behaviors of two age groups (i.e., younger and older) and investigating significant driving behaviors of the older car drivers in Malaysia. The questionnaire is given in Appendix A.

3.5.1.1 The survey participants

Survey participants consisted of 182 drivers (28% male and 72% female). They were divided into two age groups: below 50 years is Younger Group; 50 years and above is Older Group. The participants were drivers in Selangor and Kuala Lumpur which both states had the highest number of driving license holder and uppermost total number of ageing people in Malaysia. They were approach directly by the researchers and given sufficient time to answer the questionnaire. The participants were assured of anonymity and confidentiality. An identification code was included to the questionnaire for systematic recording and reference. Education levels varied from primary school to degree holder with sample size dissimilar across the groups. The requirements to become a participant were; holding a driver's license for at least half a year and having driven at least 5000 km. Calculation of the sample size is presented in detail in Appendix B.

3.5.1.2 The protocol of the survey

The protocol was approved by the UM Research Ethics Committee (UMREC). The participants provided their written informed consent to participate in this study. Questionnaires were administered to the participants by a few staff on duty. Explanation was made clear on each section of the questionnaire.

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i) ***Driver information form***. Driver information form consists of questions about demographic information and driving patterns: driving experience (e.g. "When did you get your driver's license?", "For what purposes do you drive?"), violations (e.g. tickets, demerit points) and accidents (e.g. number of accidents involved/tickets taken in the last 5 years/lifelong). It was implemented as a structured interview.

ii) ***Driving Habits***. Driving Habits Questionnaire (DHQ) was distributed to evaluate current driving status, general driving practices, driving exposure, dependence on other drivers, and driving difficulty. The DHQ has recognized construct validity and test-retest reliability with respect to older respondents; previous researches have also demonstrated that older adults can validly report their driving exposure (e.g. miles/week, miles/year) (DeCarlo et al., 2003)

iii) ***Driver Behavior***. Driver Behavior Questionnaire (DBQ), developed by Reason et al. (1990), includes 28 items and consists of four subcategories: errors, ordinary violations, lapses and aggressive violations. In the present study, the extended DBQ was translated into Malaysian language where items of violations, errors, lapses and distraction were included (Nazlin & Siti Zawiah, 2016; Schroeder, 2013).

3.6 Experimental Tasks

The experimental design involves the real driving task on the road to achieve driving performance. The main goal of the experiment is to provide an insight into the human physiological and psychological responses during the driving task. It shall be highlighted that the methodology used in this study has been approved by UM Research Ethics Committee (UMREC) as shown in Appendix C. This study was conducted using a repeated-measures design to investigate on mental workload and driving performance. The three experimental driving sessions were separated by at least 5 minutes' break (Tran et al., 2017). The classification of the driving environments (i.e. situation complexity) is

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based on specific pattern in terms of different complexities (low, medium, high), as proposed by Paxion (2014) and partly from Fastenmeier (2007). The participants were instructed not to speak unless it is related to the task during the experiment to avoid additional workload as well as signal disruptions. The experimental design used in this study is shown in Table 3.1.

Table 3.1: The experimental design used in this study

	Variables	Descriptions
Independent	Subjects	Ageing: age ≥ 50 years old Control: age < 50 years old
	Situation complexity	Simple, Moderate and Very Complex road characteristic
Dependent	EEG signals	Frequency bands
	NASA-TLX ratings	Raw task load index & weighted workload
	Reaction time	Reaction time by stimuli of PDT
	Hand reaction time	Reaction time during blink signalling event at station
	Speed	Driving speed and speed variability during each driving session
	Number of traffic violations	Driving errors
Control	Vehicle	An instrumented experimental sedan car
	Time of the experiment	9 am to 12 pm

3.6.1 The participants of the experiment

In this study, forty healthy drivers were recruited through poster advertisements and social media. Table 3.2 demonstrated the details of the participants' characteristics. Thirty ageing participants were divided into two groups, namely the main analysis group and the model validation group (twenty and ten people respectively). Ten of the total participants were young drivers assigned to the control group, purposely as comparison for each measure. The number of each gender is equal. To qualify as participants, volunteers had to fulfil the requirements, which are to hold a driver's license for at least 5 years and must have driven for at least 10,000 km during the last year.

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Table 3.2: Details of the participants' characteristics

Variable	Characteristic	Remarks
Number	30 ageing drivers 10 young drivers	20 for the main group & 10 for the model validation group The control group for comparison and model validation
Age	50 and above 25 to 35 years	-
Gender	20 males & 20 females	Equal number for each gender in each group
Experience	hold a driver's license for 5 years and above have driven for at least 10,000 km during the last year	-

They were informed of the study's goal, methodology and potential hazards in verbal and writing to which they all acknowledged afterwards. Participants received a token of appreciation for their participation in the study. Based on David (2005), a sample size of 15–25 subject is the minimum sample size for monitoring in order to obtain an adequate estimate of group average exposure. The sample size chosen for the experiments of this study was estimated from power analysis (Bausell & Li, 2002; Cohen, 1988), and the details are presented in Appendix G.

3.6.2 Experimental driving environment

The routes were identical to all participants because they need to drive through them, making the total distance of driving tasks is approximately 27 km, which took an average of about 30 to 45 minutes. To ensure the participants maintain their own driving style, the experiments were conducted at off-peak period, i.e. 9 in the morning to 12 noon before lunch hour (Joonwoo Son et al., 2015). Details of the routes and environments are shown in Table 3.3 while Figure 3.3 shows typical traffic situations on each road type during the driving task based on situation complexity (i.e. highway, rural and city). In this study, the

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speed limits of the highway, rural and city were 110 km/h, 90 km/h and 60 km/h respectively.

Table 3.3: The route settings

Descriptions	A: Simple situation (SS)	B: Moderately complex situation (MCS)	C: Very complex situation (VCS)
	SILK Highway from Kajang to Putrajaya (9.1 km)	Kampung Abu Bakar Baginda to Teras Jernang (9.9 km)	Persiaran Bangi to Persiaran Jaya (8.1 km)
Road design	Highway	Rural Road	City Road
Speed limits	110 km/h	90 km/h	60 km/h
Road layout	Straight	Few curves	Many curves
Traffic flow	Low density	Moderate density	High density
Light condition	Daytime	Daytime	Daytime
Weather condition	No rain	No rain	No rain
Other condition	Car crossings for exit	Houses on both sides Car and pedestrian crossings Pedestrians and cyclists appearing	Shops or houses on both sides Car and pedestrian crossings Traffic lights Parked buses and cars Pedestrians and cyclists appearing

a) Highway route b) Rural route c) City route

Figure 3.3: Images from the three types of route by camcorder monitoring system.

3.6.3 Experimental setup

An instrumented experimental sedan car was used during the driving tasks. In this car, a GPS sensor, two cameras, computer devices, EEG set and Peripheral Detection Task (PDT) components set were installed. The Global Positioning System (GPS) sensor and speed logger were used to obtain data regarding the position and the longitudinal speed of the car. Two cameras recorded a forward driving scene including the driver's signaling behavior. The environment during the driving task and driver’s behavior were recorded and synchronized with the EEG data. Meanwhile, the PDT device contains a signal

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controlling unit, an LED board and a pushbutton attached on the distal part of left index finger. The LED board is placed below the windscreen on the right side of the dashboard (Figure 3.4). The PDT setting based on previous studies (Arien et al., 2013; Patten et al., 2006; Jahn et al., 2005; Van Winsum et al., 1999) was adjusted based on Malaysian driving environment (driving on the left-hand side of the road which implies that the driver's seat is on the right-hand side of the car).

- At a horizontal angle of 11^0–23^0, right of the driver’s line of sight and at a vertical angle between 6” and 8^0 above the car console, the location of the PDT signal varied randomly within this area.
- The LED signal was visible for a maximum of 2s.
- Within this 2s, it went off as soon as the driver gave a response.
- The driver responded with the pushbutton on the left index finger either by pushing with the thumb or by pressing the pushbutton against the steering wheel. The data were collected on a PC at the back of the car.

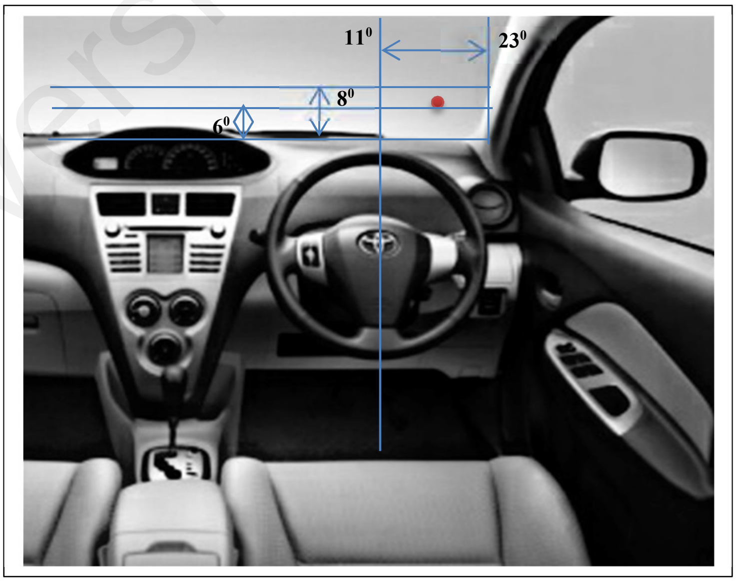

Figure 3.4: The demonstrated experimental setup showing the area in which the stimuli of the PDT (single red LEDs) were placed

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3.6.4 Mental workload measures – Subjective ratings and acquisition of Electroencephalogram (EEG) and Electrooculogram (EOG)

The NASA-TLX (Hart & Staveland, 1988) is used to evaluate the operator's subjective workload. The participants were asked to self-report their mental workload after finishing every primary task of each route session. Each participant was expected to take approximately 5 to 10 minutes to complete the subjective assessment. The NASA-TLX method includes six sub-scales (mental demand, physical demand, temporal demand, performance, effort, frustration level) and the source of workload comparison cards. The mean (raw TLX) and weighted mean (WWL, weighted workload) of these six sub-scales were calculated using paired comparisons.

The participants were fitted with a stretch AgCl electrode-cap (MP150 System and BIOPAC EEG100C) (Figure 3.5). These electrodes were pre-positioned based on the International 10/20 montage (Andreassi, 2000), with an electronically linked ear lobe reference. It is well known from tomography facts that each brain areas are presenting different functions of the brain. There are six electrodes placements that were considered will fulfill the objective of the study namely F_Z, P_Z, O_1, O_2, P_3 and P_4 (Figure 3.6). Fz and Pz provides information on intentional and motivational while locations near P3 and P4 contribute to activity of perception and differentiation. On the other hand, area O_1 and O_2 provide output on primary visual of a person (Zadry et al., 2010; Teplan, 2002).

Thereafter, EOG recording was done by using electrodes placed above and below each eye, and parallel with jumper leads when connecting to the vertical track EOG module to increase accuracy (BIOPAC Systems, Inc., 2016). Whilst the EOG signal served to identify and remove blink artifacts in the signals.

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Figure 3.5: Electroencephalogram components (*Picture source: BIOPAC Systems Inc., 2017*)

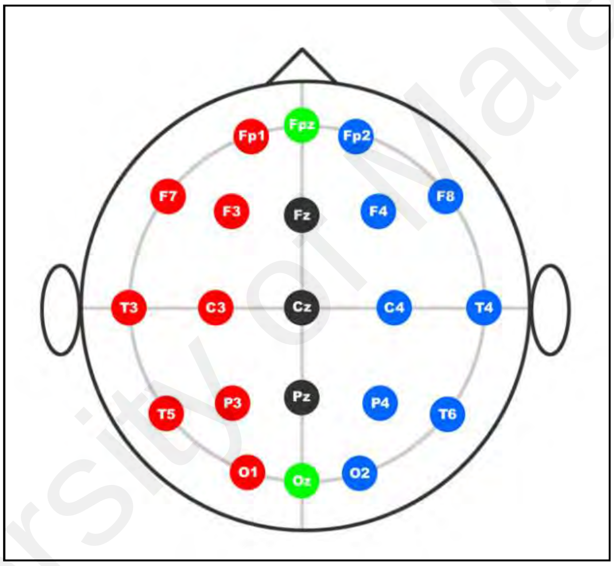

Figure 3.6: Locations of the EEG placements.

Before each assessment, the electrodes were checked to ensure that the impedance was 5 kΩ or less. The bipolar recording technique was used to record the signals. The BIOPAC EEG100C amplifiers served to amplify the signals which were sampled at a rate of 1000 samples/s. The signals processing was done using Acq-Knowledge 4.0 software (BIOPAC Systems Inc.) filtered between 1 and 100 Hz and digitally recorded (1000 Hz sample frequency) as a step to estimate Power Spectral Density (PSD). EEGs were corrected for vertical and horizontal eye movements based on EOG signals which are the method of Zadry et al. (2011, 2010). Fast Fourier Transform (FFT) was then performed

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on the selected data for every 2s segment and the PSD data (unit: μv^2) were obtained. The frequency bands that can be filtered are presented in Table 3.4. The spectral power was calculated for the three crucial EEG bands of the study: theta (4–7.99 Hz), alpha (8–12.99 Hz) and beta (13–30 Hz). In addition, a Matlab program (MATLAB R2010a, MathWorks, Natick, Massachusetts) was written to estimate the PSD of the EEG signals for each subject. After that, the output was normalized to achieve the theta, alpha and beta relative power (i.e. RPθ, RPα and RPβ) using the following equations respectively (Doufesh et al., 2014; Amodio et al., 2009):

$$RP\theta = \frac{\int_{fl}^{fh} Sx\,(f)df}{\int_{0}^{fmax} Sx\,(f)df} \times 100$$

where *Sx = power of the spectrum*, *fmax* = 95Hz, *fl* = 4Hz, *fh* = 7.99Hz; (1)

$$RP\alpha = \frac{\int_{fl}^{fh} Sx\,(f)df}{\int_{0}^{fmax} Sx\,(f)df} \times 100$$

where *Sx = power of the spectrum*, *fmax* = 95Hz, *fl* = 8Hz, *fh* = 12.99Hz; (2)

$$RP\beta = \frac{\int_{fl}^{fh} Sx\,(f)df}{\int_{0}^{fmax} Sx\,(f)df} \times 100$$

where *Sx = power of the spectrum*, *fmax* = 95Hz, *fl* = 13Hz, *fh* = 30Hz. (3)

Table 3.4: The EEG frequency bands (R. Li et al., 2017; E. Wascher et al., 2016; H.-S. Kim et al., 2014).

Bands	Frequency (Hz)	Characteristics	Location
Delta	0.5–3.99	Sleep	
Theta	4–7.99	Sleepiness	frontal, temporal
Alpha	8–12.99	Drowsiness & Relaxed	occipital, parietal
Beta	13–29.99	Active, busy	frontal, parietal, temporal
Gamma	30–100	Excitement	frontal, parietal

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3.6.5 On-the-road driving performance measures

In this study, the driving performance was measured based on three main elements related to the objective and design of the research namely number of traffic violations, speed and speed variability and reaction time of the peripheral detection task. The number of traffic violations element is based on previous studies which highlighted that it is one of the indicators of driving performance (Bouchner et al., 2006; Ma & Kaber, 2005; Brookhuis & De Waard, 2001) where fewer traffic violations would indicate a better driving performance. In this present study, traffic violations are based on errors indicated in Kurikulum Pendidikan Pemandu, The Road Transport Department Malaysia as in Table 3.5.

Table 3.5: Traffic violations based on errors according to situation complexity.

Situation complexity		Driving Errors
Simple situation (Highway)	1	Exceeding the speed limit (110)
	2	Driving on the Chevron markings (To channel the traffic).
	3	Getting into the wrong lane when approaching or being in a roundabout or a junction. (Less than 250m before)
	4	No turn signal at junction
	5	No turn signal when changing the lane
Moderately complex situation (Rural)	1	Exceeding the speed limit (90)
	2	Driving on the red light
	3	Being in the wrong lane at the roundabout
	4	No turn signal at junction/roundabout
	5	No turn signal when changing the lane
Very complex situation (City)	1	Exceeding the speed limit (60)
	2	Being in the wrong lane at the roundabout
	3	Driving on the red light
	4	No turn signal at junction/roundabout
	5	No turn signal when changing the lane

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The speed and speed variability which are part of the driving performance measurements were examined in the simple situation, moderately complex situation and very complex situation. For this study, the mean and standard deviation of speed and speed variability refer to the mean speed and variability of the driver along the route, excluding traffic light areas. The driving speed of each participant was set according to their speed comfortability. This is because, the effort and strategy required to keep a car safe on the road may vary between drivers for definite driving speeds. However, the drivers were instructed to drive not more than the speed limit of each road.

The third measure was the reaction time of peripheral detection task. The purpose of this measure is to monitor reaction time by stimuli and percentage of missing PDT signals as a measure of mental workload (Van Winsum et al., 1999). Based on the visual stimuli presented upfront at the center of their view, drivers will respond by pressing a micro switch placed on the left index finger. If a driver reacted to the PDT stimulus within two seconds, the reaction will be scored as a "hit", and the reaction time will be measured. Otherwise it will be scored as a "miss" (Törnros & Bolling, 2006). The unit will be in milliseconds (ms).

Overall driving performance score is based on three main elements of driving performance namely number of traffic violations, speed variability and reaction time of peripheral detection task. The individual driving performance measures were combined based on previous studies (Cai & Lin, 2011). Table 3.6 shows upper and lower limit performances after limiting the outliers (x < mean - 1.5SD and x > mean + 1.5SD), with the scores corresponding to 0.0 and 1.0 for each situation complexity respectively. The performance values were linearly rated between 0.0 and 1.0 for each participant. The final Overall Driving Performance Score (ODPS) is a weighted combination of the individual performance score:

$$\mathbf{ODPS = 0.33\ NTV + 0.33\ SVB + 0.33\ RT} \qquad (4)$$

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Table 3.6: Calculation of performance score for each situation complexity

Situation complexity	Items	NTV	SVB (km/hr)	PDT RT (s)	Performance score
Simple Situation	Individual performance (upper limit) (*x* max = mean + 1.5SD)	5.0	20.81	2.0	0.0
	Individual performance (bottom limit) (*x* min = mean - 1.5SD)	0.0	1.81	0.1	1.0
	Weights in overall performance	0.33	0.33	0.33	-
Moderately Complex	Individual performance (upper limit) (*x* max = mean + 1.5SD)	5.0	13.42	1.82	0.0
	Individual performance (bottom limit) (*x* min = mean - 1.5SD)	0.0	1.64	0.55	1.0
	Weights in overall performance	0.33	0.33	0.33	-
Very complex Situation	Individual performance (upper limit) (*x* max = mean + 1.5SD)	5.0	25.82	1.65	0.0
	Individual performance (bottom limit) (*x* min = mean - 1.5SD)	0.0	1.79	0.63	1.0
	Weights in overall performance	0.33	0.33	0.33	-

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3.6.6 Hand anthropometric measurements

Anthropometric measurements were obtained by following the procedures as detailed by Nurul Shahida et al. (2015). There are thirteen significant dimensions related to the primary HMI components and four fingers dimensions particularly on the turn signal lever of the experimental car (Sara & Henrik, 2012). Table 3.7 shows upper and lower limit dimensions after limiting the outliers (x < mean - 1.5SD and x > mean + 1.5SD), with the scores corresponding to 0.0 and 1.0 for each finger dimension.

Table 3.7: Calculation of Anthropometric Group score.

Items	Index finger length (cm)	Thumb circumference (cm)	Index finger circumference (cm)	Middle finger circumference (cm)	Score
95th percentile of the dimension (upper limit) (***y*** maximum = mean + 1.5SD)	7.46	8.20	7.30	7.60	1.0
5th percentile of the dimension (bottom limit) (y minimum = mean - 1.5SD)	5.02	5.80	5.20	5.20	0.0

These dimensions were adopted from previous studies (Dawal et al., 2015; Nurul Shahida et al., 2015) for the 5th and 95th percentile dimensions and used as a reference in the scoring. According to Pheasant (1996), the 5th percentile value of the anthropometry dimensions is essential in determining the reachability and limitation while the 95th percentile is used to ensure adequate clearance to avoid unwanted contact or trapping. Consequently, in the current study, each dimension value was linearly rated between 0.0 and 1.0 for each participant.

To observe the relationship between the signal lever and the significant dimensions, an Anthropometric Group was created based on the ageing drivers' anthropometric

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dimension ratings. The Anthropometric Group was sorted into four groups (i.e. A, B, C, D) based on the score value achieved and the criteria is based on the degree of association principles (grounded on Guildford's (1973) Rule of Thumb) as presented in Table 3.8. Based on the individual score, the Anthropometric Group was determined for each ageing drivers in this study. The Anthropometric Group was then correlated to the ageing drivers' errors related to the signaling during the driving tasks.

