School of Occupational Therapy and Social Work

Driving on the brain: An investigation of cerebrovascular accident and driving, and the development of a post-stroke driver profile

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Doctor of Philosophy

of

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Declaration

To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgment has been made.

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university.

The research presented and reported in this thesis was conducted in accordance with the National Health and Medical Research Council National Statement on Ethical Conduct in Human Research (2007) – updated March 2014. The proposed research study received human research ethics approval from the Curtin University Human Research Ethics Committee (EC00262), Approval Numbers: HREC OTSW-20-2011 and HR206-2014.

Signature: ___________________________________

Date: 14th March 2017

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Dedication

To complete a PhD has always been my dream and something I have undertaken for myself, to prove that I could, however I would not have been able to complete it without my support network, therefore I dedicate this work to the following:

My family: ***Mum, Dad, Kieran, Zoe and Stitch*** because of their never-ending love, support and ability to make laugh.

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Abstract

Safe driving post-stroke is a multifactorial issue, with physical, cognition and socio-demographic considerations. Previous research has tended to focus on differences between unlicensed post-stroke adults and healthy controls, without first assessing licensed post-stroke drivers as a baseline for the assessments. Without understanding how licensed post-stroke drivers are able to drive safely, despite deficits in cognition, and without reliable and accurate measures of testing, it is difficult to know who in the unlicensed population is safe to return to driving.

The aim of this thesis was to develop a post-stroke driver profile, by: investigating the appropriateness of assessments in post-stroke adults, assessing the influence of cognition on driving performance, as well as investigating the task demand and compensation strategies used in licensed post-stroke adults when driving. This thesis describes quantitative data collected from two projects with the results split into two sections (driving simulator research and on-road driving research) and reported as five individual papers, which are included in the thesis as chapters. Each paper addresses the aim through exploration of several factors predicted to influence driving in post-stroke adults. This was achieved through the utilisation of multiple on- and off-road assessments including: cognitive tasks, questionnaires, a driving simulator and an on-road observation.

Overall, two separate sets of participants were assessed. In Chapter Three, 48 post-stroke adults (24 drivers and 24 non-drivers) were assessed for self-reported socio-demographic status, performance in a driving simulator, as well as their performance on a series of cognitive tasks, and their results compared to those of 22 controls. In Chapters' Four to Seven, subsets of a sample of 85 participants (40 licensed post-stroke drivers and 45 age and gender matched controls) were assessed and data relating to their driving performance, driving behaviour, self-perceived performance, task demand and cognitive ability were compared. This provided information related to cognitive ability and how it related to driving, as well as an understanding of the task demand and compensation strategies employed by licensed post-stroke drivers.

The results found that attention, executive function and propensity for risk may be useful to assess as part of a post-stroke driving assessment and that post-stroke drivers amend their scanning patterns depending on their executive function and attentional ability. Similarly, the results found that post-stroke drivers may be more aware of their cognitive deficits, as they generally rated their performance lower than that of controls despite similar estimates of task demand. This suggested that post-stroke drivers may amend their driving behaviour to account for cognitive deficits and moderate their accepted task demand when driving.

The findings of this thesis provide a baseline for future research and assessment, as well as an understanding of the post-stroke driving behaviour that will inform rehabilitation strategies. This was achieved through examining the aspects of cognition that are impacted post-stroke, exploring how to best assess these attributes and finally through understanding the compensatory mechanisms and how they relate to cognitive deficits. Ultimately, the results of this thesis will provide hope for post-stroke drivers who may have doubted their ability to return to driving and provide a guide for medical practitioners to assist them with achieving a return to driving

Contents Page

List of Figures

List of Tables

List of appendices

Abbreviations List

ANOVA – Analysis of Variance

AUS – Australia

BART – Balloon Analogue Risk Taking Task

BJLOT – Benton Judgement of Line Orientation Task

BSAV – Begin Block Save

CAN – Canada

CI – Confidence Intervals

CSIRS – Curtin University Strategic International Research Scholarship

DBC – Driver Behaviour Checklist

DF - Degrees of Freedom

DHQ – Driving Habits Questionnaire

DKEFS TMT – Delis Kaplan Executive Function System Trail Making Task

DV - Dependent Variable

DVT – Digit Vigilance Task

EF – Executive Function

ETDRS – Early Treatment Diabetic Retinopathy Study Chart

EU – Mainland Europe

F- Female

GEE – General Estimating Equation

GLM – General Linear Model

GP – General Practitioner

GPS – Global Positioning System

HP – Hazard Perception

HREC – Human Research Ethics Committee

IQR – Interquartile Range

IV – Independent Variable

km - Kilometres

LSD - Least significant difference

M - Male

m - Metres

MoCA - Montreal Cognitive Assessment

MRT – Mean Reaction Time

Ms - Milliseconds

n – Number in group sample

N – Number in study population

N/A - Not Applicable

NASA - National Aeronautics and Space Administration

NSF – National Stroke Foundation

NZ – New Zealand

OTSW – School of Occupational Therapy and Social Work

PCA – Principal Components Analysis

PSD – Post-Stroke Drivers

PS-ND- Post-Stroke Non-Drivers

R^2 – R Squared

RSRT – Road Sign Recognition Test

RT – Reaction Time

RTs – Reaction Times

s - Seconds

SD-Standard Deviation

SMI – SensoriMotor Instrument

SRT – Simple Reaction Time

SPSS – Statistical Package for Social Sciences

SS – Simulator Sickness

TB - Terabyte

TIA – Transient Ischemic Attack

TAFE - Technical and Further Education College

TM - Trademark

TMT-B – Trail Making Test Part B

TLX – Task Load Index

UFOV – Useful Field of View

UK – United Kingdom

USA – United States of America

VA –Visual acuity

WA – Western Australia

χ^2 – Chi Square

2CRT – Two-Choice Reaction Time Task

4CRT – Four-Choice Reaction Time Task

List of Publications

List of Published Manuscripts

Blane, A., Falkmer, T., Lee, M., Parsons, R., & Lee, H. (2016). The cognitive and socio-demographic influences on driving performance and driving cessation in post-stroke drivers. *Advances in Transportation Studies* (38), 121-135.

Blane, A., Lee, H. C., Falkmer, T., & Dukic Willstrand, T. (2017). Assessing cognitive ability and simulator-based driving performance in post-stroke adults. *Behavioural Neurology, 2017* (Behavioural and Cognitive Effects of Cerebrovascular Diseases), 1-9. http://dx.doi.org/10.1155/2017/1378308

List of Accepted Manuscripts

Blane, A., Falkmer, T., Lee, H., & Dukic Willstrand, T. Investigating cognitive ability and self-reported driving performance of post-stroke adults in a driving simulator, *Topics in Stroke Rehabiliation.*

List of Manuscripts out for Review

Blane, A., Falkmer, T., Lee, H., & Dukic Willstrand, T. Cognitive ability as a predictor of task demand and self-rated driving performance in post-stroke drivers – implications for self-regulation, *Journal of Transport and Health.*

Blane, A., Falkmer, T., Lee, H., & Dukic Willstrand, T. On-road visual scanning in post-stroke drivers in relation to their cognitive functioning, *Gerontology.*

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Statement of Author Contribution

The nature and extent of the intellectual input by the candidate and co-authors has been validated by all authors, and can be found in Appendix 1.

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Dr Tania Dukic Willstrand

(Supervisor)

Chapter One: Introduction

Introduction

Safe driving is important and affects all road users, however although a physical action, driving is heavily reliant on cognitive processes. Following a cerebrovascular injury, such as a stroke, there is the increased likelihood of experiencing cognitive decline, so determining who in the post-stroke population is suitable to drive is paramount. There is limited guidance available in the literature for post-stroke adults and practitioners to understand the effect of a stroke on driving-related cognition and driving practice, particularly as there is little research investigating licensed post-stroke adults who have successfully returned to driving. Therefore, understanding the mechanisms that enable a safe return to driving in the post-stroke population will assist with the development of assessment tools and help inform rehabilitation programs. The purpose of this chapter is to outline the aim and objectives, as well as inform the structure of the thesis and provide an overview of the literature to set the thesis in context.

Aim and rationale

The overall aim of this research was to develop a post-stroke driver profile by: investigating the appropriateness of assessments in post-stroke adults, assessing the influence of cognition on driving performance, and investigating the task demand and compensation strategies used in licensed post-stroke adults when driving. There were a number of specific research objectives, all of which are outlined below and are addressed in the following chapters:

Objectives

1. Assess the relationship between deficits in cognition, executive function and driving behaviour in post-stroke drivers and non-stroke drivers.
2. Assess the socio-demographic factors influencing driving behaviour in post-stroke drivers and post-stroke non-drivers.

3. Assess the off-road driving performance of post-stroke drivers compared with the performance of healthy controls. Off-road assessment included:
    - a series of neurocognitive tasks; and
    - a driving simulator.
4. Assess the on-road driving behaviour of post-stroke drivers, compared to healthy controls using:
    - eye-tracking; and
    - an on-road observation checklist.
5. Compare the perceived level of task demand involved in different driving scenarios in post-stroke drivers to that of a comparison group of healthy controls.
6. Assess self-perception of driving behaviour and observed driving behaviour (calibration) and how it relates to cognition.
7. Assess compensation strategies for deficits in cognition that enable driving in post-stroke adults.

Thesis Overview

The format of this thesis is that of a 'hybrid' meaning that the thesis is made up of an expanded selection of published, accepted and non-published manuscripts, sandwiched between elements of a traditional typescript thesis. This thesis describes quantitative data collected from two projects with the results split into two sections (driving simulator research and on-road driving research) and reported as five individual papers, which are included in the thesis as chapters. The data included in Chapter Three was collected as part of the first project. The data in project two was collected as part of a large assessment protocol, which is described in detail in Chapter Two. As part of the assessment protocol, multiple on and off road assessments including: cognitive tasks, questionnaires, a driving simulator and an on-road observation were utilised. The results of the individual assessments were reported as individual papers and form Chapters Four – Seven. Each paper addressed the aim through exploration of several factors predicted to influence driving in post-stroke adults. A descriptive summary of each individual chapter is provided below with the format, methodologies used, and the findings and implications highlighted (Tables 1 and 2). A flow chart of the thesis outline is also provided (Figure 1).

In Chapter One, the background to the thesis has been outlined. Chapter Two will outline the methodologies utilised within the project, as well as the rationale for each.

Chapter Three is comprised of expanded material from paper published in the journal; 'Advances in Transportation Studies'. The published paper is included in Appendix 11. The study investigated the influence of demographic and socioeconomic factors, as well as cognition on the decision to continue with or to cease driving post-stroke.

Chapter Four is comprised of a manuscript published in a special issue of the journal 'Behavioural Neurology'. A copy of the author proofed manuscript for the journal is included in Appendix 13. This chapter explores the use of cognitive assessments and driving simulator performance.

Chapters Five to Seven are comprised of manuscripts currently out for review in multiple peer-reviewed journals and explore the concept of cognition, task demand, self-rated performance and driver calibration in post-stroke drivers. Chapter Five discusses cognition, task demand and calibration in a driving simulator whilst Chapter Six explores cognition, task demand and calibration on-road. Chapter Seven is the final results chapter and investigates the visual compensation strategies that licensed post-stroke drivers employ in order to safely navigate the driving task, and how visual compensation strategies relate to cognition and task demand. The implications of these results for assessment and rehabilitation of post-stroke drivers are discussed.

Finally, in Chapter Eight, the results are integrated, summarised and discussed in context. Furthermore, the limitations of the project and the overall conclusions of this project are outlined, as well as the recommendations for post-stroke drivers, recommendations for future research, recommendations for practitioners and recommendations for policy makers discussed.

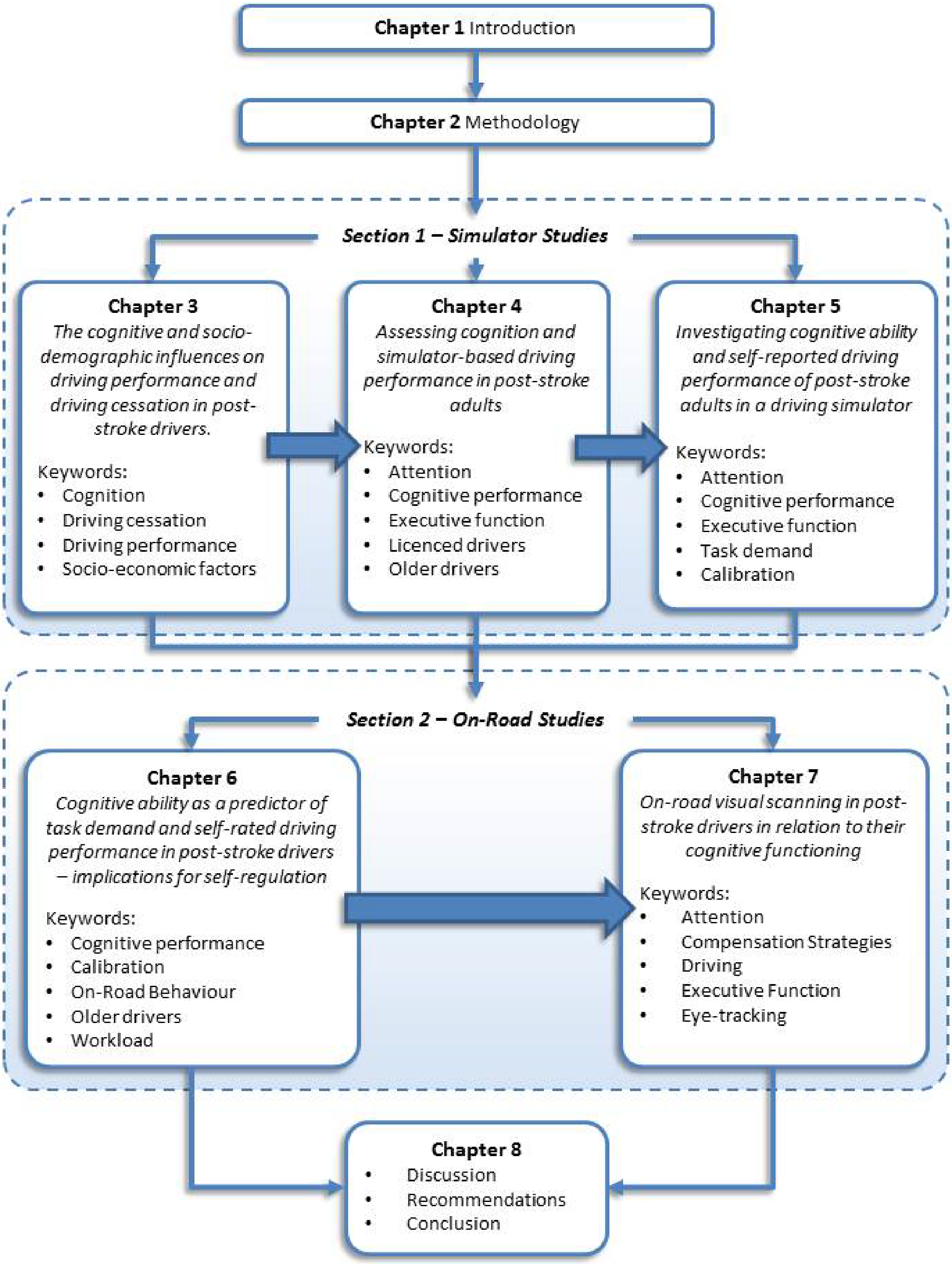

Figure 1. Flow chart of thesis outline

Table 1.

Summary table outlining thesis chapters, objectives, methodologies, findings and implications.

Chapter (Paper)	Submission Year	Format	Objectives Assessed	Design	Methodologies	Findings and Implications
Three (One)	2016	Published Paper	1, 2 & 3	***Design****:* Comparison Group ***Driving Methodology:*** Driving Simulator ***Groups:*** Post-stroke driver, post-stroke non-driver and controls	DKEFS-TMT, BJLOT, Block Design, Digit Vigilance Test, Road Sign Recognition Test, Driving Simulator	This study confirmed previous research, which found that cognition and driving performance are impaired post-stroke. The decision to return to driving after a stroke is a complicated, multifactorial process, which includes socio-demographic factors, such as education and income. Further screening tools and assessments to identify those at risk when returning to the road post-stroke are required.
Four (Two)	2017	Published Paper	1 & 3	***Design:*** Comparison Group ***Driving Methodology:*** Driving Simulator ***Groups:*** Post-stroke drivers and controls	DKEFS-TMT; UFOV; Psychomotor processing; BART, Block Design, BJLOT; Driving Simulator	Although post-stroke drivers performed more poorly on some cognitive assessments than the control group, there were few differences in driving simulator performance. Differences in driving performance suggested that the post-stroke adults exhibited more cautious driving behaviour. The use of specific cognitive assessments, as well as driving simulators when assessing fitness-to-drive is discussed.
Five (Three)	2017	Accepted Paper	1, 3, 5, 6 & 7.	***Design:*** Comparison Group ***Driving Methodology****:* Driving Simulator ***Groups:*** Post-stroke drivers and controls	DKEFS-TMT, UFOV, Driving Simulator, NASA TLX.	On average, post-stroke drivers were more conservative in their self-perceived level of driving performance and this was related to level of cognitive ability. Furthermore, there no differences in level of perceived task demand. This study suggests a level of self-awareness and behaviour modification for the post-stroke drivers and the implications for assessing self-perception and calibration of performance in off-road driving simulation assessments is discussed.

Six (Four)	2017	Submitted Manuscript Undergoing Revisions	1, 4, 5, 6, & 7.	***Design:*** Comparison Group ***Driving Methodology:*** On-Road Study ***Groups:*** Post-stroke drivers and controls	DKEFS-TMT, UFOV, BART, NASA TLX, Driving Behaviour Checklist	There were no differences between groups for self-rated task demand when driving on-road. On-average, the post-stroke drivers rated themselves lower in self-rated on-road driving performance than the control group. The post-stroke drivers displayed poorer cognitive performance than the controls and self-rated driving performance was linked to cognitive performance. This study suggests that post-stroke drivers have some level of awareness of their cognitive deficits amend their driving behaviour on-road to compensate. The implications of using cognitive assessments, as well as self-rated driving performance assessment are discussed with reference to driving rehabilitation.
Seven (Five)	2017	Submitted Manuscript Undergoing Revisions	1, 4 & 7.	***Design:*** Comparison Group ***Driving Methodology:*** On-Road Study Eye-Tracker Study ***Groups:*** Post-stroke drivers and controls	Eye-tracker; Driving Behaviour Checklist; DKEFS-TMT, UFOV,	Compared to the control participants, the post-stroke drivers had shorter fixations and an increased spread of fixations, as well as a greater total number of visual fixations, spread evenly between traffic relevant and non-relevant objects when driving on-road. The increased spread and number of fixations were related to cognitive performance (specifically attention and executive function) in the post-stroke drivers and indicated a compensation strategy to decrease task demand. The implications for using measurements of fixations within rehabilitation and fitness-to-drive assessments are discussed.

Table 2.

Methodology description and acronym list

Name	Description	Citation	Type
Driving Habit Questionnaire (DHQ)	Driving habits, driving history, demographic data and medical history was collected using the paper-based Driving Habits Questionnaire	Owsley, Stalvey, Wells, and Sloane (1999).	**Questionnaire**
NASA Task Load Index (NASA TLX)	A paper and pencil based task used to assess self-rated performance and task demand using six sub-scales: mental demand, physical demand, temporal demand, performance, effort and frustration.	Hart and Staveland (1988)	**Questionnaire**
Balloon Analogue Risk Taking Task (BART)	A computer based task involving blowing up balloons in order to win points and implemented as a task to assess propensity for risk taking behaviour. The task was administered using E-Prime (Schneider, Eschman, & Zuccolotto, 2012)	Lejuez et al. (2002)	**Cognitive**
Benton Judgement of Line Orientation Task (BJLOT)	A paper and pencil based task consisting of picking target lines from a series of reference lines and which was used to assess spatial cognition, perception and orientation ability.	Benton, Hamsher, Varney, and Spreen (1983)	**Cognitive**
Block Design	A sub-task of the Wechsler Adult Intelligence Scale used to assess non-verbal visuospatial reasoning.	Wechsler (2008)	**Cognitive**
Delis-Kaplan Trail-Making Test (DKEFS-TMT)	A paper and pencil based task that assessed various types of baseline cognitive processes as well as higher order executive functioning and cognitive flexibility.	Delis, Kaplan, and Kramer (2001)	**Cognitive**
Digit Vigilance Task (DVT)	A paper and pencil based task used to evaluate sustained attention and speed of cognitive processing	Lewis and Rennick (1979)	**Cognitive**
Montreal Cognitive Assessment (MoCA)	A 30-item cognitive screening tool that has been validated for measuring mild cognitive impairment in older adults	Nasreddine et al. (2005)	**Cognitive**
Psychomotor Performance	Several computer based tasks administered using E-Prime Software (Schneider et al., 2012). The tasks consisted of a simple reaction time task, a 2 choice reaction time task (2CRT) and a 4 choice reaction time task (4CRT).	Bunce, Handley, and Gaines (2008)	**Cognitive**

Road Sign Recognition Test	A paper-based test requiring the participant to display knowledge of road signs, visual recognition, memory, and problem solving abilities.	Lincoln and Fanthome (1994)	**Cognitive**
Useful Field of View (UFOV)	The Useful Field of View© (UFOV) is a computer based task that was developed as means of measuring visual, selective and divided attention	Ball, Owsley, Sloane, Roenker, and Bruni (1993)	**Cognitive**
STISIM Driving Simulator	A fixed-base car driving simulator programmed using the STISIM© driving software	Allen, Stein, Aponso, Rosenthal, and Hogue (1990)	**Driving**
On-Road Driving Behaviour Checklist	Score-based on-road checklist used to assess driving behaviour by measuring adherence to driving-related rules and regulations and manoeuvring performance at specific areas of interest, e.g., intersections, stop signs, roundabout, etc.	Chee, Lee, Lee, and Falkmer (2013)	**Driving**
Eye-Tracking Camera	Head-mounted eye-tracking camera. • the Arrington ViewPoint™ eye-tracking glasses • the SensoMotoric Instruments™ (SMI) eye-tracking glasses		**Driving**

Definitions

Driving

Driving is an important activity of daily living that involves adequate control and manoeuvring of a motorised vehicle, avoiding potential hazards, as well as forward planning and route navigation (Stanton & Marsden, 1996; Young, 2000). The safe completion of the driving task requires drivers to operate effectively at three hierarchical levels: strategic, tactical and operational (Michon, 1985; Ranney, 1994). The ability of the driver to do this requires the effective functioning of perceptual and cognitive processes (Anstey, Wood, Lord, & Walker, 2005). Furthermore, how a driver behaves on the road is worth defining (Evans, 2004). Specifically, driver performance is defined as what a driver can do, i.e., the limits and availability of their knowledge of driving, skills related to vehicle management, as well as their perceptual and cognitive abilities, whereas driver behaviour is defined as how a driver applies these attributes to the driving task, i.e., there is an element of choice involved (Evans, 2004). There is much debate in how to assess these concepts, however throughout this thesis, unless otherwise stated, the variables assessed in the driving simulator refer to driver performance and the on-road dependent variables refer to driver behaviour (Mullen, Charlton, Devlin, & Bedard, 2011; Ranney, 2011).

Cognitive Processes

Attention. Attentional processing is made up of a series of different sub-processes, each of which manage a specialised function, including, but not limited to, visual attention, selective attention, divided attention and sustained attention (Glisky, 2007).

- Visual attention involves a set of cognitive mechanisms that assist with processing visual information (Evans et al., 2011).
- Selective attention is a dynamic process that enables a person to focus and select appropriate information from non-relevant stimuli (Kramer & Madden, 2011). The process involves both bottom-up and top-down information in order to determine recognition of the stimuli as relevant to the task at hand (Kramer & Madden, 2011).
- Divided attention refers to attending and accurately processing information from multiple sources or senses, as well as the ability to utilise multiple independent skillsets in order to concurrently complete separate tasks (Kramer & Madden, 2011).
- Sustained attention refers to the ability of a person to maintain vigilance (i.e., to sustain concentration) to a particular task over an extended amount of time (Glisky, 2007).

Executive Function. Executive function is the collection of temporal processes that control behaviour regulation including; planning, monitoring, goal-selection, motor control and decision making (Foster, Black, Buck, & Bronskill, 1997; Gottesman

& Hillis, 2010), through a number of processes, e.g., shifting, inhibition, updating, working memory, and sustained and selective attention (Alvarez & Emory, 2006; Foster et al., 1997; Miyake et al., 2000).

Visuospatial Function. Visuospatial processing and function refers to the ability to visually identify and analyse visual and spatial stimuli, as well as process complex spatially-based relationships between objects, for example identifying object orientation and distance processing (Scott & Schoenberg, 2011).

Overview of the literature

Driving

Driving is a highly complex, acquired skill and an important activity of daily living that is heavily relied upon in modern society as a means of independent transportation (Griffen, Rapport, Coleman Bryer, & Scott, 2009; White et al., 2012). It is also a highly cognitively dependent task, requiring the use of multiple cognitive and visual functions (Anstey et al., 2005). Safe driving requires a driver to constantly interact with the vehicle and external environment (including road types and conditions, traffic and other road users etc. (Coyne, 2007)) through effective mediation between multiple components, i.e., control of the vehicle, hazard avoidance, route planning and navigation (Stanton & Marsden, 1996). As the consequences of poor driving are dangerous, particularly in an ageing population (Meuleners, Harding, Lee, & Legge, 2006), the need to be able to identify who is safe to drive is imperative. In Australia, after passing the initial driving test, there is little in the way of reassessment as compulsory testing for those under 85 years old has recently been revoked in some states, with the caveat in place that aged drivers must present for a medical assessment each year (Austroads & National Transport Commision Australia, 2016). At present, the only situation where reassessment is required under 85 years of age is following a recommendation from a medical professional or as a result of a medical incident that may affect the ability to drive (Austroads & National Transport Commision Australia, 2016).

Cerebrovascular Accident

The medical term cerebrovascular accident is generically termed a stroke and refers to a serious incident in the brain, where damage to the cerebral blood vessels prevents oxygen from circulating in the brain, resulting in cerebral hypoxia and can ultimately lead to cell death (Sacco et al., 2013). As displayed in Figure 2, a stroke is caused in one of the following ways: either by a blood clot within the brain or a blockage in a cerebral vessel, which is known as an ischemic stroke or a transient ischemic attack i.e., a TIA, or when a cerebral vessel ruptures and causes blood to leak within the brain, which is known as a haemorrhagic stroke (Scheffer, Monteiro, & De Almeida 2011). The resulting lack of oxygen from a clot or haemorrhage causes extensive damage to the brain and can temporarily or permanently impact upon a person's visual, cognitive, physical and motor abilities, which can make completing everyday tasks, such as driving, difficult (Poole, Chaudry, & Jay, 2008).

A stroke can occur at any time during a person's life, although it is most prevalent in the older adult population (Australian Bureau of Statistics, 2009; Australian Institute of Health and Welfare, 2013). It is a considered a medical emergency, as it is one of the leading causes of mortality in adults worldwide (Feigin et al., 2014; Strong, Mathers, & Bonita, 2007; Thrift et al., 2014). The global incidence of stroke-related mortality is expected to reach 7.8 million per year by 2030 (Strong et al., 2007) and the Australian Bureau of Statistics estimated that in 2015, 381,400 Australians were diagnosed with a stroke, which is approximately 1.8% of the 24 million total population (Australian Bureau of Statistics, 2009). In addition, the prevalence rate of stroke survivors and burden of stroke is increasing (Feigin et al., 2014).

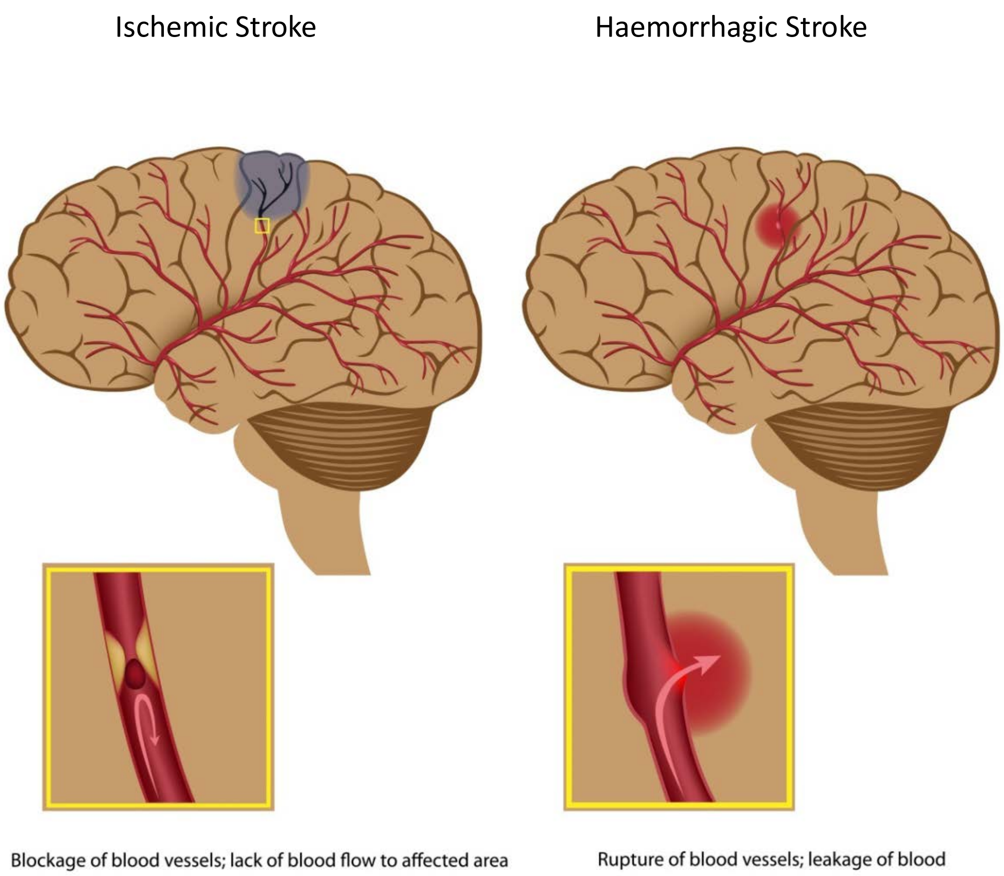

Figure 2. A diagram illustrating an ischemic and haemorrhagic stroke. Reprinted from *Shutterstock, Stock illustration ID: 78690082* by Alila Medical Media, 2017. Retrieved from https://www.shutterstock.com

Outcomes of a Stroke

The outcomes of a stroke can be severely debilitating, with the possibility for and length of recovery related to the severity of the stroke (Uc & Rizzo, 2011). The life expectancy following a haemorrhagic stroke is low and in those who survive, the damage caused is severely debilitating and lowers life expectancy (Brønnum-Hansen, Davidsen, & Thorvaldsen, 2001; Dennis et al., 1993; Sacco, Wolf, Kannel, & McNamara, 1982). In Western populations, such as the United States, it has been estimated that approximately 87% of stroke are caused by ischemia, with the remainder caused by a haemorrhage (Go et al., 2014; Uc & Rizzo, 2011). As the post-stroke survival rates are increasing, there are more people living with the subsequent disabilities associated with a stroke (Feigin et al., 2014). Uc and Rizzo (2011) reported that 50% to 70% of stroke survivors would recover from their stroke to the extent that they obtained some form of functional independence, whereas the remainder are left severely disabled.

For the post-stroke adults who recover, alongside the physical disabilities, (hemiplegia, hemiparesis, balance deficits, aphasia, dysphagia, visual deficits etc.), there is also an increased likelihood some lasting cognitive impairment (Belagaje & Butler, 2013). Cognitive impairment is not composed of a singular or unitary condition with a gradient of function, however instead consists of deficits across multiple cognitive functionalities (Jokinen et al., 2015). For example, psychomotor speed, memory, visuospatial function, attention, and executive function are frequently cited as impaired in post-stroke adults (Gottesman & Hillis, 2010; Jokinen et al., 2015), all of which are involved in driving (Anstey et al., 2005).

Stroke and Driving-Related Cognition

The safe navigation of driving tasks is heavily reliant on cognitive function (Anstey et al., 2005). The likelihood of driver errors is known to increase with increasing levels of deficit in cognitive functions e.g., memory, attention, perception, decision-making and executive function, response implementation and awareness (Uc & Rizzo, 2011). Therefore understanding the effect of cognitive performance on driving in post-stroke adults is important, particularly as cognitive deficits can persist beyond the acute physical recovery (Jokinen et al., 2015) and these deficits can impact on the return to tasks of everyday living (Gottesman & Hillis, 2010). Previous research has identified the key factors involved in safe driving are various attention-based processes (e.g., divided attention, selective attention, sustained attention switching attention and visual attention), processing speed, executive function and visuospatial function (Anstey et al., 2005; Ranney, 1994).

Cognitive Resources and Task Demand

Cognitive resources refer to the cognitive capacity, such as the memory, attentional and executive function-based resources available to manage a task (Eysenck, 1982; Glisky, 2007). Research has suggested that there is a limited and finite amount of attentional capacity available, however that the division of the processes is fluid (i.e., attentional capacity can be divided across multiple tasks) and dependent on a task demand (Kahneman, 1973). Task demand is the amount of cognitive resources and task-directed effort that are required to complete a given task (Dunn & Williamson, 2012). In the Kahneman (1973) model, arousal and effort are linked to attentional processes, meaning that as task demand increases the amount of allocated resources also increases. Therefore when learning a skill, more demand and more allocated resources are required, however as skills become more automated, the level of resources required decreases (Kahneman, 1973; Schneider & Shiffrin, 1977). Furthermore, as expertise is reached, it follows that in skilled users, when demand capacity is exceeded, cognitive resources can be downgraded, as well as strategies adjusted to compensate (Young, Brookhuis, Wickens, & Hancock, 2015). Much previous research has suggested that attentional capacity decreases with age (e.g., Craik & Byrd, 1982; Glisky, 2007). To counter this decrease, older adults have been found to employ compensatory strategies (Andrews & Westerman, 2012) and there is the possibilty for compensatory strategies to exist whilst driving (van Zomeren &Brouwer, 1994). For example, this has been observed where older drivers report a slower pace when driving, in order to compensate for slower processing and executive function deficits and to enable safe manoeuvring (Daigneault, Joly, & Frigon, 2002).

Driving-Related Task Demand

There are a number of models that address task demand when driving. According to the task-capability interface model (Figure 3) proposed by Fuller (2005), drivers are able to respond to the level of demand required for a driving task by adjusting the difficulty through behaviour modification (self-regulating), e.g., they increase or reduce the vehicle speed or by changing lane. This process of task difficulty homeostasis (Figure 4) allows the driver to align task demand with their perceived capabilities (Fuller, 2005), for example, by undertaking self-regulated driving to avoid high-stress traffic situations (Hakamies-Blomqvist & Wahlström, 1998; Molnar & Eby, 2008).

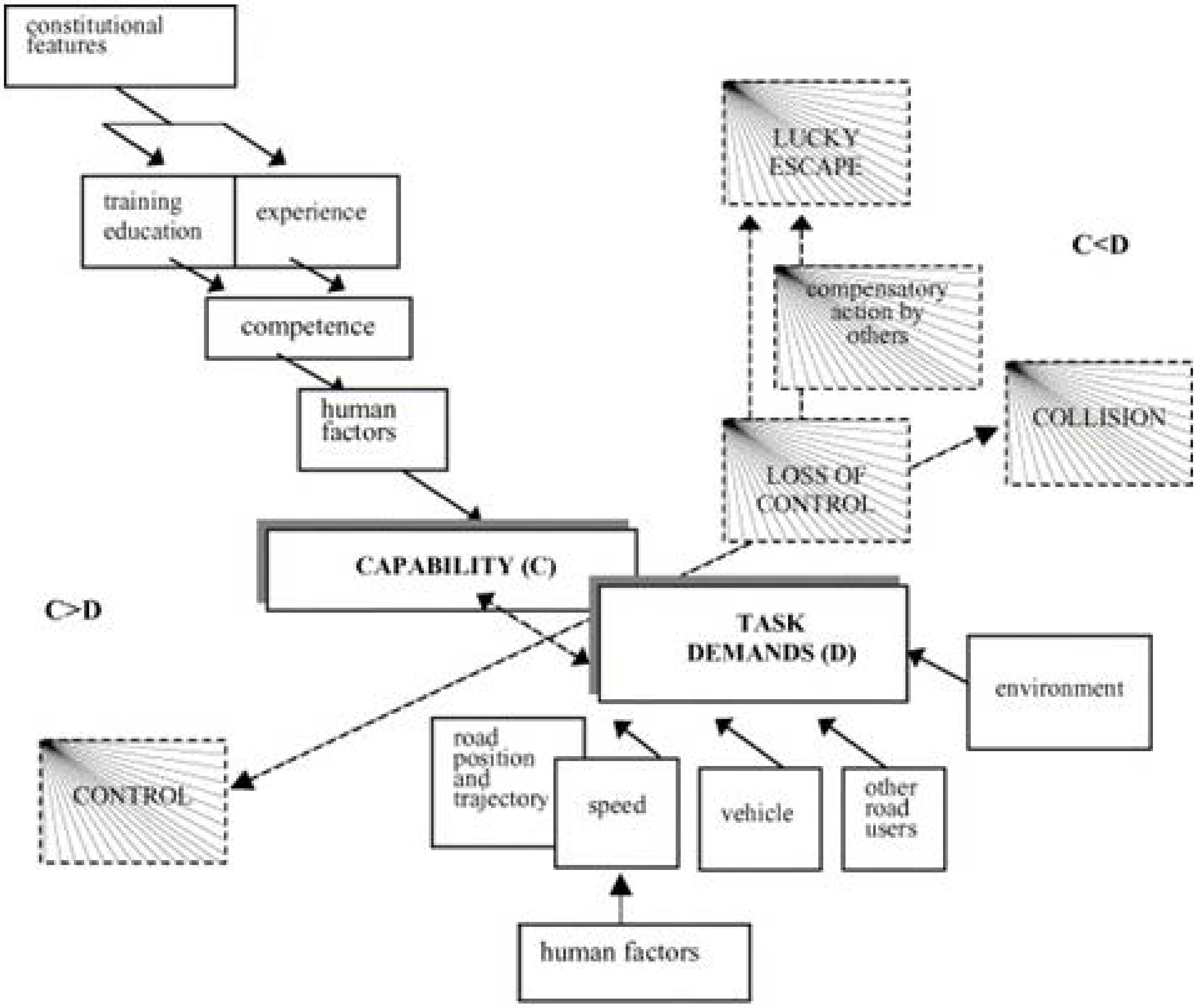

Figure 3. The Task Capability Framework. Reprinted from R. Fuller, 2005, Towards a General Theory of Driver Behaviour. *Accident Analysis & Prevention*, 37*(3), p. 465. Copyright 2005 by Elsevier Ltd.*

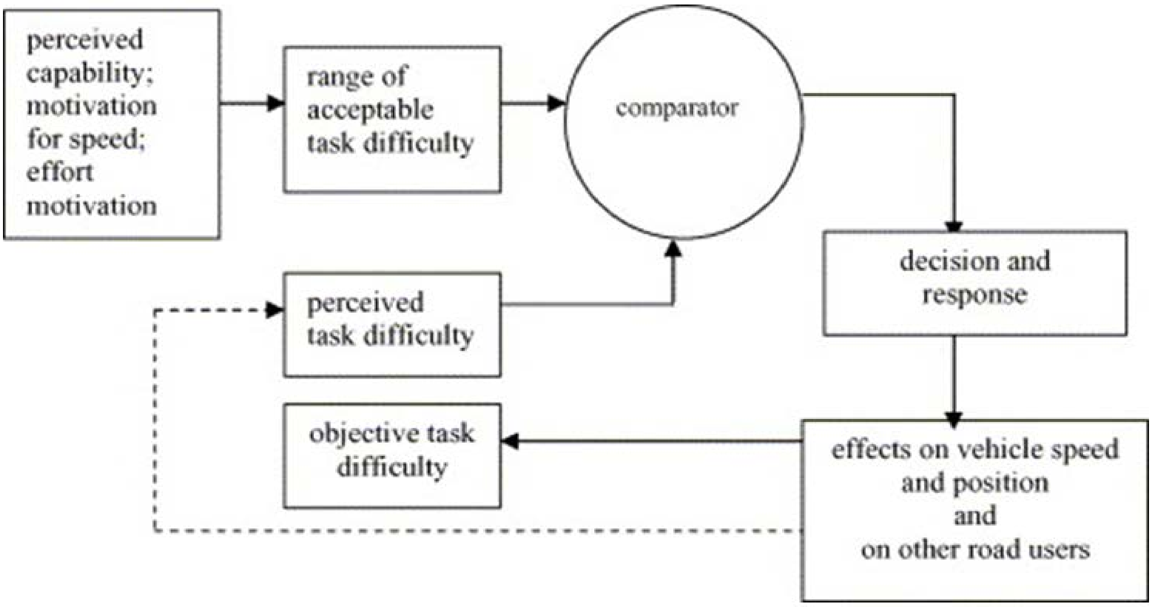

Figure 4. Task difficulty homeostasis. Reprinted from R. Fuller, 2005, Towards a General Theory of Driver Behaviour. *Accident Analysis & Prevention*, 37*(3), p. 467. Copyright 2005 by Elsevier Ltd.*

Furthermore, understanding the requirements to successfully complete a task is important for driving as failure to accurately evaluate the task processes involved can result in exceeding the levels of cognitive resources available, which can mean that drivers enter into scenarios they are ill-equipped to negotiate. This requires an accurate perception of the level of task-directed effort required to complete a task and a realistic self-evaluation of the cognitive resources available to complete the task. This is known as "calibration" (Horrey, Lesch, Mistopolous-Rubens, & Lee, 2015) and is important for self-regulation.

There is currently some debate regarding whether post-stroke drivers are capable of accurate self-assessment and calibration. Some research has identified that drivers who have suffered a stroke and continue to drive were found to overestimate their driving capabilities and take greater risks on the road (Heikkilä, Korpelainen, Turkka, Kallanranta, & Summala, 1999; Scott et al., 2009), however others have found that brain injured patients are capable of realistic judgements (Lundqvist & Alinder, 2007; Stapleton, Connolly, & O'Neill, 2012). Certainly, previous research investigating post-stroke drivers has found that they modify their driving behaviour through self-regulation (Fisk, Owsley, & Mennemeier, 2002).

Self-Regulation and Driving Cessation

The ability to continue driving is considered a key element for functional mobility and autonomy, particularly in older age (Burns, 1999; Persson, 1993). Many older drivers are reluctant to relinquish their licenses (Unsworth, Wells, Browning, Thomas, & Kendig, 2007), as driving cessation can lead to a decrease in out-of-home activity (Marottoli et al., 2000), a loss of independence (Green, Siddall, & Murdoch, 2002) and cause increased feelings of loneliness, isolation and depression (Fonda, Wallace, & Herzog, 2001; Marottoli, Mendes de Leon, Glass, & Williams, 1997; Ragland, Satariano, & MacLeod, 2005; Rudman, Friedland, Chipman, & Sciortino, 2006), particularly as there is no comprehensive scheme in place to help those who are required to stop driving remain mobile (Marin-Lamellet & Haustein, 2015). This has been found to be particularly common in post-stroke drivers (Lister, 1999; Logan, Dyas, & Gladman, 2004; Patomella, Johansson, & Tham, 2009). Instead of ceasing driving, many older adults tend to self-regulate their driving (Baldock, Mathias, McLean, & Berndt, 2006; Ball et al., 1998; Molnar & Eby, 2008).

There has been a range of research investigating the self-regulation practices of older drivers. Much of the research in this area suggests that older adults tend to self-regulate their driving by modifying the times of day that they drive, typically avoiding high demand driving situations, such as parallel parking, driving at night and driving during adverse weather conditions (Baldock et al., 2006). This pattern of behaviour has also been observed in post-stroke drivers (Fisk et al., 2002). Furthermore, post-stroke adults are also more likely to prematurely cease their driving, potentially through seeing themselves, whether correctly or not, as unfit for driving (Blane, Falkmer, Lee, Parsons, & Lee, 2016; McKay, 2007).

Driving self-regulation and driving cessation are important to consider as they have a large impact on the quality of life for the post-stroke adult. Research has shown that premature driving cessation has a detrimental effect on people's wellbeing, as it can lead to a reduced quality of life through a loss of autonomy, isolation and depression (Fonda et al., 2001; Marottoli et al., 1997; Ragland et al., 2005; Rudman et al., 2006). This is particularly problematic if there is little in the way of social support or care infrastructure (Choi, Adams, & Kahana, 2012; Donorfio, D'Ambrosio, Coughlin, & Mohyde, 2009; Griffen et al., 2009). Conversely, those who do not appropriately regulate their driving, risk becoming engaged in tasks beyond their capability and are at an increased risk of a crash (Fuller, 2005; Hassan, King, & Watt, 2015). This is particularly problematic for the older post-stroke driver who is at greater risk of mortality in a crash, due to the increased frailty associated with age (Meuleners et al., 2006). There is some debate regarding whether post-stroke adults are at an increased risk of a crash, with much variation in the results. A structured review by Perrier, Korner-Bitensky, Petzold, and Mayo (2010) reviewed multiple databases and found that five of the seven studies analysed as part of the review suggested that post-stroke drivers are more likely to report a crash than control groups. However, Perrier et al., (2007) also reported two studies which did not find an association with increased crash risk. Although the two studies that reported non-significant findings had also not adjusted for annual mileage, it is possible that part of the discrepancy in the results may stem from the differences in their stage of recovery, as well as the licence status of the driver (Perrier et al., 2010), as generally functional impairments are generally associated with crash risk (Hakamies-Blomqvist, 1998).

Self-regulation of driving is a compensation strategy often employed to assist with increased mobility and autonomy (Gwyther & Holland, 2012), however it often bears little relation to actual driving performance or ability (Baldock et al., 2006). Instead, it has been suggested that self-regulation is related to socio-demographic and lifestyle factors (Braitman & Williams, 2011), issues with driving-related confidence (McNamara, Walker, Ratcliffe, & George, 2014), as well as to cognitive impairments, and the associated increased task demand (Braitman & Williams, 2011; Rapoport et al., 2013). The ability of the post-stroke driver to successfully employ self-regulation and compensation strategies should be addressed as part of the assessment and rehabilitation phase following their diagnosis.

Post-Stroke Driving Assessment and Rehabilitation

Brain damage, such as that caused during a stroke, is known to affect the person's fitness-to-drive (van Zomeren & Brouwer, 1994). For post-stroke adults in Australia, if they receive medical clearance to drive, they may return to driving using a private licence, although there may or may not be limitations attached to the licence e.g., using adaptive equipment or a limit to the number of kilometres that they can travel (Austroads & National Transport Commision Australia, 2016). As well as achieving medical clearance, the process for returning to driving requires the affected person to observe a minimum recovery period (two weeks for a TIA or four weeks for an ischemic or haemorrhagic stroke), and requires the notification of the stroke to the relevant state licensing authority (Austroads & National Transport Commision Australia, 2016). If the medical professional believes it necessary, the post-stroke adult may be required to attend a driving assessment or further driving training before returning to driving. These assessments are carried out by Driving Assessment-Trained Occupational Therapists who assess the post-stroke adult in a number of on-road and off-road assessments. The assessments normally consist of a neuropsychological assessment, which assesses various aspects of cognition and an on-road observation with the assistance of a driving instructor using dual-controlled vehicle. The Occupational Therapist will then make a recommendation to the post-stroke adult's authorising medical professional, who will subsequently determine if they are safe to drive. However, this process is not standardised and the experience of post-stroke adults varies with regard to the advice they receive following their stroke and the evaluation they undertake (Allen, Halbert, & Huang, 2007; Galski, Bruno, & Ehle, 1992; Galski, Ehle, McDonald, & Mackevich, 2000; Lister, 1999). It has been suggested that, as well as socio-demographic and cognitive influences, potential reasons for varying numbers in post-stroke adults returning to driving are based on the lack of knowledge of the legalities, processes and availability of support in both post-stroke adults and medical professionals (Chua, McCluskey, & Smead, 2012). Although driving education is recommended for post-stroke survivors (Austroads & National Transport Commision Australia, 2016), again there is a need for consistency in the implementation of assessments and education for post-stroke adults, as currently post-stroke adult experiences of the return to drive process vary (Chua et al., 2012; McNamara, McCluskey, White, & George, 2014; White et al., 2012).

Methods of assessing driving performance and behaviour

Clinical on-road assessments. Clinical assessments of returning to driving often involve an on-road test, as does much research in the area of post-stroke driving and these are generally considered the most accurate and valid measurement of driving behaviour and performance (Hird, Vetivelu, Saposnik, & Schweizer, 2014). As part of a systematic review on the subject Hird et al. (2014) reported that there were varying degrees of pass-rates, which were dependent on the type of assessment, as well as various socio-demographic criteria. Although there have been attempts at validating on-road assessments (e.g., Odenheimer et al., 1994; Ott, Papandonatos, Davis, & Barco, 2012), there is no standardised procedure for an on-road assessment.

Eye-tracking. Driving is a highly visual-processing reliant task (Young, 2000). Whilst driving, target and environmental information is input through the foveal and optic systems from targeted visual scanning and processed in the brain using visual, cognitive and perceptual processes (Falkmer, Dahlman, Dukic, Bjällmark, & Larsson, 2008; Jonassen, 2000; Tabibi & Pfeffer, 2003). Measuring how this information is received and processed often requires a multi-stage approach. Eye-tracking is a method of measuring attentional processing and is frequently utilised in driving research, alongside neurocognitive assessments, as it is able to provide further information into a number of driving-related processes, such as visual search and cognitive workload (Harbluk, Noy, & Eizenman, 2002; Son, Oh, & Park, 2013; Young & Hulleman, 2013). For example, previous research utilising eye-tracking techniques has found that drivers at different stages of experience, will amend their visual scanning patterns in high demand situations, e.g., novice drivers tend to amend their scanning patterns through a reduced spread of fixations and exhibiting longer fixation durations than experienced drivers (Falkmer & Gregersen, 2001; Underwood, 2007). Similarly, the location and spread of visual fixations will vary depending on the level of experience with more experienced drivers utilising increasingly broad scanning patterns (Underwood, 2007; Underwood, Chapman, Brocklehurst, Underwood, & Crundall, 2003). In the post-stroke population, eye-tracking research has focused primarily on hemianopia (visual field loss) resulting from a stroke. Interestingly, it was found that post-stroke adults with hemianopia were able to compensate for their deficits using increased numbers of fixations, as well as increasing the spread of their visual search (Bahnemann et al., 2015), presumably due to the increased demand required. Due to the processing requirements and technological requirements required for eye-tracking, it is generally only used for research purposes, however eye-tracking remains a useful tool for understanding the visual scanning patterns of drivers and understanding the task demands and compensation strategies undertaken to drive. With the established link between visual scanning and cognitive workload, it stands to reason that visual scanning patterns will vary with cognitive deficits; however this has not been undertaken in the post-stroke population who do not have visual field loss.

Off-Road Assessments

Cognitive assessments. There is much debate regarding the tools used for driving assessment and rehabilitation in post-stroke adults. Poor performance in executive function, including risk taking and impulsivity (a lack of inhibition) are known to be correlated and are significant predictors of traffic crashes (Cheng & Lee, 2012; Daigneault et al., 2002), and those with executive function deficits have been found to have difficulties driving in a simulator (Motta, Lee, & Falkmer, 2014). Similarly, those with deficits in visual and attentional processing have been found to be at an increased risk of a crash (Owsley, Ball, McGwin, Jr, & et al., 1998), and those with age-related deficits in divided attention ability have also been found to exhibit poorer performance in simulator-based driving (Brouwer, Waterink, Van Wolffelaar, & Rothengatter, 1991). As these are the functions that are known to be impaired post-stroke (Gottesman & Hillis, 2010), using neurocognitive assessment tools as part of the driving assessments is common. In a systematic review, Marshall et al. (2007) found that cross-domain cognitive assessments yielded the strongest correlation with on-road driving performance in post-stroke drivers, therefore a multi-process assessment battery may be most useful when assessing cognition and driving.

Driving simulation. Although on-road driving tests are the 'gold-standard' for driving assessment, there are often occasions where it is not ethical or practicable to undertake an on-road assessment (Stedmon, Young, & Hasseldine, 2009). Furthermore, whilst driving in the real world is the most ecologically valid form of assessment, the tests are subject to multiple extraneous variables and are often stressful, costly and time consuming (Lee, Cameron, & Lee, 2003; Lee & Lee, 2005; Marshall et al., 2007; Stedmon et al., 2009). To counter this, driving simulation is one of the most heavily utilised measures of driving performance, as it is able to reliably measure driving performance whilst ensuring driver safety and eliminating extraneous variables, such as traffic density and weather conditions (Lee et al., 2003; Stedmon et al., 2009).

The information relating to post-stroke driver assessment in a driving simulator is limited and conflicted (Hird et al., 2014). Kotterba, Widdig, Brylak, and Orth (2005) reported that drivers who experienced a full cerebral haemorrhage or blockage displayed greater amounts of accidents compared to controls in a driving simulator; however this relationship was not seen in participants who had experienced a TIA. Lundqvist et al. (1997) reported that in less demanding and predictable situations, the post-stroke drivers performed comparatively to the controls, however that their reaction times and time to collision (i.e., the time between their car and the car in front) increased. Similarly, McKay, Rapport, Bryer, and Casey (2011) found that post-stroke drivers performed significantly worse in the driving simulator compared to controls, however they used a cumulative score for driving performance, which can make it difficult to determine the areas of the driving task most affected; particularly as contrary to previously outlined results, Lundqvist, Gerdle, and Rönnberg (2000), reported no differences in post-stroke driving simulator performance compared to controls in multiple driving performance variables.

Despite the paucity of research, driving simulators are considered a useful platform for assessing drivers who have had a stroke and wish to return to driving (Uc & Rizzo, 2011). Previous research in the area has shown that driving simulators have potential for driver re-training in the post-stroke population (Akinwuntan et al., 2010) and may be useful for providing feedback with self-assessment (McKay et al., 2011).

Present research

There are pros and cons to each type of driving assessment tool (Stedmon et al., 2009) and there is much variation in the use of assessments and tools in the area of post-stroke driving. As neuropsychological, cognitive and driving simulator off-road assessments have been found to be a significant aid in assessing driving performance in a safe, reliable environment (Lee et al., 2003; Lundqvist, 2001; Marshall et al., 2007), the development of a sensitive and reliable off-road assessment, including a multitude of these techniques, is likely to be a cost-effective predictor of driving performance in post-stroke drivers for use by medical practitioners, researchers and drivers alike. Currently the research investigating which tools are best for assessing post-stroke driving remain conflicted and it is hypothesised within this thesis that part of the problem may be due to the majority of research focusing on unlicensed post-stroke adults. It therefore becomes difficult to compare driving performance and determine safety to drive when there is no baseline assessment for practitioners to compare. It stands to reason that in order to successfully create and evaluate a post-stroke driving rehabilitation and assessment scheme, understanding the processes involved in licensed post-stroke adults as a baseline is required.

By assessing licensed post-stroke drivers both on- and off-road, it is possible to understand which tools are the most reliable and cost effective in determining fitness to drive. Furthermore understanding cognitive ability, self-perception of performance and any subsequent impact on level of task demand required to complete a task can provide an indication of driver compensation strategies, which can thus inform assessment and rehabilitation programmes.

Chapter One References

Akinwuntan, A. E., Devos, H., Verheyden, G., Baten, G., Kiekens, C., Feys, H., & De Weerdt, W. (2010). Retraining moderately impaired stroke survivors in driving-related visual attention skills. *Topics in Stroke Rehabilation, 17*(5), 328-336. http://dx.doi.org/10.1310/tsr1705-328

Allen, R. W., Stein, C. A., Aponso, B. L., Rosenthal, T. J., & Hogue, J. R. (1990). A low cost, part task driving simulator based on microcomputer technology*69th Annual Meeting of the Transportation Research Board., held in Washington, DC.*: Transportation Research Board

Allen, Z. A., Halbert, J., & Huang, L. (2007). Driving assessment and rehabilitation after stroke. *The Medical Journal of Australia, 187*(10), 599.

Alila Medical Media, (2017) Shutterstock illustration ID: 78690082 [image]. Retrieved from https://www.shutterstock.com

Alvarez, J. A., & Emory, E. (2006). Executive function and the frontal lobes: A meta-analytic review. *Neuropsychology Review, 16*(1), 17-42. http://dx.doi.org/10.1007/s11065-006-9002-x

Andrews, E. C., & Westerman, S. J. (2012). Age differences in simulated driving performance: Compensatory processes. *Accident Analysis & Prevention, 45*, 660-668. http://dx.doi.org/http://dx.doi.org/10.1016/j.aap.2011.09.047

Anstey, K. J., Wood, J., Lord, S., & Walker, J. G. (2005). Cognitive, sensory and physical factors enabling driving safety in older adults. *Clinical Psychology Review, 25*, 45-65. http://dx.doi.org/10.1016/j.cpr.2004.07.008

Australian Bureau of Statistics. (2009). *Profiles of Disability, Astralia*. (44290.0). Australian Bureau of Statistics.

Australian Institute of Health and Welfare. (2013). *Stroke*. Canberra: Retrieved from http://www.aihw.gov.au/WorkArea/DownloadAsset.aspx?id=60129543611

Austroads, & National Transport Commision Australia. (2016). Assessing fitness to drive for commercial and private vehicle drivers: Medical standards for licensing and clinical management guidelines., Retrieved from https://www.onlinepublications.austroads.com.au/items/AP-G56-16

Bahnemann, M., Hamel, J., De Beukelaer, S., Ohl, S., Kehrer, S., Audebert, H., . . . Brandt, S. A. (2015). Compensatory eye and head movements of patients with homonymous hemianopia in the naturalistic setting of a driving simulation. *Journal of Neurology, 262*(2), 316-325. http://dx.doi.org/10.1007/s00415-014-7554-x

Baldock, M. R. J., Mathias, J. L., McLean, A. J., & Berndt, A. (2006). Self-regulation of driving and its relationship to driving ability among older adults. *Accident*

Analysis & Prevention, 38(5), 1038-1045. http://dx.doi.org/http://dx.doi.org/10.1016/j.aap.2006.04.016

Ball, K., Owsley, C., Stalvey, B., Roenker, D. L., Sloane, M. E., & Graves, M. (1998). Driving avoidance and functional impairment in older drivers. *Accident Analysis & Prevention, 30*(3), 313-322. http://dx.doi.org/http://dx.doi.org/10.1016/S0001-4575(97)00102-4

Ball, K., Owsley, C., Sloane, M. E., Roenker, D. L., & Bruni, J. R. (1993). Visual attention problems as a predictor of vehicle crashes in older drivers. *Investigative Ophthalmology & Visual Science, 34*(11), 3110-3123.

Belagaje, S. R., & Butler, A. J. (2013). Poststroke Recovery. In K. M. Barrett, J. F. Meschia & I. ebrary (Eds.), *Stroke* (1st ed., pp. 119-136). Chichester, West Sussex: John Wiley & Sons. http://dx.doi.org/:10.1002/9781118560730.ch7

Benton, A. L., Hamsher, K., Varney, N. R., & Spreen, O. (1983). *Contributions to Neuropsychological Assessment: A Clinical Manual.* New York: Oxford University Press.

Blane, A., Falkmer, T., Lee, M., Parsons, R., & Lee, H. C. (2016). The cognitive and socio-demographic influences on driving performance and driving cessation in post-stroke drivers. *Advances in Transportation Studies: An International Journal,*(38), 121-135.

Braitman, K. A., & Williams, A. F. (2011). Changes in self-regulatory driving among older drivers over time. *Traffic Injury Prevention, 12*(6), 568-575. http://dx.doi.org/10.1080/15389588.2011.616249

Brønnum-Hansen, H., Davidsen, M., & Thorvaldsen, P. (2001). Long-term survival and causes of death after stroke. *Stroke, 32*(9), 2131-2136.

Brouwer, W. H., Waterink, W., Van Wolffelaar, P. C., & Rothengatter, T. (1991). Divided attention in experienced young and older drivers: Lane tracking and visual analysis in a dynamic driving simulator. *Human Factors, 33*(5), 573-582. http://dx.doi.org/10.1177/001872089103300508

Bunce, D., Handley, R., & Gaines Jr, S. O. (2008). Depression, anxiety, and within-person variability in adults aged 18 to 85 years. *Psychology and Aging, 23*(4), 848.

Burns, P. C. (1999). Navigation and the mobility of older drivers. The Journals of Gerontology Series B: Psychological Sciences and Social Sciences, 54(1), S49-S55.