Table 3.8: Anthropometric Group score details

Anthropometric group	Score	Descriptions
A	≥ 0.9	Dimension is more or equal to the 95th percentile
B	0.5–0.89	Dimension is more or equal to the 50th percentile and less than 95th percentile
C	0.3–0.49	Dimension is more than 5th percentile and less than the 50th percentile
D	≤ 0.29	Dimensions is less or equal to the 5th percentile

3.6.7 The hand response rate experiment

The hand response rate was done to obtain the hand reaction time at the station using Hand Reaction Test Device as shown in Figure 3.7. The aim of measurement was to evaluate the response of the drivers outside the driving task. The results can provide information on whether it is related to mental workload and driving performance. The device consists of four signal lights, timer and counter display. The subjects need to perform a simple reaction time task responding to a visual cue. The time between the presentation of a neutral stimulus and the hand tap while responding to a visual cue is estimated and used as the subject's score. The participant was asked to use his or her dominant hand to tap on the sequence of random signalized blinked light within 30 seconds. The blinked light will turn off upon sensing the participant's hand on it. After a

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random delay, a stimulus appeared on the other light in a random sequence; the participant was instructed to lift their hand as quickly as possible when they saw the stimulus and tap on the other signalized blinked light.

Figure 3.7: Hand Reaction Test Device

3.6.8 The experimental procedure

The experimental procedure was approved by UM Research Ethics Committee (UMREC). In this study, participants were individually briefed on the experiment details upon their arrival at the setup station. Once they understood all the details, the participants signed an informed consent and filled out a demographic questionnaire. Thereafter, they were all given the chance to familiarize themselves with the vehicle and environment by driving around on a two-lane practice road without any traffic. Also, it was emphasized to the participants that their priority was to drive safely. Subsequently, they were notified to drive according to the route that has been set. To achieve accurate measures, the researcher was seated at the back to monitor the measuring equipment and a research associate was seated beside the driver to give driving directions while ensuring safe vehicle operations. As shown in Figure 3.8, at the end of each of the simple situation, moderately complex situation and very complex situation session, participants were directed to pull over and park the car for a break and complete the subjective ratings based

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on that session. It is expected that the order effect due to the sequence of three roadway types would be relatively small as driving tasks were kept under control (Joonwoo Son et al., 2015).

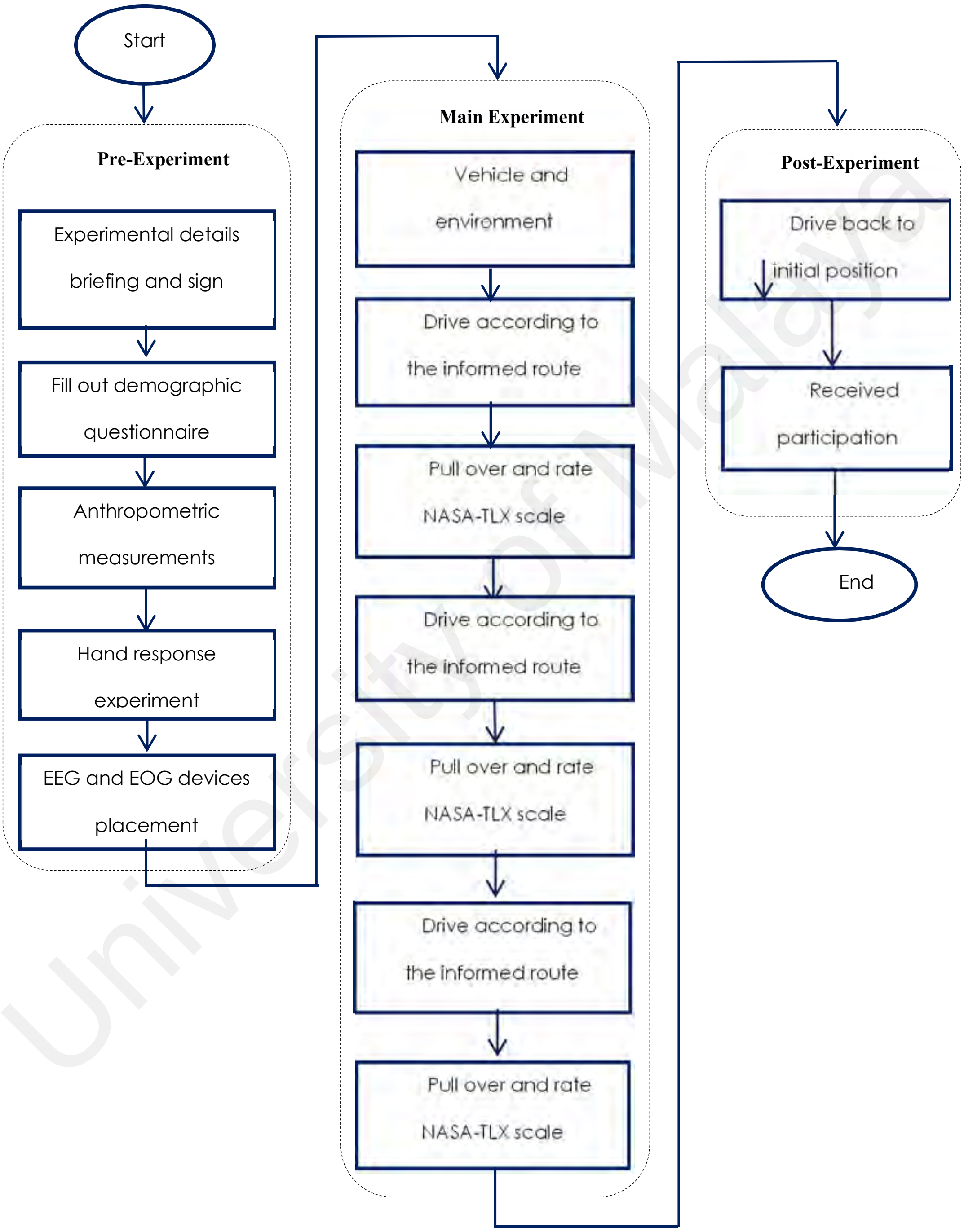

Figure 3.8: Overall experimental procedure.

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3.7 Statistical analysis

The analysis of the study was done based on the objectives which was carried out using the IBM Statistical Package for Social Science (SPSS) for Windows version 23.0 (Armonk, NY: IBM Corp). Prior to data analysis, all variables were subjected to normality test using skewness and kurtosis.

With regards to fulfilling the first and second objective, the mixed model repeated measures ANOVA was used to analyze the mental workload (NASA-TLX and EEG relative power bands) and driving performance (number of traffic violations, speed and speed variability, reaction time) measures outcome of ageing drivers in varying degrees of situation complexity. For the EEG output, the raw data was acquired from the Acq-Knowledge 4.0 software (BIOPAC Systems Inc.), processed and normalized into the relative power bands (details are as in Sections 3.5.4). The mixed model repeated measures ANOVA consists of 2 × 3 repeated measures between subject's factor (two levels; male and female) and situation complexity (three levels; simple situation, moderately complex situation and very complex situation). Next, comparisons were made between the age groups using T-test to investigate the differences. The relationship between mental workload and driving performance measures with personal characteristics was analyzed using Pearson correlation. On the other hand, Pearson correlation was used to investigate the association between the AG and the error in signal lever usage.

Next, to achieve the third objective, the correlation between NASA-TLX and EEG relative power bands with Overall Driving Performance Score was analyzed using Pearson correlation. In fulfilling the fourth objective, multiple linear regression was used to develop the Overall Driving Performance Score model. Details of the correlation and regression method are given in Appendix K. Thereafter, validation of the developed models was made with data from another 10 ageing drivers and 10 control group drivers

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(both equal number of male and female). The Standard Error of Estimate (SEE) computation was applied as an indicator of the average error of the prediction for the regression equation (Portney & Watkins, 2009). The SEE method is provided in detail in Appendix L.

3.8 Methodology summary

In this chapter, the methodology used in this study (data observation, survey and experiment) has been described in detail. The accident data for years 2013 and 2014 were obtained from Malaysia Institute of Road Safety Research (MIROS) while a questionnaire was adopted consisting of Driver Information Form, Driving Habits Questionnaire (DHQ) and Driver Behavior Questionnaire (DBQ). Next, the experimental tasks were conducted at three levels of situation complexity. NASA-TLX and Electroencephalogram (EEG) were used as the tools to measure the mental workload during the main driving task. Meanwhile, the driving errors, speed and reaction time of peripheral detection task were observed during the main experiment as measurements of the driving performance. Statistical analysis was performed to analyze the variations in the data and determine the relationship between mental workload and driving performance at different levels of situation complexity thus achieving the objectives of this study.

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CHAPTER 4: RESULTS AND ANALYSIS

4.1 Overview

This chapter presents the results and analysis performed in the study and is divided into seven main sections. First, the results as well as analysis of the accident databases acquired from the authorities are presented in Section 4.2. A survey of the drivers was conducted to obtain an insight into the current driving trends among the ageing drivers. The participants' characteristics, driving habits and behavioural data from the survey is presented in Section 4.3. Data analysis from the experimental tasks are presented in Section 4.4. The results consist of mental workload measures (i.e. NASA-TLX, EEG relative power bands) and driving performance measures (i.e. number of traffic violations, speed and speed variability, reaction time of the peripheral detection task). Comparisons using repeated measures ANOVA, T-Test and Pearson correlations were made and the outcomes are presented in this section. Next, the overall driving performance score (ODPS) is presented in Section 4.5. Results pertaining to the comparisons of ODPS between situation complexity and age groups are tabulated in this section. Correlation and regression analyses were conducted to investigate the relationships between the mental workload measures and ODPS for each situation complexity, and the results are laid out in Section 4.6. The developed ODPS regression models were validated accordingly using the standard error of estimate (SEE) and are presented in Section 4.7. Finally, the results are compared with previous studies in Section 4.8, and the summary of this chapter is presented in Section 4.9.

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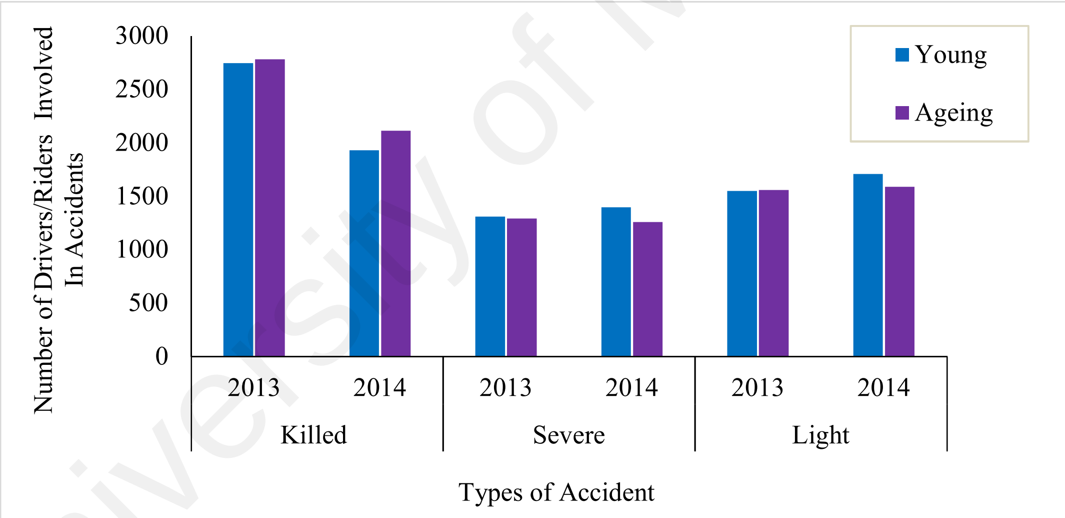
4.2 Malaysia accidents trends for year 2013 and 2014

The results highlight the trends of accidents occurring among young and ageing people in the years 2013 and 2014 (Figure 4.1). The data shows that total number of accidents were about the same between the young and ageing group. The number of young and ageing people involved in fatal accidents was higher in 2013 compared to 2014. However, light accidents recorded 10% and 2% increments in 2014 for young and ageing people respectively. Compared to young people, the ageing group recorded higher victims killed in both years. The record in 2014 shows that the number of ageing drivers were 9% compared to the young victims. From the data tabulation, the ageing drivers were more likely to be killed when involved in an accident compared to other accident types and only small number resulted in severe category.



Note: For the database presented in the above figure, the young group ages were between 30 to 41 years, while the ageing groups were between 50 years and above.

Figure 4.1: Types of accidents in 2013 and 2014 involving young and ageing drivers

When comparing the accident data based on gender, overall, males were involved in more accidents than females for both years (Figure 4.2). Males were more likely to be killed especially in 2013. Accidents involving females were apparently fewer in each year for each accident type. Moreover, all of them decreased from the year 2013 to 2014.

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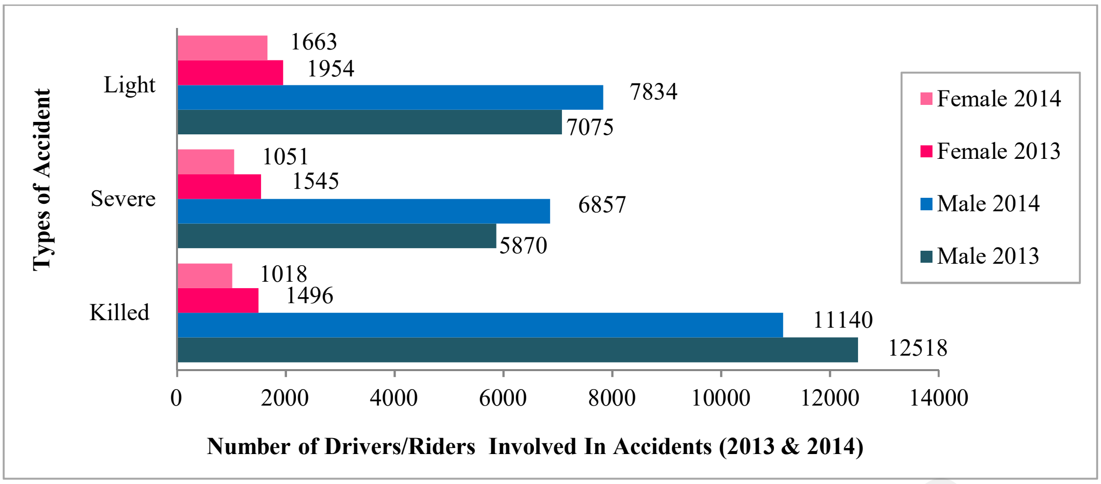

Figure 4.2: Statistics of accidents based on gender and year

In terms of the first collision type (Table 4.1), *slipped* recorded the highest number of victims killed in 2013 but greatly decreased (56%) in the next year followed by *collision* which only decreased 17% regardless of the age of the victim. For severe and light accident types, the first collision type was usually *knocking into flank*. Although *brushing past* caused deaths to less than 500 victims in 2013, it should be highlighted here that the record increased by 98% in 2014. The smallest number recorded for each accident type was caused by *crush* as the first collision type, but the percentage change generally was increasing in the second year.

Table 4.1: Percentage change of type of accident based on year 2013 and 2014 for different First Collision Type

First Collision Type /Year	Killed		*% Change*	Severe		*% Change*	Light		*% Change*
	2013	**2014**		**2013**	**2014**		**2013**	**2014**	
Collision	1391	1150	-17	689	595	-14	760	631	-17
Knocking Back	809	828	2	466	461	-1	870	919	6
Knocking Exact Flank	1179	1165	-1	1347	1192	-12	2466	2494	1
Brushing past	477	944	98	307	306	0	935	1144	22
Crush	17	19	12	4	4	0	18	23	28
Knocking animal	77	85	10	35	47	34	113	98	-13
Knocking object on the road	67	66	-1	18	28	56	74	89	20
Knocking object outside the road	78	78	0	30	21	-30	63	57	-10
Knocking Pedestrian	422	451	7	249	277	11	462	524	13
Overturned	53	53	0	13	18	38	44	44	0
Slipped	1716	750	-56	399	443	11	700	891	27
Others	22	598	2618	10	85	750	18	185	928

**Percent Change = (New Value - Old Value) / |Old Value| × 100%*

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For data presenting the type of vehicles involved in fatal accidents in 2014, cars recorded the highest number followed by motorcycles (Figure 4.3). However, the number of accidents involving lorries were also high compared to other types of vehicles. For example, accidents involving single lorries totaled 1505 while that for trailer lorries was 344. The number of accidents involving mini buses, tour buses and school buses were fortunately much lower compared to other vehicles.

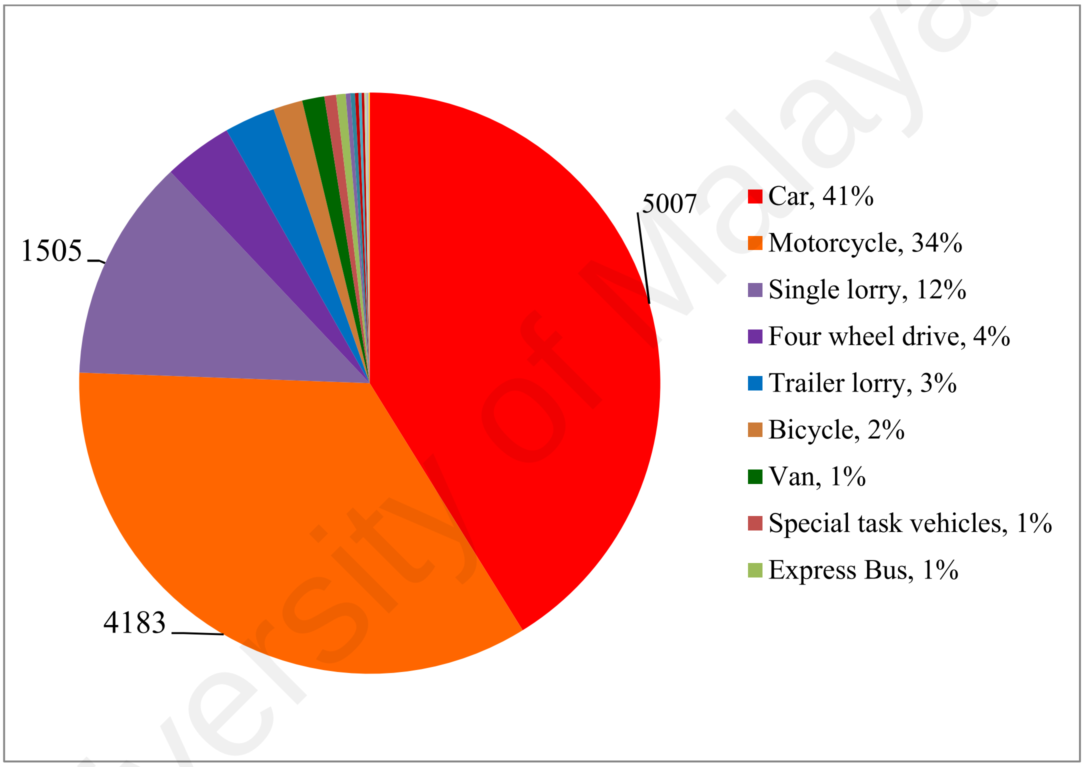

Figure 4.3: Type of vehicles involved in fatal accident in year 2014

4.2.1 Main outcome of the accident trends observation

From the accident trends observation, it can be summarized that light accidents in 2014 involving ageing drivers were higher than the previous year. Also, male drivers had higher tendency to be involved in accidents compared to female drivers. In terms of the First Collision Type, knocking exact flank, slipped and collision recorded the highest number of victims killed in 2014. For severe and light accident types, the first collision type was

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usually knocking exact flank. Meanwhile, cars recorded the highest number of involvements in fatal accidents in 2014 compared to other vehicle types. To summarize, ageing people especially male drivers, cars as the vehicle type and errors related to knocking exact flack need to be considered in designing a real-time driving experimental task to observe their overall mental workload and performance.

4.3 Survey on the Malaysian drivers' characteristics, habits and behavior

The survey on the drivers was analyzed and presented in this subsection. The analysis was done mainly based on the aim to achieve the information on the ageing drivers in designing the experimental task in the next section.

4.3.1 The characteristics of the participants

Table 4.2 presents information on demographic, educational and driving information of the participants. One-hundred of the 182 participants surveyed (54.9%) were ageing drivers. The majority of the participants had 21 years and more of driving experience (44.4%). Only two drivers had less than one year's driving experience. Most of them drove daily (55.8%) and very few (2.8%) had low driving frequency (a few days in a year). Meanwhile, the most frequent type of vehicle used was a sedan car (49.4%), followed by compact cars (23.9%) and multi-purpose vehicles (MPV) (23.3%). About 60% of the ageing drivers had experienced or were involved in accidents throughout their lives regardless of the cause of the accidents. Next, in order to observe any interesting associations between the parameters and the participants' accidents involvement, a Pearson's chi-squared test was applied. The results showed driving experience had significant correlation with accident involvement ($p = 0.010$). This indicated that there were statistically significant associations between driving experience with accident involvement.

Table 4.2: Demographic, educational and driving information of the sample and statistically significant association with involvement in an accident

	Younger Group (N=82)		Ageing Group (N=100)		*p* value
	Frequency	%	Frequency	%	
Gender [a]					0.121
Male	27	32.90	24	24.00	
Female	55	67.10	76	76.00	
Driving experience [a]					0.010*
less than 1 year	1	1.20	1	1.00	
1 - 5 years	17	20.70	3	3.00	
6 - 10 years	23	28.00	7	7.00	
11 - 15 years	19	23.20	5	5.00	
16 - 20 years	9	11.00	15	15.00	
21 years and more	11	13.40	68	68.00	
Driving Frequency					0.856
Everyday	48	58.50	53	53.00	
Nearly everyday	14	17.10	30	30.00	
A few days in a week	7	8.50	11	11.00	
A few days in a month	10	12.20	4	4.00	
A few days in a year	3	3.70	2	2.00	
The most frequent type of vehicle used [a]					0.143
Compact car	27	32.90	15	15.00	
Sedan	28	34.10	58	58.00	
Multi-Purpose Vehicle - MPV	22	26.80	20	20.00	
Pickup truck	1	1.20	1	1.00	
Others	2	2.40	3	3.00	
Accident Involvement [a]					
Yes	46	56.10	59	59.00	
No	35	42.68	40	40.00	

[a] *Total percentage of these items is not 100% due to missing data from the subjects (maximum 5 subjects)*

**Significant at $p < 0.05$*

4.3.2 The driving habits and driving exposure in current drivers.

The Driving Habits Questionnaire (DHQ) summary of result is presented in Table 4.3 pertaining to the driving habits and driving exposure in current drivers. Majority of the drivers reported wearing glasses (52% for both groups) and seatbelts while driving (78% young, 82% ageing). For both groups, approximately two-thirds preferred to drive themselves. A majority in both groups reported driving at about the same speed with the general flow of the traffic (68%), and only about 1% drove faster than the traffic flow. However, the ageing drivers group had a higher percentage of driving somewhat slower

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than the traffic flow (14.1%) compared to the younger age group (3.7%). Most drivers reported that they had never been advised to limit or stop driving (above 90%). The vast majority rated their quality of driving as good for both young (70%) and older (59.2%) drivers.

Table 4.3: Driving habits and driving exposure among current drivers in sample.

Driving Habits Questionnaire Item	Percentage of Younger Group	Percentage of Ageing Group
4. Wear glasses when driving		
Yes	52.4	52.0
No	47.5	48.0
5. Wear seatbelt when driving		
Always	77.8	81.8
Sometimes	21.0	16.2
Never	1.2	2.0
6. Way you prefer to get around		
Public transport	0	1.0
Someone else drive	35.8	30.3
Drive self	64.2	68.7
7. How fast you drive		
Somewhat slower	3.7	14.1
About the same	67.9	67.7
Somewhat Faster	27.2	17.2
Much Faster	1.2	1.0
8. Anyone suggest you limit/stop driving		
Yes	8.0	4.4
No	92.0	95.6
9. Rate quality of driving		
Poor	1.3	1.0
Fair	1.3	2.0
Average	21.3	25.5
Good	70.0	59.2
Excellent	6.3	12.2
10. What you do when you don't want to drive		
Ask a friend or relative to drive	56.0	54.8
Call a taxi or take the bus	13.6	19.4
Drive yourself regardless of feeling	14.8	10.8
Postpone plans	9.9	10.8
Others	3.7	4.3

The results of DHQ items related to driving difficulty are found in Table 4.4. Most of the drivers had difficulty driving in the rain. More than 60% in both groups did not have difficulty driving alone, performing parallel parking, doing right turns in traffic and driving on highway. Surprisingly, more young drivers reported difficulty with high volume traffic (55.7%) and rush hour (61.8%) compared to ageing drivers (44.8% & 54.1% respectively). Those who did not drive in this type of traffic situation reported that it was not because of vision issues but for other reasons. More than half of the young and

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ageing drivers reported difficulty driving at night, whereas 63% of young drivers and 68% of ageing drivers do not drive in this situation for reasons other than vision. Age was significantly associated with driving preference during these conditions; rain, right turn in traffic, heavy traffic, rush hour and night driving.

Table 4.4: Driving difficulty among current drivers in sample (DHQ).

Driving Habits Questionnaire Item	Percentage of Younger	Percentage of Ageing	p-value
17. Driving in the rain			0.031*
Difficulty	82.4	72	
No difficulty	17.6	28	
Do not drive in this situation due to vision	41.7	39.5	
Do not drive in this situation for other reasons	58.3	60.5	
18. Driving alone			0.732
Difficulty	38.4	28.6	
No difficulty	61.6	71.4	
Do not drive in this situation due to vision	23.3	25	
Do not drive in this situation for other reasons	76.7	75	
19. Parallel parking			0.219
Difficulty	37.7	41.7	
No difficulty	62.3	58.3	
Does not perform this maneuver due to vision	22.2	8.1	
Does not perform this maneuver for other reasons	77.8	91.9	
20. Right turns in traffic			0.000*
Difficulty	29.2	24.1	
No difficulty	70.8	75.9	
Does not perform this maneuver due to vision	25.9	17.1	
Does not perform this maneuver for other reasons	74.1	82.9	
21. Driving on interstates			0.059
Difficulty	30	20.9	
No difficulty	70	79.1	
Do not drive in this situation due to vision	11.5	12.9	
Do not drive in this situation for other reasons	88.5	87.1	
22. Driving in high traffic			0.047*
Difficulty	55.7	44.8	
No difficulty	44.3	55.2	
Do not drive in this situation due to vision	8.3	13.9	
Do not drive in this situation for other reasons	91.7	86.1	
23. Driving in rush hour			0.003*
Difficulty	61.8	54.1	
No difficulty	38.2	45.9	
Do not drive in this situation due to vision	11.1	15.9	
Do not drive in this situation for other reasons	88.9	84.1	
24. Driving at night			0.024*
Difficulty	56.1	58.7	
No difficulty	43.9	41.3	
Do not drive in this situation due to vision	36.7	31.6	
Do not drive in this situation for other reasons	63.3	68.4	

**The driving preference is significantly associated with age at $p < 0.05$*

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4.3.3 The distractions, violations, errors and lapses among drivers

The Driver Behavior Questionnaire (DBQ) outcome in Table 4.5 shows the mean scores for each of the individual items relating to distractions, violations, errors and lapses in the driver behavior questionnaire among drivers in two different age groups. Younger drivers scored higher for distractions items (*M* = 3.88) followed by ageing drivers (*M* = 3.17). Ageing drivers were usually distracted by chatting and interactions with passengers and children in the vehicle. There was a statistically significant difference when compared to the other age group (*p* = 0.000). The lowest score was from the ageing group (*M* = 1.43) stating that they never reported or were rarely dressing up, wearing makeup, combing hair and wearing glasses while driving.

For the violation's items, *pulling out of a junction so far that the driver with the right of way has to stop and let them out* was the most frequent violations among young drivers (*M* = 4.01) and ageing drivers (*M* = 4.31). However, both young and ageing drivers often obeyed the speed limit in a residential area road and usually kept their distance from the leading vehicle. Failure to notice that pedestrians were crossing was the most frequent error among young (*M* = 2.12) and ageing (*M* = 1.86) drivers. Also, a common error in young and older drivers was *nearly hit the car in front of you when turning into the main road* (*M* = 1.74). There were statistically significant differences in error items reported between young and older drivers such as *when checking the rear-view mirror* and *nearly hit a cyclist who has come up from opposite*. Meanwhile for lapses items, most of the items had a statistically significant difference in results between young and ageing drivers. Among the lapses, *attempt to drive away from the traffic lights in third gear* was the most frequent lapse among young (*M* = 2.79) and ageing (*M* = 1.96) drivers. Also *pressing the brake pedal on a regular basis because of concerned over the rate of up to hit the vehicle in front* was the common lapse among both young (*M* = 2.51) and ageing (*M* = 2.23) drivers.

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Table 4.5: Summary of means and standard deviations of DBQ items

Driving Habits Questionnaire Item	Younger		Ageing		p-
	Mean	SD	Mean	SD	
Distractions					
I chat and interact with passengers and children are in the vehicle.	3.88	1.08	3.17	1.08	0.000*
I dress up, wear makeup, combing hair and glasses while driving.	1.75	1.11	1.43	1.08	0.089
I receive phone calls while driving by:					
Hold using my hands.	2.26	1.56	2.03	1.18	0.000*
Use hands free.	3.03	1.49	1.64	1.21	0.005*
Using loudspeaker in mobile phone.	1.80	1.13	2.29	1.49	0.001*
Violations					
Pull out of a junction so far that the driver with right of way has to stop and let you out.	4.01	1.03	4.31	1.18	0.125
Errors					
Check your rear-view mirror before pulling out, changing lanes, etc.	4.38	0.86	4.53	0.92	0.022*
On turning right nearly hit a cyclist who has come up from opposite side.	1.74	0.92	1.31	0.74	0.004*
On turning left nearly hit a cyclist who has come up from the same side.	1.81	0.97	1.44	0.76	0.022*
Queuing to turn right onto a main road, you pay such close attention to the main stream of traffic that you nearly hit the car in front of you.	1.74	1.01	1.74	1.11	0.837
Underestimate the speed of an oncoming vehicle when overtaking.	1.58	0.88	1.26	0.66	0.020*
Lapses					
Realize that you have no clear recollection of the road along which you have just been travelling.	2.10	1.21	1.65	0.90	0.014*
Switch one thing, such as the headlights, when you meant to switch on something else, such as the wipers.	2.12	0.93	1.73	0.86	0.023*
Press the brake pedal on a regular basis because concerned over the rate of up to hit the vehicle in front.	2.51	1.18	2.23	1.18	0.171
Intending to drive to destination A, you "wake up" to find yourself on the road to destination B.	2.13	1.05	1.65	0.81	0.003*
Hit something when reversing that you had not previously seen.	2.05	1.09	1.71	0.82	0.017*
Get into the wrong lane approaching a roundabout or a junction.	2.22	0.99	1.76	0.77	0.003*
Misread the signs and exit from a roundabout on the wrong road.	2.29	1.06	1.95	0.80	0.039*
Attempt to drive away from the traffic lights in third gear.	2.79	1.22	1.96	0.99	0.000*

* *Statistically significant difference at the 0.05 level (2-tailed).*

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4.3.4 Significant outcome of the survey on drivers

The result from the survey on drivers provided an insight into the current driving trends among the ageing drivers. Based on the drivers' characteristics, the most frequent type of vehicle used was a sedan car and about 60% of the ageing drivers had experienced accidents previously. It was also found that driving experience had a significant correlation with accident involvement. Majority of the ageing drivers were driving at about the same speed with the general flow of the traffic but had a higher percentage of driving somewhat slower than the traffic flow compared to the younger age group. Most of the ageing drivers rated their driving as good and majority of them has never been advised to limit or stop driving.

The results revealed that age was significantly associated with driving preference during these conditions; rain, right turn in traffic, high traffic, rush hour and night driving. The ageing drivers were found to be usually distracted by chatting and interacting with passengers and children in the vehicle. They also rated that they usually committed violations at junctions. In terms of errors, the most frequent one is failed to notice that pedestrians are crossing during driving. Meanwhile, the most frequent lapse among ageing drivers was when they attempt to drive away from the traffic lights in third gear showing that the off-guard situation happens at the traffic lights. The presented outcome from the survey highlighted the need to design and perform a real-time car driving experiment observing the on-road driving performance adopting the main elements of distractions, violations, errors and lapses during the task. Therefore, these results have been utilized as a reference to design the appropriate experiment to achieve the main objective of the study.

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4.4 Experimental Task Results

The experiment results were reported in four main sections based on the first and second objective of the study which presenting the mental workload and driving performance. Summary of the demographic data including the selected anthropometric dimensions and reaction time (measured at the station) of the ageing participant are summarized in the Table 4.6 and while validating and control participants are in the Appendix F. The young drivers' ages were specified between 25 and 35, while the ageing drivers between 50 and 65 were selected instead of older drivers, in part due to the study focusing on ageing drivers and partly due to driving safety during field operational experiment (Son et al., 2015).

Table 4.6: The mean and standard deviation of the anthropometric dimensions of the ageing participants.

Dimension	Ageing (N=20)			
	Male		Female	
	Mean	SD	Mean	SD
Age (years)	57.60	2.32	58.00	3.16
Driving experience (years)	34.40	4.77	24.80	8.90
Average mileage per year (km/year)	42452.50	34333.78	2925.00	2018.11
Weight (kg)	73.14	8.47	64.35	9.49
Stature (cm)	165.09	6.49	151.50	9.32
Hand length (cm)	18.00	1.12	17.84	0.76
Wrist index finger length (cm)	16.71	1.98	16.98	1.04
Index finger length (cm)	6.90	0.97	7.23	0.47
Index finger breadth, proximal (cm)	2.03	0.07	2.43	0.10
Index finger breadth, distal (cm)	1.71	0.11	2.16	0.16
Wrist-thumb tip length (cm)	12.62	0.80	12.03	0.88
Hand breadth (cm)	8.62	0.38	8.12	0.43
Thumb breadth (cm)	2.20	0.11	2.75	0.18
Palm length (cm)	10.43	0.61	10.63	0.61
Hand circumference (cm)	21.76	0.50	18.88	1.03
Thumb circumference (cm)	7.36	0.45	6.56	0.37
Index finger circumference (cm)	7.11	0.31	6.42	0.53
Middle finger circumference (cm)	7.21	0.44	6.48	0.51
Reaction time (sec)	0.72	0.09	0.76	0.05

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4.4.1 Subjective driving mental workload based on driving task-related factors

Results of the subjective ratings of ageing drivers on workload measured by NASA-TLX across driving in the simple situation, moderately complex situation and very complex situation are summarized in Table 4.7. NASA-TLX scores ranged from 0, representing no demand, to 100, representing maximum demand. The overall workload score is calculated by multiplying each raw rating by the weight given to that factor by the participant. The sum of the weighted ratings is then divided by 15 (the sum of the weights) to give an absolute workload score (WWL) (Noyes et al., 2007)

4.4.1.1 Influence of situation complexity and gender on subjective ratings

A mixed model repeated measures ANOVA test was conducted to compare scores on the NASA-TLX in different situation complexity. This analysis used a 2 × 3 × 3 repeated measures ANOVA (two levels; male vs. female) as between subject's factor and Situation Complexity (three levels; simple situation, moderately complex situation and very complex situation). Prior to data analysis, all variables were subjected to a normality test and the results revealed that all research variables were distributed normally. The results of homogeneity tests of variances were analyzed and these results indicated the variances among the groups were homogenous. The mean and standard deviation are presented in Table 4.7 and Figure 4.4. The mean PD score obtained was the highest compared to others in rural and city driving for the ageing drivers. Additionally. the results also indicated that the physical demand more than doubles as the driving situation shifted from a simple situation to moderately complex and very complex situations. Furthermore, the overall weighted workload (WWL) exhibited the highest score on city roads, followed by rural roads.

Table 4.7: Descriptive Statistics for NASA-TLX scales for simple situation, moderately complex situation and very complex situation

Scale	N	SS		MCS		VCS	
		Mean	SD	Mean	SD	Mean	SD
MD	20	19.64	13.19	28.69	18.11	38.50	22.60
PD	20	15.39	5.86	37.25	26.33	43.50	21.51
TD	20	18.47	11.42	31.39	20.05	35.59	13.40
OP	20	12.71	4.70	17.02	9.80	17.48	9.05
EF	20	14.00	5.53	31.09	22.24	39.25	25.66
FR	20	10.94	10.31	18.13	12.95	14.52	8.98
WWL	20	17.66	10.54	34.18	23.33	39.42	20.27

MD: Mental Demand, PD: Physical Demand, TD: Temporal Demand, OP: Own Performance, EF: Effort, FR: Frustration, WWL: Weighted Workload

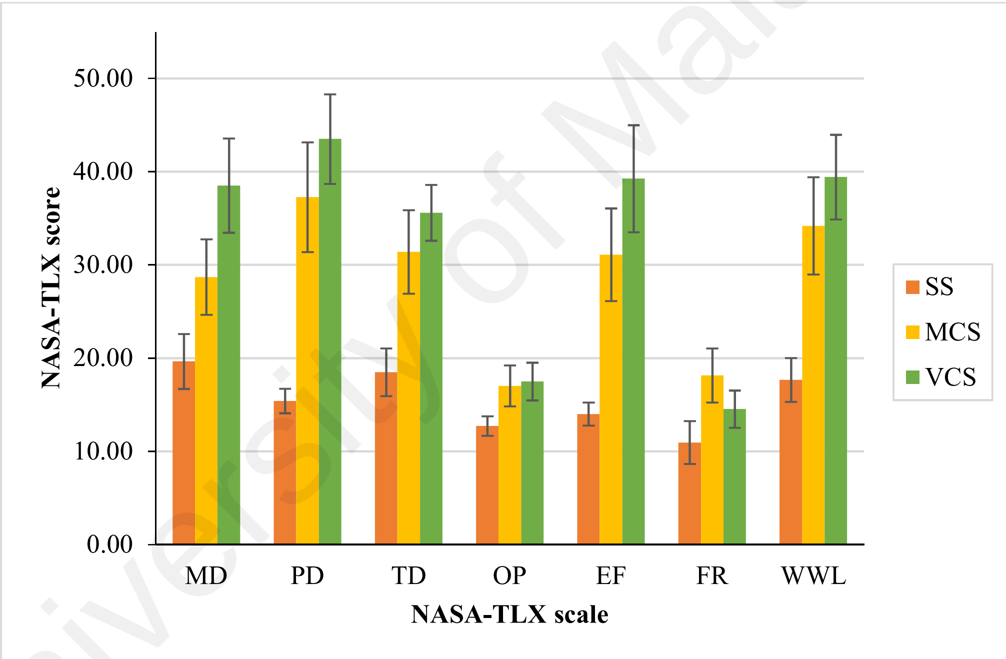

Figure 4.4: Classification of NASA-TLX mean scores of ageing drivers between situation complexity

The results of the repeated measures ANOVA test are presented in Table 4.8. The repeated measures ANOVA test revealed a significant main effect of situation complexity on all ageing drivers' subjective workload. The result showed that there was a significant effect of driving situation complexity in the ageing drivers' subjective workload ratings.

Table 4.8: Repeated measures ANOVA presents a significant main effect of situation complexity and gender on all ageing drivers' subjective workload

Scale	Factor (s)	df	F	p value	η2
MD	Situation Complexity	2.00	11.08	p < 0.001**	0.381
	Gender	1.00	0.09	0.763	0.005
	Situation Complexity * Gender	2.00	2.66	0.084	0.129
PD	Situation Complexity	2.00	18.83	p < 0.001**	0.511
	Gender	1.00	0.67	0.424	0.036
	Situation Complexity * Gender	2.00	0.36	0.703	0.019
TD	Situation Complexity	1.44	8.94	0.003**	0.332
	Gender	1.00	0.76	0.394	0.041
	Situation Complexity * Gender	1.44	2.22	0.140	0.110
OP	Situation Complexity	2.00	2.88	0.069	0.138
	Gender	1.00	4.06	0.059	0.184
	Situation Complexity * Gender	2.00	0.23	0.793	0.013
EF	Situation Complexity	2.00	13.89	p < 0.001**	0.436
	Gender	1.00	0.02	0.902	0.001
	Situation Complexity * Gender	2.00	0.13	0.881	0.007
FR	Situation Complexity	1.36	3.47	0.063	0.162
	Gender	1.00	4.36	0.051	0.195
	Situation Complexity * Gender	1.36	0.37	0.615	0.020
WWL	Situation Complexity	2.00	14.66	p < 0.001**	0.449
	Gender	1.00	0.32	0.579	0.017
	Situation Complexity * Gender	2.00	1.20	0.313	0.062

**Significant at p < 0.05*
***Significant at p < 0.01*
MD: Mental Demand, PD: Physical Demand, TD: Temporal Demand, OP: Own Performance, EF: Effort, FR: Frustration, WWL: Weighted Workload

Post hoc test (Bonferroni) was used for all the scales to compare the mean score of the scales, and the results revealed a statistically significant difference for mean mental demand between the simple situation and moderately complex situation ($p = 0.023$) and very complex situation ($p = 0.001$). Meanwhile, the results indicated that the mean physical demand in the simple situation was significantly different from the moderately complex situation ($p = 0.004$) and very complex situation ($p < 0.001$). In addition, the post-hoc test indicated that the mean temporal demand in the simple situation was significantly different from the moderately complex situation ($p = 0.009$) and very complex situation ($p < 0.001$) indicating that temporal demand was also different when comparing highways with rural and city routes. The effort also was different in comparing

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between highway, rural and city driving where a post-hoc comparisons test indicated that the mean effort in simple situation was significantly different from the moderately complex situation (p = 0.003) and very complex situation ($p < 0.001$). Furthermore, for overall weighted workload, the post-hoc comparisons using the Bonferroni test indicated that the mean weighted workload in simple situation was significantly different from the moderately complex situation (p = 0.006) and very complex situation ($p < 0.001$). On the other hand, it was found that there is no significant gender factor in its interaction with situation complexity on the NASA-TLX scales. The results show no statistically significant difference between male and female drivers' ratings.