Chee, D. Y., Lee, H. C., Lee, A. H., & Falkmer, T. (2013). Performance of drivers with Parkinson's Disease under the effect of cognitive overloading: insinuation for assessment and training. *Advances in Transportation Studies,*(29) Cheng, A. S., & Lee, H. C. (2012). Risk-taking behavior and response inhibition of commuter motorcyclists with different levels of impulsivity. *Transportation Research Part F: Traffic Psychology and Behaviour, 15*(5), 535-543. http://dx.doi.org/10.1016/j.trf.2012.05.005

Choi, M., Adams, K. B., & Kahana, E. (2012). The impact of transportation support on driving cessation among community-dwelling older adults. *Journals of Gerontology Series B: Psychological Sciences and Social Sciences, 67B*(3), 392-400. http://dx.doi.org/10.1093/geronb/gbs035

Chua, M., McCluskey, A., & Smead, J. M. (2012). Retrospective analysis of factors that affect driving assessment outcomes after stroke. *Australian Occupational Therapy Journal, 59*(2), 121-130. http://dx.doi.org/10.1111/j.1440-1630.2012.01005.x

Coyne, P. H. (2007). *Roadcraft: the essential police driver's handbook*. London, United Kingdom: The Stationary Office.

Craik, F. I. M., & Byrd, M. (1982). Aging and cognitive deficits. In F. I. M. Craik & S. Trehub (Eds.), *Aging and cognitive processes (advances in the study of communication and affect)* (Vol. 8, pp. 191-211). New York: Plenum Press.

Daigneault, G., Joly, P., & Frigon, J.-Y. (2002). Executive functions in the evaluation of accident risk of older drivers. *Journal of Clinical and Experimental Neuropsychology, 24*(2), 221-238. Retrieved from http://www.tandfonline.com/doi/pdf/10.1076/jcen.24.2.221.993

Delis, D. C., Kaplan, E., & Kramer, J. H. (2001). *Delis-Kaplan Executive Function System (D-KEFS) Examiner's Manual*. San Antonio, Texas: The Psychological Corporation.

Dennis, M. S., Burn, J., Sandercock, P., Bamford, J. M., Wade, D. T., & Warlow, C. P. (1993). Long-term survival after first-ever stroke: The Oxfordshire Community Stroke Project. *Stroke, 24*(6), 796-800.

Donorfio, L. K., D'Ambrosio, L. A., Coughlin, J. F., & Mohyde, M. (2009). To drive or not to drive, that isn't the question—the meaning of self-regulation among older drivers. *Journal of Safety Research, 40*(3), 221-226. http://dx.doi.org/10.1016/j.jsr.2009.04.002

Dunn, N., & Williamson, A. (2012). Driving monotonous routes in a train simulator: the effect of task demand on driving performance and subjective experience. *Ergonomics, 55*(9), 997-1008. http://dx.doi.org/10.1080/00140139.2012.691994

Evans, K. K., Horowitz, T. S., Howe, P., Pedersini, R., Reijnen, E., Pinto, Y., & Wolfe, J. M. (2011). Visual attention. *Wiley Interdisciplinary Reviews. Cognitive Science, 2*(5), 503-514. http://dx.doi.org/10.1002/wcs.127

Evans, L. (2004). *Traffic safety*. Bloomfield Hills, Michigan: Science Serving Society.

Eysenck, M. W. (1982). *Attention and arousal: Cognition and performance*. Berlin: Springer-Verlag.

Falkmer, T., Dahlman, J., Dukic, T., Bjällmark, A., & Larsson, M. (2008). Fixation identification in centroid versus start-point modes using eye-tracking data. *Perceptual and Motor Skills, 106*(3), 710-724.

Falkmer, T., & Gregersen, N. (2001). Fixations among experienced drivers and apprentices with and without cerebral palsy, in real traffic environments. *Transportation Research Part F: Traffic Psychology and Behaviour, 4*, 171-185.

Feigin, V. L., Forouzanfar, M. H., Krishnamurthi, R., Mensah, G. A., Connor, M., Bennett, D. A., . . . Murray, C. (2014). Global and regional burden of stroke during 1990–2010: findings from the Global Burden of Disease Study 2010. *The Lancet, 383*(9913), 245-255. http://dx.doi.org/http://dx.doi.org/10.1016/S0140-6736(13)61953-4

Fisk, G. D., Owsley, C., & Mennemeier, M. (2002). Vision, attention, and self-reported driving behaviors in community-dwelling stroke survivors. *Archives of Physical Medicine and Rehabilitation, 83*(4), 469-477. http://dx.doi.org/10.1053/apmr.2002.31179

Fonda, S. J., Wallace, R. B., & Herzog, R. A. (2001). Changes in driving patterns and worsening depressive symptoms among older adults. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences, 56*(6), S343-S351.

Foster, J. K., Black, S., Buck, B. H., & Bronskill, M. J. (1997). Ageing and executive functions: A neuroimaging perspective. In P. Rabbitt (Ed.), *Methodology of frontal and executive function* (pp. 177-190). Hove, Sussex, UK: Psychology Press.

Fuller, R. (2005). Towards a general theory of driver behaviour. *Accident Analysis & Prevention, 37*(3), 461-472. http://dx.doi.org/10.1016/j.aap.2004.11.003

Galski, T., Bruno, R. L., & Ehle, H. T. (1992). Driving after cerebral damage: A model with implications for evaluation. *American Journal of Occupational Therapy, 46*(4), 324-332.

Galski, T., Ehle, H. T., McDonald, M. A., & Mackevich, J. (2000). Evaluating fitness-to-drive after cerebral injury: Basic issues and recommendations for medical and legal communities. *The Journal of Head Trauma Rehabilitation, 15*(3), 895-908.

Glisky, E. L. (2007). Changes in cognitive function in human aging. In D. R. Riddle (Ed.), *Brain aging* (pp. 3-20). Boca Raton, Florida: CRC Press. http://dx.doi.org/:doi:10.1201/9781420005523.sec1

Go, A. S., Mozaffarian, D., Roger, V. L., Benjamin, E. J., Berry, J. D., Blaha, M. J., . . . Turner, M. B. (2014). Heart disease and stroke statistics-2014 update: a report from the American Heart Association. *Circulation, 129*(3), e28. http://dx.doi.org/10.1161/01.cir.0000441139.02102.80

Gottesman, R. F., & Hillis, A. E. (2010). Predictors and assessment of cognitive dysfunction resulting from ischaemic stroke. *The Lancet Neurology, 9*(9), 895-905. http://dx.doi.org/http://dx.doi.org/10.1016/S1474-4422(10)70164-2

Green, J., Siddall, H., & Murdoch, I. (2002). Learning to live with glaucoma: a qualitative study of diagnosis and the impact of sight loss. *Social Science & Medicine, 55*(2), 257-267. http://dx.doi.org/10.1016/S0277-9536(01)00169-1

Griffen, J. A., Rapport, L. J., Coleman Bryer, R., & Scott, C. A. (2009). Driving Status and Community Integration After Stroke. *Topics in Stroke Rehabilitation, 16*(3), 212-221. http://dx.doi.org/10.1310/tsr1603-212

Gwyther, H., & Holland, C. (2012). The effect of age, gender and attitudes on self-regulation in driving. *Accident Analysis & Prevention, 45*, 19-28. http://dx.doi.org/http://dx.doi.org/10.1016/j.aap.2011.11.022

Hart, S. G., & Staveland, L. E. (1988). Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. *Human Mental Workload, 1*(3), 139-183.

Hakamies-Blomqvist, L. (1998). Older drivers' accident risk: Conceptual and methodological issues. *Accident Analysis & Prevention, 30*(3), 293-297. http://dx.doi.org/http://dx.doi.org/10.1016/S0001-4575(97)00120-6

Hakamies-Blomqvist, L., & Wahlström, B. (1998). Why do older drivers give up driving? *Accident Analysis & Prevention, 30*(3), 305-312. http://dx.doi.org/http://dx.doi.org/10.1016/S0001-4575(97)00106-1

Harbluk, J. L., Noy, Y. I., & Eizenman, M. (2002). *The impact of cognitive distraction on driver visual behaviour and vehicle control* (00942271). Ontario, Canada: T. R. Board. Retrieved from http://www.tc.gc.ca/roads.../tp13889/pdf/tp13889es.pdf

Haselkorn, J. K., Mueller, B. A., & Rivara, F. A. (1998). Characteristics of drivers and driving record after traumatic and nontraumatic brain injury. *Archives of Physical Medicine and Rehabilitation, 79*(7), 738-742. http://dx.doi.org/http://dx.doi.org/10.1016/S0003-9993(98)90349-5

Hassan, H., King, M., & Watt, K. (2015). The perspectives of older drivers on the impact of feedback on their driving behaviours: a qualitative study. *Transportation Research Part F: Traffic Psychology and Behaviour, 28*, 25-39. http://dx.doi.org/10.1016/j.trf.2014.11.003

Heikkilä, V. M., Korpelainen, J., Turkka, J., Kallanranta, T., & Summala, H. (1999). Clinical evaluation of the driving ability in stroke patients. *Acta Neurologica Scandinavica, 99*(6), 349-355. http://dx.doi.org/10.1111/j.1600-0404.1999.tb07363.x

Hird, M. A., Vetivelu, A., Saposnik, G., & Schweizer, T. A. (2014). Cognitive, on-road, and simulator-based driving assessment after stroke. *Journal of Stroke and Cerebrovascular Diseases, 23*(10), 2654-2670. http://dx.doi.org/10.1016/j.jstrokecerebrovasdis.2014.06.010

Horrey, W. J., Lesch, M. F., Mistopolous-Rubens, E., & Lee, J. D. (2015). Calibration of skills and judgement in driving: Development of a conceptual framework and the implications for road safety. *Accident Analysis & Prevention, 76*, 25-33. http://dx.doi.org/http://dx.doi.org/10.1016/j.aap.2014.12.017

Jokinen, H., Melkas, S., Ylikoski, R., Pohjasvaara, T., Kaste, M., Erkinjuntti, T., & Hietanen, M. (2015). Post-stroke cognitive impairment is common even after successful clinical recovery. *European Journal of Neurology, 22*(9), 1288-1294. http://dx.doi.org/10.1111/ene.12743

Jonassen, D. (2000). Toward a design theory of problem solving. *Educational Technology Research and Development, 48*(4), 63-85. http://dx.doi.org/10.1007/BF02300500

Kahneman, D. (1973). *Attention and effort*. Englewood Cliffs, New Jersey: Prentice-Hall Inc.

Kotterba, S., Widdig, W., Brylak, S., & Orth, M. (2005). Driving after cerebral ischemia – a driving simulator investigation. *Wien Med Wochenschr, 155*(15), 348-353. http://dx.doi.org/10.1007/s10354-005-0191-3

Kramer, A. F., & Madden, D. J. (2011). Attention. In F. I. M. Craik & T. A. Salthouse (Eds.), *The handbook of aging and cognition* (pp. 189-249). London, UK: Taylor and Francis. Retrieved from http://ebookcentral.proquest.com/lib/curtin/detail.action?docID=672429

Lee, H. C., Cameron, D., & Lee, A. H. (2003). Assessing the driving performance of older adult drivers: On-road versus simulated driving. *Accident Analysis & Prevention, 35*(5), 797-803. http://dx.doi.org/10.1016/S0001-4575(02)00083-0

Lee, H. C., & Lee, A. H. (2005). Identifying older drivers at risk of traffic violations by using a driving simulator: A 3-year longitudinal study. *The American Journal of Occupational Therapy, 59*(1), 97-100.

Lejuez, C., Read, J. P., Kahler, C. W., Richards, J. B., Ramsey, S. E., Stuart, G. L., . . . Brown, R. A. (2002). Evaluation of a behavioral measure of risk taking: the Balloon Analogue Risk Task (BART). *Journal of Experimental Psychology: Applied, 8*(2), 75.

Lewis, R., & Rennick, P. (1979). Manual for the repeatable cognitive-perceptual-motor battery. *Gross Point, MI: Axon,*

Lincoln, N., & Fanthome, Y. (1994). Reliability of the stroke drivers screening assessment. *Clinical Rehabilitation, 8*(2), 157-160.

Lister, R. (1999). Loss of ability to drive following a stroke: The early experiences of three elderly people on discharge from hospital. *The British Journal of Occupational Therapy, 62*(11), 514-520. Retrieved from http://www.ingentaconnect.com/content/cot/bjot/1999/00000062/00000011/art00006

Logan, P. A., Dyas, J., & Gladman, J. R. (2004). Using an interview study of transport use by people who have had a stroke to inform rehabilitation. *Clinical Rehabilitation, 18*(6), 703-708. http://dx.doi.org/10.1191/0269215504cr742oa

Lundqvist, A. (2001). Neuropsychological aspects of driving characteristics. *Brain Injury, 15*(11), 981-994. http://dx.doi.org/doi:10.1080/02699050110065637

Lundqvist, A., & Alinder, J. (2007). Driving after brain injury: Self-awareness and coping at the tactical level of control. *Brain Injury, 21*(11), 1109-1117. http://dx.doi.org/10.1080/02699050701651660

Lundqvist, A., Alinder, J., Alm, H., Gerdle, B., Levander, S., & Ronnberg, J. (1997). Neuropsychological aspects of driving after brain lesion: Simulator study and on-road driving. *Applied Neuropsychology, 4*(4), 220-230. http://dx.doi.org/10.1207/s15324826an0404_3

Lundqvist, A., Gerdle, B., & Rönnberg, J. (2000). Neuropsychological aspects of driving after a stroke—in the simulator and on the road. *Applied Cognitive Psychology, 14*(2), 135-150. http://dx.doi.org/10.1002/(SICI)1099-0720(200003/04)14:2<135::AID-ACP628>3.0.CO;2-S

Marin-Lamellet, C., & Haustein, S. (2015). Managing the safe mobility of older road users: How to cope with their diversity? *Journal of Transport & Health, 2*(1), 22-31. http://dx.doi.org/10.1016/j.jth.2014.07.006

Marottoli, R. A., Mendes de Leon, C. F., Glass, T. A., & Williams, C. S. (1997). Driving cessation and increased depressive symptoms: Prospective evidence from the New Haven EPESE. *Journal of the American Geriatrics Society, 45*(2), 202-206. http://dx.doi.org/10.1111/j.1532-5415.1997.tb04508.x

Marottoli, R. A., Mendes de Leon, C. F., Glass, T. A., Williams, C. S., Cooney, L. M., & Berkman, L. F. (2000). Consequences of driving cessation: Decreased out-of-home activity levels. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences, 55*(6), S334-S340. http://dx.doi.org/10.1093/geronb/55.6.S334

Marshall, S. C., Molnar, F., Man-Son-Hing, M., Blair, R., Brosseau, L., Finestone, H. M., . . . Wilson, K. G. (2007). Predictors of driving ability following stroke: A systematic review. *Topics in Stroke Rehabilitation, 14*(1), 98-114. http://dx.doi.org/10.1310/tsr1401-98

McKay, C. (2007). *Self-evaluation of driving simulator performance in stroke patients.* PhD. University of Windsor. Retrieved from http://scholar.uwindsor.ca/etd/4687

McKay, C., Rapport, L., Bryer, R., & Casey, J. (2011). Self-evaluation of driving simulator performance after stroke. *Topics in Stroke Rehabilitation, 18*(5), 549-561. http://dx.doi.org/10.1310/tsr1805-549

McNamara, A., McCluskey, A., White, J., & George, S. (2014). The need for consistency and equity in driver education and assessment post-stroke. *Journal of Transport & Health, 1*(2), 95-99. http://dx.doi.org/http://dx.doi.org/10.1016/j.jth.2014.02.002

McNamara, A., Walker, R., Ratcliffe, J., & George, S. (2014). Perceived confidence relates to driving habits post-stroke. *Disability & Rehabilitation, 37*(14), 1228-1233. http://dx.doi.org/10.3109/09638288.2014.958619

Meuleners, L. B., Harding, A., Lee, A. H., & Legge, M. (2006). Fragility and crash over-representation among older drivers in Western Australia. *Accident Analysis & Prevention, 38*, 1006-1010.

Michon, J. A. (1985). A critical view of driver behavior models: what do we know, what should we do? USA: Springer.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex “frontal lobe” tasks: A latent variable analysis.

Cognitive Psychology, 41(1), 49-100. http://dx.doi.org/http://dx.doi.org/10.1006/cogp.1999.0734

Molnar, L. J., & Eby, D. W. (2008). The relationship between self-regulation and driving-related abilities in older drivers: an exploratory study. *Traffic Injury Prevention, 9*(4), 314-319. Retrieved from http://www.tandfonline.com/doi/pdf/10.1080/15389580801895319

Motta, K., Lee, H. C., & Falkmer, T. (2014). Post-stroke driving: Examining the effect of executive dysfunction. *Journal of Safety Research, 49*, 33.e31. http://dx.doi.org/10.1016/j.jsr.2014.02.005

Mullen, N., Charlton, J., Devlin, A., & Bedard, M. (2011). Simulator validity: Behaviors observed on the simulator and on the road. In D. L. Fisher, M. Rizzo, J. K. Caird & J. D. Lee (Eds.), *Handbook of driving simulation for engineering, medicine and psychology*. United States: CRC Press, Taylor and Francis. http://dx.doi.org/:10.1201/b10836-14

Nasreddine, Z. S., Phillips, N. A., Bédirian, V., Charbonneau, S., Whitehead, V., Collin, I., . . . Chertkow, H. (2005). The Montreal Cognitive Assessment, MoCA: A brief screening tool for mild cognitive impairment. *Journal of the American Geriatrics Society, 53*(4), 695-699.

Odenheimer, G. L., Beaudet, M., Jette, A. M., Albert, M. S., Grande, L., & Minaker, K. L. (1994). Performance-based driving evaluation of the elderly driver: Safety, reliability, and validity. *Journal of Gerontology, 49*(4), M153-M159. Retrieved from http://geronj.oxfordjournals.org/content/49/4/M153.full.pdf

Ott, B. R., Papandonatos, G. D., Davis, J. D., & Barco, P. P. (2012). Naturalistic validation of an on-road driving test of older drivers. *Human Factors, 54*(4), 663-674. http://dx.doi.org/10.1177/0018720811435235

Owsley, C., Ball, K., McGwin, Jr, G., & et al. (1998). Visual processing impairment and risk of motor vehicle crash among older adults. *JAMA, 279*(14), 1083-1088. http://dx.doi.org/10.1001/jama.279.14.1083

Owsley, C., Stalvey, B., Wells, J., & Sloane, M. E. (1999). Older drivers and cataract: driving habits and crash risk. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 54*(4), M203-M211.

Patomella, A.-H., Johansson, K., & Tham, K. (2009). Lived experience of driving ability following stroke. *Disability & Rehabilitation, 31*(9), 726-733. http://dx.doi.org/10.1080/09638280802306539

Perrier, M.-J., Korner-Bitensky, N., Petzold, A., & Mayo, N. (2010). The risk of motor vehicle crashes and traffic citations post-stroke: A structured review. *Topics in*

Stroke Rehabilitation, 17(3), 191-196. http://dx.doi.org.dbgw.lis.curtin.edu.au/10.1310/tsr1703-191

Persson, D. (1993). The elderly driver: Deciding when to stop. *The Gerontologist, 33*(1), 88-91. http://dx.doi.org/10.1093/geront/33.1.88

Poole, D., Chaudry, F., & Jay, W. M. (2008). Stroke and driving. *Topics in Stroke Rehabilitation, 15*(1), 37-41. http://dx.doi.org/10.1310/tsr1501-37

Ragland, D. R., Satariano, W. A., & MacLeod, K. E. (2005). Driving cessation and increased depressive symptoms. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences., 60*(3), 399-403.

Ranney, T. A. (1994). Models of driving behavior: A review of their evolution. *Accident Analysis & Prevention, 26*(6), 733-750. http://dx.doi.org/http://dx.doi.org/10.1016/0001-4575(94)90051-5

Ranney, T. A. (2011). Psychological fidelity *Handbook of driving simulation for engineering, medicine, and psychology*: CRC Press. http://dx.doi.org/:doi:10.1201/b10836-10

Rapoport, M. J., Naglie, G., Weegar, K., Myers, A., Cameron, D., Crizzle, A., . . . Marshall, S. (2013). The relationship between cognitive performance, perceptions of driving comfort and abilities, and self-reported driving restrictions among healthy older drivers. *Accident Analysis & Prevention, 61*, 288-295. http://dx.doi.org/10.1016/j.aap.2013.03.030

Rudman, D. L., Friedland, J., Chipman, M., & Sciortino, P. (2006). Holding on and letting go: The perspectives of pre-seniors and seniors on driving self-regulation in later life. *Canadian Journal on Aging, 25*(1), 65-76.

Sacco, R., Wolf, P. A., Kannel, W., & McNamara, P. (1982). Survival and recurrence following stroke. The Framingham study. *Stroke, 13*(3), 290-295.

Sacco, R. L., Kasner, S. E., Broderick, J. P. Caplan, L. R., Connors, J. J., Culebras, A., … Vinters, H. V. (2013). An updated definition of stroke for the 21st century. *Stroke, 44*(7), 2064-2089. http://dx.doi.org/10.1161/STR.0b013e318296aeca

Scheffer, M,., Monteiro, J. K., & De Almeida, R. M. M. (2011). Frontal stroke: problem solving, decision making, impulsiveness, and depressive symptoms in men and women. *Psychology & Neuroscience, 4*(2), 267-278. http://dx.doi.org/10.3922/j.psns.2011.2.012

Schneider, W., Eschman, A., & Zuccolotto, A. (2012). E-Prime 2.0 (Version 2.0). Pittsburgh: Psychology Software Tools, Inc.

Schneider, W., & Shiffrin, R. M. (1977). Controlled and automatic human information processing: II. Perceptual learning, automatic attending and a general theory.

Psychological Review, 84(2), 127-190. http://dx.doi.org/10.1037/0033-295X.84.2.127

Scott, C. A., Rapport, L. J., Coleman Bryer, R., Griffen, J., Hanks, R., & McKay, C. (2009). Self-assessment of driving ability and the decision to resume driving following stroke. *Journal of Clinical and Experimental Neuropsychology, 31*(3), 353-362. http://dx.doi.org/10.1080/13803390802169067

Scott, J. G., & Schoenberg, M. R. (2011). Deficits in visuospatial/visuoconstructional skills and motor praxis. In M. R. Schoenberg & J. G. Scott (Eds.), *The little black book of neuropsychology: A syndrome-based approach* (pp. 201-218). Boston, Massachusetts, USA: Springer USA. http://dx.doi.org/:10.1007/978-0-387-76978-3_9

Son, J., Oh, H., & Park, M. (2013). Identification of driver cognitive workload using support vector machines with driving performance, physiology and eye movement in a driving Simulator. *International Journal of Precision Engineering Manufacturing, 14*(8), 1321-1327. http://dx.doi.org/10.1007/s12541-013-0179-7

Stanton, N. A., & Marsden, P. (1996). From fly-by-wire to drive-by-wire: Safety implications of automation in vehicles. *Safety Science, 24*(1), 35-49. http://dx.doi.org/http://dx.doi.org/10.1016/S0925-7535(96)00067-7

Stapleton, T., Connolly, D., & O'Neill, D. (2012). Exploring the relationship between self-awareness of driving efficacy and that of a proxy when determining fitness to drive after stroke. *Australian Occupational Therapy Journal, 59*(1), 63-70. http://dx.doi.org/10.1111/j.1440-1630.2011.00980.x

Stedmon, A., Young, M. S., & Hasseldine, B. (2009). Keeping it real or faking it: The trials and tribulations of real road studies and simulators in transport research. In P. D. Bust (Ed.), *Contemporary Ergonomics 2009: Proceedings of the International Conference on Contemporary Ergonomics 2009*, CRC Press, London, UK,

Strong, K., Mathers, C., & Bonita, R. (2007). Preventing stroke: saving lives around the world. *The Lancet Neurology, 6*(2), 182-187. http://dx.doi.org/10.1016/S1474-4422(07)70031-5

Tabibi, Z., & Pfeffer, K. (2003). Choosing a safe place to cross the road: the relationship between attention and identification of safe and dangerous road-crossing sites. *Child: Care, Health and Development, 29*(4), 237-244. http://dx.doi.org/10.1046/j.1365-2214.2003.00336.x

Thrift, A. G., Cadilhac, D. A., Thayabaranathan, T., Howard, G., Howard, V. J., Rothwell, P. M., & Donnan, G. A. (2014). Global stroke statistics. *International Journal of Stroke: Official Journal of The International Stroke Society, 9*(1), 6-18. http://dx.doi.org/10.1111/ijs.12245

Uc, E., & Rizzo, M. (2011). Driving in Alzheimer's disease, Parkinson's disease and stroke. In D. L. Fisher, M. Rizzo, J. K. Caird & J. D. Lee (Eds.), *Handbook of driving simulation for engineering, medicine, and psychology*. Boca Raton, Florida, USA: CRC Press: Taylor and Francis. http://dx.doi.org/:doi:10.1201/b10836-49

Underwood, G. (2007). Visual attention and the transition from novice to advanced driver. *Ergonomics, 50*(8), 1235-1249. http://dx.doi.org/10.1080/00140130701318707

Underwood, G., Chapman, P., Brocklehurst, N., Underwood, J., & Crundall, D. (2003). Visual attention while driving: sequences of eye fixations made by experienced and novice drivers. *Ergonomics, 46*(6), 629-646. http://dx.doi.org/10.1080/0014013031000090116

Unsworth, C. A., Wells, Y., Browning, C., Thomas, S. A., & Kendig, H. (2007). To continue, modify or relinquish driving: Findings from a longitudinal study of healthy ageing. *Gerontology, 53*(6), 423-431. Retrieved from http://www.karger.com/DOI/10.1159/000111489

Wechsler, D. (2008). Wechsler Adult Intelligence Scale–Fourth Edition (WAIS–IV). *San Antonio, TX: NCS Pearson,* White, J. H., Miller, B., Magin, P., Attia, J., Sturm, J., & Pollack, M. (2012). Access and participation in the community: a prospective qualitative study of driving post-stroke. *Disability and Rehabilitation, 34*(10), 831-838. http://dx.doi.org/10.3109/09638288.2011.623754

Young, A. H., & Hulleman, J. (2013). Eye movements reveal how task difficulty moulds visual search. *Journal of Experimental Psychology: Human Perception and Performance, 39*(1), 168-190. http://dx.doi.org/10.1037/a0028679

Young, M. S. (2000). Attention, automaticity, and automation: New perspectives on mental underload and performance. PhD. University of Southampton.

Young, M. S., Brookhuis, K. A., Wickens, C. D., & Hancock, P. A. (2015). State of science: mental workload in ergonomics. *Ergonomics, 58*(1), 1-17. http://dx.doi.org/10.1080/00140139.2014.956151

van Zomeren, A. H., & Brouwer, W. H. (1994). *Clinical neuropsychology of attention*. New York: Oxford University Press

Chapter Two: Research Methodology

Chapter Outline and Rationale

The purpose of this chapter is to outline in depth the research design and methodologies used in as part of this research.

Introduction

This chapter will outline the methodology and research design used for this thesis. It will also outline the data collection procedures undertaken as part of the research, as well as the data analysis procedures and detail the rationale for each. The ethical considerations for this research will also be addressed.

Research Designs

The research employed a mixture of quasi experimental design techniques, as well as observational assessments. Study participants were recruited based on post-stroke diagnosis (post-stroke driver, non-driver or control) and were assessed using a mixture of driving protocols, i.e., undertaking a battery of cognitive assessments, one – to two scenarios on a driving simulator and / or an on-road driving observation.

Participants

Inclusion and Exclusion Criteria

There were a number of inclusion and exclusion criteria involved in the research. All participants were required to have normal or corrected-to-normal vision with a minimum visual acuity score of better than 20/40 (the minimum requirement to drive in Western Australia), possess a full driver's licence valid in Australia, have access to an insured vehicle, drive at least twice a week and live within the Perth metropolitan area. Specific criteria for community-dwelling post-stroke drivers were that they had previously been diagnosed with a stroke (either ischemic, haemorrhagic or a transient ischemic attack), had been cleared to drive by a medical professional and, either they, or their medical professional, had declared the stroke to the

Department of Transport. This was based on criteria for licensing, as advised by the Australian Driving Licensing Authority (Austroads & National Transport Commision Australia, 2016).

Although a stroke is more common in the older population (Australian Institute of Health and Welfare, 2013), it can happen at any age. Due to difficulties with recruiting a sufficient number of participants for the study, it was decided to not impose an age limit on participants, and to try as far as possible to age and gender match the participants at group level.

Subjects with hemispheric neglect, co-morbid traumatic brain injury or neurodegenerative disorders, such as Parkinson's disease, Alzheimer's disease or any other type of dementia, were excluded as the cognitive decline inherent to those disorders would be considered a confounding variable. Hemianopia or quadrantanopia are known co-morbidities following a stroke (Luu, Lee, Daly, & Chen, 2010), however providing that participants were assessed as fit to drive and held a valid (usually conditional) licence, they could be included in the study. Two participants presented with congenital minor visual field loss and one participant had a minor quadrantopia but had been cleared to drive, therefore all were included in the research. Hemiplegia and aphasia were not considered exclusion criteria as part of this research, provided that the potential participant had been cleared to drive by a medical professional, and fulfilled all the conditions on their licence (e.g., used adaptive controls). Diagnosis of post-stroke adults was, where possible, confirmed by the sighting of medical records that were requested of all post-stroke participants. Participants in the control group were included if they fulfilled the general inclusion criteria, had not been diagnosed with a stroke as per self-report or any of the comorbid disorders listed in the exclusion criteria. All participants were requested to show their driver's licence before participation.

Participant Demographic Profile

The total number of participants involved in the research was 85, including 40 post-stroke drivers (male = 32, female = 8) and 45 controls (male = 38, female = 8). It was discovered post testing that one male control group participant had a previously non-disclosed diagnosis of frontal lobe-dementia, and although he had been cleared to drive by his medical professional, he was subsequently removed from the analysis. The variations to age range are reported for each section of results in the following chapters, however the demographic information for the all included participants are listed in Tables 3 to 6.

Table 3.

The demographic matching variables for post-stroke drivers and controls (M=male, F=female, SD=standard deviation, km = kilometres, N/A=not applicable)

Group	n	Gender		Age (years)		Annual Millage (km)		Length of Licence (years)		Time since stroke (years)	
		M	F	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Post-stroke	40	32	8	65.85	8.94	16512	12946	48	8.33	5.64	5.73
Control	45	36	8	66.09	9.73	15380	7971	48	10.35	N/A	

Between groups analysis

It was of interest in this research to investigate the differences in driving performance and behaviour in post-stroke adults, compared to matched controls. In order to ensure that the observed differences were related to the outcome of a stroke, the groups were matched for gender, age and driving exposure (Evans, 2004).

In order to assess whether participant groups were well-matched, continuous variables (age, driving exposure as measured by annual millage and licence length) were assessed using an independent samples t-test and categorical variables (gender) assessed using the chi-square test. No significant differences were reported between groups, therefore the groups were considered well matched. After data collection had concluded, and normality of each variable assessed, two male participants aged 28 and 90 years respectively were found to skew the control group's age distribution, therefore both were excluded from the final analyses.