4.4.1.2 Comparison of weighted workload of NASA-TLX between age groups

An independent samples *t*-test was conducted to compare overall weighted workload ratings in ageing drivers and the control group in each situation complexity and the result is tabulated in Table 4.9. It is evident that there is a statistically significant difference in the scores for ageing drivers weighted workload (M = 17.66, SD = 10.54) and the control group weighted workload (M = 32.15, SD = 16.28); t (28) = -2.953, p = 0.006 in the simple situation. This shows that there is a significant different between overall weighted workload in highway between ageing and young driver. There is no significant difference found on the moderately complex situation and very complex situation.

Table 4.9: Independent sample *t*-test result comparing between ageing drivers and control group

Situation Complexity	Scale	Ageing		Control		t-value	p- value
		Mean	SD	Mean	SD		
SS	WWL	17.66	10.54	32.15	16.28	-2.953	0.006**
MCS		34.18	23.33	43.57	19.80	-1.089	0.285
VCS		39.42	20.27	53.38	14.14	-1.946	0.062

**Significant at p < 0.05*
***Significant at p < 0.01*
WWL: Weighted Workload

4.4.1.3 Correlation between NASA-TLX Scale and personal characteristics

A correlation analysis was performed for all NASA-TLX scales in each driving situation complexity with personal characteristics and the results are summarized in Table 4.10. In very complex situation, there was a negative correlation between age with temporal demand (r = -0.588, p = 0.006). This result reveals that as age increases, the amount of pressure felt due to the rate of task elements occurrence decreases. On the other hand, mental demand is related to reaction time (at the station), r = 0.462, p = 0.040. The result reveals that as reaction time increases, mental demand (in the very complex situation) increases as well.

Table 4.10: Correlation between NASA-TLX Scale and Ageing Drivers' Personal Characteristics

Situation Complexity	Scale(s)	Age	Experience	Reaction Time	Average Mileage per Year
SS	MD	-0.006	0.24	0.221	0.036
	PD	0.019	0.194	0.105	-0.034
	TD	-0.174	0.333	0.000	0.042
	OP	-0.303	0.279	0.081	0.326
	EF	0.004	0.287	0.308	0.078
	FR	-0.057	0.081	0.068	0.262
	WWL	-0.002	0.219	0.254	0.063
MCS	MD	0.282	0.073	0.29	-0.141
	PD	0.191	-0.017	0.348	-0.16
	TD	0.119	0.056	0.206	-0.14
	OP	0.156	0.106	0.102	0.017
	EF	0.078	0.187	0.248	-0.172
	FR	0.128	0.300	0.087	0.068
	WWL	0.215	0.012	0.385	-0.133
VCS	MD	-0.009	-0.081	0.462*	-0.299
	PD	-0.072	0.179	0.104	-0.015
	TD	-0.588**	-0.162	-0.124	-0.121
	OP	-0.112	0.130	-0.316	0.261
	EF	-0.120	-0.018	0.360	-0.154
	FR	0.083	-0.070	0.360	0.216
	WWL	-0.173	-0.026	0.377	-0.149

**. Correlation is significant at the 0.05 level (2-tailed).*
***. Correlation is significant at the 0.01 level (2-tailed).*
MD: Mental Demand, PD: Physical Demand, TD: Temporal Demand, OP: Own Performance, EF: Effort, FR: Frustration, WWL: Weighted Workload

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4.4.2 Objective driving mental workload based on driving task-related factors

The EEG band power ratio was calculated in the three major EEG bands: theta (4–8 Hz), alpha (8–12 Hz) and beta (12–30 Hz). These frequencies were chosen as they can reflect sleepiness (theta), drowsiness and relaxation (alpha) and active (beta) condition which are important elements in mental workload variations monitoring. The average power in these bands was obtained over three main channel location F_ZP_Z, O_1O_2 and P_3P_4. Average time taken to complete each task was approximately 10 minutes for each participant. Only purely driving state EEG recording were used for analysis, thus data was analyzed for 9 minutes of driving in the 20 ageing driver participants who completed the driving task.

4.4.2.1 Influence of situation complexity, time on task (ToT) and gender on EEG fluctuations

The results of the 2×3×3 repeated measure ANOVA with gender (male vs female) as between subject factor and with situation complexity (three levels; simple situation, moderately complex situation and very complex situation) and time on task (ToT) (S1 to S3) as within subject factors for EEG frequency bands of ageing drivers are reported in Table 4.11 to Table 4.13. Prior to data analysis, all variables were subjected to a normality test and the results revealed that all research variables were distributed normally. The results of homogeneity tests of variance were analyzed and most of the results indicated the variances among groups were homogenous. However, there was at some small part of the result and sphericity was not met, therefore a Greenhouse-Geisser correction was used to evaluate the difference on within subject effect.

For RPθ of channel F_ZP_Z, there was a significant effect of the situation complexity ($p < 0.001$). Post-hoc comparisons using the Bonferroni test indicated that the mean RPθ for the very complex situation (M = 16.21, SE = 0.89) was significantly different from the simple situation (M = 19.63, SE =0.98), p = 0.012 and from the moderately complex

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situation (M = 19.73, SE =1.05), p = 0.002. It was also found that overall, there was a statistically significant difference between male (M = 24.24, SE =1.16) and female (M = 12.81, SE = 1.16), $p < 0.001$.

For the RPθ of channel O_1O_2, there was a significant effect of the interaction between ToT and gender (p = 0.013). Post-hoc comparisons using the Bonferroni test indicated that in ToT S1, the mean RPθ for the male (M = 19.91, SE = 1.32) was significantly different from the female (M = 11.43, SE = 1.32), $p < 0.001$. Meanwhile in ToT S2, the mean RPθ for the male (M = 19.11, SE = 1.44) was significantly different from the female (M = 12.59, SD = 1.44), p = 0.005. Next, in ToT S3, the mean RPθ for the male (M = 18.56, SE = 1.40) was significantly different from the female (M = 12.84, SE = 1.40), p = 0.010. It was also found that, overall, there was a statistically significant difference between male (M = 19.19, SE = 1.35) and female (M = 12.29, SE = 1.65), p = 0.002. For the RPθ of channel P3P4, there was an overall significant effect of gender on the RPθ band ($p < 0.001$), which post-hoc comparisons using the Bonferroni test indicated that male (M = 20.82, SE = 1.23) was significantly different from female (M = 8.89, SE = 1.23).

Table 4.11: Electroencephalography RPθ results of ageing male vs. female drivers using 2 x 3 x 3 repeated measure ANOVA.

Channel location	Factor (s)	df	F	p-value	η2
F_ZP_Z	Situation Complexity	2.00	9.73	p<0.001**	0.351
	Situation Complexity * Gender	2.00	2.23	0.122	0.110
	Tot	1.45	1.20	0.305	0.062
	Tot * Gender	1.45	2.62	0.106	0.127
	Situation Complexity * Tot	2.63	2.27	0.100	0.112
	Situation Complexity * Tot * Gender	2.63	0.71	0.534	0.038
	Gender	1.00	48.53	p<0.001**	0.729
O_1O_2	Situation Complexity	1.50	3.41	0.060	0.159
	Situation Complexity * Gender	1.50	2.81	0.091	0.135
	Tot	1.50	0.11	0.841	0.006
	Tot * Gender	1.50	5.86	0.013*	0.246
	Situation Complexity * Tot	4.00	1.74	0.150	0.088
	Situation Complexity * Tot * Gender	4.00	1.35	0.261	0.070
	Gender	1.00	13.14	0.002**	0.422

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P_3P_4	Situation Complexity	2.00	0.38	0.687	0.021
	Situation Complexity * Gender	2.00	0.83	0.446	0.044
	Tot	2.00	3.19	0.053	0.151
	Tot * Gender	2.00	2.61	0.087	0.127
	Situation Complexity * Tot	2.58	0.77	0.500	0.041
	Situation Complexity * Tot * Gender	2.58	1.23	0.309	0.064
	Gender	1.00	46.80	p<0.001**	0.722

**. Significant at the 0.05 level (2-tailed).*
***. Significant at the 0.01 level (2-tailed).*

For the RPα of channel F_ZP_Z, there was a significant effect of the interaction between situation complexity and gender (p = 0.034). Post-hoc comparisons using the Bonferroni test indicated that for females, the RPα for the simple situation (M = 9.81, SE = 1.35) was significantly different from the very complex situation (M = 6.22, SE = 1.40), p = 0.032. It was also found that there was a significant effect of interaction between situation complexity and ToT (p = 0.013). Post-hoc comparisons using the Bonferroni test indicated that for ToT S1, the RPα for the moderately complex situation (M = 11.65, SE = 0.79) was significantly different from the very complex situation (M = 9.62, SE = 0.79), p = 0.005. Meanwhile, it was also found that there was overall a statistically significant difference between males (M = 14.28, SE = 1.16) and females (M = 8.13, SE = 1.16), p = 0.001.

For the RPα of channel O_1O_2, there was a significant effect of the situation complexity (p = 0.023). Post-hoc comparisons using the Bonferroni test indicated that the RPα for the moderately complex situation (M = 10.48, SE = 0.89) was significantly different from the very complex situation (M = 8.63, SE = 0.61), p = 0.036. For the RPα band of channel P_3P_4, there was a significant overall effect of gender on the RPα band (p < 0.001). Post-hoc comparisons using the Bonferroni test indicated that the results for males (M = 15.35, SE = 1.32) were significantly different from females (M = 6.40, SE = 1.32).

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Table 4.12: Electroencephalography RPα results of ageing male vs. female drivers using 2 x 3 x 3 repeated measures ANOVA.

Channel location	Factor (s)	df	F	p-value	η2
F_ZP_Z	Situation Complexity	2.00	2.67	0.083	0.129
	Situation Complexity * Gender	2.00	3.71	0.034*	0.171
	Tot	2.00	1.78	0.183	0.090
	Tot * Gender	2.00	2.43	0.103	0.119
	Situation Complexity * Tot	4.00	3.44	0.013*	0.160
	Situation Complexity * Tot * Gender	4.00	0.33	0.860	0.018
	Gender	1.00	14.13	0.001**	0.440
O_1O_2	Situation Complexity	2.00	4.17	0.023*	0.188
	Situation Complexity * Gender	2.00	1.48	0.241	0.076
	Tot	2.00	0.06	0.942	0.003
	Tot * Gender	2.00	1.44	0.250	0.074
	Situation Complexity * Tot	4.00	1.93	0.114	0.097
	Situation Complexity * Tot * Gender	4.00	0.74	0.568	0.039
	Gender	1.00	1.68	0.211	0.085
P_3P_4	Situation Complexity	2.00	1.28	0.289	0.067
	Situation Complexity * Gender	2.00	0.38	0.684	0.021
	Tot	2.00	0.55	0.582	0.030
	Tot * Gender	2.00	0.48	0.620	0.026
	Situation Complexity * Tot	2.60	2.38	0.089	0.117
	Situation Complexity * Tot * Gender	2.60	1.06	0.368	0.056
	Gender	1.00	23.11	$p<0.001$**	0.562

**. Significant at the 0.05 level (2-tailed).*
***. Significant at the 0.01 level (2-tailed).*

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For the RPβ of channel F_ZP_Z, there was a significant effect of the ToT (p = 0.040). Post-hoc comparisons using the Bonferroni test indicated that there was no statistically significant difference in the RPβ among the ToT. For the RPβ of channel O_1O_2, there was a significant effect of the interaction between situation complexity and gender (p = 0.044). Post-hoc comparisons using the Bonferroni test indicated that there were no statistically significant differences between males and females among the situation complexity. For the RPβ of channel P_3P_4, there were no significant effects of any factors tested on the RPβ.

Table 4.13: Electroencephalography RPβ results of ageing male vs. female drivers using 2 x 3 x 3 repeated measures ANOVA.

Channel location	Factor (s)	df	F	p-value	η2
	Situation Complexity	2.00	1.57	0.222	0.080
	Situation Complexity * Gender	2.00	0.79	0.461	0.042
	Tot	2.00	3.54	0.040*	0.164
F_ZP_Z	Tot * Gender	2.00	0.07	0.930	0.004
	Situation Complexity * Tot	2.55	2.66	0.068	0.129
	Situation Complexity * Tot * Gender	2.55	0.34	0.763	0.019
	Gender	1.00	1.50	0.236	0.077
	Situation Complexity	2.00	0.24	0.786	0.013
	Situation Complexity * Gender	2.00	3.41	0.044*	0.159
	Tot	2.00	2.28	0.117	0.112
O_1O_2	Tot * Gender	2.00	0.63	0.540	0.034
	Situation Complexity * Tot	4.00	1.14	0.344	0.060
	Situation Complexity * Tot * Gender	4.00	0.03	0.998	0.002
	Gender	1.00	0.00	0.949	0.000
	Situation Complexity	2.00	0.59	0.561	0.032
	Situation Complexity * Gender	2.00	0.00	0.996	0.000
	Tot	2.00	0.10	0.904	0.006
P_3P_4	Tot * Gender	2.00	0.07	0.934	0.004
	Situation Complexity * Tot	1.83	2.44	0.107	0.119
	Situation Complexity * Tot * Gender	1.83	1.20	0.312	0.062
	Gender	1.00	0.75	0.398	0.040

**. Significant at the 0.05 level (2-tailed).*
***. Significant at the 0.01 level (2-tailed).*

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4.4.2.2 Comparison of EEG between ageing drivers and control group

An independent samples *t*-test was conducted to compare the mean EEG bands in the ageing drivers group and the control group. The result is presented in Table 4.14 to 4.16. It is evident that there was a statistically significant difference in the RPθ band at channel location P_3P_4 of the ageing drivers (M = 14.86, SD = 7.03) and the control group (M = 25.19, SD = 11.07); $t(28) = -3.123$, $p = 0.004$ in moderately complex situation. There was no significant found difference in the RPα band at all channel locations ($p>0.05$).

Table 4.14: Electroencephalography RPθ band results of ageing vs. control group drivers

Channel location	Situation complexity	Age group	N	Mean	SD	t value	p value
F_ZP_Z	SS	Ageing	20	19.60	6.82	-0.137	0.892
		Control	10	19.95	6.10		
	MCS	Ageing	20	19.73	6.98	-0.770	0.448
		Control	10	21.81	6.88		
	VCS	Ageing	20	16.21	8.00	-0.307	0.761
		Control	10	17.12	6.88		
O_1O_2	SS	Ageing	20	15.45	5.59	0.344	0.733
		Control	10	14.58	8.09		
	MCS	Ageing	20	17.04	6.28	1.150	0.260
		Control	10	14.28	6.06		
	VCS	Ageing	20	14.68	6.06	0.994	0.329
		Control	10	12.51	4.66		
P_3P_4	SS	Ageing	20	15.23	7.86	-1.665	0.107
		Control	10	20.57	9.12		
	MCS	Ageing	20	14.86	7.03	-3.123	0.004*
		Control	10	25.19	11.07		
	VCS	Ageing	20	14.46	7.67	-2.298	0.029*
		Control	10	21.56	8.58		

**. Significant at the 0.05 level (2-tailed).*
***. Significant at the 0.01 level (2-tailed).*

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Table 4.15: Electroencephalography RPα band results of ageing vs. control group drivers.

Channel location	Situation complexity	Age group	N	Mean	SD	t value	p value
F_ZP_Z	SS	Ageing	20	11.81	4.66	-0.25	0.805
		Control	10	12.23	3.39		
	MCS	Ageing	20	11.50	4.75	-1.688	0.103
		Control	10	14.75	5.41		
	VCS	Ageing	20	10.24	5.98	-0.727	0.473
		Control	10	11.83	4.90		
O_1O_2	SS	Ageing	20	9.45	3.95	-0.387	0.705
		Control	10	10.28	6.13		
	MCS	Ageing	20	10.47	3.89	-0.234	-0.234
		Control	10	10.98	6.31		
	VCS	Ageing	20	8.60	3.05	-1.508	0.143
		Control	10	10.92	5.40		
P_3P_4	SS	Ageing	20	11.66	6.94	-1.113	0.275
		Control	10	14.86	8.33		
	MCS	Ageing	20	10.32	6.47	-1.838	0.077
		Control	10	15.41	8.41		
	VCS	Ageing	20	10.60	6.19	-1.499	0.145
		Control	10	14.35	7.01		

**. Significant at the 0.05 level (2-tailed).*
***. Significant at the 0.01 level (2-tailed).*

A statistically significant difference was also found in very complex situation where the RPβ of ageing drivers (*M* = 14.46, *SD* = 7.67) was significantly lower than the control group (*M* = 21.56, *SD* = 8.58); t (28) = -2.298, p = 0.029. Additionally, there was also a statistically significant difference in the RPβ at channel location O_1O_2 in very complex situation where the RPβ band of ageing drivers (*M* = 11.36, *SD* = 5.83) was significantly lower than the control group (*M* = 24.04, *SD* = 12.79); t (28) = -2.984, p = 0.013.

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Table 4.16: Electroencephalography RPβ band results of ageing vs. control group drivers

Channel location	Situation complexity	Age group	N	Mean	SD	t value	p value
F_ZP_Z	SS	Ageing	20	12.26	5.03	-1.175	0.263
		Control	10	16.00	9.42		
	MCS	Ageing	20	13.04	5.81	-0.49	0.628
		Control	10	14.16	5.97		
	VCS	Ageing	20	11.37	6.51	-1.942	0.062
		Control	10	18.62	14.14		
O_1O_2	SS	Ageing	20	12.29	7.49	-1.867	0.087
		Control	10	20.83	13.45		
	MCS	Ageing	20	11.83	5.37	-1.738	0.112
		Control	10	19.82	14.04		
	VCS	Ageing	20	11.36	5.83	-2.984	0.013*
		Control	10	24.04	12.79		
P_3P_4	SS	Ageing	20	18.27	8.01	1.16	0.256
		Control	10	14.70	7.74		
	MCS	Ageing	20	17.20	10.26	0.857	0.399
		Control	10	14.17	6.15		
	VCS	Ageing	20	17.07	8.19	0.019	0.985
		Control	10	17.01	7.67		

**. Significant at the 0.05 level (2-tailed).*
***. Significant at the 0.01 level (2-tailed).*

4.4.2.3 Correlation between EEG signals and personal characteristics

A correlation analysis was performed for all EEG signals at every channel location in each driving situation complexity with personal characteristic and the results are summarized in Table 4.17. For channel location F_ZP_Z, the results for ageing drivers show that there were significant positive correlations between driving experience and RPθ in the simple situation (r = 0.463, p = 0.040), moderately complex situation (r = 0.549, p = 0.012) and very complex situation (r = 0.549, p = 0.012). These results show that as experience increased, the theta also increased as well in channel F_ZP_Z. Meanwhile for channel O_1O_2, there were significant negative correlations between RPβ and age in the simple situation (r = -0.414, p = 0.023), moderately complex situation (r = -0.375, p = 0.041) and very complex situation (r = -0.579, p = 0.001). These results show that as age increased, the beta decreased in channel reflecting visualization. On the other hand, there were significant negative correlations between RPβ and experience in the simple situation (r = -0.438, p = 0.015), moderately complex situation (r = -0.473, p = 0.008) and very complex situation (r = -0.561, p = 0.001). These results show that as experience increased, the beta decreased.

In the meantime, there were significant positive correlations between theta and experience in the moderately complex situation (r = 0.407, p = 0.026), very complex situation (r = 0.408, p = 0.025). These results show that as experience increased, the theta also increased as well. In addition, there were significant positive correlations between RPθ and average mileage per year in very complex situation (r = 0.439, p = 0.017) showing that as the average mileage per year increased, the theta also increased as well. For channel location P_3P_4, the results for ageing drivers show that there were significant negative correlations between age and RPθ in the moderately complex situation (r = -0.494, p = 0.006) and very complex situation (r = -0.397, p = 0.030). There were also significant negative correlations found between RT and theta bands in the simple situation (r = -0.458, p = 0.011). This result shows that as age increased, there was a decrease in RPθ which means that older participants were experiencing less sleepiness compared to younger ones. In addition, it shows that as reaction time increased, RPθ was decreased as well which shows that those with slower reaction (at the station) had experienced less sleepiness during the driving task. In contrast, there were significant positive correlations between RPβ and reaction times in the simple situation (r = 0.415, p = 0.022) and average mileage per year in the moderately complex situation (r = 0.384, p = 0.040).