Information relating participants' marital status, living status, employment status, education and country of birth were also collected, in order to provide a full demographic profile (Tables 4 to 6), particularly as these have been found to influence driving behaviour (Blane, Falkmer, Lee, Parsons, & Lee, 2016; D'Ambrosio, Donorfio, Coughlin, Mohyde, & Meyer, 2008; Donorfio, D'Ambrosio, Coughlin, & Mohyde, 2009). Between group differences of the aforementioned categorical variables were assessed using the chi-square statistic, and no significant between groups' differences were reported. Although there was a greater percentage of the control group born overseas (52% control, 45% post-stroke), there were no statistically significant differences between groups for country of birth and both groups were above the national percentage for overseas born residents (28 %; Australian Bureau of Statistics, 2016).

Table 4.

The country of birth distribution for post-stroke and control participants

Group	AUS	NZ	UK	EU	Africa	Asia	USA / CAN	None	Total
Post-stroke	22	1	9	4	1	0	2	1	40
Control	21	2	13	4	2	2	0	0	44
Total	43	3	22	8	3	2	2	1	84

Note: AUS – Australia, CAN – Canada, EU – Mainland Europe, NZ – New Zealand, UK – United Kingdom, USA – United States of America

Table 5.

Living arrangement status and marital status of the post-stroke drivers and controls

Group	Live alone		Marital Status				
	Yes	No	Never Married	Married	De-facto partnership	Separated/ Widowed/ Divorced	Did not answer
Post-stroke	11	28	0	27	0	12	1
Control	11	33	1	30	5	8	0
Total	22	61	1	57	5	20	1

Table 6.

Highest education level achieved for post-stroke drivers and controls

Group	Primary School	Secondary School	TAFE / College Certificate	University Degree	Did not answer	Total
Post-stroke	1	15	13	10	1	40
Control	0	11	13	20	0	44
Total	1	26	26	30	1	84

Table 7.

Demographic data for type of stroke and stroke location

Stroke Type	Stroke Location				
	Left Hemisphere	Right Hemisphere	Brain Stem	Unknown	Total
Haemorrhagic	4	3	3	1	11
Ischemic	10	8	0	4	22
Unknown	2	2	0	3	7
Total	16	13	3	8	40

Post-stroke diagnosis

Due to the self-nomination of participants in the study, the type and location of the stroke varied (Table 7). For the purposes of this research, participants who reported one or more transient ischemic attacks (TIA) were grouped with participants who reported an ischemic stroke. There were a greater proportion of ischemic strokes, to haemorrhagic stroke. Females were more likely to report an ischemic stroke (n=6). Only one female reported a haemorrhagic stroke and one female participant reported that she was not sure of the type of stroke. Overall, 55% of participants reported an ischemic stroke, 27% reported a haemorrhagic stroke and 18% reported that they were not sure or could not remember.

Measures and data processing

Off-road measures

Visual Acuity. In order to screen for potential confounding effects of poor visual acuity (VA), and to ensure compliance with the minimum VA for safe driving in Western Australia, bilateral VA for each participant was assessed using the Early Treatment Diabetic Retinopathy Study (ETDRS) chart (Precision Vision). All participants were required to achieve a bilateral score of 20/40 VA in order to participate. All participants met the minimum VA requirements for this research.

Demographics and Health

Demographic and Driving Background. A self-report questionnaire (Appendix 2.) was used to collect socio-demographic details. Data collected included: participants' age, gender, marital status, education, ethnicity, spectacle usage, co-morbid medical conditions, current medications and self-reported stroke details. Data were also collected relating to driving experience (years of driving), driving exposure (annual mileage), driving dependence and driving avoidance using an amended version of the Driving Habits Questionnaire (DHQ; Owsley, Stalvey, Wells, and Sloane (1999). Specific amendments were made to the driving avoidance scale, where the questions were amended to reflect changes in habits due to post-stroke repercussions rather than visual problems. The DHQ has been well-utilised in older populations (Decarlo, Scilley, Wells, & Owsley, 2003; Owsley et al., 1999) and provided scored data relating to driving habits and exposure.

These details were collected for descriptive purposes and in order adjust statistical analyses for potential confounders. Driving exposure is a known confounder in driving research (Evans, 2004), therefore these data were used, along with age and gender to match groups. The questionnaire was completed by the participant either by hand or by using the Curtin University Licensed Qualtrics online survey tool (Qualtrics, 2015).

Post-stroke participants were requested to bring to the assessment any medical documentation to which they had access. This was sighted by the researcher, in order to confirm the approximate type and location of their stroke, as well as the duration since diagnosis.

Neurocognitive Assessment

A selection of neurocognitive assessments were used throughout this thesis. A summary of each assessment is provided below, as well as an indication of the consistency and validity scores of each (Table 8).

Reaction Time. Reaction times have been shown to be an indicator of visual driving performance (Plainis & Murray, 2002) and post-stroke adults are known to be deficient in psychomotor abilities (Heikkilä, Korpelainen, Turkka, Kallanranta, & Summala, 1999), therefore this research sought to investigate psychomotor function and visual processing using E-prime© software. Following criteria previously implemented in similar cognitive research (Bunce, Handley, & Gaines Jr, 2008; Bunce, Young, Blane, & Khugputh, 2012), the participants completed a simple reaction time task (SRT); a two-choice reaction time task (2CRT) and a 4-choice reaction time task (4CRT). On all tasks, the participants were instructed to answer both as quickly and as accurately as possible. Hit, miss and false alarm (where relevant) were recorded. In order to account for response bias all response data reported were adjusted for hit rate. The presentation of the E-Prime© based reaction time tasks was randomised using the participant number to determine which display was used. For the all reaction time based E-prime© tasks, there was a centralised fixation of one second prior to the display of the target array. The target array was displayed for an unlimited amount of milliseconds in the visual search task, which would remain until the participant had provided an answer. The target array in the SRT, 2CRT and 4CRT task was displayed for a maximum of 10 seconds, unless the participant provided an answer.

SRT. Baseline reaction time was measured using a SRT. Participants were presented with the letter X in the middle of the display and told to press the space bar as soon as the X appeared. Participants completed eight practice trials prior to undertaking the experimental trials.

2CRT. This task involved 12 practise trials and 48 test trials where participants were presented with a fixation point of 500ms followed by a target 25mm diameter black circle lasting for 1s. Participants were asked to press the corresponding key as to where the circle appeared spatially on screen, i.e., if the circle appeared on the left side of the screen the participant was to press X on the keyboard and if the circle appeared on the right side then the participant was to press M. All targets were presented randomly.

4CRT. The four choice reaction time task involved the same black circle and fixation point and a similar process to the 2CRT task, however in the 4CRT task participants were asked to press the corresponding key to four possible spatial positions of the target circle. These positions were: top left (S key), top right (L key), bottom left (X key) and bottom right (M key). Participants completed eight practice trials prior to undertaking the experimental trials.

Visual Search. A simple visual search task, consisting of identifying an embedded Q amongst a 6x6 array of the letter O, was used to assess selective attention and utilising an objective data collection methodology. Following the procedure outlined in previous driving research (Bunce et al., 2012), participants were instructed to search for the appearance of the letter Q, and after each display, indicate whether it had been present. The instructions given to each participant were to press the corresponding key (X for yes, M for no) on the keyboard to determine the presence of a Q as quickly and accurately as possible. The 6x6 display was presented, as well as accuracy and raw reaction time in milliseconds recorded using E-Prime Version2.0 (Schneider, Eschman, & Zuccolotto, 2012). Throughout the 64 experimental trials, the number of yes and no answers were equally distributed; however the sequence was randomised for each participant. Participants completed 16 practice trials prior to undertaking the experimental trials.

Delis-Kaplan Executive Function System Trail Making Task. The Delis-Kaplan Trail Making Task© (DKEFS-TMT) is a cognitive assessment used to measure attention and executive function (Delis, Kaplan, & Kramer, 2001a). The DKEFS-TMT has previously been used to assess cognitive performance in post-stroke patients and found to be sensitive to cognitive decline, particularly in frontal lobe function (Homack, Lee, & Riccio, 2005; Wolf & Rognstad, 2013). Patients with pre-frontal lesions have been found to have poor performance on the trail task (Yochim, Baldo, Nelson, & Delis, 2007) and previous versions of the task have been utilised in driving research (Motta, Lee, & Falkmer, 2014), particularly as operational executive function is essential for driving (Anstey, Wood, Lord, & Walker, 2005). The DKEFS-TMT measure included five separate paper-based component tasks that assessed different levels of cognition. Task one was comprised of a visual cancellation task, whereas tasks two, three and five consisted of several connect the circle tasks. Tasks one, two three and five were used to provide a baseline performance score of key components of cognition used within executive function: specifically, visual scanning, number sequencing, letter sequencing, and motor speed (Swanson, 2005). Task four was a number-letter switching task, which was used to asses executive function, specifically through assessing visuospatial thought flexibility (Swanson, 2005).

Useful Field of View. Vision and attention are highly important to driving safely and both can be impaired in post-stroke drivers (Fisk, Owsley, & Mennemeier, 2002). The Useful Field of View© (UFOV) task was developed as means of measuring visual, selective and divided attention, as well as executive functioning (Ball & Owsley, 1993) and has been regularly implemented in post-stroke driving research (Fisk et al., 2002; George & Crotty, 2010). The UFOV was presented using a Windows 7™ laptop and 5:3 ratio screen. Lower scores on the three subscales are indicative of better performance (Selander, Lee, Johansson, & Falkmer, 2011).

Balloon Analogue Risk Taking Task. The Balloon Analogue Risk Task (Lejuez et al., 2002) was used as a measure of risk-taking and aversive behaviour. The objective was to pump up the balloon displayed on screen and collect the most points without allowing the balloon to burst. The number of pumps required for the balloon to burst was randomised and was programmed to the standard range for the BART: 2-128 pumps (Lejuez et al., 2002). Participants with lower scores and fewer burst balloons are considered to be risk aversive, whereas participants with higher scores and more burst balloons have a greater propensity for risk. The BART was administered using E-Prime© Software and number of balloons saved and adjusted average number of pumps for each balloon recorded.

Benton Judgement of Line Orientation. The Benton Judgement of Line Orientation Task (BJLOT; Benton, Hamsher, Varney, & Spreen, 1983) measured spatial cognition, perception and orientation ability. The test consisted of a series of reference lines arranged in a semi-circle, from which participants have to identify specified target lines. The rotation and angle alteration of the target lines increased the difficulty of the task as the test progresses.

Wechsler Block Design Task. Post-stroke adults often experience deficits in visuospatial function (Kaplan & Hier, 1982; Stone et al., 1991). The Wechsler (2008) block design task is a subset of the Wechsler Adult Intelligence Scale and was used to measure non-verbal visuospatial reasoning (Wechsler, 2008). The test involves constructing a specified design made of out of a series of cuboid blocks as quickly and as accurately as possible.

NASA TLX. Perceived cognitive workload and performance was measured using the NASA Task Load Index (TLX; Hart & Staveland, 1988). This questionnaire assessed the participants' perceived amount of effort required on six different levels: mental demand, physical demand, temporal demand, performance, effort and frustration, after each trial in the driving simulator and after the on-road assessment.

Table 8.

Consistency and validity scores for measurement tools used as part of thesis

Assessment	Consistency Score	Validity Score		Reference
BART	Test-retest reliability of between 0.81 and 0.92	Incremental validity score 0.45		Lejuez et al. (2002)
BJLOT	Test-retest reliability of 0.90	Low to moderate construct validity		Lundberg, Caneman, Samuelsson, Hakamies-Blomqvist, and Almkvist (2003) Riccio and Hynd (1992)
DKEFS TMT	Low to moderate consistency for individual items	Adequate validity for multiple populations, however further study required.		Homack et al. (2005) Delis, Kaplan, and Kramer (2001b)
DVT	Test retest reliability of 0.80 – 0.93	Good convergent validity		Kelland and Lewis (1996)
DHQ	Test retest reliability of sub-scales Dependence - 0.57 Difficulty – 0.87	Adequate validity, however further study required.		Song, Chun, and Chung (2015)
MoCA	Test-retest reliability of 0.70-0.92	90% - 100% sensitivity 87 – 90% specificity reported		Nasreddine et al. (2005)
NASA TLX	Test-retest of 0.83	Good inner consistency and validity		Hart and Staveland (1988) Xiao, Wang, Wang, and Lan (2005)
DBC	No details available but utilised in previous driving research			Chee, Lee, Lee, and Falkmer (2013) Chee, Lee, Patomella, and Falkmer (2017)
Psychomotor Assessments	No details available but utilised in previous driving research			Bunce et al. (2012)
RSRT	No details available but previously utilised in driving research			Blane et al. (2016) Lee, Lee, and Cameron (2003) Motta et al. (2014)
UFOV	Test retest reliability score of 0.88	Sensitivity: 77.5% (UFOV 2) 85.7% (UFOV 3)	Specificity 88.9% (UFOV 3) 69.4% (UFOV 2)	Edwards et al. (2005) (George & Crotty, 2010)
Block Design	Test-retest reliability of between 0.88 and 0.93.	Moderate validity		Kaufman (1983) Groth-Marnat and Teal (2000)

Driving Simulator

The Curtin University STISIM© Driving Simulator is a fixed-base car driving simulator that has mid-level physical fidelity and consists of a driving console with three ASUS (24" 16:9 ratio) display screens (Figure 5), onto which the forward facing and peripheral driving scenes are displayed (Figure 5). Driving related auditory feedback, such as traffic and engine noise, was provided through the digital auditory output system, therefore providing a more immersive experience. A prior version of the STISIM© simulator has been validated for use on older adults (Lee et al., 2003).

The simulator uses the Windows 7™ operating system and runs using STISIM© driving software (Allen, Stein, Aponso, Rosenthal, & Hogue, 1990). A practice scenario was utilised for each participant, in order for them to become familiar with the driving console controls and visual stimuli. The practice scenario lasted approximately 10 minutes and included a 60km dual single lane road. Two experimental driving scenarios were programmed using a text code-based scenario definition language (Appendix 3). These scenarios consisted of a lead-car scenario and a hazard perception scenario, which lasted approximately five and 15 minutes, respectively. Both contained 60km per hour roads.

The *lead-car scenario* required participants to follow a lead-car for the duration of the scenario and their main task was to maintain a safe, consistent distance between themselves and the car in front. The scenario was designed with few distractions and was the easier of the two scenarios to complete.

The *hazard perception scenario* was designed to be more challenging than the lead-car scenario and included various traffic-based events that would test the participants' driving performance, hazard perception skills and / or knowledge of road rules and regulations. The hazard perception display was programmed to include negotiating traffic lights, intersections, traffic cone diversions and other road users (cyclists, pedestrians, cars, etc.) who would often pull out into the participants' path within close proximity. There was also an emergency stop style manoeuvre programmed, which was used to measure braking reaction time. Due to constraints on the participants' time (five participants including four controls and one post-stroke driver) or the onset of simulator sickness (22 participants including 11 controls, 11 post-stroke), 27 participants did not complete the hazard perception scenario to completion, which resulted in a total of 66 (30 post-stroke, 36 control) participants recording speed and lateral lane position variables and 48 (22 post-stroke and 26 control) participants recording reaction time variables.

Figure 5. The Curtin University STISIM Driving Simulator and the SMI head-mounted eye-tracker

On-Road Measures

On-Road Assessment Route

Participants were asked to undertake an observed drive on a pre-defined driving route around the Curtin University Campus and surrounding Bentley area (Figure 6). The route was 13km and took approximately 20 - 25 minutes to complete. Participants were unaware of the route prior to the drive and were given directions by the researcher. The route was specifically designed to include driving scenarios that required significant cognitive capacity, such as turning right, stop signs, pedestrian crossings, etc. The specific scenarios of interest are outlined in identified in each results chapter. The drive took place in the participants' own insured vehicle, which included any vehicle modifications they required as part of their licensing conditions, such as adaptive pedals or steering. All participants were asked to provide their licence for sighting prior to study commencement. Two researchers accompanied the participant in the car for each assessment.

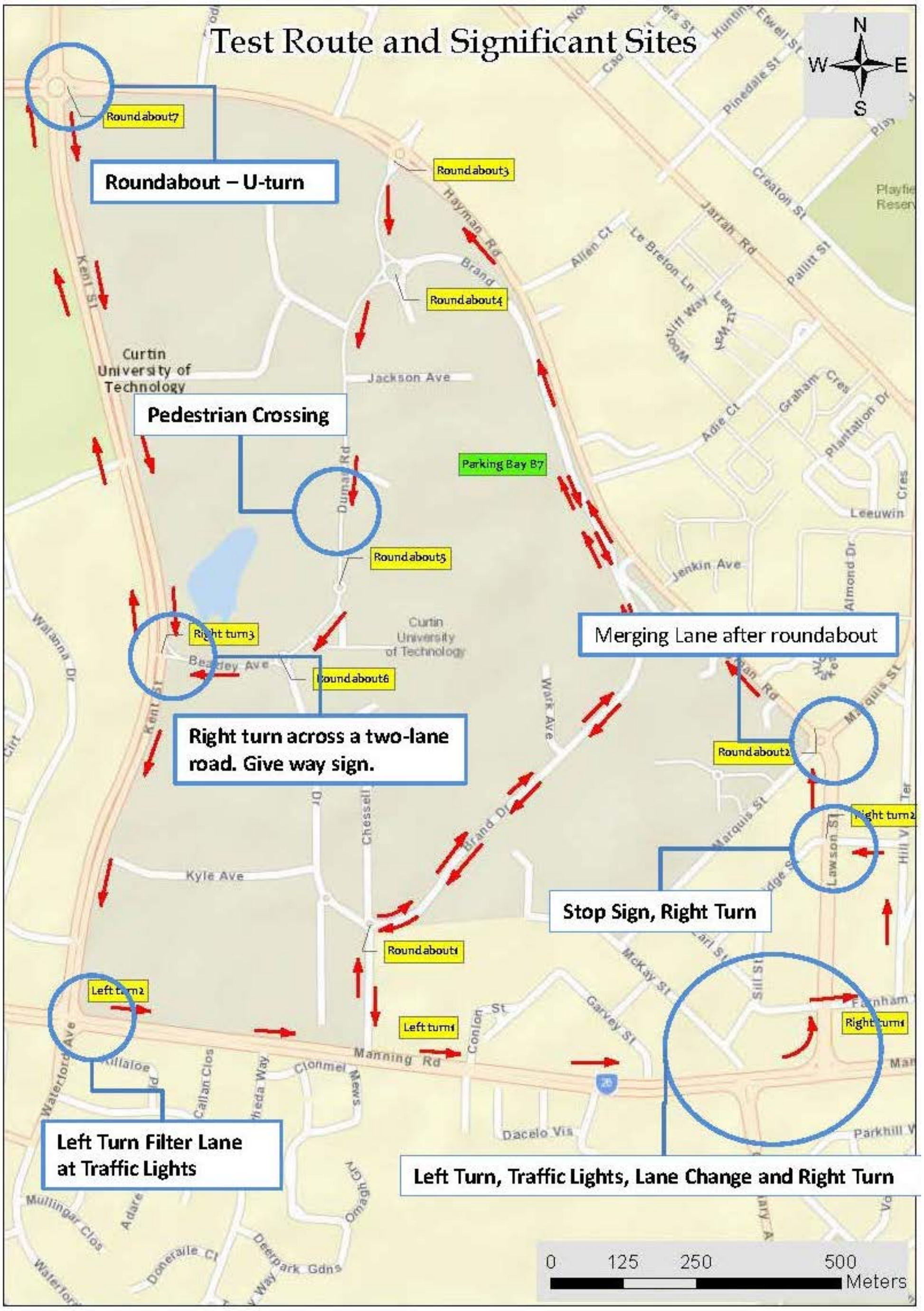

Figure 6. Map of the on-road assessment route with areas of interest marked. Adapted from Google Maps. Retrieved from https://www.google.com.au/maps/@-32.0066262,115.8927424,15.75z

Eye-tracker

Of particular interest in this study was the visual scanning patterns of post-stroke drivers. As visual scanning and perception are potentially impacted following a stroke (Leśniak, Bak, Czepiel, Seniów, & Członkowska, 2008) the number of fixations and fixation duration were recorded for both groups and each individual fixation within specified areas of interest were coded for traffic relevancy. The areas of interest are outlined in Figure 6.

Two different eye-tracking devices were used as part of this research: the Arrington ViewPoint^{TM} head-mounted monocular eye-tracking glasses (Figure 7 - reft) and the SensoMotoric Instruments^{TM} (SMI) head-mounted binocular eye-tracking glasses (Figure 7 - right). During assessments, both units were controlled using a Dell Latitude laptop or a SMI laptop which were each equipped with the appropriate eye-tracking recording software and recorded information in 60Hz.

The SMI eye-tracker was the primary eye-tracker used in this research as the calibration sequence was most the efficient. However, as the groups involved in this study were older adults, there were occasionally issues with calibration as the camera on the SMI eye-tracker was static. On these occasions or when there were other technical difficulties with the SMI eye-tracker, the Arrington eye-tracker was used as a back-up. Overall, 13 control participants' fixations and one post-stroke driver's fixations were assessed using the Arrington eye-tracker.

Figure 7. The two different eye-trackers used in this research. Left - the Arrington ViewPoint eye-tracker. Right - the SMI head-mounted eye-tracker Reprinted from http://www.businesswire.com/news/home/20141219005468/en/SMI-Eye-Tracking-Glasses-Set-Industry-Standard

Driving Behaviour Checklist

Observed driver behaviours were recorded for each participant using a driving behaviour checklist (DBC; Appendix 4. This is a researcher administered checklist based on the Michon model of driving (Michon, 1985) and P-drive on-road driving assessment and was developed as an easy-to-administer on-road driving checklist when observing drivers with pathologies (Chee et al., 2013; Chee et al., 2017). The original checklist was collaboratively amended to fit the driving route and coded based upon the 'B-on Road' protocol used in Sweden (Broberg & Dukic Willstrand, 2014). This process allowed the researcher to identify the type of error made (e.g., not checking a mirror was considered a lapse in attention).

Data Collection and Procedure

Recruitment

Participants were community-dwelling volunteers recruited using purposive sampling techniques. Volunteers would self-nominate for participation in response to advertisements in local community media (newspapers, newsletters, radio stations), as well as in response to verbal and printed advertisements given to local community and post-stroke support groups (Appendix 5).

Procedure

Participants were provided with a participant information sheet and screened using the revised charts 1-3 from the 2000 ETDRS visual acuity chart (Precision Vision). The order of completion for the cognitive tasks was pseudo-randomised for each participant using a Latin squares method, however, where possible, the driving simulator was run as the final assessment in order to minimise the effects of possible simulator sickness. Participants completed the NASA TLX after both simulator tasks and the on-road observation task. Overall the process lasted approximately two to three hours.

Simulator sickness protocol

A protocol was put in place to minimise the potential for simulator sickness. This protocol included: minimising bends and turns within the simulation, ensuring the room was dark other than the simulator, switching on a fan for extra air flow and having all instructions given to the participant via the audio output on the simulator so that they did not need to turn their heads to listen the experimenter (Classen, Bewernitz, & Shechtman, 2011; Stoner, Fisher, & Mollenhauer, 2011). As simulator sickness is more common in the older population (Brooks et al., 2010; Kawano et al., 2012), participants were made aware of the potential for simulator sickness, as well as notifying them of the likely symptoms (nausea, light-headedness, dizziness, temperature changes, sweating, yawning, etc.). Prior to the simulator assessment, participants were instructed, that if they experienced any symptoms or felt uneasy at any point, they were to inform the researcher immediately, the assessment would be halted and they would be attended to. When simulator sickness occurred, the simulation was ceased, the lights turned on, the window blinds opened and the participant was offered water and ginger tea to relieve any nausea. The participant was given the opportunity to remain in the lab until the sickness had passed and they were able to safely drive themselves home. They were informed that if they were too unwell to drive, they would be driven home by a researcher or taken home in a taxi and transportation of their vehicle would be arranged.

Remuneration

Participants were offered a $15 Coles / Myer gift card as a token of appreciation for their time and travel costs.

Data processing, analysis and quality assurance

Cognitive Assessments

Psychomotor (SRT, 2CRT, 4CRT) and Visual Search Assessments. For both the psychomotor assessments and visual search assessment, participants were instructed to answer both as quickly and as accurately as possible. Hit, miss and false alarm (where relevant) were recorded. In order to account for response bias, all response data reported were adjusted for hit rate. The data were screened for any accidental key presses and excessively fast or slow latencies using Microsoft Excel© and E-DataAid©. Excessively fast or slow latencies were classified based on previous research (Bunce et al., 2008; Bunce et al., 2012) as reaction times less than 150ms and reaction times greater than the mean + 3 intra-individual standard deviations, and were excluded without replacement. Following data cleaning and collation mean and accuracy rate were recomputed. Finally, the baseline reaction time recorded using the simple reaction time task was subtracted from the 2CRT, 4CRT and visual search tasks to give an indication of specific task-based performance independent of raw reaction time ability.

DKEFS Trail Making Task. Processing for the DKEFS trail-making task consisted of several stages of data recoding. In the initial stage, participants with time-to-completion scores greater than 150s for assessments one to three and five were recoded to reflect 150s in the final analysis. For assessment four, participants with time-to-completion scores greater than 240s for assessment four (number-letter sequencing task) were recoded to 240s.

The second stage of processing for the DKEFS trail making task, involved scaling the raw time-to-completion scores. This involved converting the time-to-completion score to a number ranged between one and 19. The scaled score was calculated based upon time to completion and the age of the participant. As cognition is known to decline with age, the scaled score provided an adjusted indication of performance, independent of age effects (Delis et al., 2001a).

The final stage of the processing involved calculating several contrast scores, which would provide indications of higher-level cognitive process performance, independent of baseline cognitive performance (Table 9).

Table 9.

DKEFS contrast scores variable names, calculation and the associated cognitive process

Variable Acronym	Variable Name	Calculation	Cognitive Process
DKEFS-TMT EF1	Visual Scanning	Condition 4 – Condition 1	Executive function independent of visual scanning
DKEFS-TMT EF2	Number Sequencing	Condition 4 – Condition 2	Executive function independent of numerical skill
DKEFS-TMT EF3	Letter Sequencing	Condition 4 – Condition 3	Executive function independent of verbal skill
DKEFS-TMT EF4	Combined Number Sequencing and Letter Sequencing	Condition 4 – (Condition 2 + Condition 3)	Executive function independent of numerical and verbal skills
DKEFS-TMT EF5	Motor Skills	Condition 4 – Condition 5	Executive function independent of raw processing speed.

Adapted from D. C., Delis, E., Kaplan, & J. H. Kramer, (2001a). Delis-Kaplan Executive Function System (D-KEFS) Examiner's Manual. San Antonio, Texas: The Psychological Corporation, p.47. Copyright The Psychological Corporation.

Balloon Analogue Risk-Taking Task (BART). Raw BART E-Prime© data were imported into Microsoft Excel©, whereby the number of balloons saved were separated using the filtering function and the mean number of balloon pump presses calculated to provide the adjusted average. This adjusted mean, as well as the number of balloons saved were then imported into the master spreadsheet.

Driving Measures

Driving Habits Questionnaire

The data from the DHQ, which was collated using the Qualtrics Survey software, was exported into Microsoft Excel© for data checking and cleaning. Following data cleaning, the data were exported in SPSS v22 (IBM Corporation, 2013) for analysis. Driving exposure, driving avoidance and driving dependence were calculated using criteria specified in the original literature (Owsley et al., 1999).

Driving Simulator

There are multiple considerations to take into account and many way of assessing driving performance and behaviour in a driving simulator (Fisher, Rizzo, Caird, & Lee, 2011). Some research has utilised checklists of driving behaviour (e.g., Meuleners & Fraser, 2015), whereas others have chosen to utilise the summary data and / or raw data output from the driving simulator (e.g., Bunce et al., 2012). Generally, using only the summary data (e.g., number of crashes, number of centreline crossings, lane excursions) does not provide specific enough information to determine differences in driving performance. The raw data output of the STISIM driving simulator is determined by the specified "begin block save" (BSAV) variables in the computer programming (Appendix 3). For this research, the driving simulator was programmed to record specific variables in 2Hz (specifically, lateral lane position, speed, headway, braking reaction time and steering input). Using these variables is appropriate, as moment-to-moment analysis can be conducted. Similar to using the method of only comparing collated crash and incident data using the summary, measures of central tendency calculated from the moment-to-moment data do not provide enough specificity. It was therefore decided to assess driving performance by calculating the moment-to-moment instability of each driving dependent variable (headway, speed, lateral lane position and steering input), with the measures of central tendency used to report braking reaction time.

Bloomfield and Carroll (1996, p. 336) describe instability as *"…a linear equation that is the line of best fit for a series of points on the track of a vehicle can be used to describe the position of the vehicle relative to the centre of the lane."* Therefore, following their procedure, also utilised in subsequent driving research (e.g., Young & Stanton, 2002), a standard error regression was performed with each driving variable listed as the independent variable and the time recorded in 0.5 second increments utilised as the independent variable. This technique was used to provide a collated moment-to-moment measure of instability consisting of residuals for the target driving variable. The process of calculating the residual data to be used as a dependent variable in the final analysis was conducted using a Microsoft Excel©-

based macro, programmed using Visual Basic for Applications (Microsoft Office, 2010).

Eye-tracking

Both eye-trackers recorded a real-time moment-to-moment recording of both the visual stimuli through a video-recording of the surrounding environment, and the eye movement data, including accumulated measures of fixation-based information. Data were recorded in 60Hz. The number of fixations and duration of fixations were recorded for each participant and these data were overlaid with the video recording of the environment, in order to code each fixation for traffic relevancy. Based on previous eye-tracking research (e.g., Falkmer & Gregersen, 2005) a fixation was defined as the mean of the X,Y fixation coordinates within a 1° x 1° area and ≥100ms in duration. Fixations for both Arrington and SMI collected data were generated using the centroid-mode algorithm (Falkmer, Dahlman, Dukic, Bjällmark, & Larsson, 2008).

Data collation and management

Cognitive and questionnaire data

Cognitive data collected using the E-prime software were collated and condensed using E-DataAid© and E-Merge© software (Schneider et al., 2012) before being uploaded into Microsoft Excel© for data cleaning. Demographic and questionnaire data were recorded using the Qualtrics online survey software before downloaded into the Statistical Package for Social Sciences [SPSS] v.22 (IBM Corporation, 2013) and Microsoft Excel© for data checking and cleaning. Individual spreadsheets were merged using the add cases and add variables functions in SPSS.