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Table 4.17: Correlation between EEG signals and Ageing Drivers' Personal Characteristics

Channel location	Situation complexity	Frequency	Age	Experience	RT	Average mileage per year
F_ZP_Z	SS	RPθ	0.006	0.463*	-0.064	0.380
		RPα	0.043	0.277	0.102	0.245
		RPβ	0.122	0.065	0.220	0.062
	MCS	RPθ	-0.039	0.549*	-0.215	0.358
		RPα	-0.060	0.423	-0.090	0.381
		RPβ	0.067	0.095	-0.028	0.130
	VCS	RPθ	-0.172	0.549*	-0.286	0.340
		RPα	-0.380	0.399	-0.061	0.202
		RPβ	-0.259	0.272	0.106	0.019
O_1O_2	SS	RPθ	0.024	0.280	0.056	0.231
		RPα	-0.120	-0.047	0.078	0.012
		RPβ	-0.414*	-0.438*	-0.067	-0.073
	MCS	RPθ	0.174	0.407*	0.015	0.320
		RPα	-0.042	-0.033	0.309	0.025
		RPβ	-0.375*	-0.473**	0.137	-0.097
	VCS	RPθ	0.150	0.408*	0.021	0.439*
		RPα	-0.297	-0.221	0.021	0.084
		RPβ	-0.579**	-0.561**	-0.23	-0.133
P_3P_4	SS	RPθ	-0.308	-0.070	-0.131	0.289
		RPα	-0.211	-0.038	0.038	0.212
		RPβ	0.240	0.171	0.415*	0.183
	MCS	RPθ	-0.494**	-0.269	-0.458*	0.166
		RPα	-0.302	-0.179	-0.046	0.275
		RPβ	0.203	0.126	0.278	0.384*
	VCS	RPθ	-0.397*	-0.105	-0.275	0.287
		RPα	-0.287	-0.094	-0.096	0.257
		RPβ	0.035	-0.068	0.298	0.169

**. Significant at the 0.05 level (2-tailed).*
***. Significant at the 0.01 level (2-tailed).*

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4.4.3 Primary-task driving performance measures based on driving task-related factors.

The primary-task driving performance measures involved in this study were the number of traffic violations based on the driving errors as presented in Chapter 3 and the longitudinal motion of the vehicle measures namely the speed and speed variability. The analysis of the results are presented in the next subsections.

4.4.3.1 Number of traffic violations ascribed to driving situation complexity and gender

A driver who commits fewer errors leads to a smaller total number of traffic violations (NTV) thus indicating a better driving performance. The maximum score among the ageing participants was found in very complex situation (5 errors) while the minimum score was 0 errors occurred in each of the situation complexity. The highest mean NTV was in the very complex situation ($M = 2.5$, $SD = 1.32$) and the lowest mean was in the moderately complex situation ($M = 1.55$, $SD = 0.18$) as in Figure 4.5. A mixed model repeated measures ANOVA revealed a significant main effect of situation complexity on NTV ($F(2, 36) = 3.686$, $p = 0.035$, $\eta 2 = 0.170$). A Bonferroni post hoc test showed that there was no statistically significant difference found between the situation complexity. There is no significant effect of gender or its interaction with situation complexity on the NTV ($p > 0.05$).

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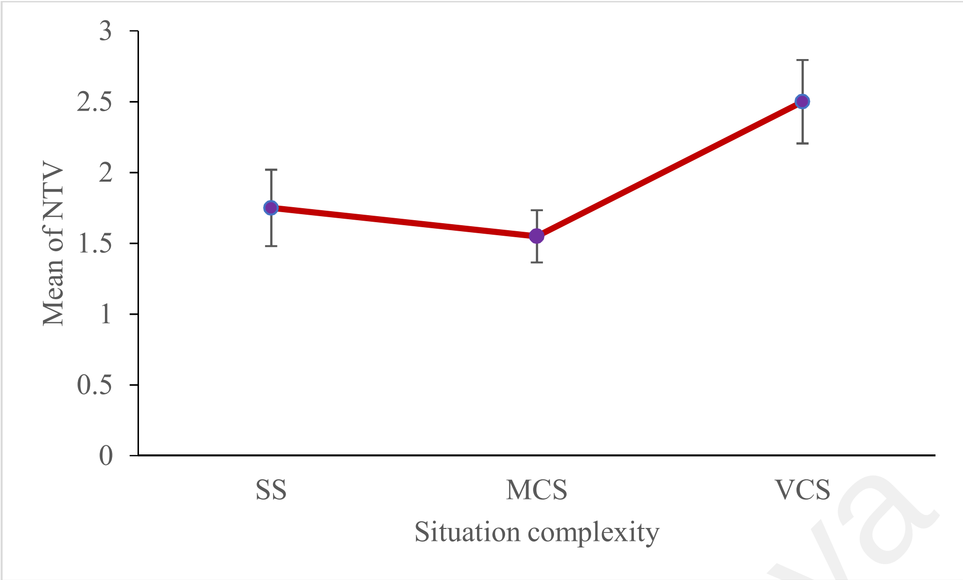

Figure 4.5: The mean number of traffic violations among the ageing drivers.

4.4.3.2 Comparison of number of traffic violations between ageing drivers and control groups

A comparison of the NTV was made between the ageing drivers and the control group using an independent sample *t*-test and the result is presented in Table 4.18. It was found that there is no statistically significant difference in NTV between ageing and control group drivers.

Table 4.18: NTV comparison between ageing drivers and the control group.

	Group	N	Mean	SD	t value	p value
SS	Ageing	20	1.75	1.21	-0.101	0.920
	Control	10	1.80	1.40		
MCS	Ageing	20	1.55	0.83	-0.164	0.871
	Control	10	1.60	0.70		
VCS	Ageing	20	2.50	1.32	0.628	0.535
	Control	10	2.20	1.03		

4.4.3.3 Correlation between number of traffic violations with personal characteristics

A correlation analysis was performed for NTV in each driving situation complexity with personal characteristic and the results are summarized in Table 4.19. In the simple

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situation, there were positive correlations between NTV and experience (r = 0.470, p = 0.002) and average mileage per year (r = 0.500, p = 0.041). These results indicated that as driving experience and average mileage increased, the NTV also increased as well. Meanwhile, there was a negative correlation between reaction time and NTV (r = -0.472, p = 0.020). Interestingly, this indicated that faster reaction times resulted in an increase in the NTV.

Table 4.19: Correlation between NTV and the ageing drivers' personal characteristics

	Age	Exp	RT	Average mileage per year
SS	-0.209	0.470*	-0.472*	0.500*
MCS	0.005	-0.109	-0.020	0.041
VCS	-0.280	0.038	-0.330	-0.262

**. Significant at the 0.05 level (2-tailed).*

4.4.3.4 Correlation between driving errors of number of traffic violations with the Anthropometric Group

The summary of the anthropometric group determined for the ageing drivers is presented in Appendix I. In general, most of the male ageing drivers were in group B for all dimensions which is below than 95th percentile dimension group. On the other hand, the female ageing drivers' dimension were more varies. For the index finger length, most of them were more on the group A which is the 95th percentile dimensions. The other dimensions resulted them to be in group B and C which is their dimension is below than 95th percentile dimension group and above the 5th percentile dimension group respectively. The anthropometric group were then correlated to the ageing drivers' errors related to the signaling during the driving tasks.

A correlation analysis was performed for errors related to signal lever usage that contributed to the number of traffic violations with the anthropometric group and the results are summarized in Table 4.20. There were significant correlations found in the simple situation where error of signaling at junctions were positively correlated to the

Anthropometric Group for index finger length (*r* = 0.547, *p* = 0.013) and middle finger circumference (*r* = 0.547, p = 0.013). These positive relationship shows that as the anthropometric dimension increases, the errors increase as well in the highway task. In addition, it was found that there is no correlation of error of signaling with peripheral detection task reaction time (p > 0.05). The details of the result can be seen in Appendix Q.

Table 4.20: Correlation between NTV and the ageing drivers' Anthropometric group

		Anthropometric Group for Index Finger Length	Anthropometric Group for Thumb Circumference	Anthropometric Group for Index Finger Circumference	Anthropometric Group for Middle Finger Circumference
SS	No turn signal at junctions	-0.372	0.333	0.547*	0.547*
	No turn signal when changing	0.041	0.200	0.328	0.182
MCS	No turn signal at junctions	-0.188	-0.424	-0.404	-0.404
	No turn signal when changing	0.041	-0.067	0.182	0.328
VCS	No turn signal at junctions	0.413	-0.061	-0.271	-0.007
	No turn signal when changing	0.180	0.058	0.336	0.082

**. Significant at the 0.05 level (2-tailed).*

4.4.3.5 Mean speed and speed variability based on driving situation complexity and gender

The mean speed and speed variability were analysed using the repeated measures ANOVA and the results are tabulated in Table 4.21. The results revealed that there is a significant effect of situation complexity on ageing drivers' speed ($p < 0.001$). Post-hoc comparisons using the Bonferroni test indicated that the mean speed in the simple situation (Mean = 77.14, *SE* = 1.39) was significantly different from the moderately complex situation (Mean = 60.13, *SE* = 1.03, $p < 0.001$) and very complex situation (Mean = 62.69, *SE* = 1.37, $p < 0.001$). In addition, significant effects of interaction between

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situation complexity and gender were found on ageing drivers' speed ($p < 0.001$). Post-hoc comparisons using the Bonferroni test indicated that the mean speed of male drivers in the simple situation (Mean = 82.77, *SE* = 1.97) was significantly different from the moderately complex situation (Mean = 54.45, *SE* = 1.46, $p < 0.001$) and very complex situation (Mean = 56.53, *SE* = 1.94, $p < 0.001$). Overall, a significant main effect of gender was found on the speed ($p = 0.007$). Post-hoc comparisons using the Bonferroni test indicated that the mean speed of male drivers (Mean = 64.58, *SE* = 0.96) was significantly different from the female drivers (Mean = 68.72, *SE* = 0.96, $p = 0.007$).

It was found that situation complexity had a significant main effect on ageing drivers' speed variability ($p = 0.004$). Post-hoc comparisons using the Bonferroni test indicated that the mean speed variability in the moderately complex situation (Mean = 6.20, *SE* = 0.52) was significantly different from the simple situation (Mean = 8.00, *SE* = 0.46, $p = 0.025$) and very complex situation (Mean = 8.81, *SE* = 0.69, $p = 0.007$). In addition, significant effects of interaction between situation complexity and gender were found on ageing drivers' speed variability ($p = 0.012$). Post-hoc comparisons using the Bonferroni test indicated that the mean speed variability of male drivers in the moderately complex situation (Mean = 7.41, *SE* = 0.74) was significantly different from the very complex situation (Mean = 11.72, *SE* = 0.98, $p < 0.001$).

Meanwhile, the mean speed variability of female drivers in the simple situation (Mean = 7.37, *SE* = 0.65) was significantly different from the moderately complex situation (Mean = 5.00, *SE* = 0.74, $p = 0.038$). Overall, a significant main effect of gender was found on the speed ($p = 0.007$). Post-hoc comparisons using the Bonferroni test indicated that the mean speed variability of male drivers (Mean = 9.25, *SE* = 0.52) was significantly different from the female drivers (Mean = 6.09, *SE* = 0.82, $p < 0.001$).

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Table 4.21: Result of repeated measures ANOVA on mean speed and speed variability of ageing drivers in different situation complexity

		df	F	p value	η2
Speed	Situation Complexity	2.00	47.97	p<0.001**	0.727
	Situation Complexity * Gender	2.00	25.39	p<0.001**	0.585
	Gender	1.00	9.34	0.007**	0.342
Speed Variability	Situation Complexity	2.00	6.38	0.004**	0.262
	Situation Complexity * Gender	2.00	5.00	0.012*	0.217
	Gender	1.00	18.56	p<0.001**	0.508

**. Significant at the 0.05 level (2-tailed).*
***. Significant at the 0.01 level (2-tailed).*

4.4.3.6 Comparison of mean speed and speed variability between the ageing drivers and the control group

For A comparison of the mean speed and speed variability was made between the ageing drivers and the control group using an independent sample *t*-test and the result is presented in Table 4.22. It was found that there was no statistically significant difference in the speed and speed variability between ageing drivers and the control group.

Table 4.22: Comparison between ageing drivers and the control group on speed and speed variability in the simple situation, moderately complex situation and very complex situation

Variables	Situation complexity	Group	N	Mean	SD	t value	p value
Speed	SS	Ageing	20	77.14	8.38	-0.229	0.821
		Control	10	77.86	7.48		
	MCS	Ageing	20	60.13	7.35	-0.605	0.550
		Control	10	61.74	5.67		
	VCS	Ageing	20	62.69	8.69	-1.153	0.259
		Control	10	66.36	7.09		
Speed variability	SS	Ageing	20	8.00	2.09	-2.022	0.053
		Control	10	10.09	3.60		
	MCS	Ageing	20	6.20	2.59	-1.071	0.293
		Control	10	7.26	2.44		
	VCS	Ageing	20	8.81	4.23	-0.237	0.814
		Control	10	9.18	3.50		

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4.4.3.7 Correlation between mean speed and speed variability with personal characteristics

A correlation analysis was performed for speed and speed variability in each driving situation complexity with personal characteristics and the results are summarized in Table 4.23. A significant correlation was found where the results for ageing drivers show significant positive correlations between experience and speed variability in the very complex situation ($r = 0.522, p = 0.018$). These results revealed that as driving experience increases, the speed variability increases as well.

Table 4.23: Correlation between mean speed and speed variability with personal characteristics

		Age	Experience	RT	Average mileage per year
Speed	SS	-0.151	0.371	-0.189	-0.400
	MCS	-0.173	-0.396	0.251	0.181
	VCS	-0.087	-0.304	0.230	-0.126
Speed variability	SS	0.194	0.404	-0.172	-0.210
	MCS	-0.057	0.361	-0.141	-0.245
	VCS	-0.272	0.522*	0.201	-0.205

**. Significant at the 0.05 level (2-tailed).*

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4.4.4 Secondary-task driving performance measures of ageing drivers based on driving task-related factors

The secondary-task driving performance measures were analyzed and presented in the next subsection. In this study, the reaction time of the peripheral detection task measure was to identify the reaction time by the visual stimuli and adopt the reaction time as part of the overall driving performance elements for each situation complexity.

4.4.4.1 The reaction time of the peripheral detection task ascribed to driving situation complexity and gender

The peripheral detection task (PDT) was the secondary-task driving performance measure that was assessed to determine variations in mental workload in this study. The mean PDT reaction time of the ageing drivers is presented in Figure 4.6. A repeated measures ANOVA revealed no significant main effect of situation complexity on RT ($p = 0.729$) as in Table 4.24. However, a significant main effect of interaction between situation complexity and gender was found on the RT ($p = 0.026$). Post-hoc comparisons using the Bonferroni test indicated that for the very complex situation, the RT for the male ($M = 1.19$, $SE = 0.06$) had a marginally statistically significant difference with the female ($M = 1.01$, $SE = 0.06$), $p = 0.057$. Meanwhile, it was also found that overall, there was no statistically significant difference between males and females ($p > 0.001$).

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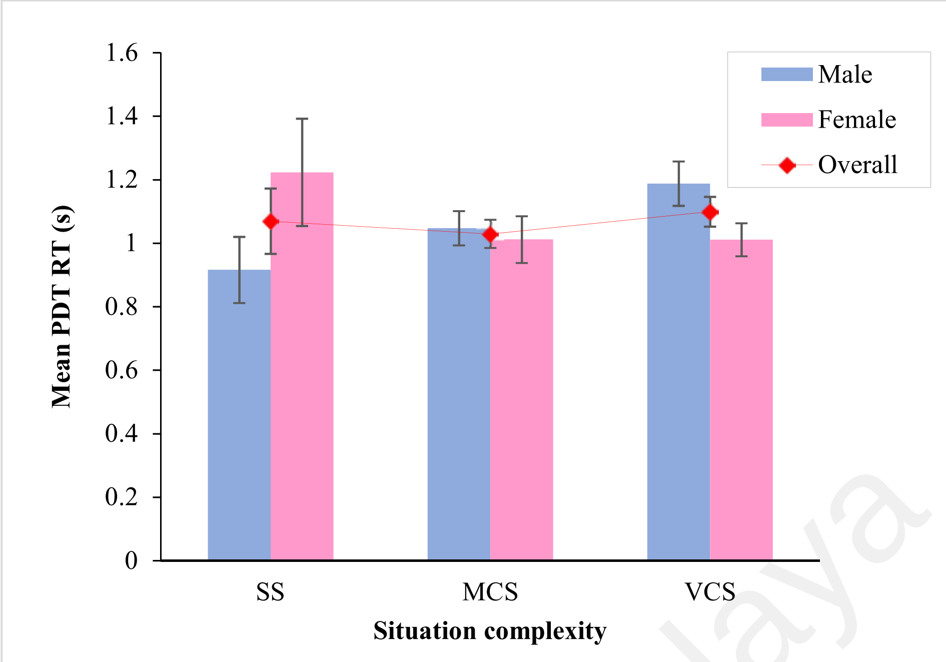

Figure 4.6: The mean reaction time of the peripheral detection task of the ageing drivers.

Table 4.24: Result of repeated measures ANOVA on mean reaction time of the peripheral detection task of ageing drivers in different situation complexity

Variables	df	F	p value	η2
Situation Complexity	2.00	0.319	0.729	0.017
Situation Complexity * Gender	2.00	4.032	0.026*	0.183
Gender	1.00	0.123	0.730	0.007

**. Significant at the 0.05 level (2-tailed).*

4.4.4.2 Comparison of the reaction time of the peripheral detection task between ageing drivers and the control group

A comparison of the mean reaction time of the peripheral detection was made between ageing drivers and the control group using an independent sample *t*-test and the result is presented in Table 4.25. It was found that there were no statistically significant differences of RT between ageing drivers and the control group in all driving situations.

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Table 4.25: Comparison between ageing drivers and the control group on reaction time in the simple situation, moderately complex situation and very complex situation

Situation Complexity	Age Group	N	Mean	SD	t value	p value
SS	Ageing	20	1.07	0.46	0.528	0.602
	Control	10	0.98	0.29		
MCS	Ageing	20	1.03	0.20	-0.156	0.877
	Control	10	1.05	0.37		
VCS	Ageing	20	1.10	0.21	0.853	0.401
	Control	10	1.01	0.40		

4.4.4.3 Correlation between mean reaction time of the peripheral detection task with personal characteristics

A correlation analysis was performed for the reaction time of the peripheral detection task in each driving situation complexity with personal characteristics and the results are summarized in Table 4.26. There was a significant correlation found in the simple situation where reaction time at the station was significantly correlated to the reaction time of the peripheral detection task during the driving task (r = 0.403, p = 0.027). The positive correlation revealed that as the reaction time at the station increased, the reaction time during the driving task also increased in the simple situation. Additionally, it was found that there is no correlation of Body mass index (BMI) with peripheral detection task reaction time ($p > 0.05$). The details of the result can be seen in Appendix Q.

Table 4.26: Correlation between the reaction time of the peripheral detection task with personal characteristics

Situation Complexity	Age	Experience	RT	Average mileage per year
SS	0.126	-0.003	0.403*	0.040
MCS	-0.025	-0.196	0.086	0.001
VCS	0.179	0.244	0.110	0.160

**. Significant at the 0.05 level (2-tailed).*

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4.5 Overall driving performance score (ODPS) based on driving task-related factors.

Driving performance is represented by the mean values of the primary task and secondary tasks of each participants. To observe how overall driving performance score (ODPS) changes with situation, individual driving performance measures were combined by linear rating and weighted combination. A mixed model repeated measures ANOVA was conducted to compare scores on the ODPS with the situation complexity (i.e.: simple situation, moderately complex situation and very complex situation) and the result is presented in Table 4.28 and Figure 4.7.

Table 4.27: Result of repeated measures ANOVA on ODPS of ageing drivers in different situation complexity

	df	F	p value	η2
Situation Complexity	2.00	3.168	0.054	0.15
Situation Complexity * Gender	2.00	1.326	0.278	0.069
Gender	1.00	7.436	0.014*	0.292

**. Significant at the 0.05 level (2-tailed).*

It was found that there was a marginally significant effect of situation complexity on the ODPS ($p = 0.054$). There was no significant effect found in the interaction between situation complexity and gender ($p < 0.001$). However, it was found that overall, there was a significant main effect of gender on the ODPS. Post-hoc comparisons using the Bonferroni test indicated that there was a statistically significant difference between the ODPS of males ($M = 0.47$, $SE = 0.029$) and females ($M = 0.58$, $SE = 0.029$), $p = 0.014$.

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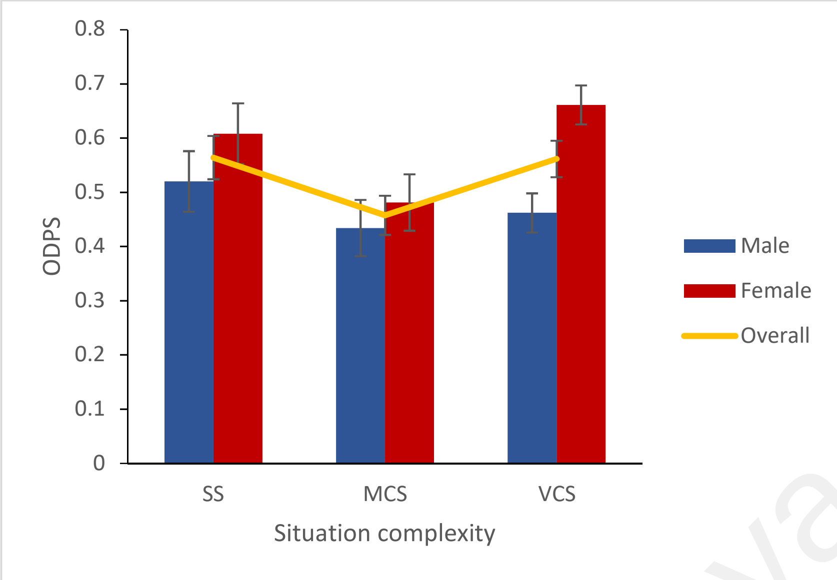

Figure 4.7: The ageing drivers ODPS comparison along different driving situation complexity.