Eye-tracking

The eye-tracking data were cleaned and assessed using, the SMI BeGaze software version 3.6 (SMI, 2011) and Microsoft Excel©. Individual data recordings for each participant recorded on the SMI recording device were uploaded into the BeGaze programme. The calibration of each recording was checked and the raw event and fixation data were exported as a video based .avi file and a Microsoft Excel© file. The raw data were then processed and cleaned using MATLAB (Mathworks, 1998). Data collected using the Arrington were processed using the ViewPoint data analysis programme (Arrington Research, 2006) and raw fixation data exported into Microsoft Excel© for coding. Participant coding for each area of interest were then merged into a single database and data for each area of interest were counted and coded and loaded into SPSS v.22 (IBM Corporation, 2013) for analysis. Data were then analysed using the General Estimating Equations (GEE) analysis.

Data cleaning and quality assurance

Subsequently all cognitive, demographic and driving variables were entered onto a master Microsoft Excel© database. Although data were regularly screened using range checks, quality assurance of the data was also ensured through independent moderation and data entry checks on 30% of the total sample data. Where possible, data were calculated using Microsoft Excel©-based macros programmed using Visual Basic (Microsoft Office, 2010). When macros were used for calculations, data comparability was ensured through Microsoft Excel©-based matching using the conditional formatting function. This was achieved through manual calculation of the scores for 20% of the sample and then using Microsoft Excel© to check whether the data produced using the macro was the same. Any data differences were then investigated and corrected.

Missing data. Where data were missing, because a participant had missed a question (e.g., as part of the online questionnaire or hand written questionnaire) steps were taken to obtain these data from the participant, through email or telephone calls. However, participants were not asked to repeat cognitive assessments as there would likely have been practice effects. Where a participant had missing data from the driving simulator, most often due to simulator sickness or due to technological failures in the eye-tracker, the data were logged as missing and not replaced.

Ethical Considerations

This research and the associated protocols involved were approved by the Curtin University Human Research Ethics Committee (HREC), approval number: HR206-2014 and HREC OTSW-20-2011 (Appendix 7) and all procedures conformed to the Declaration of Helsinki. Annual reports and all study amendments were provided to the Curtin University HREC to ensure proper compliance.

Informed consent and right to withdraw. Participants were verbally briefed and provided with a study brochure (Appendix 6) and participant information sheet (Appendix 8) before agreeing to take part in the research. Participants were given the opportunity to ask questions and were required to read and sign an informed consent form (Appendix 8) prior to participation. Participants were volunteers to the study and made aware both verbally and as part of the informed consent form that they had the right to withdraw at any point without incurring any negative consequences. Participants were also informed that the data would be de-identified for analysis and that the results would be used to develop a post-stroke driver profile and the results of which would be disseminated as a PhD thesis and a series of scientific manuscripts.

Confidentiality and data storage. Participants were assigned an identification number and analyses were performed on de-identified data only. Although the participants' identification documents (medical documentation, full name, etc.) were collected, this re-identifiable information was stored separately from cognitive data and was only accessed for data checking purposes. All collected data were entered into numbered electronic databases and stored on the Curtin University firewall-protected local network server, and a copy of these data was stored, along with all individual original electronic individual files, on a password protected Western Digital 2TB hard disk. The hard disk and all original hand-written data (including the participant information sheets) were stored in a locked cabinet in the Curtin University School of Occupational Therapy and Social Work. The intention was to securely store these data in electronic format or as hard copies in a securely locked cabinet for seven years after conclusion of the study. After this time, all data will be confidentially destroyed in line with the guidelines issued by Curtin University and the Western Australian University Sector Disposal Authority.

On-road driving, licensing and safety considerations. With all driving research and in particular for those with any pathology, there is the possibility of questioning driver competence, as well as the question of safety. A risk assessment was undertaken prior to the study commencement (Appendix 9) and several measures undertaken during the research design phase to help minimise the associated risks. Firstly, the research involved only licensed drivers, in their own insured vehicles, complete with any driving modifications, e.g., a steering knob or adapted foot pedal. Compliance with licensing restrictions was ensured through sighting the participants' driver's licences and ensuring that all restrictions were adhered to whilst taking part in the research.

If during the course of the research, a participant presented with obvious driving difficulty, the following procedure would be implemented: the experiment would be ended prematurely and the participant would be offered complementary driving counselling with the primary supervisor (a Driving Assessment Trained Occupational Therapist). Similarly, if the participant did not meet the minimum VA requirement, they would be advised to visit their regular optometrist or medical practitioner and asked to return once they had suitable aids to assist them with meeting the required VA score. Participants were also informed that although it was not the purpose of the study to review their driving performance for licensing purposes, that any medical review that they undertook upon advice, could lead to a potential review of their ability to drive.

The safety of all involved in the research assessments was ensured through assigning a Research Assistant to accompany the participant and primary researcher for all assessments.

Chapter Summary and Progression

This chapter has outlined the methodologies used in the thesis. The following chapters will discuss the results of each individual study. The first section of results will discuss driving simulation studies, the first of which investigated the influences of socio-demographic and cognitive performance on post-stroke driving status.

Chapter Two References

Allen, R. W., Stein, C. A., Aponso, B. L., Rosenthal, T. J., & Hogue, J. R. (1990). *A low cost, part task driving simulator based on microcomputer technology.* Paper presented at the 69th Annual Meeting of the Transportation Research Board., Washington, DC.

Anstey, K. J., Wood, J., Lord, S., & Walker, J. G. (2005). Cognitive, sensory and physical factors enabling driving safety in older adults. *Clinical Psychology Review, 25*, 45-65. http://dx.doi.org/10.1016/j.cpr.2004.07.008

Arrington Research. (2006). ViewPoint EyeTracker®. Retrieved from http://www.arringtonresearch.com/viewpoint.html

Australian Bureau of Statistics. (2016). *Migration, Australia, 2014-2015*. Canberra: Australian Bureau of Statistics. .Retrieved from http://www.abs.gov.au/ausstats/abs@.nsf/mf/3412.0

Australian Institute of Health and Welfare. (2013). *Stroke*. Canberra: Retrieved from http://www.aihw.gov.au/WorkArea/DownloadAsset.aspx?id=60129543611

Austroads, & National Transport Commision Australia. (2016). Assessing fitness to drive for commercial and private vehicle drivers: Medical standards for licensing and clinical management guidelines., Retrieved from https://www.onlinepublications.austroads.com.au/items/AP-G56-16

Ball, K., & Owsley, C. (1993). The Useful Field of View test: A new technique for evaluating age-related declines in visual function. *Journal of the American Optometric Association, 64*(1), 71-79.

Benton, A. L., Hamsher, K., Varney, N. R., & Spreen, O. (1983). *Judgment of line orientation*. New York: Oxford University Press

Blane, A., Falkmer, T., Lee, M., Parsons, R., & Lee, H. C. (2016). The cognitive and socio-demographic influences on driving performance and driving cessation in post-stroke drivers. *Advances in Transportation Studies: An International Journal,*(38), 121-135.

Bloomfield, J. R., & Carroll, S. A. (1996). New measures of driving performance. In S. A. Robertson (Ed.), *Contemporary Ergonomics* (pp. 335-340). London: Taylor & Francis.

Broberg, T., & Dukic Willstrand, T. (2014). Safe mobility for elderly drivers: Considerations based on expert and self-assessment. *Accident Analysis & Prevention, 66*, 104-113. http://dx.doi.org/http://dx.doi.org/10.1016/j.aap.2014.01.014

Brooks, J. O., Goodenough, R. R., Crisler, M. C., Klein, N. D., Alley, R. L., Koon, B. L., . . . Wills, R. F. (2010). Simulator sickness during driving simulation studies.

Accident Analysis & Prevention, 42(3), 788-796. http://dx.doi.org/http://dx.doi.org/10.1016/j.aap.2009.04.013

Bunce, D., Handley, R., & Gaines Jr, S. O. (2008). Depression, anxiety, and within-person variability in adults aged 18 to 85 years. *Psychology and Aging, 23*(4), 848-858.

Bunce, D., Young, M. S., Blane, A., & Khugputh, P. (2012). Age and inconsistency in driving performance. *Accident Analysis & Prevention, 49*, 293-299. http://dx.doi.org/10.1016/j.aap.2012.01.001

Business Wire (2017).[image] Retrieved from http://www.businesswire.com/news/home/20141219005468/en/SMI-Eye-Tracking-Glasses-Set-Industry-Standard

Chee, D. Y., Lee, H. C., Lee, A. H., & Falkmer, T. (2013). Performance of drivers with Parkinson's Disease under the effect of cognitive overloading: insinuation for assessment and training. *Advances in Transportation Studies: An International Journal,*(29), 5-17.

Chee, D. Y., Lee, H. C., Patomella, A. H., & Falkmer, T. (2017). Performance of drivers with Parkinson's disease under the effect of cognitive overloading: insinuation for assessment and training. *Journal of Autism and Developmental Disorders* (in press)

Classen, S., Bewernitz, M., & Shechtman, O. (2011). Driving simulator sickness: An evidence-based review of the literature. *American Journal of Occupational Therapy, 65*(2), 179-188. http://dx.doi.org/10.5014/ajot.2011.000802

D'Ambrosio, L. A., Donorfio, L. K., Coughlin, J. F., Mohyde, M., & Meyer, J. (2008). Gender differences in self-regulation patterns and attitudes toward driving among older adults. *Journal of Women & Aging, 20*(3-4), 265-282. http://dx.doi.org/10.1080/08952840801984758

Decarlo, D. K., Scilley, K., Wells, J., & Owsley, C. (2003). Driving habits and health-related quality of life in patients with age-related maculopathy. *Optometry & Vision Science, 80*(3), 207-213. Retrieved from http://journals.lww.com/optvissci/Fulltext/2003/03000/Driving_Habits_and_Health_Related_Quality_of_Life.10.aspx

Delis, D. C., Kaplan, E., & Kramer, J. H. (2001a). *Delis-Kaplan Executive Function System (D-KEFS) examiner's manual*. San Antonio, Texas: The Psychological Corporation.

Delis, D. C., Kaplan, E., & Kramer, J. H. (2001b). *Delis-Kaplan Executive Function System (D-KEFS) technical manual*. San Antonio, Texas: The Psychological Corporation. .

Donorfio, L. K., D'Ambrosio, L. A., Coughlin, J. F., & Mohyde, M. (2009). To drive or not to drive, that isn't the question—the meaning of self-regulation among older drivers. *Journal of Safety Research, 40*(3), 221-226. http://dx.doi.org/10.1016/j.jsr.2009.04.002

Edwards, J. D., Vance, D. E., Wadley, V. G., Cissell, G. M., Roenker, D. L., & Ball, K. K. (2005). Reliability and validity of Useful Field of View test scores as administered by personal computer. *Journal of Clinical and Experimental Neuropsychology, 27*(5), 529-543. http://dx.doi.org/10.1080/13803390490515432

Evans, L. (2004). *Traffic safety*. Bloomfield Hills, Michigan: Science Serving Society.

Falkmer, T., Dahlman, J., Dukic, T., Bjällmark, A., & Larsson, M. (2008). Fixation identification in centroid versus start-point modes using eye-tracking data. *Perceptual and Motor Skills, 106*(3), 710-724.

Falkmer, T., & Gregersen, N. P. (2005). A comparison of eye movement behavior of inexperienced and experienced drivers in real traffic environments. *Optometry & Vision Science, 82*(8), 732-739.

Fisher, D. L., Rizzo, M., Caird, J., & Lee, J. D. (2011). *Handbook of driving simulation for engineering, medicine, and psychology*. Hoboken: Taylor and Francis.

Fisk, G. D., Owsley, C., & Mennemeier, M. (2002). Vision, attention, and self-reported driving behaviors in community-dwelling stroke survivors. *Archives of Physical Medicine and Rehabilitation, 83*(4), 469-477. http://dx.doi.org/10.1053/apmr.2002.31179

George, S., & Crotty, M. (2010). Establishing criterion validity of the Useful Field of View assessment and Stroke Drivers' Screening Assessment: Comparison to the result of on-road assessment. *American Journal of Occupational Therapy, 64*(1), 114-122.

Google Maps (2017) [image] Retrieved from https://www.google.com.au/maps/@-32.0066262,115.8927424,15.75z

Groth-Marnat, G., & Teal, M. (2000). Block Design as a measure of everyday spatial ability: A study of ecological validity. *Perceptual and Motor Skills, 90*(2), 522-526. http://dx.doi.org/10.2466/pms.2000.90.2.522

Hart, S. G., & Staveland, L. E. (1988). Development of the NASA-TLX (Task Load Index): Results of empirical and theoretical research. *Human Mental Workload, 1*(3), 139-183.

Heikkilä, V. M., Korpelainen, J., Turkka, J., Kallanranta, T., & Summala, H. (1999). Clinical evaluation of the driving ability in stroke patients. *Acta Neurologica*

Scandinavica, 99(6), 349-355. http://dx.doi.org/10.1111/j.1600-0404.1999.tb07363.x

Homack, S., Lee, D., & Riccio, C. A. (2005). Test review: Delis-Kaplan Executive Function System. *Journal of Clinical and Experimental Neuropsychology, 27*(5), 599-609. http://dx.doi.org/http://dx.doi.org/10.1080/13803390490918444

IBM Corporation. (2013). IBM SPSS Statistics for Windows, Version 22.0. Armonk, NY: IBM Corp.

Kaplan, J., & Hier, D. B. (1982). Visuospatial deficits after right hemisphere stroke. *American Journal of Occupational Therapy, 36*(5), 314-321.

Kaufman, A. S. (1983). Test Review: Wechsler, D. Manual for the Wechsler Adult Intelligence Scale, Revised. New York: Psychological Corporation, 1981. *Journal of Psychoeducational Assessment, 1*(3), 309-313. http://dx.doi.org/10.1177/073428298300100310

Kawano, N., Iwamoto, K., Ebe, K., Aleksic, B., Noda, A., Umegaki, H., . . . Ozaki, N. (2012). Slower adaptation to driving simulator and simulator sickness in older adults. *Aging Clinical and Experimental Research, 24*(3), 285-289. http://dx.doi.org/10.1007/bf03325260

Kelland, D. Z., & Lewis, R. F. (1996). The Digit Vigilance Test: reliability, validity, and sensitivity to diazepam. *Archives of Clinical Neuropsychology, 11*(4), 339-344. http://dx.doi.org/10.1093/arclin/11.4.339

Lee, H. C., Lee, A. H., & Cameron, D. (2003). Validation of a driving simulator by measuring the visual attention skill of older adult drivers. *The American Journal of Occupational Therapy, 57*(3), 324-328. Retrieved from http://graphics.tx.ovid.com/ovftpdfs/FPDDNCLBAHJKIJ00/fs047/ovft/live/gv024/00000448/00000448-200305000-00010.pdf

Lejuez, C., Read, J. P., Kahler, C. W., Richards, J. B., Ramsey, S. E., Stuart, G. L., . . . Brown, R. A. (2002). Evaluation of a behavioral measure of risk taking: the Balloon Analogue Risk Task (BART). *Journal of Experimental Psychology: Applied, 8*(2), 75-84. http://dx.doi.org/10.1037/1076-898X.8.2.75

Leśniak, M., Bak, T., Czepiel, W., Seniów, J., & Członkowska, A. (2008). Frequency and prognostic value of cognitive disorders in stroke patients. *Dementia and Geriatric Cognitive Disorders, 26*(4), 356-363. http://dx.doi.org/10.1159/000162262

Lundberg, C., Caneman, G., Samuelsson, S. M., Hakamies-Blomqvist, L., & Almkvist, O. (2003). The assessment of fitness-to-drive after a stroke: The Nordic Stroke Driver Screening Assessment. *Scandinavian Journal of Psychology, 44*(1), 23-30. http://dx.doi.org/10.1111/1467-9450.00317

Luu, S., Lee, A. W., Daly, A., & Chen, C. S. (2010). Visual field defects after stroke: A practical guide for gps. *Australian Family Physician, 39*(7), 499-503.

Mathworks, T. (1998). MATLAB User's Guide. In *Natick, Inc., MA* (Vol. 5.

Meuleners, L., & Fraser, M. (2015). A validation study of driving errors using a driving simulator. *Transportation Research Part F: Psychology and Behaviour, 29*, 14-21. http://dx.doi.org/10.1016/j.trf.2014.11.009

Michon, J. A. (1985). A critical view of driver behavior models: what do we know, what should we do? USA: Springer.

Microsoft Office. (2010). Visual Basic For Applications.

Motta, K., Lee, H. C., & Falkmer, T. (2014). Post-stroke driving: Examining the effect of executive dysfunction. *Journal of Safety Research, 49*, 33.e31. http://dx.doi.org/10.1016/j.jsr.2014.02.005

Nasreddine, Z. S., Phillips, N. A., Bédirian, V., Charbonneau, S., Whitehead, V., Collin, I., . . . Chertkow, H. (2005). The Montreal Cognitive Assessment, MoCA: A brief screening tool for mild cognitive impairment. *Journal of the American Geriatrics Society, 53*(4), 695-699. http://dx.doi.org/10.1111/j.1532-5415.2005.53221.x

Owsley, C., Stalvey, B., Wells, J., & Sloane, M. E. (1999). Older drivers and cataract: driving habits and crash risk. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 54*(4), M203-M211. http://dx.doi.org/10.1093/gerona/54.4.M203

Plainis, S., & Murray, I. J. (2002). Reaction times as an index of visual conspicuity when driving at night. *Ophthalmic and Physiological Optics, 22*(5), 409-415. http://dx.doi.org/10.1046/j.1475-1313.2002.00076.x

Precision Vision. 2000 Series Revised ETDRS Charts. La Salle, Illinois: (Precision Vision).

Qualtrics. (2015). Qualtrics. Provo, Utah, USA.

Riccio, C. A., & Hynd, G. W. (1992). Validity of Benton's Judgement of Line Orientation Test. *Journal of Psychoeducational Assessment, 10*(3), 210-218. http://dx.doi.org/10.1177/073428299201000301

Schneider, W., Eschman, A., & Zuccolotto, A. (2012). E-Prime (Version 2.0). Pittsburgh: Psychology Software Tools, Inc.

Selander, H., Lee, H. C., Johansson, K., & Falkmer, T. (2011). Older drivers: On-road and off-road test results. *Accident Analysis & Prevention, 43* (4), 1348-1354. http://dx.doi.org/10.1016/j.aap.2011.02.007

SensoriMotoric Instruments. (2011). SMI BeGaze™ Eye Tracking Analysis Software (Version 3.6). Retrieved from http://twiki.cis.rit.edu/twiki/pub/MVRL/SmiTracker/begaze2.pdf

Song, C.-S., Chun, B.-Y., & Chung, H.-S. (2015). Test-retest reliability of the driving habits questionnaire in older self-driving adults. *Journal of Physical Therapy Science, 27*(11), 3597-3599. http://dx.doi.org/10.1589/jpts.27.3597

Stone, S., Wilson, B., Wroot, A., Halligan, P., Lange, L., Marshall, J., & Greenwood, R. (1991). The assessment of visuo-spatial neglect after acute stroke. *Journal of Neurology, Neurosurgery & Psychiatry, 54*(4), 345-350. http://dx.doi.org/10.1136/jnnp.54.4.345

Stoner, H., Fisher, D., & Mollenhauer, J. M. (2011). Simulator and scenario factors influencing simulator sickness. In D. L. Fisher, M. Rizzo, J. K. Caird & J. D. Lee (Eds.), *Handbook of driving simulation for engineering, medicine, and psychology*. London. UK: CRC Press: Taylor and Francis. http://dx.doi.org/:doi:10.1201/b10836-15

Swanson, J. (2005). The Delis-Kaplan Executive Function System: A review. *Canadian Journal of School Psychology, 20*(1/2), 117-128. http://dx.doi.org/10.1177/0829573506295469

Wechsler, D. (2008). *Wechsler Adult Intelligence Scale–Fourth Edition (WAIS–IV)*. San Antonio, Texas, USA: NCS Pearson.

Wolf, T. J., & Rognstad, M. C. (2013). Changes in cognition following mild stroke. *Neuropsychological Rehabilitation, 23*(2), 256-266. http://dx.doi.org/10.1080/09602011.2012.748672

Xiao, Y. M., Wang, Z. M., Wang, M. Z., & Lan, Y. J. (2005). The appraisal of reliability and validity of subjective workload assessment technique and NASA-task load index. *Chinese Journal of Industrial Hygience and Occupational Disease, 23*(3), 178-181.

Yochim, B., Baldo, J., Nelson, A., & Delis, D. C. (2007). D-KEFS Trail Making Test performance in patients with lateral prefrontal cortex lesions. *Journal of the International Neuropsychological Society, 13*(04), 704-709. http://dx.doi.org/10.1017/S1355617707070907

Young, M. S., & Stanton, N. A. (2002). Attention and automation: new perspectives on mental underload and performance. *Theoretical Issues in Ergonomics Science, 3*(2), 178-194. http://dx.doi.org/10.1080/14639220210123789

Section One

Driving Simulation Research

Chapter Three: The cognitive and socio-demographic influences on driving performance and driving cessation in post-stroke drivers.

This chapter contains material published in the below listed journal (see Appendix 10 for approval permissions and Appendix 11 for the manuscript as it appears in full in Advances in Transportation Studies)

Blane, A., Falkmer, T., Lee, M., Parsons, R., & Lee, H. (2016). The cognitive and socio-demographic influences on driving performance and driving cessation in post-stroke drivers. *Advances in Transportation Studies* (38), 121-135.

Chapter Outline and Rationale

The purpose of this chapter was to address objectives one (assess the relationship between deficits in cognition, executive function and driving behaviour in post-stroke drivers and non-stroke drivers), two (assess the socio-demographic factors influencing driving behaviour in post-stroke drivers and post-stroke non-drivers) and three (assess the off-road driving performance of post-stroke drivers compared with the performance of healthy controls), as well as explore the cognitive and socio-demographic influences of a stroke on driving status. This chapter will outline the reasons post-stroke adults chose to continue and cease driving, as well as lay the foundations for assessing calibration between perceived task demand and performance, which is explored in more depth in later chapters. The chapter is comprised of an expanded version of the aforementioned published manuscript, and outlines the study background, methodologies and results. The chapter concludes by discussing the socio-demographic reasons for post-stroke driving status, as well as detailing the implications for post-stroke driver assessment.

Abstract

Driving is a complex activity requiring highly integrated cognitive and perceptual functions that can be negatively affected following a stroke. The decision to continue or cease driving after a stroke may not be exclusively dependent on deficits in cognitive and motor abilities. Instead, it is possible that social supports, alternative means of transportation, education level, income, self-regulation ability and the awareness of personal health problems may also influence the decision. The aim of this research was to explore the influence of personal and socioeconomic factors, in addition to existing cognitive impairment, on the decision of post-stroke adults who return to driving. A comparison group design was employed to compare the driving performance of 48 individuals who had experienced a stroke and 22 volunteer healthy control participants. Half of the post-stroke cohort (N=24) had continued driving and the other half had ceased driving. Socio-demographic and driving-related cognitive performance data were collected to characterise the comparison groups before driving performance was assessed in a driving simulator. Overall, the post-stroke groups did not perform as well as the control participants in the cognitive and driving assessments. The perceived ability to drive after a stroke was not significantly correlated with participants' actual driving ability. Post-stroke adults were more likely to continue driving if they reported having a tertiary level education and a greater income. The decision to return to driving after a stroke is a complicated, multifactorial process. This study confirms previous research, which found that cognition and driving performance are impaired post-stroke. The findings also suggest that post-stroke drivers' decision to return to driving was not linked to their ability to drive, but more to socio-demographic and environmental factors. Further screening tools and assessments to identify those at risk when returning to the road post-stroke are required.

Keywords: Australia, Cognition, Driving Cessation, Driving Performance, Driving Simulator, Post-Stroke, Socio-Economic Factors

Introduction

The ability to maintain driving is often considered a crucial part of an individual's identity (Dickerson, Reistetter, Davis, & Monahan, 2011; Griffen, Rapport, Coleman Bryer, & Scott, 2009) and is a key element for functional mobility and autonomy, particularly in older age (Burns, 1999). Driving is a complex and multifaceted activity requiring highly integrated functions, including: visual and motor functions, as well as, cognitive abilities (e.g., perceptual and executive functioning (Anstey, Wood, Lord, & Walker, 2005)), all of which can be affected following the onset of a stroke (Akinwuntan et al., 2006; Marshall et al., 2007). Research has shown that up to 30% of stroke survivors will return to driving (Fisk, Owsley, & Pulley, 1997). As the population ages, the risk of a stroke increases (Australian Bureau of Statistics, 2009; Australian Institute of Health and Welfare, 2013). Therefore it is not surprising that the incidence of stroke survivors who wish to continue driving is significant given the necessity among older people to use their car as a means of independent transportation (Ponsford, Viitanen, Lundberg, & Johansson, 2008).

Safe driving regulation in the ageing population is a worldwide multifactorial problem. The decision to continue or cease driving after a stroke may not be dependent on an individual's visual, motor or cognitive abilities. Regardless of substandard driving performance or ability, many older drivers are reluctant to relinquish their licences (Unsworth, Wells, Browning, Thomas, & Kendig, 2007), as driving cessation can lead to a decrease in out-of-home activity (Marottoli et al., 2000), a loss of independence (Adler & Rottunda, 2006) and cause increased feelings of loneliness, isolation and depression (Fonda, Wallace, & Herzog, 2001; Ragland, Satariano, & MacLeod, 2005; Rudman, Friedland, Chipman, & Sciortino, 2006). Reluctance to give up driving has been found to be particularly common in post-stroke drivers (Lister, 1999; Logan, Dyas, & Gladman, 2004; Patomella, Johansson, & Tham, 2009). Previous literature investigating older drivers has reported that social supports, alternative means of transportation, education level, sense of identity, income, self-regulation ability, and the awareness of personal health problems can all influence the decision to continue or to cease driving (Adler & Rottunda, 2006; Donorfio, D'Ambrosio, Coughlin, & Mohyde, 2009; Kostyniuk & Shope, 2003).

Screening assessments for post-stroke individuals at risk of unsafe driving practices are essential in order to maintain the safety of all road users. In Australia, the process for post-stroke driving evaluation includes general road knowledge questionnaires and cognitive assessments, as well as an on-road driving assessment (National Stroke Foundation, 2013). However, final clearance to drive is usually given by a medical practitioner and the experience of this process between drivers can vary (Lister, 1999). Off-road assessments have previously been identified as useful for identifying those at-risk of failing a driving test (Devos et al., 2011), however many physicians are unfamiliar with off-road-based tests (Odenheimer, 2011) and there is still potential for post-stroke drivers who have undertaken a driving evaluation to be unsafe drivers as "…the quality of driving evaluations…may not be sufficient to detect potential deficits in driving skills" (Fisk et al., 1997, p. 1344). Therefore assessments that incorporate screening of an individual's personal and socioeconomic profile may also assist with identifying those at-risk.

Currently there is limited research that investigates the socio-demographic factors influencing the decision of stroke adults to return to drive. Available research consists of over-the-phone interviews (Perrier, Korner-Bitensky, & Mayo, 2010), which failed to capture several personal and contextual factors. The participants' level of insight into personal health, level of education, what, if any, advice they received regarding driving post-stroke, and to what alternative means of transportation they have regular access have not been investigated. Therefore, the aim of this study was to identify personal and socioeconomic factors, in addition to cognitive impairment that influence the decision of individuals to return to or cease driving post-stroke.

Methods

A comparison group design was applied to compare the cognitive performance and driving performance in post-stroke adults compared to healthy controls. Further analysis was applied to investigate the socio-demographic variables associated with driving performance and driving cessation in post-stroke adults who continued with driving and those who had ceased driving.

Participants

Participants comprised 24 post-stroke adults (male = 24) who were driving (post-stroke drivers) aged between 56 – 78 years (M = 67, SD = 7), 24 post-stroke adults (male = 18) who had ceased driving (post-stroke non-drivers) aged between 30 and 83 years (M = 68, SD = 17) and 22 control participants (male = 17) aged between 53 and 79 years (M = 64, SD = 6).

Sampling and recruitment

Purposive sampling techniques were employed during the recruitment process, which was conducted during February, March, May and June 2013. Healthy controls were recruited through advertisements in the community, whereas recruitment of the post-stroke groups was accomplished with the assistance of Home and Driving Occupational Therapy Services and Osborne Park Hospital in Western Australia, as well as, through advertisements placed with several community-based organisations. Inclusion criteria were stipulated for all participants. These included: that participants were community-dwelling, held a current driver’s licence valid in Western Australia, actively drove for a minimum of two hours a week (or had done so prior to stroke for post-stroke non-drivers) and had no further significant confounding comorbid condition, such as dementia or physical impairment. A further criterion for post-stroke adults was that they previously had been diagnosed with a stroke, at least six months prior to the assessment. Participants were screened for visual acuity using the Snellen Visual Acuity Chart. No participants were excluded based on the visual acuity (VA) score. All participants were able to read the chart at a distance equal to a VA score of 20/40 or better, which is the minimum VA score required in order to legally drive in Australia.

Performance measures and equipment

Cognitive measures

In order to obtain an overall measure of the cognitive and perceptual abilities of all participants, psychometric assessments were administered. The assessments included the Montreal Cognitive Assessment, Benton Judgment of Line Orientation Test, Digit Vigilance Test, Trail Making Test Part B, and a Road Sign Recognition Test.

The Montreal Cognitive Assessment (MoCA; Nasreddine et al., 2005) is a 30-item cognitive screening tool that has been validated for measuring mild cognitive impairment in older adults. Lower scores were indicative of increased cognitive decline. It has moderate test-retest reliability of 70%-92% (Nasreddine et al., 2005). The MoCA has previously been implemented in various pathology groups, including a stroke population (Pendlebury, Cuthbertson, Welch, Mehta, & Rothwell, 2010).

The Benton Judgment of Line Orientation Task (BJLOT; Benton, Hamsher, Varney, & Spreen, 1983) is a commonly used neuropsychological assessment to measure visuospatial function (Qualls, Bliwise, & Stringer, 2000). Spatial perception is a higher order cognitive function that affects driving ability and is a predictor of driving continuation post-stroke (Marshall et al., 2007; Nouri & Lincoln, 1992). The test required participants to correctly match two adjoining lines, to a pair of longer lines from within a semi-circular line set. The orientation of the target line pair altered with each test iteration. A total score of correct answers in calculated and higher scores are indicative of greater performance. The assessment has been reported to have high test-retest reliability of 0.90 (Lundberg, Caneman, Samuelsson, Hakamies-Blomqvist, & Almkvist, 2003) and has been found a highly reliable predictor of simulated driving performance (Mathias & Lucas, 2009).

The Digit Vigilance Task (DVT; Lewis & Rennick, 1979) is a reliable and valid neuropsychological assessment that is used to evaluate sustained attention and speed of cognitive processing (Kelland & Lewis, 1996). The assessment required participants to identify and put a cross through target numbers (six or nine) as quickly and accurately as possible. Total time taken, as well as errors and omissions committed were recorded for all participants, therefore lower scores on the DVT were indicative of greater cognitive performance.