4.5.1 Comparison of ODPS between ageing drivers and the control group

A comparison of the mean ODPS was made between ageing drivers and the control group using an independent sample *t*-test and the result is presented in Table 4.29. It was found that there were no statistically significant differences of RT between ageing drivers and the control group in all driving situations.

Table 4.28. Comparison of ageing drivers and control group on ODPS in simple situation, moderately complex situation and very complex situation

Situation Complexity	Age Group	N	Mean	SD	t value	p value
SS	Ageing	20	0.56	0.18	0.607	0.549
	Control	10	0.52	0.20		
MCS	Ageing	20	0.46	0.16	-0.069	0.946
	Control	10	0.46	0.18		
VCS	Ageing	20	0.56	0.15	0.023	0.982
	Control	10	0.56	0.20		

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4.6 Relationship between EEG, NASA-TLX and ODPS at different levels of situation complexity

This section presents the outcome for the third and fourth objective of the study. Three overall driving performance score (ODPS) conceptual models were developed in this study to investigate the variations of mental workload at different levels of situation complexity and their relationships with driving performance. The mental workload investigated in this study were subjective ratings and EEG brain signals.

The models were developed based on the hypothesis that different levels of situation complexity will yield different mental workload, which in turn will influence the ODPS. It was found that driving in different situation complexity lead to different mental workload results, hence the ODPS models were developed separately for the simple situation, moderately complex situation and very complex situation based on the NASA-TLX and EEG relative power bands. The variations of mental workload were further investigated to quantify their relationships with ODPS. Correlation and regression analysis were carried out for this purpose.

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4.6.1 ODPS model for the simple situation

The experimental results of the ageing drivers revealed that there were significant correlations between the ODPS with RPβ ($r = 0.795$, $p < 0.001$) and RPθ ($r = -0.568$, $p = 0.017$) of channel location O_1O_2 and with mental demand (MD) ($r = -0.718$, $p = 0.001$) and effort (EF) ($r = 0.512$, $p = 0.036$) of NASA-TLX score. Strong correlations were found for these factors where R-value is above 0.5 (Pallant, 2013; Cohen, 1988; Guildford, 1973).

Table 4.29: Regression model summary of ODPS for the simple situation

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
ODPS	0.861	0.741	0.671	0.10245

A multiple linear regression was calculated for the ODPS of the simple situation based on their relative power bands of EEG and the NASA-TLX scores. The regression model summary is shown in Table 4.30. The complete results of the linear regression analysis are presented in Appendix S. A significant regression equation was found ($F (4, 15) = 10.706$, $p < 0.001$), with an adjusted R^2 of 0.671. All four variables added statistically significantly to the prediction, $p < 0.05$. The participants' predicted ODPS in the simple situation:

$$Y = 0.550 + 0.018 (X1) - 0.009 (X2) - 0.012 (X3) + 0.011 (X4)$$

where

***Y* = ODPS**

***X1* = RPβ of channel location O_1O_2**

***X2* = Mental demand (MD) score of NASA-TLX**

***X3* = RPθ of channel location O_1O_2**

***X4* = Effort (EF) score of NASA-TLX**

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4.6.2 ODPS model for moderately complex situation

Experimental results of the ageing drivers revealed that there were significant correlations between the ODPS with own performance (OP) (r = -0.801, $p < 0.001$) and temporal demand (TD) (r = 0.720, p = 0.001) of NASA-TLX score and with RPβ (r = -0.500, p = 0.035) of channel location O_1O_2.

Table 4.30: Regression model summary of ODPS for the moderately complex situation

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
ODPS	0.813	0.660	0.597	0.10279

A multiple linear regression was calculated for the ODPS of the moderately complex situation based on their NASA-TLX scores and relative power band of EEG. The regression model summary is shown in Table 4.31. The complete results of the linear regression analysis are presented in Appendix S. A significant regression equation was found (F (3, 16) = 10.365, $p < 0.001$), with an adjusted R^2 of 0.597. All three variables added statistically significantly to the prediction, $p < 0.05$. The participants' predicted ODPS in the moderately complex situation:

Y = 0.676 - 0.018 (X1) + 0.007 (X2) - 0.010 (X3)

where

***Y* = ODPS**

***X1* = Own performance (OP) score of NASA-TLX**

***X2* = Temporal demand (TD) score of NASA-TLX**

***X3* = RPβ of channel location O_1O_2**

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4.6.3 ODPS model for Very Complex Situation

The experimental results of the ageing drivers revealed that there were significant correlations between the RPα of channel location F_ZP_Z (r = -0.794, $p < 0.001$). A multiple linear regression was calculated for the ODPS of the very complex situation based on their relative power band of EEG and the summary is shown in Table 4.32. The complete results of the linear regression analysis are presented in Appendix S.

Table 4.31: Regression model summary of ODPS for the very complex situation

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
ODPS	0.749	0.631	0.610	0.09423

A significant regression model was found (F (1, 18) = 30.767, $p < 0.001$), with an adjusted R^2 of 0.610. Overall, the regression model statistically significantly predicts the ODPS with one significant variable (p <0.05). Thus, the participants' predicted ODPS for the very complex situation:

Y = 0.660 – 0.020 (X1)

where

***Y* = ODPS**

***X1* = RPα of channel location F_ZP_Z**

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4.7 Validation of ODPS models

The developed models were validated with the data from 10 ageing drivers and 10 control group drivers (both equal number of males and females). The Standard Error of Estimate (SEE) was used as an indicator of the average error of the prediction for the regression equation. The SEE for the ODPS of the ageing and control drivers are presented in Table 4.33 and 4.34, respectively. The detailed results are given in the Appendix T.

Based on the result, the SEE of ageing control group was small and close to the value of the main ageing group. If the SEE of prediction is close to SEE of the regression model, then the SEE for the regression model is not seriously biased and gives an appropriate indication of the predictive ability of the model. This outcome validate that the model can be used by other ageing drivers beside the main ageing participants selected for the experiment. Meanwhile, for the younger control group, the SEE result shows larger value of SEE (>0.1). A larger SEE would mean that the population is less likely to be close to the population mean which in this case the main ageing participants group. This indicated that the model cannot be applied to younger group and specifically appropriate for ageing drivers only which fulfilled the scope of the study.

Table 4.32: Standard error of estimates for the ODPS Model of ageing drivers.

Model	Situation complexity	SEE
ODPS	**SS**	0.10678
	MCS	0.10679
	VCS	0.11613

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Table 4.33: Standard error of estimates for the ODPS Model of control drivers.

Model	Situation complexity	SEE
ODPS	**SS**	0.36664
	MCS	0.26623
	VCS	0.26503

4.8 Benchmarking

The experimental results were compared with those from previous studies. To date, there has been no experimental studies which investigated the link between ODPS and mental workload measure (NASA-TLX and EEG relative band ratios) of real-time driving at different levels of situation complexity in Malaysia. Hence, the results were benchmarked against the studies related to driving performance in driving tasks by other researchers and are summarized in Table 4.35. Detail comparison and discussion on the benchmarking is presented in a special section in Chapter 5.

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Table 4.34: Benchmarking with the studies related to driving performance in driving tasks

Variables	Cai & Lin, 2011	Qin et al., 2014	Kappel et al., 2017	Tran et al., 2017	Kim et al., 2019	Fuente et al., 2019	Current study
Task	Driving with dual task	Driving and secondary visual task	Driving	Driving	Driving	Driving and deal with two particular driving events (overtaking and pedestrian occurrence	Driving and responding to PDT
Independent Variable (s)	Tasks for emotion elicitation	Visual Demand	Task occasion	Task complexity	Task complexity	Task event, task complexity	Situation complexity
Dependent Variable (s)	Driving performance (NTV, lane deviation, brake RT) Emotion rating	Driving performance (lateral position, speed, deceleration, steering angle, & breaking times) Visual attention demands (VD) Curvature change rate	Driving maneuver error rates Functional performance Self-reported	Number of errors pupil dilation blink rate heart rate	Engine RPM, vehicle speed, lane changes, and turns.	NASA TLX, skin conductance level, heart & heart rate variability, driving performance (SDLP and response to speed change of the lead vehicle: coherence, delay and gain)	Performance score (NTV, SV and PDT RT). EEG signals NASA-TLX scores
Participants (drivers)	Students	Ageing Young	Elderly	Students	Ageing Young	Young	Ageing Young
Method	Driving simulator	Driving simulator	On-road driving	Driving simulator	On-road driving	Driving simulator	On-road driving
Outcome	ODP	Driving VD	Driving maneuver error rates	Performance (number of errors)	Driving-workload prediction model	Driver's mental workload estimation	ODPS model for SS, MCS and VCS for ageing drivers

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4.9 Significant findings based on the accident data, survey on drivers and the experimental tasks

Results and analysis of the data collected from the accident data, survey on drivers and the experimental tasks have been presented in this chapter. The key findings are summarized as follows. For the accident database observation, male driver had higher tendency to be involved in an accident compared to the female. In terms of the first collision type, *knocking exact flank, slipped* and *collision* were the most critical for the ageing drivers. Cars recorded the highest number of involvements in fatal accidents compared to other vehicle types. Interestingly, the result from the survey similarly revealed that the most frequent type of vehicle used was a sedan car.

From the survey outcome, about 60% of the ageing and 56% of the younger drivers have been involved in accidents previously. It was also was discovered that driving experience had significant correlation with accident involvement. Most of the ageing drivers still feel have confidence in their driving skills. It was found that ageing drivers had driving difficulty during the rain (72%), rush hour (57%) and at night (59%). Examining the ageing drivers' distractions, chatting and interacting with passengers and children that were in the vehicle was rated the highest compared to others. It was interesting to note that they also admitted to committing violations at junctions. The most frequent error among the ageing drivers is failing to notice pedestrians crossing while the most frequent lapse was being caught off-guard at the traffic lights.

The result of the experimental task reveals that mental workload increases with harder situation complexity. The analysis of the NASA-TLX scores result showed that there was a significant effect of driving situation complexity in the ageing drivers' subjective workload ratings. The mean physical demand score obtained was the highest compared to others in rural and city driving for the ageing drivers. Additionally. the results also indicated that the physical demand more than doubles as the driving situation shifted from

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a simple situation to moderately complex and very complex situations. Furthermore, the overall weighted workload (WWL) exhibited the highest score on city roads, followed by rural roads. The mean WWL score was found to be 76% and 63% higher for moderately complex and very complex situations, respectively, compared to the simple situation.

Likewise, for the EEG signals fluctuation, the result showed that situation complexity had a very significant effect. The main effect was found in RPθ and RPα of channel location F_ZP_Z and O_1O_2. It was found that both frequencies were lower in city compared to rural roads. Meanwhile, the results indicated a significant effect of the interaction between situation complexity and gender. Further analysis indicated that for female drivers, the RPα for the simple situation was significantly higher than for the very complex situation. Examining the effects of time on task (ToT), captivatingly it was found that there was a significant effect of interaction between situation complexity and ToT where in the first three minutes of driving (S1), the RPα for the moderately complex situation was significantly higher than the very complex situation. An analysis of the effect of gender on the EEG bands indicated a significant one in most cases of RPθ and RPα. Regardless of the situation complexity and ToT, frequency bands were higher among male drivers compared to female.

The result obtained from the driving performance measures revealed that there is a significant effect of the situation complexity on the number of traffic violations but no significant different in the mean of the number of traffic violations between the situation complexity. However, the highest number of traffic violations was in the very complex situation indicating that ageing drivers were likely to commit more errors in the city driving task. The result indicated 35% higher mean of the number of traffic violations occur in city driving compared to the simple situation (i.e. highways). It was revealed that there was no statistically significant difference in the errors committed between male and female drivers. Meanwhile, the results revealed that there was a significant main effect of situation complexity on ageing drivers' speed and speed variability. It was found that the mean speed in the simple situation was significantly higher than the moderately complex situation and very complex situation, while the mean speed variability in the moderately complex situation was significantly lower than the simple situation and very complex situation. Examining the effects of gender, it was found that females had 6% higher speed compared to males. It is also interesting to note that the speed variability of male drivers was 41% higher than female drivers regardless of the situation complexity. On the other hand, it was found that there was no statistically significant difference in the reaction time of the peripheral detection task between the different situation complexity. However, the maximum reaction time was in the very complex situation where it was 6% slower than the minimum reaction time obtained in the moderately complex situation.

The results obtained from the correlation analysis revealed that there is a significant correlation between mental workload measures and ODPS. In the simple situation, there were significant correlations between the ODPS with RPβ ($r = 0.795$, $p < 0.001$) and RPθ ($r = -0.568$, $p = 0.017$) of channel location O_1O_2 and with mental demand (MD) ($r = -0.718$, $p = 0.001$) and effort (EF) ($r = 0.512$, $p = 0.036$) of NASA-TLX score. A regression model has been developed based on the relationship to predict the ODPS in the simple situation. Next, in the moderately complex situation, there were significant correlations between the ODPS with own performance (OP) ($r = -0.801$, $p < 0.001$) and temporal demand (TD) ($r = 0.720$, $p = 0.001$) of NASA-TLX score and with RPβ ($r = -0.500$, $p = 0.035$) of channel location O_1O_2. Thus, a regression model that predicts the ODPS in the moderately complex situation was developed based on the associations found. Next, it was found that there were significant correlations between the RPα of channel location F_ZP_Z ($r = -0.794$, $p < 0.001$) in very complex situation. Following this, a simple regression model was developed to predict the ODPS of ageing drivers in very complex situation. All three models have been validated using data obtained from 10 ageing drivers and 10

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drivers of the control group. Finally, a benchmarking was carried out to compare the experimental results with previous studies. Most of the previous research on driving performance were concerned with other driving performance measures but not on the link between ODPS and mental workload measure (NASA-TLX and EEG relative band ratio) of real-time driving.

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CHAPTER 5: DISCUSSION

5.1 Overview

This chapter highlighted the key findings and comparison is made with the result of previous studies, and the implications of the findings are discussed. The main result for the accident database and survey on drivers are discussed in Section 5.2, where significant driving task-related factors and their effects were highlighted from the outcome of the analysis. The results of the significant mental workload measures were based on the different situation complexities, which are discussed in Section 5.3. Meanwhile, the variations of the primary and secondary driving performance measures are discussed in Section 5.4. The ODPS are also discussed thoroughly under the subsection. Next, the relationship between the mental workload (NASA-TLX and EEG relative power bands) and ODPS based on situation complexity are discussed in Section 5.5. Then, the development and validation of the ODPS models are discussed in the subsection. In Section 5.6, the findings of the study are compared with the design and outcome of the experiment from significant previous studies.

5.2 Significant driving task-related factors and their effects on the ageing drivers' driving task.

The accident trends observation and survey on drivers were done to obtain an insight on the ageing drivers' trend and significant factors that can affect their mental workload and performance. The result highlighted that the ageing drivers' accident records were lower in 2014 compared to the previous year. In most previous studies, ageing drivers have had lower risk of accident compared to the younger drivers, but they had a high

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probability of fatality and hospitalization when they are involved in accidents (Cuenen et al., 2015; Ichikawa et al., 2015; Foon et al., 2011; Eby, 2009; Hakamies-Blomqvist, 1994), while drivers aged 85 and older faced the highest risk of their own death (Tefft, 2008).

One of the important factors related to the drivers is the main difference between male and female drivers. Numerous studies have found statistically significant differences in vehicle accident rates between the males and females (Ichikawa et al., 2015; Islam & Mannering, 2006; Massie et al., 1995; Mannering, 1993; Laberge-Nadeau et al., 1992), and others have found statistically significant differences between males and females in accident injury severities (Dellinger, 2005; Ulfarsson & Mannering, 2004; Abdelwahab & Abdel-Aty, 2001; L Evans, 2001). From this study, the rate of accident occurrence appeared to be greater among the male drivers, which is similar to the findings by Bener et al. (2013) that male drivers have reported road traffic accidents nearly four times as often as the female drivers in four groups of drivers with different ethnicity. Based on the outcome, these research attempts to highlight the significant behavioral and physiological differences between the male and female drivers that influence the severity of these vehicle accidents. These differences may change as the drivers age. Furthermore, these findings highlighted the need to execute more gender-sensitive safety measures among the drivers.

Examining the highest factor in term of the first collision type of accidents, this study has found that slipping was proven to be the crucial factor for victims killed in the first year. For a vehicle, a slip can happen when the wheel's rotational speed is greater or less than the free-rolling speed. It is a nonlinear function of the wheel velocity and the vehicle's velocity (Kachroo & Tomizuka, 1994). In the meantime, accidents in Malaysia involving cars and motorcycles were highest, regardless of the age of the drivers. These findings are largely consistent with the findings by Manan and Várhelyi (2012). However,

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they highlighted in their study that the highest number of accident fatalities are mainly caused by motorcycles, with the majority being riders aged 16 to 20 years old.

On the other hand, one of the main factors related to accident involvement is driving experience. The survey on drivers indicated that approximately 60% of the ageing drivers have had experience with accident involvement. There is a significant support that the ageing drivers' behavioral differences may have negative impacts on the driving task (Rosenbloom, 2001; Ball et al., 1998; Strahan et al., 1997; J. W. Eberhard, 1996; T. A Ranney & Pulling, 1990). This study found that driving experience impose significant impacts on the accident involvement of the drivers. It was also found in previous studies that driving experience that affected the driving performance, in which the error was usually made by experienced driver, was comparatively lower than that by the inexperienced driver (Nabatilan et al., 2012; Patten et al., 2006; Shinar et al., 2005). However, there was a previous study that highlighted the driving experience contributed to only a small proportion of the variance in the specific driving measures in the experiment (Cuenen et al., 2015).

Driving is the primary mode of travel in the Malaysian society and driving capability is a symbol of independence in the culture. It was found that ageing drivers who were taken as samples in this research prefer to travel by driving the vehicle themselves. These results might be associated with the assurance of independent mobility on their own well-being (Song et al., 2015; Ravulaparthy et al., 2013) and the avoidance to be socially isolated and depressed among the populations (Fonda et al., 2001; Marottoli et al., 1997). Interestingly, more ageing drivers have voted themselves as excellent drivers compared to the younger samples. In terms of driving difficulty, both age groups had a higher percentage in rainy situation, driving in rush hour and driving at night. These findings are consistent with many researches that highlighted on these situations, which gave the impacts in terms of visibility, concentration and sleepiness level, and emission rates, thus having higher negative impacts on the safety and traffic risk to the drivers, regardless of the age groups (Qu et al., 2015; Hallvig et al., 2014; Wang et al., 2002).

Next, this present study has evaluated the key items of distraction, violations, errors, and lapses. The data showed that in overall, younger drivers have been reported to have had a higher number of distractions as compared to that in ageing drivers. Furthermore, from the correlation analysis done, there is a significant negative correlation between the age and distraction level, indicating that the younger drivers tend to be more easily distracted, proportionately with the decreasing in age. This finding is parallel with the previous study that stated young drivers appeared to be most susceptible to distraction-related crashes (Governors Highway Safety Association, 2010; McEvoy et al., 2006). Meanwhile, it can be highlighted in this study that violations often occur among ageing drivers at the junction. These findings are consistent with the previous findings by Hopkin & Morris (2010), which reported that older drivers are prone to having problems at the junctions on high-speed roads when entering a main road or roundabout, or when turning right. Besides that, a previous study by Oxley et al. (2006) had performed a crash analysis over 400 older drivers and highlighted on an issue that older drivers have on the complexity of the intersection and presence of other (fast-moving) traffic interferes. Furthermore, it was revealed that the most frequent error made by ageing drivers is failing to notice the pedestrians crossing the road while driving. Other than that, the most frequent lapses among the ageing drivers were when they attempt to drive away from the traffic lights in the third gear, showing that the off-guard situation happened mostly at the traffic lights. These conditions might be partly due to the deterioration in their cognitive and visual search, which are very crucial in a driving task (Karthaus et al., 2016).