The Trail Making Test Part B (TMT-B; Reitan & Wolfson, 1985) is a highly utilized psychometric test that is used to asses an individual's higher order functioning, including divided attention, visual perception, and executive functioning. The test required participants to draw lines alternating between letters and numbers as quickly and as accurately as possible. The participant is timed to completion and quicker times are scored higher indicating greater cognitive performance. The test is widely used in driving assessments, and has been found to be a significant predictor of outcomes of on-road and off-road driving assessment in post-stroke drivers (Marshall et al., 2007; Motta, Lee, & Falkmer, 2014; Radford & Lincoln, 2004).

The Road Sign Recognition Test (RSRT; Lincoln & Fanthome, 1994) assessed knowledge of road signs, visual recognition, memory, and problem solving abilities (Lincoln & Fanthome, 1994; Radford & Lincoln, 2004). The test involved a series of road signs used in Western Australia and asked the participant to explain the meaning of the sign. Higher scores of correct answers on the RSRT are indicative of greater performance. The test has good face validity and required the participants to demonstrate knowledge of common road rules and regulations required for safe driving. Similar tests have been previously utilized in driving research with valid and reliable results (Lincoln & Fanthome, 1994; MacGregor, Freeman, & Zhang, 2001; Radford & Lincoln, 2004).

Each participant completed an off-road driving assessment using the interactive driving simulator located in the Driving Assessment Lab at Curtin University in Western Australia. The Curtin University Driving Simulator is a fixed-base simulator that has mid-level physical fidelity and consists of a driving console and three display screens (Figure 8). The driving console is made up of an adjustable sedan style seat with acceleration, brake pedals and a fully functioning steering wheel. Driving related auditory feedback, such as traffic and engine noise is provided through the digital auditory output system, therefore providing a more immersive experience. The simulator has previously been validated for use on older adults (Lee,

Lee, & Cameron, 2003) and has good reported transference to real-world driving performance (Devos et al., 2009).

Driving Performance Measures

Figure 8: The STISIM Driving Simulator

A specially designed driving scenario was programmed using the STISIM© driving software (Allen, Stein, Aponso, Rosenthal, & Hogue, 1990) and included various traffic scenarios that would assess participants' cognitive and perceptual abilities, as well as, knowledge of road rules and regulations. The variables recorded as a measure of driving performance included: the number of collisions, pedestrians hit, speed exceedances, traffic light violations, centreline crossings, road edge excursions and stops at traffic lights. The driving performance of the participants was gauged by a total driving score, based on these seven variables. The scenario was comprised of a mixture of urban four-lane and two-lane road each participant was afforded a 10 minute practice run in order to become familiar with the simulator visuals and with operating the driving console. The experimental trial was programmed to a distance of 8.25 kilometres and took approximately 15 minutes to complete.

Simulator Sickness. Simulator sickness (SS) is a common occurrence in driving simulator research and it has been reported that approximately 9% of older adults experience symptoms (Lee, Cameron, & Lee, 2003). There were a number of strategies employed to reduce the chances of simulator sickness. The simulation was configured without any sharp right turns, winding roads or a need for excessive braking, and the room was made dark, and a fan used to increase air flow as further measures to reduce the chances of SS (Classen, Bewernitz, & Shechtman, 2011). Participants were constantly monitored for symptoms of SS by researchers (e.g., sweating, headache, yawning, nausea) and the simulation was immediately discontinued in any participants expressed discomfort. All participants completed the simulator assessment and only one participant (4% of the total sample) reported feelings of SS post-assessment.

Procedure

After completing the participant information sheet, participants were screened using the Snellen Visual Acuity Chart (Precision Vision). Participants then completed the MoCA, BJLOT, the DVT and the TMT-B. Following previous research by Perrier et al. (2010), participants' personal and socioeconomic information was collected and included: driving exposure, medical history, level of education, availability of social supports, access to alternative means of transportation and if advice on driving post-stroke had been previously given. Participants were also asked to rate their own driving performance compared to other adults of their age group. This was in order to obtain an indication of the participants' perception and insight into their own driving ability. Participants rated their performance using a Likert scale that ranged from one (compared to others my own age, I am not a good driver), through five (compared to others my own age, I am an average driver) to 10 (compared to others my own age, I am a highly competent driver). Finally, participants completed the driving assessment in the driving simulator. Instructions for the simulator were given prior to each assessment. Overall, the total assessment process lasted approximately two hours.

Ethical approval

The study was approved by Curtin University's Human Research Ethics Committee (HREC OTSW-20-2011, Appendix 7). Written consent to participate was obtained from all participants and confidentiality of records was maintained in line with the Declaration of Helsinki and the Western Australian University Sector Disposal Authority. All participants were informed that they could withdraw from the study at any time without incurring any negative consequences. Furthermore, in the event that a participant's performance indicated unsafe driving, a referral would be made for the participant to obtain complementary driver counselling and advice.

Statistical analysis

All collected data including the background and socio-demographic data, screening, psychometric assessments, and driving simulator were exported into Microsoft Excel© and analysed using SPSS version 22.0 (IBM Corporation, 2013). Descriptive and univariate statistics were used to describe the demographics of each group. Normality of data was assessed for all continuous measures. Only the TMT-B presented with positively skewed data, therefore statistical analysis was performed on the logarithm of this variable. Between groups analysis of cognitive performance was analysed using a one-way ANOVA with LSD post-hoc analysis. A cumulative score for overall cognitive performance and driving performance was calculated using PCA analysis on the individual cognitive variables and driving simulator outputs respectively. The effect of cognitive decline on driving performance was then investigated using linear regression modelling; after adjusting for driving exposure (driving in hours per week), duration since diagnosis with stroke in months and changes in driving habits (frequency of using alternative means of transportation). Binary logistic regression was employed to identify whether socio-economic factors (availability of carers / friends/ family members to drive participants around and their level of education and income) had an effect on the decision of post-stroke participants to continue driving. A p-value of <0.05 was taken to indicate a statistically significant association in all tests.

Results

Demographic characteristics

Significant differences in the demographic profile (Table 10) were found in the following variables: years of driving, hours driven per week (Table 10), reported highest level of education (Table 11) and individual income (Table 12). Hours driven per week became non-significant when post-stroke non-driving status was controlled for $t(44) = 0.64$, $p>0.05$, 95% CI [-2.8, 5.42]. No significant differences were reported in gender distribution between the post-stroke and control groups $\chi^2 = 2.38$, $p>0.05$ but there was a significant difference in gender distribution between the post-stroke cohorts as all post-stroke female participants had ceased driving $\chi^2 = 6.86$ $p=0.009$. When comparing the overall demographic profile of post-stroke drivers and post-stroke non-drivers, no differences were found in age, years of driving or individual income.

A large proportion of post-stroke drivers reported having completed tertiary education $\chi^2 = 10.25$; $p=0.02$ with fewer reporting earning $85,000 or more. More post-stroke non-drivers had received advice regarding driving after their stroke compared to the post-stroke drivers (75% and 41% respectively). In total, 58% of the post-stroke group reported having declared their stroke to the appropriate medical and transport authorities and 41% percent of the post-stroke participants had not received advice on driving capacity. More than half of the post-stroke participants continued to drive without having consulted a medical or driving professional. Across the 48 post-stroke participants, the length of time since stroke diagnosis ranged from six months – 138 months. Although the reported distribution of the length of time since stroke diagnosis was positively skewed, there was no significant difference in length of time since stroke diagnosis between the post-stroke drivers and post-stroke non-drivers $t(46) = -0.25$, $p>0.05$, 95% CI [-32.99, 25.63].

Table 10.

Demographic information of post-stroke cohort and control groups

Variables	Controls (N = 22)		Post-Stroke Driver (N = 24)		Post-Stroke Non-Driver (N = 24)		Statistic Value	p-value
	Mean	SD	Mean	SD	Mean	SD		
Age	64.8	6.7	67.8	17.7	68.2	7.8	0.56	0.58
Licence length in years	45.9	7.1	56.9	9.0	54.6	11.0	9.02	0.001**
Hours of Driving (weekly)	11.1	7.7	9.82	6.1	N/A			0.52
Recovery period (month)	N/A		48.6	52.6	44.9	48.3	t (46) = -0.25	0.35
Declared stroke to authorities	N/A		Yes = 14 (58%)	No = 10 (42%)	Yes = 14 (58%)	No = 10 (42%)	χ^2 = 1.3	1.00
Received advice on driving	N/A		Yes = 14 (58%)	No = 10 (42%)	Yes = 18 (75%)	No = 6 (25%)	χ^2 = 5.49	0.02*
Use of public transport	N/A		Yes = 14 (58%)	No=10% (42%)	Yes = 12 (50%)	No = 12 (50%)	χ^2 = 0.34	0.77
Availability of help / other drivers	N/A		Friends = 22 (92%)	Family = 2 (8%)	Friends = 12 (50%)	Family = 12 (50%)	χ^2 = 10.08	0.03*

*p-value <0.05

**p-value <0.001

Table 11.

Education level information of post-stroke cohort and control groups

Education Level	Controls (N = 22)	Post-Stroke Driver (N = 24)	Post-Stroke Non-Driver (N = 24)	Chi-Square Statistic	p-value
Tertiary	(14) 64%	(14) 58%	(4) 17%	$\chi^2 = 19.7$	0.003*
Year 12	(2) 9%	(5) 21%	(6) 25%		
Year 10	(6) 27%	(3) 13%	(6) 25%		
Primary	0	(2) 8%	(8) 33%		

*p-value <0.05

Table 12.

Income level information of post-stroke cohort and control groups

Income Level	Controls (N = 22)	Post-Stroke Driver (N = 24)	Post-Stroke Non-Driver (N = 24)	Chi-Square Statistic	p-value
≤$5,000	0	(4) 17%	(2) 8%	$\chi^2 = 13.86$	0.008*
$5,000 - $84,999	(3) 14%	(12) 50%	(8) 33%		
≥ $85,000	(19) 86%	(8) 33%	(14) 59%		

*p-value <0.05

Between-groups analysis of cognition and driving performance

A one-way ANOVA (Table 13) was performed to assess cognitive performance between groups. There were significant between group differences for all cognitive variables with the exception of errors in the DVT. It was evident that the post-stroke adults had greater cognitive deficits as there was a significant between-group difference for performance on the MoCA with both the post-stroke drivers and post-stroke non-drivers obtaining a mean score below the MoCA cut off >26.

Further, post-hoc LSD analyses (Table 14) revealed that there were clear differences in all cognitive performance variables between groups. Analysis of variance in the post-stroke driver and the control group showed that in all variables, with the exception of the BJLOT and the DVT errors, the post-stroke drivers displayed poorer cognitive performance compared to that of controls. Furthermore, the differences between the post-stroke non drivers and controls were significant for all variables. Finally, there were differences between groups for the post-stroke drivers and the post-stroke non-drivers for all variables, with the exception of the DVT errors and TMT-B.

Table 13.

Between groups analysis of psychometric task performance

Psychometric Task	Control (N = 22)		Post-Stroke Driver (N = 24)		Post-Stroke Non-Driver (N = 24)		*F*-value (df = 2, 67)	*p*-value
	Mean	SD	Mean	SD	Mean	SD		
MoCA	26.82	1.82	25.21	2.90	23.29	2.97	10.32	0.001**
Benton (# items correct)	25.55	4.46	25.17	4.29	21.25	4.48	6.85	0.002*
TMT-B	77.59	25.59	125.31	38.66	171.67	95.35	13.23	0.001**
RSRT (# correct)	4.14	1.13	3.25	1.39	3.17	1.44	3.70	0.03
DVT (Errors)	4.77	6.57	10.08	5.038	15.00	23.47	2.84	0.065
DVT (Time)	437.09	92.53	529.71	142.00	656.08	144.59	16.62	<0.001

*p-value <0.05

**p-value <0.001

Table 14.

Post-hoc LSD between groups analysis of psychometric task performance

Dependent Variable	Cohort		Sig.
MoCA (score)	Post-Stroke Driver	Control	0.04*
		Post-Stroke Non-Driver	0.01*
	Post-Stroke Non-Driver	Control	0.001**
Benton (# correct)	Post-Stroke Driver	Control	0.77
		Post-Stroke Non-Driver	0.003*
	Post-Stroke Non-Driver	Control	0.002*
TMT-B	Post-Stroke Driver	Control	0.001**
		Post-Stroke Non-Driver	0.05
	Post-Stroke Non-Driver	Control	0.001**
RSRT	Post-Stroke Driver	Control	0.03*
		Post-Stroke Non-Driver	0.83
	Post-Stroke Non-Driver	Control	0.02*
DVT (errors)	Post-Stroke Driver	Control	0.22
		Post-Stroke Non-Driver	0.25
	Post-Stroke Non-Driver	Control	0.02*
DVT Time	Post-Stroke Driver	Control	0.02*
		Post-Stroke Non-Driver	0.001**
	Post-Stroke Non-Driver	Control	0.001**

*p-value <0.05

**p-value <0.001

Assumptions of the current research were that the psychometric measures represented overall driving-related cognitive function and that the simulator measures represented driving performance. Principle component analysis (PCA) was conducted on the five psychometric measures (BJLOT, TMT-B, DVT errors, MoCA and RSRT). The first component, as shown in Equation 1, which explained 38% of the variance, was identified as an "overall cognitive score", and was calculated for each participant in the following way:

(1)

** Overall cognition score = 0.87 *MoCA + 0.53 *Benton - 0.72 * TMT-B + 0.52 * RSRT -0.25 * DVT (# errors) – 0.71 *DVT (# time)*

All of the driving criteria measured as part of the simulator assessment were combined to form three variables: number of collisions (vehicle or roadway collisions, and pedestrians hit), driver errors (speed exceedances and traffic light tickets,) and unsafe driving manoeuvers (unsafe manoeuvring, centreline crossings, road edge excursions and inappropriate indicator use). A lower score indicated fewer errors and therefore better driving performance.

PCA analysis was employed to aggregate the individual driving variables into a single driving performance variable, which could be viewed as a total weighted average of all the assessment criteria. A lower overall driving performance score indicated fewer errors and therefore better driving performance. This procedure is based on the previous research by Lee, Drake, and Cameron (2002) and has been previously validated for use in older driver research (Cordell, Lee, Granger, Vieira, & Lee, 2008; Lee, Lee, Cameron, & Li-Tsang, 2003). The first component of PCA explained 68% of the variance of the overall driving performance score; therefore it was adopted and calculated as shown in equation 2:

(2)

Overall driving performance = 0.75 Number of Collisions + 0.91 * Driver Errors + 0.81 *Unsafe Driving Manoeuvres*

A one-way ANOVA was applied to the controls, post-stroke drivers and post-stroke non-drivers. Significant differences were found between groups in overall driving performance $F(2) = 8.08$, $p<0.01$ and overall cognitive performance $F(2) = 31.78$, $p<0.001$. Post-hoc LSD analysis revealed significant differences in overall cognitive performance between the controls and post-stroke drivers $p<0.001$, 95% CI [0.43, 1.35], the controls and post-stroke non-drivers $p<0.001$, 95% CI [1.11, 2.02], and between the post-stroke drivers and post-stroke non-drivers $p<0.05$, 95% CI [0.23, 1.13].

Further post-hoc LSD analysis revealed significant differences in overall driving performance between the healthy controls and post-stroke non-drivers $p<0.001$, 95% CI [-1.61, 0.57] and between the post-stroke drivers and post-stroke non-drivers $p<0.05$, 95% CI [-1.12, -0.72]. Differences between the controls and post-stroke drivers in overall driving performance were non-significant p=0.079 CI [1.02, 0.06]. In general, the post-stroke non-drivers scored worst among the three groups.

In order to determine whether there was a relationship between overall cognitive performance and overall driving performance, general linear regression was conducted. Analysis was run on overall driving performance and overall cognitive performance in the post-stroke groups, whilst controlling for driving exposure, which is known confounder in driving research (Evans, 2004). It was found that there was no significant relationship between the two variables R^2= 0.06, F (4, 43) = 0.73, p=0.58 in the post-stroke group.

Predictive value of personal and socioeconomic criteria on return to driving post-stroke

Further analysis was conducted to identify the variables that post-stroke adults consider when making the decision on whether or not to continue driving. Forwards stepwise logistic regression analysis was applied to identify the main personal and socioeconomic factors attributed to the cessation of driving after stroke. Driving status of the post-stroke cohort (driver = 1, non-driver = 0) was entered as the dependent variable.

Table 15.

Logistic regression model predicting driving cessation in post-stroke adults (95% CI based on 48 samples).

Variable	Odds Ratio	p-value	95% C.I. for Odds Ratio	
			Lower	Upper
Education		0.01*		
Primary	0.010	0.001**	0.001	0.174
Year 10	0.064	0.02*	0.006	0.634
High School	0.132	0.04*	0.018	0.980
University/Diploma	1 (reference)			
Income (annual in $)		0.03*		
50000	36.929	0.02*	1.734	786.643
50,000 – 84,999	9.372	0.02*	1.393	63.068
85,000 or above	1 (reference)			
Constant	1.785	0.354		

Nagelkerke $R^2 = 0.48$; Cox & Snell $R^2 = 0.36$; pseudo $R^2 = 0.67$

*p-value <0.05

**p-value <0.001

Education, the availability of other drivers, individual income, driving perception, whether the participant had been advised on their driving and whether or not the participant had reported their stroke to the authorities, as well as, overall driving performance were included as independent variables. Control participants' data were excluded from this analysis and there was no missing data in any variable within the post-stroke cohort.

The model (Table 15) suggested that individuals who had a university education, had a significantly increased likelihood of continuing to drive post-stroke than their lower educated counterparts. Also the likelihood that individuals with annual earnings of $85,000 or above would continue to driving post-stroke was significantly lower than those in lower income groups. Tests for multicollinearity and tolerance statistics were conducted with no violation of assumptions.

Interestingly, variables removed as non-significant in the analysis were the availability of the other drivers and perceived driving ability. This suggested that insight into driving ability has limited influence driving cessation compared to other factors, such as education and economics, which appear to have a greater impact on the decision to stop driving following a stroke. Figure 9 shows a scatter plot of the overall driving performance scores for both drivers and non-drivers in the post-stroke group. It can be seen that there were post-stroke adults who continued to drive despite having achieved similar or worse driving performance scores than the post-stroke adults who have ceased driving. For example while participant (A) performed best in the driving assessment and had stopped driving, participants (B, C and D) were ranked low in their performance during the driving assessment, yet they all continued to drive.

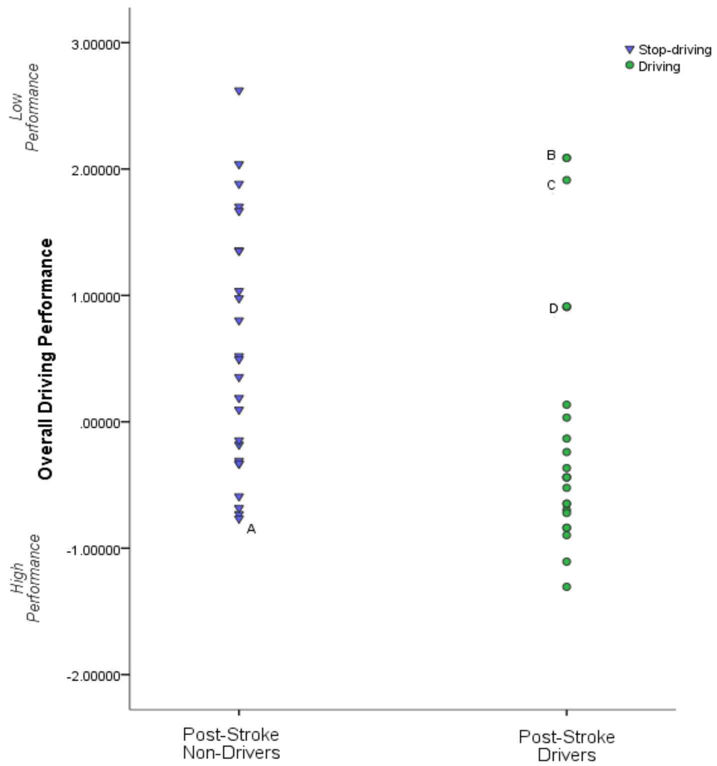

Figure 9. A scatter-plot outlining the individual scores of post-stroke drivers in each group.

When compared to Figure 10, it can be seen that actual driving performance was also not correlated with perceived driving ability. Participants who rated themselves as most competent had ceased driving, while there were participants who scored poorly in the driving performance measures who rated themselves above average – highly competent and who were continuing to drive. Specifically, participants (E, F and G) rated their driving as very good (8/10) or excellent (9/10) and continued to drive, however they performed poorly during their driving assessment. Participants (H and I) rated their driving as above average and continued to drive however they also performed poorly in the driving assessment. Participant (J) rated her driving ability as average (6/10) had ceased driving, but performed very well during the driving assessment. Participant (K) rated his driving ability as excellent (10/10), performed well in the driving assessment and yet had ceased driving. Finally, participant (L) rated his driving as just above average, performed well and continued to drive.

Overall, this finding may suggest either a lack of insight in post-stroke drivers or a potential disregard for personal risk and has implications for reliance upon self-regulation practices. Although not included as significant in the final model, it is worth noting that an independent t-test suggested that post-stroke drivers had statistically fewer drivers available to assist them than post-stroke non-drivers $t(46) = 2.27$, $p>0.05$, d=0.33, 95% CI [0.08, 1.42] and overall, statistically fewer social supports than post-stroke non-drivers $t(46) = 2.67$, $p=0.01$, d=0.41, 95% CI [0.03, 1.91].

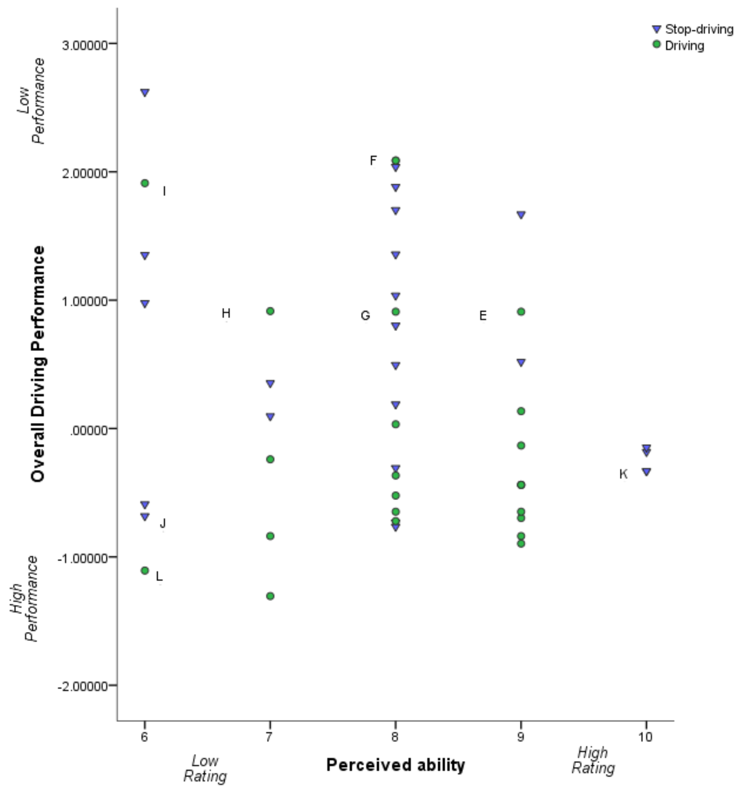

Figure 10. A scatterplot of the post-stroke cohort individual scores of driving performance compared to perceived driving ability and separated by driving status.

Discussion

Summary of findings

The primary aim for this study was to examine the personal, socio-demographic and socioeconomic factors, in addition to cognitive impairment, that influenced driving performance and driving cessation in post-stroke adults. As expected, the driving and cognitive performances of post-stroke adults were significantly poorer than for the controls (Motta et al., 2014). The findings suggest that driving-related cognition including spatial, sustained and divided attention, visual perceptual and visuospatial ability, executive function, and the speed of cognitive processing (Lee, Cameron, et al., 2003; Marshall et al., 2007; Motta et al., 2014), as measured by the cognitive variables (MoCA, DVT, BJLOT, RSRT and TMT-B), are impaired in a post-stroke cohort. However, in contrast to previous research (e.g., Marshall et al., 2007), which looked at individual aspects of cognition, this study found that overall cognitive performance was not a strong predictor of post-stroke driving performance.

In line with previous research investigating older post-stroke drivers, it was found that the level of perceived driving ability bore little resemblance to actual driving performance (Freund, Colgrove, Burke, & McLeod, 2005; Horswill, Anstey, Hatherly, Wood, & Pachana, 2011; Patomella, Kottorp, & Tham, 2008; Selander, Lee, Johansson, & Falkmer, 2011). Although the overall driving performance of the post-stroke driver cohort was better than post-stroke non-drivers, the individual scores suggest that some post-stroke adults who continued to drive performed on par, or in some cases, worse than post-stroke adults who had ceased driving. This is consistent with previous studies, which found that drivers who have suffered a stroke and continued to drive have been known to overestimate their driving capabilities and tend to be riskier on the roads as evaluated by health professionals (Heikkilä, Korpelainen, Turkka, Kallanranta, & Summala, 1999). These results suggest that some post-stroke adults lacked insight into their performance as evidenced by their bias in self-rating and poorer performance. However, whether the stroke-related cognitive deficit caused this lack of insight could not be determined. Alternatively, in the case of the post-stroke drivers, it is also possible that the participants' perceived need to drive outweighed their personal sense of risk, particularly as deficits in executive function often experienced by post-stroke adults can lead to an increase in impulsivity and risk-taking behaviour (Scheffer, Monteiro, & De Almeida, 2011).

It is also important to consider that the driving performance of some of the post-stroke adults who had ceased driving was better than that of some post-stroke drivers, yet their perceived ability was less. Considering the negative health outcomes associated with the loss of independence due to driving cessation (Harrison & Ragland, 2003; Ragland et al., 2005), it is critical to ensure that unnecessary self-regulation is not relied upon for post-stroke driving management.

It appears that in the present study, the level of cognitive impairment, although significant in post-stroke drivers, was not the major influencing factor in the decision to return to, or cease, driving post-stroke. Preliminary analysis suggested that level of education and individual income, accounted for much of the reasoning behind driving cessation. This corroborates the findings of previous research, which have investigated factors influencing older adult driving cessation or continuation (Kulikov, 2010; Ragland, Satariano, & MacLeod, 2004). Further in-depth research is required to determine causality, for example, it is possible that those on a lower income were not able to afford the post-stroke driving assessment and were thus unaware of the driving modifications available, or they were unable to afford driving modifications required to drive following their stroke.

All post-stroke females in the present study had ceased driving, regardless of actual driving ability, which is in line with previous older driver research that found that older female drivers, despite being less likely to fail an on-road test, are more likely to undertake driving avoidance behaviours (Classen, Wang, Crizzle, Winter, & Lanford, 2012).

Although social support in the form of other available drivers was excluded from the regression analysis, the post-hoc t-tests revealed that most of the post-stroke drivers did not have family available to help them with driving in day-to-day life, and this could partly explain why post-stroke adults felt an increased need to continue to drive.

These results suggest that, although some post-stroke adults undertake voluntary driving self-regulation, some do not, and the deficits in driving performance are a cause for concern. Future research should focus on identifying reliable screening tools and rehabilitation programs to assist with identifying post-stroke adults who are at risk of unsafe driving.

Limitations

This study is not without limitations. There were significant differences between the control and post-stroke cohorts in length of licence and driving exposure, although only the driving exposure was significantly different between the post-stroke groups. Data collected in the post-stroke driver cohort involved an all-male sample set, whereas the non-driver and control cohort contained data from both male and a small number of female participants, which is as a result of the sampling method used. It is therefore difficult to determine whether gender is a factor in the decision of post-stroke adults to cease driving, however it has been previously found that older females, particularly those with deteriorating health, are more likely to relinquish their driver’s licences (Siren, Hakamies-Blomqvist, & Lindeman, 2004). Participants were recruited from a small section of the post-stroke community and therefore the results may not generalise beyond the study population. There was the additional limitation that no medical data were sighted in order to further confirm stroke diagnosis, therefore the experiment relied on self-report information and there is subsequent potential for differences in stroke type, locale and severity to further confound the results. The self-report nature of the research creates the possibility for social desirability bias. Focus groups with family members of post-stroke adults may be used to obtain unbiased information regarding participant insight or awareness of personal health status. Purposive sampling and volunteer sampling were the main sources of recruitment, creating the unavoidable potential for self-selection bias. Due to the nature of the research, more robust methods of sampling, such as random sampling, were not economically viable or practicable.

The self-selected comparison group nature of the research means that it is ultimately difficult to determine causality. For example, the level of education, which was significantly different between the post-stroke groups, has been found to be a moderator of cognitive decline in older adults, i.e., older adults with higher levels of education tend to exhibit less cognitive decline (Ardila, Ostrosky-Solis, Rosselli, & Gómez, 2000; Arenaza-Urquijo et al., 2013; Beydoun et al., 2014; Evans et al., 1993). It is therefore difficult to determine whether education acted as a moderator for cognitive function in the post-stroke groups and thus impacted driving performance or whether education is an independent contributing factor.

For reasons of logistical practicality, there were a limited number of cognitive assessments used as part of this study, the results from which were combined to provide a measure of overall driving-related cognitive function. It is possible that individual cognitive processes may provide greater depth of understanding rather than global cognition (Yamin, Stinchcombe, & Gagnon, 2016). Therefore, the absence of individual assessment modelling and further cognitive assessments, particularly those of divided and selective attention, and working memory, which have been previously implicated in post-stroke driving performance (e.g., Marshall et al., 2007), may account for some the missing predictive variance. Further research is required to address these issues. There has been much debate in transport research as to whether driving simulators are a valid predictor of on-road performance (Lee, Cameron, et al., 2003; Selander et al., 2011; Stedmon, Young, & Hasseldine, 2009) with on-road assessments still being considered the 'gold standard' for driving research (Lee, Cameron, et al., 2003; Lee & Lee, 2005; Marshall et al., 2007; Odenheimer et al., 1994). However, it can be argued that the driving simulator may be a useful and more economical tool to assess on-road behaviour and identify those unsafe to drive on-road, in a reliable and safe environment before progressing to on-road assessments (Lee & Lee, 2005; Lee, Lee, & Cameron, 2003; Stedmon et al., 2009).

Conclusion

In conclusion, the results of this study support the finding that older post-stroke adults exhibit cognitive deficits and poorer driving performance than healthy adults of the same age. However, cognitive deficits and driving performance were not a direct contributing factor to post-stroke driving status. In addition, perceived ability of driving performance appears to have no impact on actual driving performance or post-stroke driving status. In contrast, personal and socio-economic factors including level of education and individual income appeared to influence driving status and self-regulation in post-stroke adults. Development of a screening tool that incorporates an individual's personal and socioeconomic profile may be beneficial in assisting health professionals to identify individuals who are safe to return to driving post-stroke.

Chapter Summary and Progression

This chapter has provided the foundation for the thesis and outlined the socio-demographic and cognitive influences on driving performance in post-stroke drivers and in post-stroke non-drivers. The following chapter will start the development of the licensed post-stroke profile, by investigating the influence of cognition on simulated driving performance in licensed post-stroke drivers and healthy controls.

Chapter Three References

Adler, G., & Rottunda, S. (2006). Older adults' perspectives on driving cessation. *Journal of Aging Studies, 20*(3), 227-235. http://dx.doi.org/http://dx.doi.org/10.1016/j.jaging.2005.09.003

Akinwuntan, A. E., Feys, H., De Weerdt, W., Baten, G., Arno, P., & Kiekens, C. (2006). Prediction of driving after stroke: a prospective study. *Neurorehabilitation and Neural Repair, 20*(3), 417-423. http://dx.doi.org/10.1177/1545968306287157

Allen, R. W., Stein, C. A., Aponso, B. L., Rosenthal, T. J., & Hogue, J. R. (1990). *A low cost, part task driving simulator based on microcomputer technology.* Paper presented at the 69th Annual Meeting of the Transportation Research Board., Washington, DC.

Anstey, K. J., Wood, J., Lord, S., & Walker, J. G. (2005). Cognitive, sensory and physical factors enabling driving safety in older adults. *Clinical Psychology Review, 25*, 45-65. http://dx.doi.org/10.1016/j.cpr.2004.07.008

Ardila, A., Ostrosky-Solis, F., Rosselli, M., & Gómez, C. (2000). Age-related cognitive decline during normal aging: The complex effect of education. *Archives of Clinical Neuropsychology, 15*(6), 495-513. http://dx.doi.org/http://dx.doi.org/10.1016/S0887-6177(99)00040-2

Arenaza-Urquijo, E. M., Landeau, B., La Joie, R., Mevel, K., Mézenge, F., Perrotin, A., . . . Chételat, G. (2013). Relationships between years of education and gray matter volume, metabolism and functional connectivity in healthy elders. *Neuroimage, 83*, 450-457. http://dx.doi.org/10.1016/j.neuroimage.2013.06.053

Australian Bureau of Statistics. (2009). *Profiles of Disability, Astralia*. (44290.0). Australian Bureau of Statistics.

Australian Institute of Health and Welfare. (2013). *Stroke*. Canberra: Retrieved from http://www.aihw.gov.au/WorkArea/DownloadAsset.aspx?id=60129543611

Benton, A. L., Hamsher, K., Varney, N. R., & Spreen, O. (1983). *Judgment of line orientation*. New York: Oxford University Press

Beydoun, M. A., Beydoun, H. A., Gamaldo, A. A., Teel, A., Zonderman, A. B., & Wang, Y. (2014). Epidemiologic studies of modifiable factors associated with cognition and dementia: Systematic review and meta-analysis. *BMC Public Health, 14*(1)Retrieved from http://www.scopus.com/inward/record.url?eid=2-s2.0-84904348791&partnerID=40&md5=ab0ae83513049f49163b68e5d30d60f4

Burns, P. C. (1999). Navigation and the mobility of older drivers. The Journals of Gerontology Series B: Psychological Sciences and Social Sciences, 54(1), S49-S55.

Classen, S., Bewernitz, M., & Shechtman, O. (2011). Driving simulator sickness: An evidence-based review of the literature. *American Journal of Occupational Therapy, 65*(2), 179-188. http://dx.doi.org/10.5014/ajot.2011.000802

Classen, S., Wang, Y., Crizzle, A. M., Winter, S. M., & Lanford, D. N. (2012). Gender differences among older drivers in a comprehensive driving evaluation. *Accident Analysis & Prevention, 61*, 146-152. http://dx.doi.org/10.1016/j.aap.2012.10.010

Cordell, R., Lee, H. C., Granger, A., Vieira, B., & Lee, A. H. (2008). Driving assessment in Parkinson's disease—A novel predictor of performance? *Movement Disorders, 23*(9), 1217-1222. http://dx.doi.org/10.1002/mds.21762

Devos, H., Akinwuntan, A. E., Nieuwboer, A., Tant, M., Truijen, S., De Wit, L., . . . De Weerdt, W. (2009). Comparison of the effect of two driving retraining programs on on-road performance after stroke. *Neurorehabilitation and Neural Repair, 23*(7), 699-705. http://dx.doi.org/10.1177/1545968309334208

Devos, H., Akinwuntan, A. E., Nieuwboer, A., Truijen, S., Tant, M., & De Weerdt, W. (2011). Screening for fitness to drive after stroke A systematic review and meta-analysis. *Neurology, 76*(8), 747-756.

Dickerson, A. E., Reistetter, T., Davis, E. S., & Monahan, M. (2011). Evaluating driving as a valued instrumental activity of daily living. *American Journal of Occupational Therapy, 65*(1), 64-75. Retrieved from http://search.proquest.com.dbgw.lis.curtin.edu.au/docview/835030492?rfr_id=info%3Axri%2Fsid%3Aprimo

Donorfio, L. K., D'Ambrosio, L. A., Coughlin, J. F., & Mohyde, M. (2009). To drive or not to drive, that isn't the question—the meaning of self-regulation among older drivers. *Journal of Safety Research, 40*(3), 221-226. http://dx.doi.org/10.1016/j.jsr.2009.04.002

Evans, D. A., Beckett, L. A., Albert, M. S., Hebert, L. E., Scherr, P. A., Funkenstein, H. H., & Taylor, J. O. (1993). Level of education and change in cognitive function in a community population of older persons. *Annals of Epidemiology, 3*(1), 71-77. http://dx.doi.org/10.1016/1047-2797(93)90012-S

Evans, L. (2004). *Traffic safety*. Bloomfield Hills, Michigan: Science Serving Society.

Fisk, G. D., Owsley, C., & Pulley, L. V. (1997). Driving after stroke: Driving exposure, advice, and evaluations. *Archives of Physical Medicine and Rehabilitation,* *78*(12), 1338-1345. http://dx.doi.org/http://dx.doi.org/10.1016/S0003-9993(97)90307-5

Fonda, S. J., Wallace, R. B., & Herzog, R. A. (2001). Changes in driving patterns and worsening depressive symptoms among older adults. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences, 56*(6), S343-S351.

Freund, B., Colgrove, L. A., Burke, B. L., & McLeod, R. (2005). Self-rated driving performance among elderly drivers referred for driving evaluation. *Accident Analysis & Prevention, 37*(4), 613-618. http://dx.doi.org/10.1016/j.aap.2005.03.002

Griffen, J. A., Rapport, L. J., Coleman Bryer, R., & Scott, C. A. (2009). Driving Status and Community Integration After Stroke. *Topics in Stroke Rehabilitation, 16*(3), 212-221. http://dx.doi.org/10.1310/tsr1603-212

Harrison, A., & Ragland, D. (2003). Consequences of driving reduction or cessation for older adults. *Transportation Research Record: Journal of the Transportation Research Board, 1843*, 96-104. http://dx.doi.org/doi:10.3141/1843-12

Heikkilä, V. M., Korpelainen, J., Turkka, J., Kallanranta, T., & Summala, H. (1999). Clinical evaluation of the driving ability in stroke patients. *Acta Neurologica*

Scandinavica, 99(6), 349-355. http://dx.doi.org/10.1111/j.1600-0404.1999.tb07363.x

Horswill, M. S., Anstey, K. J., Hatherly, C., Wood, J. M., & Pachana, N. A. (2011). Older drivers' insight into their hazard perception ability. *Accident Analysis & Prevention, 43*(6), 2121-2127. http://dx.doi.org/http://dx.doi.org/10.1016/j.aap.2011.05.035

IBM Corporation. (2012). IBM SPSS Statistics for Windows, Version 21.0. Armonk, NY: IBM Corp.

Kelland, D. Z., & Lewis, R. F. (1996). The Digit Vigilance Test: reliability, validity, and sensitivity to diazepam. *Archives of Clinical Neuropsychology, 11*(4), 339-344. http://dx.doi.org/10.1093/arclin/11.4.339

Kostyniuk, L. P., & Shope, J. T. (2003). Driving and alternatives: Older drivers in Michigan. *Journal of Safety Research, 34*(4), 407-414. http://dx.doi.org/http://dx.doi.org/10.1016/j.jsr.2003.09.001

Kulikov, E. (2010). The social and policy predictors of driving mobility among older adults. *Journal of Aging & Social Policy, 23*(1), 1-18. http://dx.doi.org/10.1080/08959420.2011.531991

Lee, H. C., Cameron, D., & Lee, A. H. (2003). Assessing the driving performance of older adult drivers: On-road versus simulated driving. *Accident Analysis & Prevention, 35*(5), 797-803. http://dx.doi.org/10.1016/S0001-4575(02)00083-0

Lee, H. C., Drake, V., & Cameron, D. (2002). Identification of appropriate assessment criteria to measure older adults' driving performance in simulated driving. *Australian Occupational Therapy Journal, 49*(3), 138-145. http://dx.doi.org/10.1046/j.1440-1630.2002.00314.x

Lee, H. C., & Lee, A. H. (2005). Identifying older drivers at risk of traffic violations by using a driving simulator: A 3-year longitudinal study. *The American Journal of Occupational Therapy, 59*(1), 97-100.

Lee, H. C., Lee, A. H., & Cameron, D. (2003). Validation of a driving simulator by measuring the visual attention skill of older adult drivers. *The American Journal of Occupational Therapy, 57*(3), 324-328. Retrieved from http://graphics.tx.ovid.com/ovftpdfs/FPDDNCLBAHJKIJ00/fs047/ovft/live/gv024/00000448/00000448-200305000-00010.pdf

Lee, H. C., Lee, A. H., Cameron, D., & Li-Tsang, C. (2003). Using a driving simulator to identify older drivers at inflated risk of motor vehicle crashes. *Journal of Safety Research, 34*(4), 453-459. http://dx.doi.org/http://dx.doi.org/10.1016/j.jsr.2003.09.007

Lewis, R., & Rennick, P. (1979). Manual for the repeatable cognitive-perceptual-motor battery. *Gross Point, MI: Axon,*

Lincoln, N., & Fanthome, Y. (1994). Reliability of the stroke drivers screening assessment. *Clinical Rehabilitation, 8*(2), 157-160.

Lister, R. (1999). Loss of ability to drive following a stroke: The early experiences of three elderly people on discharge from hospital. *The British Journal of Occupational Therapy, 62*(11), 514-520. Retrieved from http://www.ingentaconnect.com/content/cot/bjot/1999/00000062/00000011/art00006

Logan, P. A., Dyas, J., & Gladman, J. R. (2004). Using an interview study of transport use by people who have had a stroke to inform rehabilitation. *Clinical Rehabilitation, 18*(6), 703-708. http://dx.doi.org/10.1191/0269215504cr742oa

Lundberg, C., Caneman, G., Samuelsson, S. M., Hakamies-Blomqvist, L., & Almkvist, O. (2003). The assessment of fitness-to-drive after a stroke: The Nordic Stroke Driver Screening Assessment. *Scandinavian Journal of Psychology, 44*(1), 23-30. http://dx.doi.org/10.1111/1467-9450.00317

MacGregor, J. M., Freeman, D. H., & Zhang, D. (2001). A traffic sign recognition test can discriminate between older drivers who have and have not had a motor vehicle crash. *Journal of the American Geriatrics Society, 49*(4), 466-469. http://dx.doi.org/10.1046/j.1532-5415.2001.49095.x

Marottoli, R. A., Mendes de Leon, C. F., Glass, T. A., Williams, C. S., Cooney, L. M., & Berkman, L. F. (2000). Consequences of driving cessation: Decreased out-of-home activity levels. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences, 55*(6), S334-S340. http://dx.doi.org/10.1093/geronb/55.6.S334

Marshall, S. C., Molnar, F., Man-Son-Hing, M., Blair, R., Brosseau, L., Finestone, H. M., . . . Wilson, K. G. (2007). Predictors of driving ability following stroke: A systematic review. *Topics in Stroke Rehabilitation, 14*(1), 98-114. http://dx.doi.org/10.1310/tsr1401-98

Mathias, J. L., & Lucas, L. K. (2009). Cognitive predictors of unsafe driving in older drivers: A meta-analysis. *International Psychogeriatrics, 21*(04), 637-653. http://dx.doi.org/10.1017/S1041610209009119

Motta, K., Lee, H. C., & Falkmer, T. (2014). Post-stroke driving: Examining the effect of executive dysfunction. *Journal of Safety Research, 49*, 33.e31. http://dx.doi.org/10.1016/j.jsr.2014.02.005

Nasreddine, Z. S., Phillips, N. A., Bédirian, V., Charbonneau, S., Whitehead, V., Collin, I., . . . Chertkow, H. (2005). The Montreal Cognitive Assessment, MoCA: A brief screening tool for mild cognitive impairment. *Journal of the American Geriatrics Society, 53*(4), 695-699. http://dx.doi.org/10.1111/j.1532-5415.2005.53221.x

National Stroke Foundation. (2013). Driving after stroke. Retrieved from https://strokefoundation.com.au/~/media/strokewebsite/resources/factsheets/fs01_driving_web.ashx?la=en

Nouri, F. M., & Lincoln, N. B. (1992). Validation of a cognitive assessment: Predicting driving performance after stroke. *Clinical Rehabilitation, 6*(4), 275-281. http://dx.doi.org/10.1177/026921559200600402

Odenheimer, G. L. (2011). Which patients are fit to drive after a stroke? *Journal Watch. Neurology,* http://dx.doi.org/10.1056/JN201103150000001

Odenheimer, G. L., Beaudet, M., Jette, A. M., Albert, M. S., Grande, L., & Minaker, K. L. (1994). Performance-based driving evaluation of the elderly driver: Safety, reliability, and validity. *Journal of Gerontology, 49*(4), M153-M159. Retrieved from http://geronj.oxfordjournals.org/content/49/4/M153.full.pdf

Patomella, A.-H., Johansson, K., & Tham, K. (2009). Lived experience of driving ability following stroke. *Disability & Rehabilitation, 31*(9), 726-733. http://dx.doi.org/10.1080/09638280802306539

Patomella, A.-H., Kottorp, A., & Tham, K. (2008). Awareness of driving disability in people with stroke tested in a simulator. *Scandinavian Journal of Occupational Therapy, 15*(3), 184-192. http://dx.doi.org/10.1080/11038120802087600

Pendlebury, S. T., Cuthbertson, F. C., Welch, S. J. V., Mehta, Z., & Rothwell, P. M. (2010). Underestimation of cognitive impairment by Mini-Mental State Examination versus the Montreal Cognitive Assessment in patients with transient ischemic attack and stroke: A population-based study. *Stroke, 41*(6), 1290-1293. http://dx.doi.org/10.1161/strokeaha.110.579888

Perrier, M.-J., Korner-Bitensky, N., & Mayo, N. E. (2010). Patient factors associated with return to driving poststroke: Findings from a multicenter cohort study. *Archives of Physical Medicine and Rehabilitation, 91*(6), 868-873. http://dx.doi.org/10.1016/j.apmr.2010.03.009

Ponsford, A. S., Viitanen, M., Lundberg, C., & Johansson, K. (2008). Assessment of driving after stroke-a pluridisciplinary task. *Accident Analysis & Prevention, 40*(2), 452-460. http://dx.doi.org/10.1016/j.aap.2007.07.015

Precision Vision. Snellen Visual Acuity Chart. La Salle, Illinois: (Precision Vision).

Qualls, C. E., Bliwise, N. G., & Stringer, A. Y. (2000). Short forms of the Benton Judgment of Line Orientation test: Development and psychometric properties. *Archives of Clinical Neuropsychology, 15*(2), 159-163. http://dx.doi.org/http://dx.doi.org/10.1016/S0887-6177(98)00043-2

Radford, K. A., & Lincoln, N. B. (2004). Concurrent validity of the stroke drivers screening assessment. *Archives of Physical Medicine and Rehabilitation, 85*(2), 324-328. http://dx.doi.org/10.1016/S0003-9993(03)00765-2

Ragland, D. R., Satariano, W. A., & MacLeod, K. E. (2004). Reasons given by older people for limitation or avoidance of driving. *The Gerontologist, 44*(2), 237-244.

Ragland, D. R., Satariano, W. A., & MacLeod, K. E. (2005). Driving cessation and increased depressive symptoms. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences., 60*(3), 399-403.

Reitan, R. M., & Wolfson, D. (1985). The Halstead-Reitan Neuropsychological Test Battery: Theory and clinical interpretation. Tucson, Arizona, USA: Neuropsychology Press.

Rudman, D. L., Friedland, J., Chipman, M., & Sciortino, P. (2006). Holding on and letting go: The perspectives of pre-seniors and seniors on driving self-regulation in later life. *Canadian Journal on Aging, 25*(1), 65-76.

Scheffer, M., Monteiro, J. K., & De Almeida, R. M. M.. (2011). Frontal stroke: problem solving, decision making, impulsiveness, and depressive symptoms in men and women. *Psychology & Neuroscience, 4*(2), 267-278. http://dx.doi.org/10.3922/j.psns.2011.2.012

Selander, H., Lee, H. C., Johansson, K., & Falkmer, T. (2011). Older drivers: On-road and off-road test results. *Accident Analysis & Prevention, 43* (4), 1348-1354. http://dx.doi.org/10.1016/j.aap.2011.02.007

Siren, A., Hakamies-Blomqvist, L., & Lindeman, M. (2004). Driving Cessation and Health in Older Women. *Journal of Applied Gerontology, 23*(1), 58-69. http://dx.doi.org/10.1177/0733464804263129

Stedmon, A., Young, M. S., & Hasseldine, B. (2009). Keeping it real or faking it: The trials and tribulations of real road studies and simulators in transport research. In P. D. Bust (Ed.), *Contemporary Ergonomics 2009: Proceedings of the International Conference on Contemporary Ergonomics 2009*, CRC Press, London, UK, Unsworth, C. A., Wells, Y., Browning, C., Thomas, S. A., & Kendig, H. (2007). To continue, modify or relinquish driving: Findings from a longitudinal study of healthy ageing. *Gerontology, 53*(6), 423-431. Retrieved from http://www.karger.com/DOI/10.1159/000111489

Yamin, S., Stinchcombe, A., & Gagnon, S. (2016). Deficits in attention and visual processing but not global cognition predict simulated driving errors in drivers diagnosed with mild Alzheimer's disease. *American Journal of Alzheimer's Disease & Other Dementias, 31*(4), 351-360. http://dx.doi.org/10.1177/1533317515618898

Chapter Four: Assessing Cognition and Simulator-Based Driving Performance in Post-Stroke Adults

This chapter contains material published in the below listed journal (see Appendix 12: approval permissions and appendix 13 for published manuscript)

Blane, A., Lee, H. C., Falkmer, T., & Dukic Willstrand, T. (2017). Assessing cognitive ability and simulator-based driving performance in post-stroke adults. *Behavioural Neurology, 2017* (Behavioural and Cognitive Effects of Cerebrovascular Diseases), 1-9. http://dx.doi.org/10.1155/2017/1378308

Chapter Outline and Rationale

The purpose of this chapter was to further address objectives one (assess the relationship between deficits in cognition, executive function and driving behaviour in post-stroke drivers and non-stroke drivers) and three (assess the off-road driving performance of post-stroke drivers compared with the performance of healthy controls) and explore cognition and off-road driving in licensed post-stroke adults compared to healthy controls. The chapter is comprised of an expanded version of the aforementioned published manuscript and formatted in line with the style of the thesis. The chapter outlines the background to the study, the methodologies considered, describes the results of the study and concludes by discussing the prospective usefulness of a several cognitive measures, as well as using a driving simulator for post-stroke driver assessment and rehabilitation. The rationale for this chapter was to explore the assessments able to detect performance in licensed post-stroke adults, and to determine their potential use as a baseline in future research, as well as in unlicensed post-stroke drivers' assessments. The results reported in this chapter also provided direction for the areas of cognition on which to focus when investigating calibration and compensatory behaviours, which then form the focus of the following chapters.

Abstract

Driving is an important activity of daily living, which is increasingly relied upon as the population ages. It has been well established that cognitive processes decline following a stroke and these process may influence driving performance. There is much debate on the use of off-road neurological assessments and driving simulators as tools to predict driving performance, however the majority of research uses unlicensed post-stroke drivers, making the comparability of post-stroke adults to a control group difficult. In order to determine whether simulators and cognitive assessments can accurately assess driving performance, the baseline should be set by those who are already licensed to drive. Therefore the aim of this study was to assess for differences in cognitive ability and driving simulator performance in licensed community dwelling post-stroke drivers and controls. Two groups of licensed drivers (37 post-stroke and 43 controls) were assessed using several cognitive tasks and using a driving simulator. The post-stroke adults exhibited poorer cognitive ability however, there were no between group differences in simulator performance except that the post-stroke drivers demonstrated less variability in driver headway. The application of these results as a pre-screening toolbox for post-stroke driver is discussed.

Keywords: Australia, Cerebrovascular Accident, Cognitive Performance Driving Simulator, Licensed Driver, Older Drivers

Introduction

It is well established that safe driving, as an important activity for daily living, is heavily reliant on functioning cognitive processes (Anstey, Wood, Lord, & Walker, 2005; Groeger, 2000). It is also well acknowledged that cognitive processes decline following a stroke and that this may impact on their ability to drive (Marshall et al., 2007). There is great debate regarding whether post-stroke adults are at an increased risk of a crash, with much variation in the results, including research suggesting that post-stroke drivers are up-to three times more likely to crash (Perrier, Korner-Bitensky, Petzold, & Mayo, 2010), whereas others suggest there is no association with the increased crash risk (Haselkorn, Mueller, & Rivara, 1998). With this uncertainty and the knowledge that this sub-population will only increase (Strong, Mathers, & Bonita, 2007), understanding the extent of cognitive decline and the safe limit of decline required to return to driving on the road is essential.

It has been estimated that between 30% - 50% of post-stroke adults will return to driving (Bryer, Rapport, & Hanks, 2006; Fisk, Owsley, & Pulley, 1997). Currently, the Australian process for returning to driving after a stroke (using a private vehicle licence) requires the individual to wait a minimum of two weeks for a transient ischemic attack and four weeks after a fully ischemic stroke or haemorrhagic stroke (Austroads & National Transport Commision Australia, 2016). It is also a requirement that all post-stroke adults inform the relevant state transport licensing authority of their stroke and obtain medical clearance prior to driving on the road (Austroads & National Transport Commision Australia, 2016). Only a medical professional (usually a general practitioner) can advise whether a person is safe to drive. If the respective medical professional believes it necessary, the post-stroke adult may be required to undergo a driving assessment or further driver training before returning to the road (Austroads & National Transport Commision Australia, 2016). Ideally, post-stroke adults with questionable driving capability should undertake a two-stage assessment process, i.e., a neurological examination and an on-road observation, however limited guidelines are available for medical practitioners to determine fitness-to-drive (Murie-Fernandez, Iturralde, Cenoz, Casado, & Teasell, 2014). Although on-road driving tests remain the ‘gold-standard’ for driving assessment, they are arguably subjective, highly stressful, costly and time consuming (Lee, Cameron, & Lee, 2003; Lee & Lee, 2005), as well as carry inherent risks to safety (Galski, Ehle, McDonald, & Mackevich, 2000). Therefore, using off-road techniques are required to estimate the stage of recovery, as well as to provide reliable information for driver-targeted rehabilitation. Neuropsychological assessments have regularly been implemented to assess cognition and there is a strong correlation between the results and the client's driving performance, however cognitive ability should be assessed alongside actual driving behaviour, rather than in isolation (Marshall et al., 2007).

Driving simulation is an alternative measure of driving performance and is one of the most heavily utilised measures of driving performance (Stedmon, Young, & Hasseldine, 2009). This is due to its ability to reliably measure driving performance whilst ensuring driver safety and eliminating extraneous variables, such as traffic density and weather conditions (Lee, Cameron, et al., 2003; Stedmon et al., 2009). The limited research using driving simulators to assess driving performance in a post-stroke population have found varying results. Some studies have reported that post-stroke adults perform significantly worse in a driving simulator assessment, having exhibited more errors when compared to controls, (Hird et al., 2015; Kotterba, Widdig, Brylak, & Orth, 2005; McKay, Rapport, Bryer, & Casey, 2011). However, others have reported that although post-stroke drivers exhibit difficulty with secondary tasks, such as listening span tasks whilst driving, there were no differences in actual driving performance variables (Lundqvist, Gerdle, & Rönnberg, 2000). A possible explanation for the discrepancy and subsequent predictive value of previous simulator-based research may be due to the fact that the majority of simulated driving research has focused on unlicensed post-stroke drivers. It stands to reason that in order to determine whether simulators and cognitive assessments can accurately assess driving performance, the baseline should be set by those who are already licensed to drive. Therefore, the aim of this study was to assess for differences in driving simulator performance in licensed community dwelling post-stroke drivers and controls, as well as to assess whether differences in cognition account for differences in driving performance.

Method

Design

A quasi-experimental comparison group design, involving a group of licensed post-stroke drivers and a control group of licensed drivers of the same age and gender, was utilised to perform the assessments.

Participants

The inclusion criteria for study participation were that all participants held a driver's licence valid within Australia, had at least one year of overall driving experience, drove at least twice a week and had access to a fully insured vehicle. Further criteria for the post-stroke group were that they had previously been diagnosed with a stroke (either ischemic or haemorrhagic) and had obtained medical clearance. Post-stroke participants self-reported their condition however, where possible, participants were asked to bring in any medical documents relating to their stroke, for demographic verification purposes. Participants were excluded if they had been diagnosed with any neurodegenerative disease, such as Parkinson's disease or dementia, or if they required a wheelchair for mobility. Some post-stroke participants had hemiparesis and used assistive equipment whilst driving (e.g., a steering knob, modified pedals or a foot brace), however as all participants were community dwelling and were driving their own vehicles, they were considered a level two or below on the Modified Rankin Scale (Rankin, 1957; van Swieten, Koudstaal, Visser, Schouten, & van Gijn, 1988). Participants were recruited using purposive sampling techniques including: speaking at and recruiting from local community groups and post-stroke support groups, as well as advertising in community newspapers and on local radio stations. The recruitment and assessment of participants took place between April 2015 and February 2016.

The total sample consisted of 80 participants including 37 post-stroke drivers (male = 30) and 43 controls (male = 35). The mean age of the post-stroke group was 65 years (SD = 9) and the ages ranged from 37 – 81 years. The mean age of the control group was slightly older at 66 years (SD = 7), and ages ranged from 49 – 81 years, however the age difference between groups was not significant, t = -0.61, df= 81 p<0.05. Driving exposure data were collected from each participant as an estimate of their annual millage in kilometres (km). The post-stroke group reported an annual mean of 15,529 km (SD = 12,440), whereas the controls reported 15,341 km per year (SD = 8,066) and the difference was non-significant t=0.78, df=70, p<0.05. The licence length of the post-stroke group was slightly shorter than the control group with means of 47 years, (SD = 8) and 49 years (SD = 8), respectively with the difference again non-significant, t=-0.86, df=78 p<0.05. As there were no significant differences found for these variables, based on previously researched driving criteria the groups were considered well matched (Evans, 2004).

Measures

Driving Simulator. The Driving Simulator based at the Curtin University, School of Occupational Therapy and Social Work is a fixed-base car driving simulator that has mid-level physical fidelity and consists of a driving console with three ASUS (24" 16:9 ratio) display screens, onto which the forward facing and peripheral driving scenes are displayed (Figure 11). For consistency, the simulator was configured to automatic transmission use for all participants. A steering knob was installed onto the steering wheel if required by the participant, and the simulator configurations were modified to use the left side pedal or right side pedal as the acceleration pedal. This was implemented in order to best simulate any vehicle modifications found in the participant's own vehicle.

Driving scenarios were programmed using the STISIM© driving software (Allen, Stein, Aponso, Rosenthal, & Hogue, 1990) and consisted of a practice scenario, a lead-car scenario and an emergency stop scenario, which all contained 60km per hour roads. A practice scenario that lasted approximately 10 minutes and included dual lane road was utilised for each participant, in order for them to become familiar with the driving console controls and visual stimuli. The lead-car scenario, in a two lane suburban road required participants to follow a lead-car for the duration of the scenario and their main task was to maintain a safe, consistent distance between themselves and the car in front. The emergency stop scenario, a four lane suburban road, required participants to apply the brake as soon as a stop sign appeared and time to react was recorded. Due to the limited time availability of enrolled participants (five participants including four controls and one post-stroke driver) or the onset of simulator sickness (22 participants including 11 controls, 11 post-stroke), 27 participants did not complete the emergency stop scenario. A further five participants (three controls, two post-stroke drivers) failed to stop within the allotted time for the emergency stop task, therefore no reaction time data were recorded for these participants and the total number of responses recorded for the emergency stop scenario was 48.

Figure 11. The Curtin University STISIM Driving Simulator

Cognitive measures. A series of cognitive measures were utilised to assess different aspects of cognition: psychomotor processing, attention, executive function, propensity for risk taking, spatial cognition and visuospatial function.

Psychomotor Processing. Following the criteria and procedures previously implemented in similar cognitive research (Bunce, Handley, & Gaines Jr, 2008; Bunce, Young, Blane, & Khugputh, 2012), the participants completed a simple reaction time task, a two choice reaction time task (2CRT) and a four choice reaction time task (4CRT). On all tasks the participants were instructed to answer as quickly and as accurately as possible. Hit, miss and false alarm (where appropriate) were recorded. In order to account for response bias, all response data reported were adjusted for hit rate. Baseline reaction time was measured using a simple reaction time task (SRT), whereby participants were presented with the letter X in the middle of the display and instructed to press the space bar as soon as the X appeared. During the 2CRT and 4CRT, participants were instructed to press the specified key corresponding to where the circle spatially appeared on the screen. All targets were presented randomly. In order to provide an indication of task-based performance independent of processing speed, the SRT time was subtracted from the adjusted 2CRT and 4CRT tasks. Higher rates of accuracy and lower reaction time were indicators of increased performance.

Attention and Executive Function. There were two types of attention measured as part of this study: selective attention and divided attention. Both were measured using the Useful Field of View Task (UFOV). The UFOV task was developed as means of measuring visual, selective and divided attention (Ball & Owsley, 1993) and has been regularly implemented in post-stroke driving research (Fisk, Owsley, & Mennemeier, 2002; George & Crotty, 2010). Shorter processing speeds for accurate answers were indicative of greater performance.