5.3 The experimental methodology implemented in the study.

The aim of the experimental study was to investigate driving mental workload and performance of ageing drivers in real time driving environment, which can potentially be

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used to developed strategies and approaches for safety issues raised. To begin with, the participants recruitment was very important and has been done systematically. Although the experimental participants were recruited through poster advertisement and social media, not all applications for participation in the study have been accepted. To minimize the selection bias, each application as a participant has been selectively screened based on certain criteria such as age, in good health that enables the individual to drive a car, living in the states of most senior citizens (Selangor and Kuala Lumpur), hold a driver's license for at least 5 years and must have driven for at least 10,000 km during the last year. This study emphasized on safety during field operational experiment by selecting the ageing drivers between 50 and 65 instead of older drivers (Son et al., 2015). This study has proved that it is important to conduct the experiments at off-peak period, i.e. in in the morning after a worker goes to work to noon before lunch hour (Joonwoo Son et al., 2015) to avoid skews results due to undesirable factors such the traffic congestions and accidents. For the experimental setup, it is crucial to prepare the component such as the PDT based on Malaysian driving environment (the driver's seat is on the right-hand side of the car). On the other hand, it is crucial for experimental procedure to be approved by the ethic to minimize risk of harm and protect the participants and the experimenter (University College London, 2016). In this study, the research associates were presents in the experimental car for the purpose of monitoring the measuring equipment and giving driving directions while ensuring safe vehicle operations. The unfamiliarity issue between the participants and the research associates was anticipated during the experimental design phase. This issue was control by involving the assistant and the participants since the earliest stage of the experiment (i.e. the experimental introduction and briefing, the measurements of the demographic data at the station, the equipment setup) to increase familiarity between them. Besides, the briefing of the experimental procedure emphasized on the importance of the participants to be focusing mainly on the driving task and not on

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other matters concern (namely the evaluation on the error and mistakes). According to Larson (2010), working in the presence of others improves performance on well learned tasks. In this context, the driving task was a well learned task since the participants involved in the experiment were frequent drivers. Furthermore, they were given time to familiarize themselves with the task and the experimental setup beforehand. The experimental design involving research associates during the driving task was based on previous studies such as Kim et al. (2018), Hallvig et al. (2014), Ekanayake, et al. (2013) and Yang et al. (2013) to ensure the experimental control and safety.

To manipulate the mental workload, the participants of the study were exposed to three types of situation complexity that were set relative to the type of road characteristics. In addition, since increasing workload levels normally affects human performance, participants were presented with three explicit driving performance evaluations represented as the direct and indirect performance measure. To distinguish between the mental workload and performance levels, repeated measure ANOVA were used while correlation and linear regression were applied to develop the models. Further discussion on the reliability of the outcome from the measurement and analysis methods applied in this study is elaborated in next sections.

5.4 Driving mental workload of ageing drivers based on driving task-related factors.

One of the key findings of this study concerns the mental workload determination at different complexities of the driving task. The mental workload measures involved were subjective ratings and brain signal monitoring. Overall, the findings on the mental workload were in line with the previous research, suggesting that the complexity of the driving environment had impacted the level of driving mental workload of the drivers (Arien et al., 2013; M. S. Young et al., 2009; Patten et al., 2006; Törnros & Bolling, 2006;

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Jahn et al., 2005; Victor et al., 2005; Verwey, 2000). The variations of the responses based on the situation complexity are discussed in the following sub-sections.

5.4.1 Subjective measurements based on NASA-TLX

It is known that the mental workload not only concerns the mental workload demand from the driver, but also of other components that contributed to the overall workload during the task execution. In this study, it was found that the situation complexity significantly affects almost all of the ageing drivers' NASA-TLX scores. This finding is consistent with the previous studies (Arien et al., 2013; Patten et al., 2006; Törnros & Bolling, 2006; Jahn et al., 2005; Verwey, 2000), which found the differences in the subjective ratings based on the difficulty of the task assigned. Focusing on the ageing drivers' ratings, the mean physical demand score was highest compared to others in rural and city driving. As expected, the traffic density required a higher physical effort. Meanwhile, the results reveal that the mean physical demand rating in rural and city areas were 83% and 95% in difference, respectively, as compared to that in highway roads. The results also indicated that the physical demand is more than double, as the driving situation shifted from the simple situation to moderately complex and very complex situations. This finding is consistent with Teh et al. (2014), where their result revealed a significantly higher physical demand in medium and high traffic complexity compared to that in low traffic complexity. They also highlighted that there was an increasing linear trend in workload having an increasing traffic density. Parallel with the findings by Hopkin & Morris (2010), the traffic rating on physical demand in this study might be due to the effort and requirements to control the vehicle on the roads with more curves.

Interestingly, mental demand was rated highest in highway driving (i.e., simple situation) compared to the scales of other score. The result indicated that this type of road required more mental effort to maintain a safe driving task with a monotonous route.

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However, comparing the situation complexity in this study, the highest mental demand was found in the city driving (65% in difference from highway driving), where higher demand in terms of road and traffic densities occurred during the driving task execution. This result is in agreement with the findings of Fallahi et al. (2016), where in their study, mental demand was most important in the proposed required task, and they explained that the higher the average mental requirement is, the more the operator felt that his job was demanding. On the other hand, the temporal demand related to the amount of pressure felt due to the rate of task elements occurrence shows that the score was highest in the city driving, followed closely by the rural driving. This result indicates that the ageing drivers felt higher pressure in busier traffics, which the findings are consistent with the previous studies that highlighted the impact of these situations on the visibility, concentration and sleepiness level, and emission rates, thus having higher negative impacts on the safety and traffic risk to the drivers, regardless of the age groups (Qu et al., 2015; Wang et al., 2002). In addition, the findings on the rural road score is parallel with the outcome highlighted by Thompson et al. (2013), where they presented that there were specific elements of rural driving environments that put older drivers who live there at a greater risk of serious injury, hence, improvements such as providing better delineation and reduction in the number of road junctions that are adjacent to curved roads and crests of hills can be made. Consistent with the findings by Hopkin & Morris (2010), they reported that older drivers are prone to having problems at the junctions, especially at higher speed roads.

It was observed that the effort was highest on the very complex situation, which was parallel with the findings on physical demand, mental demand and temporal demand scales. The rating given by the ageing drivers on how they must work the hardest in the city route was 95% higher compared to the efforts made in highway roads to accomplish their level of driving performance. This involved the requirement of the route itself, which

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consisted of more vehicles and pedestrian. In the city route, some of the vehicle drivers might make a sudden stop or last-minute decisions in turning their vehicle. This condition is very dangerous, particularly to ageing driver, as they were highlighted to have difficulties in overtaking another vehicle. As people age, their visual perception ability decreases, and so do their cognitive and psychomotor functions (Eby, 2009; Anstey et al., 2005). The reason is, older age group had more functional limitations compared to the younger age group, including impaired physical health.

On the other hand, the overall weighted workload exhibited the highest score at the city road, followed by the rural road. The result in this study revealed that the mean weighted workload score was 76% and 63% higher for moderately complex and very complex situations, respectively, compared to the simple situation. These results confirmed that the city and rural roads gave higher load of subjective perception of the ageing drivers whom have had the experience of functional impairment, resulting in an increased vulnerability to environmental challenges (Vysata et al., 2014). These results also indicated that the complexity of the driving environment have also impacted on the drivers' overall mental workload level. The overall workload of a task should not be too low or too high, as for most human operators, the performance indicator will be degraded when this situation happens (Hwang et al., 2007).

Overall, there was no statistically significant difference between the ratings given by the male and female drivers on the subjective workload in each task. This finding agrees with the previously reported results by Teh et al. (2014), where they found that there was no significant effect of gender on all of the NASA-TLX scale scores in their driving experiments. These findings are contradictory with the findings by Seeker (2014), which he found that the women have higher average mental workload than men do. The contradiction might be due to different demographic characteristics of the participants involved in the study. Meanwhile, comparison was made to see the difference between

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the control group and the ageing drivers on the weighted workload. The control group's weighted workload score was higher in all situation complexity, with the statistically significant difference found in the simple situation. Although the young drivers were treated only as the comparison control group, they rated a higher score for the overall weighted workload compared to the ageing drivers. For the simple situation, young drivers scored 58% higher compared to the ageing drivers. This finding is parallel with Paxion et al.(2015) , where it was found that the lack of experience was a part of contributor to the increment of the subjective workload. In addition, it is risky for ageing drivers to have too low mental workload level in monotonous road which this can cause boredom and reduce attentiveness thus accident occurrence.

5.4.2 Electroencephalogram signals fluctuation at different levels of situation complexity

It is known that driving task would result in fluctuations of the brain signal of the drivers. In this study, the frequency related to the mental workload variations that were considered were the theta, alpha and beta. Relative power ratio of each frequency was calculated to see the normalized result, thus providing a more definitive outcome of the signals. For the EEG signals fluctuation, the result showed that there were significant effects of the situation complexity; these findings are parallel with some of the previous studies (Maglione et al., 2014; Hong J. Eoh et al., 2005). The main effect was found in $RP\theta$ and $RP\alpha$ of channel locations that indicated intention and motivation (i.e., F_ZP_Z) and occipital location (i.e., O_1O_2) that usually reflects visualization (Borghini et al., 2014b, 2014a; Hare et al., 2009; Teplan, 2002). Both frequencies were found to be lower in the city compared to in rural roads. These findings were in line with the concepts of theta and alpha activities, in which the power in this frequency band is related to sleepiness and information processing for the activities mentioned, respectively. In the city driving, intentional and visualization were highly needed by the drivers, resulting in lower alpha (reflecting the increment of attentional demands (Ryu & Myung, 2005; Sterman et al., 1994) and lower theta (less sleepiness occurred) compared to other typse of roads. On the other hand, there was a significant effect of the interaction between the situation complexity and gender found, which further analysis indicated that for female, the RPα for the simple situation was significantly higher from the very complex situation. This finding indicated that there was an increment in the information processing activity of a very complex situation compared to the one in the simple situation. There was no significant effect of situation complexity on RPβ, except for the interactions with the gender at occipital location that reflected visualizations. However, there was no statistically significant difference when further analysis was done. These findings indicated that the mean beta frequency associated to the alertness and arousal level (Hong Jun Eoh et al., 2005) did not vary within the driving task at different levels of situation complexity.

Inspecting the effects of time on task (ToT), interestingly, it was found that there was a significant effect in the interaction between the situation complexity and ToT, where in the first three minutes of driving (S1), the RPα for the moderately complex situation was significantly higher than that in a very complex situation. This result indicated that at the earlier stage of the driving task, the ageing drivers had experienced a higher demand (higher amount of information processing activity) in city driving compared to rural driving. The result is consistent with the findings of the previous studies, where they highlighted that the alpha power is sensitive to the changes in the task load (Maglione et al., 2014; Lei & Roetting, 2011). On the other hand, Li et al. (2017) found that the alpha power increased when the driver was sleepy in their driving experiment. Their finding is parallel with the current study, where boredom might occur during the driving task in

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rural road driving, thus experiencing an attentional withdrawal (Edmund Wascher et al., 2016).

Analyzing the effect of gender on the EEG band frequency, the result indicated that the significant effect of gender was found in most cases of RPθ and RPα. Regardless the situation complexity and ToT, frequency bands were higher among male drivers compared to female drivers. Examining further on the significant interactions, for channel O_1O_2, overall in each ToT, the RPθ was higher among the male drivers. Lower RPθ was found among female drivers, indicating that less sleepiness have occurred among female drivers compared to male drivers found along the time on task (Filtness et al., 2012; Sandberg et al., 2011; Hong J. Eoh et al., 2005; Otmani, Rogé, et al., 2005; Strijkstra et al., 2003; Kecklund & ÅKerstedt, 1993; Åkerstedt & Gillberg, 1990). Since the channel locations were indicating the visual activity of the task, the female drivers showed more engagement and effort to keep the visualization on monitoring driving conflicts during the task. These findings were contradictory with the findings by Kim et al. (2014) and Larue et al. (2011), where statistically significant differences between the male and female drivers were not found in most cases of their studies on quantifying the driving workload on a real road and a simulator one. The contradiction might be due to the design of the study, such as the age of the participants, time of the experiment and type of task assigned to the participants. Significant interaction between the situation complexity and gender was found on the RPα of channel F_ZP_Z, where further analysis indicated that the alpha frequency of the ageing female drivers was significantly higher in the simple situation compared to in the very complex situation. This finding also highlighted that highway driving acquired lower information processing activity compared to the city driving. The result reflected that the highway road required less mental effort, thus resulting in a higher potential of sleepiness occurrence, especially in a driving task with a monotonous route.

On the other hand, the EEG frequencies were compared between the ageing drivers and the control group. It was found that there were statistically significant differences in the mean RPθ at the parietal location of moderate and very complex situations, and the mean RPβ at the occipital location in the very complex situation. This result indicated that ageing drivers experienced less drowsiness in rural (52%) and city (39%) driving compared to the control group. In addition, in terms of visual, the control group experienced 72% higher arousal compared to the ageing drivers in the city driving task. This might be due to the visual search impairment in ageing drivers (Karthaus et al., 2018).

5.4.3 Correlation between mental workload measures and ageing drivers' personal characteristics

The aim of finding the correlation between the mental workload and the personal characteristic, and anthropometric group was to identify the relationship between the driving related factors (i.e., human and vehicle) and mental workload responses. For the NASA-TLX, all correlations were found in the very complex situation. It was found that as the age increases, the temporal demand score decreases. This result indicated that the older or ageing drivers felt more pressure along the task execution in the city road. With increasing age, the age-related functional changes in terms of perceptive, motor and cognitive did have an impact on the task performed, particularly under time pressure (Karthaus et al., 2018). On the other hand, as the reaction time increases, mental demand increases as well. It is observed from the result that for ageing drivers with slower reaction, they felt that higher amount of mental and perceptual activities were required during the city road task execution. The age-related motor changes may influence the driving ability and general mobility (Karthaus et al., 2018), thus affecting their perceptions on the workload.

The relationship between the EEG frequency fluctuations with personal characteristic were also analysed. It is observed from the results that as the age increased, the mean RPβ decreases at occipital location in all situation complexity. This result indicated that the older ageing drivers had lower alertness level during the driving task, since the beta power reflects in an increased alertness and arousal (Hong Jun Eoh et al., 2005). Meanwhile, as the age increased, the mean RPθ decreased in location reflecting the decision-making process in the moderately and very complex situations. This result indicated that the older or ageing drivers had experienced lower sleepiness and drowsiness in decision-making process in both driving situations (H.-S. Kim et al., 2014). Meanwhile, the RPθ was found to be significantly correlated to the experience level in channel location that indicated intention and motivation (i.e., F_ZP_Z) and occipital location (i.e., O_1O_2) that usually reflects on visualisation (Borghini et al., 2014a; Hare et al., 2009; Teplan, 2002). These results showed that as the level of experience increased, the theta also increased. This result indicated that the intention and visualisation processes have caused higher sleepiness on more experienced ageing drivers compared to the less experienced drivers, especially in moderately and very complex situations. Concurrently, as the experience level increased, the mean RPβ was found to be significantly decreasing at the occipital channel location. This result revealed that more experienced ageing drivers have had less arousal level during all situation complexity.

Meanwhile, the mean RPθ in channel location indicated that the decision-making process had decreased as the reaction time increased. This result reflected that for ageing drivers with slower reaction, they experienced lower drowsiness in the decision-making activity during the rural driving task. This result proved that the ageing drivers realized that they have reduced the speed of movement and impaired motor functions (Stelmach & Nahom, 1992), thus struggling to stay awake during the moderately complex situation as a strategy to be more careful. In addition, the mean RPβ had increased as the reaction time increased, which is in parallel with the findings on the theta power. Ageing drivers with slower reaction time had experienced higher alertness level during the driving task, particularly in highway driving. On a straight road layout, drivers must be able to maintain alertness on a monotonous task, which is believed to affect the driving task (Perrier et al., 2016; 2014; Ratcliff & Strayer, 2014; Calhoun et al., 2002; Brouwer & Ponds, 1994; Avolio et al., 1985).

In this study, the average mileage per year of the ageing drivers was found to be positively correlated to the RPβ of occipital location in city driving and RPθ of parietal location in rural driving task. The higher mileage indicates that the driver is a frequent driver. Drivers with higher mileage experienced higher alertness in city driving task in terms of visualisation. However, in rural driving, the drowsiness level is higher in drivers with higher mileage. This finding indicates that even with a high mileage, the ageing driver still experienced drowsiness in rural road, where the layout had more curves compared to the highway, moderate traffic density and narrow lane (Pavlou et al., 2016; Paxion et al., 2014).

5.5 Driving performance elements of ageing drivers based on driving task-related factors.

Examining the situation complexity effects on the driving performance, and the variations of performance responses were discussed in the following sections. This study focuses on the relevant performance measures related to the mental workload and real-time driving experiment, which is the number of traffic violations, speed, speed variability, and the reaction time of the peripheral detection task.

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5.5.1 Primary-task driving performance measures at different levels of situation complexity

It In this study, the number of traffic violation is based on the number of errors done by the driver during the task driving. In this study, the highest number of traffic violations was in the very complex situation, indicating that the ageing drivers were likely to do more errors in the city driving task. This finding was consistent with the previous studies, where they suggested that city road has had higher complexity in terms of its road design, road layout and traffic flow (Paxion et al., 2014; Fastenmeier & Gstalter, 2007). Parallel with the findings by Tran et al. (2017), city driving with fast-moving traffic and high vehicular traffic density had induced higher rate of error than the less density and quiet traffic. The result indicated 35% higher mean of the number of traffic violation that occurred in the city driving compared to when in simple situation (i.e., highway). The ageing drivers might feel a higher workload demand in the city driving, where the visual attention was more focused on the surrounding environment that consists of busy road condition, such as in the appearance of more vehicles and pedestrian crossings, traffic lights, and cyclists, resulting in room for more errors. This finding is in agreement with the previously reported results on the disturbed attention that leads to a greater amount of human errors (Cai & Lin, 2011).

It was found in this study that there is a significant effect of the situation complexity on the NTV. However, there was no statistically significant difference in the mean of the number of traffic violation between the situation complexity. This finding contradicts with the the findings byTran et al. (2017), where they found the number of errors in their performance measure showed that the higher tasks would significantly result in higher error than the lower tasks will. This contradiction might due to the different driving task characteristics of the study. In addition, there were no gender effects on the of the number of traffic violation, indicating that there was no statistically significant difference on the errors made between the male and female drivers. Past similar study that consisted of both male and female participants did not highlight the effects of gender, which it assumed that they did not found the significant effects of it on the number of traffic violation (Cai & Lin, 2011). Comparison of the number of traffic violation was made between the ageing drivers and the control group, but no statistically significant difference was found in the study. This finding revealed that drivers in both age groups were making the same number of errors in highway, rural and city driving, regardless the gender. This finding contradicts with a previous study, where they found that the older people tend to do more errors compared to the younger subjects (Karthaus et al., 2018). It was highlighted that with increasing age, the search time rises and error rate will also increase. The contradiction might be due to the experimental design, where this current study acquires driving performed in real traffic accompanied by greater situational variations, which leads to detecting different real-driving performance of each participant involved. In the meantime, the correlation analysis was done for errors that contributed to the number of traffic violation, which is related to the signal lever usage with Anthropometric group. It was found that in SS, as the anthropometric dimensions of the index and middle fingers circumference increases, the errors also increase in the highway driving task. This result indicated that the ageing drivers with bigger index finger and middle finger has higher potential on making errors in signaling during the driving task. This might be partly due to the unsuitable signal lever size. This finding is parallel with the previous studies that found the lever type and discomfort were related to one another, where this resulted in an inappropriate workload and performance (Sara & Henrik, 2012; Hägg et al., 2009). In addition, there was no correlation between the driver's error in signaling with peripheral detection task reaction time which shows that the physical reaction is not related to the signaling task. This findings is contradicted with findings by Salvia et al. (2016a) which shows that reaction time, error rate and task difficulty had significant relationship. The

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reason behind this contradiction might due to different type of error and task complexity with the current study.

On the other hand, to see the situation complexity effect on other primary driving performance measures, the speed and speed variability was analyzed. The results revealed that there is a significant main effect of situation complexity on the ageing drivers' speed. This result contradicted with the findings by Thomas et al. (2015), where they found no significant effects of the routes on speed in their real-time driving experiments. In the current study, the mean speed in the simple situation was significantly higher from the moderately complex situation and very complex situation (42% and 38 respectively). Regardless the gender, all ageing drivers drove with a higher speed on the highway compared to rural and city road. In previous studies, decline in good driving performance was defined by higher velocities and more speeding, as it was the most prevalent cause of fatal crashes (Roidl et al., 2013; AAA Foundation for Traffic Safety, 2009). Parallel with the findings by Bauldaf et al. (2009), drivers will be able to maintain better constant speed on a straight road condition. Based on this, ageing drivers in this study indicated that they can still drive at high speed and maintain control. In rural and city driving, the low mean speed in ageing drivers indicates the conservative driving behaviour and sometimes, self-regulation of the driving behaviour caused by the awareness of their deprived driving performance (Pavlou et al., 2016). Thus, the low speed is an indication of workload increment, since the drivers have allocated more mental capacity for the task.

Meanwhile, it was found that there is a significant main effect of situation complexity on the drivers' speed variability. In this study, the mean speed variability in the moderately complex situation was significantly lower from the simple situation (25%) and very complex situation (35%). This might due to the road conditions that forced the drivers to drive at slower and constant speeds as a strategy in performing the task safely. Uneven roadway design can produce unexpected changes in dynamic and speed

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conditions, which may impose high workloads that can interrupt the focus of the driver (Lyu et al., 2017). Thus, this condition usually leads to operational errors and driving performance impairment. Horberry et al. (2006) stated that speed variability is shown to have increased, as the drivers engage in concurrent tasks that reflect higher mental workload. This can be related to the current study which the drivers need to be more alert and careful with the very complex driving situation characteristics (i.e., city road) resulting in higher speed variability during the driving task performed.

Investigating the differences between the gender, significant effects of gender were found on both speed and speed variability. It was found that the female drivers had 6% higher speed compared to the male drivers and interestingly, the speed variability of male drivers was 41% higher than that of the female drivers, regardless the situation complexity. Contradicting the current result, NHTSA's National Center for Statistics and Analysis (2012) reported that the percent of speeding for fatal crashes in 2009 in ageing male drivers was higher than that in ageing female drivers. In the current study, it was also found that the male drivers had higher speed in the simple situation compared to the more complex situation. Parallel with the findings by Bauldaf et al. (2009), they found in their study that drivers experienced higher difficulty in city driving, but partly in contradiction is that they found that drivers experienced harder driving conditions in a continuous speed. In the case of the current study, the male ageing drivers were more likely to experience higher difficulty in the city and rural roads compared to the highway road. However, examining the speed variability resulted in male ageing drivers with 45% higher speed variabilities in rural driving compared to city driving. This condition reflected that the male drivers were more likely to drive in an inconstant speed compared to in rural road, leading to more variations of driving performance along the roads. Reduced capacity to maintain the speed was part of the observable changes in driving performance, which is manifested by the reduced capacity to maintain vigilance caused by drowsiness (Aidman et al., 2015; May & Baldwin, 2009). Similarly, De Waard (1996) highlighted that the driving performance is impaired with an increase of speed variation and a reduction of safety perimeter. Comparison of the mean speed and speed variability were made between the ageing drivers and the control group to see the age group different responses. There were no statistically significant differences found on the speed and speed variability when comparing both groups, indicating that the ageing drivers in this study were performing the same speeding strategy as the younger drivers do in all the driving situation complexity. This finding contradicts the findings by Son et al. (2010), where they reported that older drivers showed significant degradation in maintaining speed, especially under cognitive secondary workload, compared to the younger drivers, which are then associated to the decline in cognitive capacity (McDowd et al., 2003; Rogers & Fisk, 2001).

5.5.2 Secondary-task driving performance measure at different levels of situation complexity

Peripheral detection task (PDT) is one of the measurements of driving performance that acquires measure reaction time to detecte stimuli (visual or auditory) and percentage missed PDT signals as a measure of mental workload. In this study, the reaction time based on the visual PDT signal was measured during the driving task assignment given to the ageing drivers. It was found that there is no statistically significant difference of the reaction time of the PDT between the situation complexities. However, the maximum reaction time was in the very complex situation, where it was 6% slower than the minimum reaction time obtained in the moderately complex situation. Similar to the finding of the previous studies, city driving has yielded longer reaction time compared to others (Patten et al., 2006).

The factors that contributed to the lengthening driver reaction time might be due to the anxiety related to the pedestrian appearance (Paxion et al., 2015) and mental capacity

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allocated for the primary task that involve other road users. It was found that there is a significant effect of the interaction between the situation complexity and genders. The reaction time of female drivers was 16% faster than that of male drivers in city driving. These findings are parallel with the study of Wallis & Horswill (2007), where it found that the high temporal pressure to avoid the pedestrian could have provoked a high level of anxiety, resulting in long reaction times among the drivers. Similarly, in Arien et al. (2013) findings, they found that drivers experienced a higher workload when driving along the road curves. Comparison on the reaction time of the peripheral detection task was done and it was found that there is no statistically significant difference between the ageing drivers and the control group. This result is parallel with the findings by Stinchcombe and Gagnon (2013), where they found that there were no differences between age groups in reaction time of the peripheral detection task in their experimental driving scenarios.

5.5.3 Correlation between driving performance measures and ageing drivers' personal characteristics

The relationship between the driving measures and personal characteristics was performed to further investigate the associations based on the complexity of each situation. Interestingly, the result indicated that as the experience and average mileage increase, the number of traffic violation also increases in the simple situation. This result indicated that older drivers and more experienced ones are prone to making more errors on the highway route. Again, these findings are parallel with Hopkin & Morris (2010), which they reported that older drivers are prone to have problems especially at higher speed road. On the other hand, the results indicated that as the reaction time is faster, the number of traffic violation also increases. This is a fascinating finding because it shows that the ageing drivers with less cognitive impairment tend to make more errors during their driving in the highway. This might due to their behavior, especially on a straight

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road driving, where they feel more confident and less distracted compared to when they are in other complex situations. Meanwhile, it was found that the speed variability increases as the driving experiences increases in the very complex situation. This result reflected that the more experienced drivers tend to change their speed during a complex driving task, reflecting a higher mental workload (Horberry et al., 2006) compared to the younger ones. In addition, the result revealed that as the reaction time at the station increases, the reaction time of the peripheral detection task during the driving task also increases in the simple situation. This finding reflected that in simple driving situation, the reaction time pattern is similar to when they are not performing the driving task. This result also reflected that the ageing drivers feel less demand on the monotonous and less density route (Paxion et al., 2014) that they can allocate their capacity to react to the stimuli given during the driving task. In addition, it was found that there is no correlation of Body mass index (BMI) with peripheral detection task reaction time. This finding indicated that whether the BMI is low or high, it does not affect the reaction rate of an individual in a driving task. However, result from previous research by Skurvydas et al. stated that, participants from the group with greater body mass index reacted significantly slower than others in their off-road task study. Reaction time is considered to include different consecutive periods for preparation of neuro-muscular system for future movement, such as instructional, attentional, neurophysiological and also the temporal delay of reactivity of executing muscles. This resulted in different outcome in more complex activity such as in a driving task.

5.5.4 Overall driving performance score (ODPS) based on situation complexity

The overall driving performance score ODPS was achieved by the weighted combination of individual driving performance measures related to the mental workload (i.e., number of traffic violations, speed and speed variability, reaction time of the

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peripheral detection task). Although the result indicated a slight significant effect of the situation complexity, it was observed that the ODPS in simple and very complex situations were 20% higher than the ODPS in moderately complex situation. These findings indicated that the ageing drivers are prone to having a lower overall performance in the rural road. The result is consistent with the previous studies (M. S. Young et al., 2009; Victor et al., 2005), claiming that the rural road had resulted in poorer performance due to the road type. It was highlighted in the studies that the performance measure was degraded in the rural environment due to characteristics such as road curves and fixations along the road. On the other hand, the current study is contradictory with a previous study (Törnros & Bolling, 2006), which showed that city driving resulted in lower driving performance of the secondary task assigned due to the attentional resources. However, these studies were focusing more on the individual driving performance measures and not computing the overall performance as in the current study has done. ODPS comparison between the genders indicated that the female drivers had 21% higher mean ODPS compared to male drivers, regardless the type of situation complexity. This result indicates a better overall performance in terms of traffic violations, speed changing and reaction time.

5.6 Relationship between EEG, NASA-TLX and ODPS at different levels of situation complexity

Correlation and regression analysis were performed to further investigate the relationship between the ODPS and the mental workload measures (i.e., NASA-TLX score and EEG relative power bands) on each situation complexity. The correlation forms the basis to identify the relationship among the significant factors and develop regression models, which are used to predict the overall driving performance of the ageing drivers. Three regression models were developed in this study, in which the first model predicts the ageing drivers ODPS in the simple situation (i.e., highway), second model for the

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moderately complex situation (i.e., rural road), followed by the third one for the very complex situation (i.e., city road).

5.6.1 ODPS Model and Validation

Three models of ODPS for the ageing drivers in simple, moderately and very complex situations were developed. The first model was developed based on the strong significant correlations between the RPβ of channel location O_1O_2 and ODPS ($r = 0.795$, $p < 0.001$), RPθ of channel location O_1O_2 and ODPS ($r= -0.568$, $p = 0.017$), mental demand (MD) of NASA-TLX and ODPS ($r = -0.718$, $p = 0.001$), as well as the effort (EF) of NASA-TLX ($r = 0.512$, $p = 0.036$) and ODPS. The second model was developed based on the significant correlations between its own performance (OP) of NASA-TLX ($r = -0.801$, $p < 0.001$) and ODPS, temporal demand (TD) and ODPS ($r = 0.720$, $p = 0.001$), as well as RPβ ($r = -0.500$, $p = 0.035$) of channel location O_1O_2 and ODPS. The third model was based on the correlation between the RPα of channel location F_ZP_Z and ODPS ($r = -0.794$, $p < 0.001$). The coefficient of Pearson correlations (R) is most frequently used to determine how well a model fits a set of data. It was found that there is a strong relationship between the variables for the simple situation ($R = 0.861$), moderately complex situation ($R = 0.813$) and very complex situation ($R = 0.749$). In overall, an R value that is more than 0.5 indicates that there is a strong correlation among the variables; thus in this study, it is apparent that multiple linear regression model will give the best fit to predict the ODPS (Pallant, 2013; Cohen, 1988). The adjusted R-squared value represents the variance of ODPS, and the values obtained are 0.671 for the simple situation, 0.597 for moderately complex situation and 0.610 for the very complex situation. This indicates 67%, 60% and 61% of the total variances in ODPS, as explained by the regression model for the simple situation, moderately complex situation and very complex situation, respectively.

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5.7 Benchmarking with previous studies

Most previous studies pertaining to driving performance were conducted independently (Loeches De La Fuente et al., 2019; H. S. Kim et al., 2018; Koppel et al., 2017; Tran et al., 2017; Qin et al., 2014; Cai & Lin, 2011) involving experimental task at various driving situations. Also, there are very limited studies that investigated the relationship between the mental workload and overall driving performance in different real-time driving situations, particularly on the ageing drivers. Their focus was mainly on the driving performance and other dependent variables (Koppel et al., 2017; Tran et al., 2017; Qin et al., 2014). In the meantime, Cai and Lin (2011) produced an overall driving performance that involved number of traffic violations, lane deviation, and brake reaction time, which were then associated to the emotional level of the students involved. It is important to investigate the driving performance elements on the specific and critical participants that the drivers usually experience on the road and relate it to significant issues that commonly contribute to performance impairment. The outcome of the ODP was based on the study conducted in the United States among the university student population. Studies by Qin et al. (2014) (2014) and Koppel et al. (2017) consisted of participants aged 50 years, relating the driving performance with functional impairments such as the visual, cognitive and motoric functions. The former studies have focused on the highway route, while the latter distinguished the route complexity by traffic density, speed zone and number of road lanes. Driving performance measures such as lateral position, speed, deceleration, steering angle, breaking times, and maneuver error were investigated. In the final outcome, Qin et al. (2014) produced a prediction model that can evaluate the drivers' visual attention demands at the initial stage of constructions, while Koppel et al. (2017) showed that the total driving maneuver error rates were significantly related to age, but not significantly related to any functional performance measure and/or self-reported driving experiences. Nevertheless, the variations of mental workload

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responses and ODPS (i.e., number of traffic violation, speed variability, reaction time of the peripheral detection task) were not investigated in this study.

A different study has discovered that mental workload measures (subjective rating and six physiological indices) were found to vary according to the level of situation complexity (i.e., low, medium and high complexities) (Tran et al., 2017). It was highlighted that the mental workload measures (NASA-TLX, pupil dilation, blink and fixation duration, and heart rate) were significantly correlated to the number of errors. However, the best significant predictor factors in the driving performance measure of their study were the pupil dilation, blink rate and heart rate of the drivers.

On the other hand, most previous studies measure the driving performance based on the driving simulator task, rather than on the on-road driving measurements (Loeches De La Fuente et al., 2019; Tran et al., 2017; Qin et al., 2014; Cai & Lin, 2011). The current study agrees with Koppel et al. (2017) that measuring the driving task on the real on-road driving can provide a better understanding on the drivers' true driving ability. It is coincided that as a common range of traffic conditions at an appropriate level of difficulty are performed by a driver, the level of competence can be more accurately evaluated, enabling the researchers to observe the critical aspects of a driver's performance.

In addition, a study by Kim et al., (2018) has also highlighted that it is more effective to perform workload data collection while driving on an actual road instead of a simulated environment. Similar to the current study, they have focused their studies onto two groups namely the younger (male and female in 20s) and older (male and female in 50s). They have collected driving performance measures such as engine rotation per minutes, vehicle speed, lane changes and turns which then predict the mental workload based on EEG level of driver. In the meantime, a recent study by Fuente et al., (2019) has focused on task event and task complexity in a driving simulator study to measure the increment of mental workload among only young drivers. However, instead of using brain signal monitoring

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for mental workload monitoring like in the current study, they have chosen electrocardiogram which produce heart rate data as the physiological parameters. Their results showed that both performance and physiological variables differed as a function of traffic conditions and time pressure. For the end outcome, this study was more onto discussing in term of mental workload estimation and suggestions about the safety systems instead of developing prediction model for mental workload or driving performance.

It has been shown from the previous studies that most of the research on driving performance were focusing on the individual driving performance based on the various dependent driving elements of the young and ageing drivers. There is a lack of study that relates the mental workload measures and ODPS (based on primary and secondary task) in a real on-road driving experiment, particularly on the ageing drivers. Therefore, this study offers a new insight on the relationship between the ODPS and mental workload responses (NASA-TLX and EEG relative power bands) at different situation complexities for the ageing drivers using real driving task. Moreover, this current study found that the ageing drivers had different mental workloads at different situation complexities. Thus, the ODPS models were developed separately for the simple, moderately and very complex situations.

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CHAPTER 6: CONCLUSION AND RECOMMENDATIONS FOR FUTURE WORK

6.1 General conclusion

This study shows a close relationship between mental workload and driving performance was demonstrated. Overall, the results established that it was achievable to accurately estimate mental workload of ageing drivers based on multichannel EEG relative power bands and NASA-TLX ratings. This study confirmed the reliability of using number of traffic violations, speed variability and reaction time of the peripheral detection task as measures of driving performance, thus in developing ODPS. The research hypotheses were tested. Results revealed that there were statistically significant differences in mental workload and driving performance of ageing drivers on different driving task-related factors, which indicate that the null hypothesis (i.e. Ho: no statistically significant difference) can be refuted. For the second hypothesis, results revealed that there were statistically significant relationships in mental workload and driving performance of ageing drivers at different levels of situation complexity, which indicate that the null hypothesis (i.e. Ho: no statistically significant relationship) can be rejected. In this chapter, the conclusion is presented based on each objective of the study.

The first objective of the study was to determine the driving mental workload key factors of ageing drivers based on driving task-related factors. The driving mental workload key factors were mental capacity and driving task demand where variations were found based on human, vehicle and environment factors. The results of the real time driving experiment revealed that there was significant effect of driving situation complexity in the ageing drivers' subjective workload ratings *($p<0.05$)* where the highest

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overall workload was in the very complex situation. On the other hand, the EEG relative power bands showed that there was significant effect of the situation complexity mainly on RPθ and RPα *($p<0.05$)* of channel locations that indicate intention and motivation; with occipital location that reflects visualization. Both frequencies were found to be significantly lower in city road compared to other roads, indicating lower levels of sleepiness and drowsiness, respectively.

The second objective of this study was to identify the driving performance key elements of ageing drivers based on driving task-related factors. There were three main elements of driving performance in this study namely drivers (human), driving (activity) and context (driving in different situation complexity). It was found that the highest NTVs was recorded in the very complex situation indicating that the ageing drivers were likely to commit more errors during city driving. On the other hand, the mean speed variability in the moderately complex situation was significantly lower *($p<0.05$)* than that of the simple situation and very complex situation. It was found that the maximum RT was recorded in the city, where it was six percent slower than the minimum RT obtained in the rural road. The Overall Driving Performance Score (ODPS) was calculated through weighted combination of individual driving performance measures in relation to mental workload (i.e. NTV, speed variability and reaction time of the peripheral detection task).

The third objective of this study was to determine the relationship between the driving mental workload and performance of ageing drivers. It was found that the subjective ratings and brain signals of mental workload measures had medium to strong significant relationship with ODPS ($R>0.5$ to $R>0.7$). It can be concluded that there were changes in driving performance of different situation complexity based on varying levels of mental workload.

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The fourth objective of this study was to develop and validate an overall driving performance score (ODPS) model which quantifies the driving mental workload on the driving performance of ageing drivers. Three regression model were developed to quantify and predict the ODPS. First, the regression model has been developed to predict the ODPS for the simple situation as a function of mental demand (MD) and effort (EF) of NASA-TLX and RPβ and RPθ of EEG. The relationship among these variables was found to be significantly linear (R=0.861). Second, the regression model has been developed to predict the ODPS for the moderately complex situation as a function of own performance (OP) and temporal demand (TD) of NASA-TLX as well as RPβ of EEG. The relationship among these variables was found to be significantly linear (R=0.813). The third regression model has been developed to predict the ODPS for the very complex situation as a function of RPα of EEG. The relationship among these variables was found to be significantly linear (R=0.749).

All three models have been validated using SEE and can be used as a guideline for designers, manufacturers, developers and policy makers, in designing better driving environment for ageing drivers which will integrate safety and transportation to optimize and sustain driving performance while minimizing accident risks for them as well as other road users

6.2 Major contributions of the study

This study has several major contributions particularly in engineering, ergonomics and transportation fields. This study has developed a new approach to determine the driving performance of ageing drivers based on their mental workload measures. The method involves assessing the subjective and objective mental workload of the drivers, with primary and secondary elements of the driving performance. This method will be useful for organizations and policy makers to optimize and sustain ageing drivers' performance

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while minimizing risks of accidents due to unsuitable mental workload on the road. The methodology developed in this study offers transportation ergonomists a systematic approach to evaluate the mental workload and the driving performance not only on ageing drivers, but other age groups as well. It can also be considered as a guideline to evaluate other types of drivers of other transportation modes such as commercial transportation (e.g. lorries and buses).

Models have been developed to predict the ODPS in simple, moderately complex and very complex situations. These models will be useful for designers, engineers, manufacturers and developers in designing solutions that integrate safety elements in the vehicle with environmental features (e.g. road characteristics). Based on these findings, several recommendations can be utilized in developing ageing drivers' support systems considering the correlated factors that affect their driving performance elements. Designers are able to optimize the vehicle design based on the mental workload and situations requirements such as improving the ergonomics design of signal lever in terms of reachability, size and shapes. Results from this study will help policy makers to improve transportation planning in minimizing the risk of accidents for ageing drivers as well as other road users. For example, policy maker can use these findings to improve or develop new polices to increase road safety such as making it compulsory to display ageing drivers' signage on the vehicle and attend additional training class on road safety upon license renewal. Through this study, ageing drivers will be able to gain insights into their vehicle navigation and of the potential to manage and improve their driving mental workload.

Finally, the research findings including the methods and models have contributed to the fundamental knowledge on the relationship between mental workload measures (NASA-TLX ratings and EEG relative power bands) and ODPS (number of traffic violation, speed variability and reaction time of the peripheral detection task), to minimize

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the risks of inappropriate performance and accidents on the road. They provide references for the ageing drivers to plan their driving activities, which take into consideration the capacity and demand of the tasks especially in Malaysia's routes as in the methodology done in the study.

6.3 Recommendations for future study

In this study, ODPS models have been developed successfully. The variation of mental workload responses as well as their relationship with driving performance at different situation complexities have been investigated. However, it shall be noted that several research factors (e.g.: distractions of passengers, gadget usage and operating support systems during driving task) were not considered in this study due to several constraints. Therefore, future studies can be conducted to investigate these factors.

The physiological measures used in this study were limited to brain signal monitoring. Thus, variations of other physiological measures (e.g. Heart Rate, Eye Blink and Heart Rate Variability (HRV)) and their relationships with driving performance will be worthy of investigation in future studies. This study highlighted that the variations of mental workload in driving tasks were potentially measured using physiological measures. On the other hand, driving performance measures used in this study were limited to driving errors, speed and reaction time of the secondary task. Hence, other performance measures that are suitable with on-the-road experiments can be implemented to achieve variations of driving performance measures.

Furthermore, this study focused on Malay ageing drivers which make up the majority population in the country. In future studies, the participant characteristics can be expanded depending on the scope to include other age groups, race and background features.

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2. **Rahman, N.I.A.**, Dawal, S.Z.M., Yusoff N., Kamil N. S. M. (2018). Anthropometric measurements among four Asian countries in designing sitting and standing workstation. Sadhana Academy Proceedings in Engineering Science (ISI Q4- Published).
3. **Rahman, N.I.A.**, Dawal, S.Z.M. and Yusoff N. Ageing drivers subjective mental workload and response rate in real-time driving task. Journal of Engineering Research. (ISI Q4-Under review).
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7. **Rahman, N.I.A.**, Dawal, S.Z.M. and Yusoff N. (2017). Subjective responses of mental workload during real time driving: A pilot field study. International TECH-POST Conference 2017. Faculty of Engineering, University of Malaya. (Published).

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