A second selective attention task, utilised in previous driving research (Bunce et al., 2012) was administered to assess raw individual reaction times to visual search stimuli. Using E-Prime 2.0 (Schneider, Eschman, & Zuccolotto, 2012), participants were presented with a 6x6 rectangular arrangement of multiple letter O's and told to look for the embedded target letter (Q) amongst them. For each display, participants were instructed to press the corresponding key (X for yes, M for no) on the keyboard to determine the presence of a Q as quickly and accurately as possible. Throughout the 64 experimental trials, the number of yes and no answers were equally distributed; however the sequence was randomised for each participant. Shorter reaction times for accurate answers were indicative of greater performance.

Executive function was assessed using the Delis-Kaplan Trail Making Task (Delis, Kaplan, & Kramer, 2001). The task included five individual component paper-based tasks that assessed different levels of cognition. Task one was a visual cancellation task and tasks two, three and five comprised several connect the circle tasks. These tasks were used to provide a baseline performance score of key components of cognition used within executive functioning: specifically, visual scanning, number sequencing, letter sequencing, and motor speed respectively (Swanson, 2005). Task four assessed executive function, specifically through assessing visuospatial thought flexibility and involved a number-letter switching task (Swanson, 2005). The total time to complete for each task was recorded and to control for the baseline functions represented in trail tasks one to three and five, contrast scores were calculated (Delis et al., 2001). The raw time-to-completion scores were scaled in order to account for age effects (Delis et al., 2001). Higher scaled scores were indicative of greater performance. The tests have previously been used to assess cognitive performance in post-stroke patients and reported to be sensitive to cognitive decline, particularly in frontal lobe function (Homack, Lee, & Riccio, 2005; Wolf & Rognstad, 2013).

Propensity for risk. The Balloon Analogue Risk Task (BART; Lejuez et al., 2002) was used to measure propensity for risk-taking and aversive behaviour. The objective of the task was to pump up the balloon displayed on screen and collect the most points without allowing the balloon to burst. The number of pumps required for the balloon to burst was randomized and ranged between one – 128 pumps, which is the standard for the BART (Lejuez et al., 2002). Participants with lower scores and fewer burst balloons are considered to be risk averse, whereas participants with higher scores and more burst balloons have a greater propensity for risk. The BART was administered using E-Prime© v 2.0 Software and the number of balloons saved, as well as the adjusted average number of pumps for each balloon were recorded.

Spatial cognition and visuospatial function. Post-stroke adults often experience deficits in visuospatial function (Kaplan & Hier, 1982; Stone et al., 1991), therefore to test this, the block design task (a subtask of the Wechsler Adult Intelligence Scale), was used to measure non-verbal visuospatial reasoning (Wechsler, 2008). The test involved constructing a specified design with a series of cuboid blocks as quickly and as accurately as possible. The difficulty increased with each alteration of the design and the time limit allowed for each design subsequently increased. Participants were scored depending on the number of completed designs within each allocated time. A time bonus was added depending on the time taken to complete each design. The task was discontinued once the participant had failed to complete the design within time for two consecutive designs. Higher scores were indicative of greater performance.

Spatial cognition, perception and orientation ability were measured using the Benton Judgement of Line Orientation Task (Benton, Hamsher, Varney, & Spreen, 1983). The test consisted of a series of reference lines arranged in a semi-circle, from which participants had to identify specified target lines. The rotation and angle alteration of the target lines progressively increased the difficulty of the task. The amount of correctly identified lines was recorded. Higher scores were indicative of greater performance.

Data Collection and Procedure

Participants were provided with a participant information sheet, consent form and screened for minimum visual acuity using the revised charts 1-3 from the 2000 ETDRS visual acuity chart (Precision Vision). All participants displayed visual acuity greater than or equal to 20/40, which is the minimum level to drive legally in Western Australia. This screening was implemented to control for any confounding influence of poor visual acuity in the cognitive and driving simulation tasks. Participants completed the cognitive tasks before undertaking the driving simulator tasks and the order of completion for the cognitive tasks was randomised for each participant using a Latin squares method (Grant, 1948). Overall, the process lasted approximately 1 ½ hours for each participant.

Data Analysis and Processing

Performance in the simulator was assessed by calculating the moment-to-moment instability of each driving dependent variable (headway, speed, lateral lane position, steering input), with the measures of central tendency used to report braking reaction time. Finally, the cumulative number of speed exceedances and the cumulative number of crashes in the follow car scenario were calculated. Reaction time in the simulator was assessed using two variables: braking reaction time and braking stopping time. Braking reaction time was defined as the time it took for the participant to react to the stop sign and the braking stopping time was the total amount of time taken for the car to completely stop following the stop sign. Following previously implemented driving simulator research (Bunce et al., 2012), analysis consisted of performing a standard error regression with each driving variable (headway, speed, lateral lane position, steering input), listed as the dependent variable and the time recorded in 0.5 second increments as the independent variable. This technique was used to provide a collated moment-to-moment measure of instability consisting of residuals for the target driving variable (Bloomfield & Carroll, 1996, p. 336). The process of calculating the residual data as a dependent variable in the final analysis was conducted using a Microsoft Excel-based macro, programmed using Visual Basic for Applications (Microsoft Office, 2010).

Statistical Analysis. Normality of all variables was assessed using a histogram, Q-Q plots, and measures of skewness and kurtosis. A box-cox transformation was conducted on the UFOV data, DKEFS data, visual search data, reaction time task data and headway calculation to improve normality. Between groups differences in simulator performance and cognitive performance were assessed using an independent samples t-test. Following transformation, analysis of non-normally distributed data between groups was performed using a Mann-Whitney U test.

For the cognitive variables and variation in performance simulator variables, with 37 and 43 participants in the respective groups, there was 80% power to detect an effect size of 0.64 between the posts-stroke drivers and controls (Cohen, 1988). For the braking reaction time task, due to significant drop out there were 22 participants in the smallest group and the standardised difference value dropped. Therefore there was 80% power to detect an effect size of 0.82. A p-value of <0.05 was taken to indicate a statistically significant association for all tests.

Ethical Considerations

This research and the associated study protocols were approved by the Curtin University Human Research Ethics Committee – approval number: HR206-2014 and conformed to the principles of the Declaration of Helsinki. Participants were presented with an information sheet, given the opportunity to ask questions and each provided a signed informed consent prior to participation. Participants were also informed that they could leave the study at any time without incurring any negative consequences. Participants were offered a gift voucher worth $15 as a token of appreciation for their time and travel costs.

Results

Differences in simulator

Overall, the post-stroke drivers displayed greater variability in speed, lateral lane position and steering input suggesting that the post-stroke drivers varied their speed more often, varied their position on the road and moved the steering wheel more than the control group, however these results were non-significant at group level (Table 16). Interestingly, although the post-stroke drivers were on average quicker to respond to the braking task, they took longer to fully stop the car (Figure 12), although again, these results were non-significant at group level (Table 16). The main significant difference between the groups was that the post-stroke group displayed less variability in headway (Table 16) suggesting that the post-stroke drivers' headway was more consistent than the control group.

Table 16.

The between group differences in simulator performance

Variables	Post-Stroke Driver			Controls			t-value	df	p-value
	n	Mean	SD	n	Mean	SD			
Headway	37	3.26	1.87	43	1.71	1.36	-2.20	48.58	0.03*
Lateral Lane Position	37	0.73	0.39	43	0.64	0.35	1.18	78	0.24
Speed	37	8.83	1.75	43	8.41	1.14	1.29	78	0.20
Steering Input	37	1.48	1.06	43	1.13	0.66	1.80	78	0.13
Braking Reaction Time	22	1.07	0.31	26	1.08	0.27	-0.19	46	0.85
Braking Stopping Time	22	6.32	11.03	26	3.98	1.35	1.07	46	0.29

*p-value <0.05

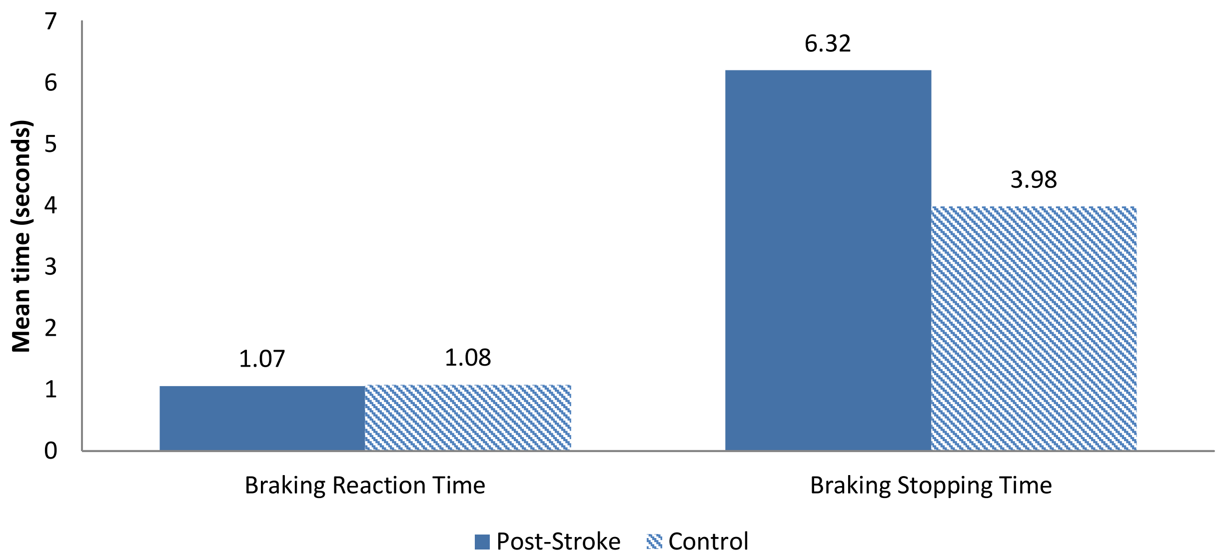

Figure 12. The mean braking reaction time and stopping time in seconds for the post-stroke and control group.

There was also no between groups difference reported for cumulative number of crashes as there were zero crashes reported. The speed exceedances were grouped into 6 proportionally distributed categories using the binning function in SPSS. The number of speed exceedances recorded was relatively evenly distributed across both groups although the largest differences appeared to be that 40% of post-stroke drivers were recorded as having committed ≤4 speed exceedances compared to 21% of the control group and 10% of the post-stroke drivers recorded ≥12 speed exceedances compared to 19% of the control groups (Figure 13). However, overall, there was no significant difference in speed exceedances between groups $\chi^2 = 4.76$, df=5, $p>0.05$.

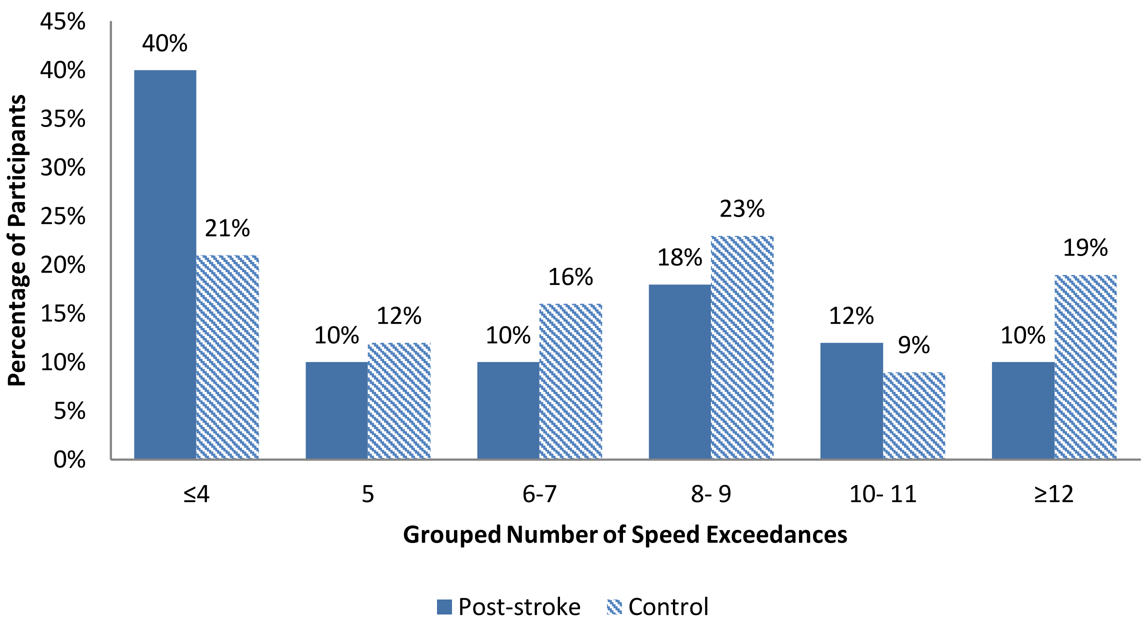

Figure 13. The grouped number of speed exceedances in the post-stroke and control groups

Differences in cognition

Table 17.

The between groups analysis of cognitive variables

Variables	Post-Stroke Driver			Controls			t-value	df	p-value
	n	Mean	SD	n	Mean	SD			
BART mean # pumps	37	25.16	3.32	43	27.49	17.78	2.46	78	0.02*
BART mean # saved balloons	37	20.15	10.18	43	22.90	4.71	-2.31	68.51	0.02*
BJLOT	36	24.64	5.07	43	25.44	9.93	-0.78	65.33	0.44
Block design	37	37.60	10.50	43	40.40	10.22	-1.21	78	0.23
SRT RT (milliseconds)	34	375.59	161.35	43	244.19	78.05	1.12	78	0.27
2CRT RT (milliseconds)	34	97.99	172.91	43	50.58	88.64	1.46	46.56	0.15
4CRT RT (milliseconds)	34	427.62	258.67	43	333.33	255.92	1.60	75	0.11
Simple visual search	34	693.99	422.08	43	494.11	150.97	2.89	39.70	0.01*
2CRT # correct	34	45.41	1.76	43	45.70	4.21	-0.37	75	0.71
4CRT # correct	34	44.77	4.69	43	46.40	3.66	-1.71	75	0.09
Simple visual search # correct	34	56.50	15.00	43	61.54	5.35	-1.87	36.66	0.07
UFOV 2	35	82.89	112.33	42	36.29	38.84	2.52	40.78	0.02*
UFOV 3	35	144.31	110.33	41	90.13	50.70	2.82	46.09	0.01*
	n	Median	Mean	IQR	n	Median	Mean	IQR	p-value
UFOV 1	35	13.8	19.31	0.10	42	13.8	14.53	0.10	0.82

*Significant data; p-value <0.05

There were significant between groups' differences in several of the cognitive variables: BART, visual search, D-KEFS – Number Letter Switching and UFOV (Tables 17 and 18). The post-stroke drivers saved more balloons in the BART and also had a lower average amount of pumps per balloon, both of which indicate a greater tendency for risk averseness than those in the control group. In the UFOV Divided Attention, UFOV Selective Attention and Visual Search Task, the post-stroke drivers had significantly longer reaction times, all of which indicated poor performance. There were no statistically significant differences between groups' for any of the following measures; BJLOT, Block Design, UFOV 1 or any of the psychomotor tasks (either RT or error rate).

Table 18.

The between groups analysis of D-KEFS TMT variables

Variables	Post-Stroke Driver			Controls			t-value	df	p-value
	n	Mean	SD	n	Mean	SD			
DKEFS TMT 1	37	7.38	3.62	43	10.90	2.17	-5.19	57.06	0.001**
DKEFS TMT 2	37	9.08	3.75	43	11.47	3.01	-3.16	78	0.003*
DKEFS TMT 3	37	8.51	4.07	43	11.72	2.57	-4.14	58.97	0.001**
DKEFS TMT 4	37	8.27	4.43	43	11.65	2.35	-4.16	52.86	0.001**
DKEFS TMT 5	37	9.68	2.92	43	12.02	1.71	-4.30	56.26	0.001**
DKEFS TMT 2+ TMT3	37	9.12	4.02	43	12.35	2.89	-4.04	64.29	0.001**
	n	Median	Mean	IQR	n	Median	Mean	IQR	p-value
DKEFS EF 4	37	1.00	2.92	4.50	43	1.00	1.67	0.00	0.02*

*p-value <0.05

**p-value <0.001

Discussion

Summary of findings

As mentioned in the introduction, full driving assessments, i.e., including an on-road component, are both time consuming and costly (Lee, Cameron, et al., 2003; Lee & Lee, 2005), and constitute a real risk to both the candidate and the assessor (Galski et al., 2000). Furthermore, they inherently comprise an uncontrollable component as other road users' actions and interactions cannot be controlled (Carsten & Jamson, 2011; Stedmon et al., 2009). Hence, if there was a safe way to assess post-stroke drivers prior to returning to drive, it would be both time and cost-effective, as well as increase road safety. However, limited information is currently available regarding individual assessment requirements and strategies for adapting the assessments for older post-stroke drivers. The problem is further compounded by the fact that post-stroke drivers predominantly will be older. In the present study a combination of driving simulator scenarios and psychometric tests were implemented in order to assist with that decision; thus capturing actual post-stroke driving profile would provide support for determining where they would differ from the non-affected older driver.

Whilst most simulator driving variables did not differ between the two groups, as was expected given that all participants were licensed drivers, of greater concern was the finding that the older adults in the control group varied their headway, more than post-stroke participants. This was an unexpected finding, albeit consistent with the simultaneous finding that on-average, post-stroke drivers were more risk aversive than controls. Headway is a known predictor of safe driving and has been established as a valuable assessment in simulator research (Vogel, 2003), therefore this finding is also quite challenging given that the present study aimed to identify post-stroke specific indicators that could assist driving assessments by allied health professionals. The fact that the control group performed better in several of the cognitive tasks, yet displayed greater headway appears counterintuitive. However, when taken with the result that the post-stroke drivers were more risk aversive, this may suggest that less headway variation in the post-stroke group is due to the licensed drivers' awareness of their limitations and amending their driving as a result of executive function deficits. Although further exploration of this relationship is beyond the scope of the present study, more research is planned to investigate this, specifically, whether post-stroke awareness of cognitive deficits is associated with amended driving behaviour.

In many of the cognitive tests the post-stroke drivers were found to have poorer scores than their control group counterparts. These findings corroborate previous research, suggesting that a mixture of off-road neuropsychological tasks, as well as driving a simulator, may be beneficial in establishing who is safe to drive, prior to undertaking an on-road assessment (Lew et al., 2005). Specifically, this study suggests that a battery of tasks assessing attention, baseline cognitive and executive function and propensity for risk (i.e., the UFOV, the DKEFS TMT and the BART) may be able to be a good screening tool for post-stroke driving assessments prior to making a full assessment, i.e., going on road, and may also provide a baseline for assistive post-stroke driver training. The final finding of the current study is that the following tests did not contribute to the pre on-road screening, psychomotor processing ability (SRT, 2CRT and 4CRT), spatial cognition, perception and orientation ability (BJLOT) and visuospatial function (Block Design). This suggests that although post-stroke drivers may be lacking in these cognitive skills, ultimately it may not affect their ability to drive, and therefore using them as a pre-screening for driving ability is unnecessary.

Limitations

As with all simulator research, there is much debate on the use of driving simulators for driving assessments (Stedmon et al., 2009). This study aimed to emulate driving on-road in a safe, replicable environment for the purpose of establishing baseline driving performance in licensed drivers, therefore a simulator was used, which has previously been validated for on-road driving performance (Lee, Lee, & Cameron, 2003). Similarly, although on-road performance was not the focus of the present study, the participants sampled were licensed drivers, in order to ensure that all participants were of a sufficient standard to drive, therefore it is easier to generalise to on-road driving capability. Despite the driving simulator validation, it should also be noted that participants completed a non-complex scenario and spent a relatively short amount of time in the driving simulator, which can limit the representativeness of the results (Carsten & Jamson, 2011). This was partly due to the measurements being assessed and partly to minimise the effects of simulator sickness (Carsten & Jamson, 2011). As part of this research, the majority of participants attempted all scenarios, however there was a relatively small attrition rate for the emergency stop task as many of the participants developed simulator sickness and the assessment was halted. There was also a small number of participants who did not have data recorded for some cognitive assessments, due to a mixture of logging errors, participant choice or restraints on the participant's time. Due to this attrition rate and the initial relatively small sample size, there were fewer participants with recorded data, which increases the potential for a type II error, therefore the results should be interpreted with caution and further research with a larger sample is required for verification.

Conclusion

Although post-stroke adults have decreased cognitive ability, they can perform at a similar level in a driving simulator to licensed controls. As this research was conducted on licensed drivers, it presents a useful baseline indication for the use of off-road and simulator assessments as predictive tools. Specifically, the study suggests that driving simulators and those tasks assessing performance in propensity for risk, executive function, selective attention and divided attention may be useful for future researchers and clinicians as assessment, rehabilitation and training tools for non-licensed post-stroke adults who wish to return to driving.

Chapter Summary and Progression

This chapter has investigated licensed post-stoke driver in a driving simulator, compared to healthy controls. Using the tools identified as useful assessments, the following chapter discusses post-stroke driver behaviour in the simulator in response to cognition and task demand, with the aim of developing an understanding of driver calibration.

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Chapter Four References

Allen, R. W., Stein, C. A., Aponso, B. L., Rosenthal, T. J., & Hogue, J. R. (1990). *A low cost, part task driving simulator based on microcomputer technology.* Paper presented at the 69th Annual Meeting of the Transportation Research Board., Washington, DC.

Anstey, K. J., Wood, J., Lord, S., & Walker, J. G. (2005). Cognitive, sensory and physical factors enabling driving safety in older adults. *Clinical Psychology Review, 25*, 45-65. http://dx.doi.org/10.1016/j.cpr.2004.07.008

Austroads, & National Transport Commision Australia. (2016). Assessing fitness to drive for commercial and private vehicle drivers: Medical standards for licensing and clinical management guidelines., Retrieved from https://www.onlinepublications.austroads.com.au/items/AP-G56-16

Ball, K., & Owsley, C. (1993). The Useful Field of View test: A new technique for evaluating age-related declines in visual function. *Journal of the American Optometric Association, 64*(1), 71-79.

Benton, A. L., Hamsher, K., Varney, N. R., & Spreen, O. (1983). *Judgment of line orientation*. New York: Oxford University Press

Bloomfield, J. R., & Carroll, S. A. (1996). New measures of driving performance. In S. A. Robertson (Ed.), *Contemporary Ergonomics* (pp. 335-340). London: Taylor & Francis.

Bryer, R. C., Rapport, L. J., & Hanks, R. A. (2006). Determining fitness to drive: Neuropsychological and psychological considerations In J. M. Pellerito (Ed.), *Driver Rehabilitation and Community Mobility* (pp. 165-184). Saint Louis, USA: Mosby. http://dx.doi.org/:http://dx.doi.org/10.1016/B978-032302937-7.50013-7

Bunce, D., Handley, R., & Gaines Jr, S. O. (2008). Depression, anxiety, and within-person variability in adults aged 18 to 85 years. *Psychology and Aging, 23*(4), 848-858.

Bunce, D., Young, M. S., Blane, A., & Khugputh, P. (2012). Age and inconsistency in driving performance. *Accident Analysis & Prevention, 49*, 293-299. http://dx.doi.org/10.1016/j.aap.2012.01.001

Carsten, O., & Jamson, A. H. (2011). Driving simulators as research tools in traffic psychology. In B. E. C. Porter (Ed.), *Handbook of traffic psychology* (pp. 87-96). Burlington: Elsevier Science.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, New Jersey: L. Erlbaum Associates.

Delis, D. C., Kaplan, E., & Kramer, J. H. (2001). *Delis-Kaplan Executive Function System (D-KEFS) examiner's manual*. San Antonio, Texas: The Psychological Corporation.

Evans, L. (2004). *Traffic safety*. Bloomfield Hills, Michigan: Science Serving Society.

Fisk, G. D., Owsley, C., & Mennemeier, M. (2002). Vision, attention, and self-reported driving behaviors in community-dwelling stroke survivors. *Archives of Physical Medicine and Rehabilitation, 83*(4), 469-477. http://dx.doi.org/10.1053/apmr.2002.31179

Fisk, G. D., Owsley, C., & Pulley, L. V. (1997). Driving after stroke: Driving exposure, advice, and evaluations. *Archives of Physical Medicine and Rehabilitation, 78*(12), 1338-1345. http://dx.doi.org/http://dx.doi.org/10.1016/S0003-9993(97)90307-5

Galski, T., Ehle, H. T., McDonald, M. A., & Mackevich, J. (2000). Evaluating fitness-to-drive after cerebral injury: Basic issues and recommendations for medical and legal communities. *The Journal of Head Trauma Rehabilitation, 15*(3), 895-908.

George, S., & Crotty, M. (2010). Establishing criterion validity of the Useful Field of View assessment and Stroke Drivers' Screening Assessment: Comparison to the result of on-road assessment. *American Journal of Occupational Therapy, 64*(1), 114-122.

Grant, D. A. (1948). The latin square principle in the design and analysis of psychological experiments. *Psychological Bulletin, 45*(5), 427-442. http://dx.doi.org/10.1037/h0053912

Groeger, J. A. (2000). Understanding driving: Applying cognitive psychology to a complex everyday task. Hove, East Sussex, UK: Psychology Press.

Haselkorn, J. K., Mueller, B. A., & Rivara, F. A. (1998). Characteristics of drivers and driving record after traumatic and nontraumatic brain injury. *Archives of Physical Medicine and Rehabilitation, 79*(7), 738-742. http://dx.doi.org/http://dx.doi.org/10.1016/S0003-9993(98)90349-5

Hird, M. A., Vesely, K. A., Christie, L. E., Alves, M. A., Pongmoragot, J., Saposnik, G., & Schweizer, T. A. (2015). Is it safe to drive after acute mild stroke? A preliminary report. *Journal of the Neurological Sciences, 354*(1), 46-50. http://dx.doi.org/10.1016/j.jns.2015.04.043

Homack, S., Lee, D., & Riccio, C. A. (2005). Test review: Delis-Kaplan Executive Function System. *Journal of Clinical and Experimental Neuropsychology, 27*(5), 599-609. http://dx.doi.org/http://dx.doi.org/10.1080/13803390490918444

Kaplan, J., & Hier, D. B. (1982). Visuospatial deficits after right hemisphere stroke. *American Journal of Occupational Therapy, 36*(5), 314-321.

Kotterba, S., Widdig, W., Brylak, S., & Orth, M. (2005). Driving after cerebral ischemia – a driving simulator investigation. *Wien Med Wochenschr, 155*(15), 348-353. http://dx.doi.org/10.1007/s10354-005-0191-3

Lee, H. C., Cameron, D., & Lee, A. H. (2003). Assessing the driving performance of older adult drivers: On-road versus simulated driving. *Accident Analysis & Prevention, 35*(5), 797-803. http://dx.doi.org/10.1016/S0001-4575(02)00083-0

Lee, H. C., & Lee, A. H. (2005). Identifying older drivers at risk of traffic violations by using a driving simulator: A 3-year longitudinal study. *The American Journal of Occupational Therapy, 59*(1), 97-100.

Lee, H. C., Lee, A. H., & Cameron, D. (2003). Validation of a driving simulator by measuring the visual attention skill of older adult drivers. *The American Journal of Occupational Therapy, 57*(3), 324-328. Retrieved from http://graphics.tx.ovid.com/ovftpdfs/FPDDNCLBAHJKIJ00/fs047/ovft/live/gv024/00000448/00000448-200305000-00010.pdf

Lejuez, C., Read, J. P., Kahler, C. W., Richards, J. B., Ramsey, S. E., Stuart, G. L., . . . Brown, R. A. (2002). Evaluation of a behavioral measure of risk taking: the Balloon Analogue Risk Task (BART). *Journal of Experimental Psychology: Applied, 8*(2), 75-84. http://dx.doi.org/10.1037/1076-898X.8.2.75

Lew, H. L., Poole, J. H., Lee, E. H., Jaffe, D. L., Huang, H.-C., & Brodd, E. (2005). Predictive validity of driving-simulator assessments following traumatic brain injury: a preliminary study. *Brain Injury, 19*(3), 177-188. http://dx.doi.org/10.1080/02699050400017171

Lundqvist, A., Gerdle, B., & Rönnberg, J. (2000). Neuropsychological aspects of driving after a stroke—in the simulator and on the road. *Applied Cognitive Psychology, 14*(2), 135-150. http://dx.doi.org/10.1002/(SICI)1099-0720(200003/04)14:2<135::AID-ACP628>3.0.CO;2-S

Marshall, S. C., Molnar, F., Man-Son-Hing, M., Blair, R., Brosseau, L., Finestone, H. M., . . . Wilson, K. G. (2007). Predictors of driving ability following stroke: A systematic review. *Topics in Stroke Rehabilitation, 14*(1), 98-114. http://dx.doi.org/10.1310/tsr1401-98

McKay, C., Rapport, L., Bryer, R., & Casey, J. (2011). Self-evaluation of driving simulator performance after stroke. *Topics in Stroke Rehabilitation, 18*(5), 549-561. http://dx.doi.org/10.1310/tsr1805-549

Microsoft Office. (2010). Visual Basic For Applications.

Murie-Fernandez, M., Iturralde, S., Cenoz, M., Casado, M., & Teasell, R. (2014). Driving ability after a stroke: Evaluation and recovery. *Neurología (English Edition), 29*(3), 161-167. http://dx.doi.org/http://dx.doi.org/10.1016/j.nrleng.2012.05.008

Perrier, M.-J., Korner-Bitensky, N., Petzold, A., & Mayo, N. (2010). The risk of motor vehicle crashes and traffic citations post-stroke: A structured review. *Topics in Stroke Rehabilitation, 17*(3), 191-196. http://dx.doi.org.dbgw.lis.curtin.edu.au/10.1310/tsr1703-191

Precision Vision. 2000 Series Revised ETDRS Charts. La Salle, Illinois: (Precision Vision).

Rankin, J. (1957). Cerebral vascular accidents in patients over the age of 60: II. Prognosis. *Scottish Medical Journal, 2*(5), 200-215.

Schneider, W., Eschman, A., & Zuccolotto, A. (2012). E-Prime (Version 2.0). Pittsburgh: Psychology Software Tools, Inc.

Stedmon, A., Young, M. S., & Hasseldine, B. (2009). Keeping it real or faking it: The trials and tribulations of real road studies and simulators in transport research. In P. D. Bust (Ed.), *Contemporary Ergonomics 2009: Proceedings of* *the International Conference on Contemporary Ergonomics 2009*, CRC Press, London, UK,

Stone, S., Wilson, B., Wroot, A., Halligan, P., Lange, L., Marshall, J., & Greenwood, R. (1991). The assessment of visuo-spatial neglect after acute stroke. *Journal of Neurology, Neurosurgery & Psychiatry, 54*(4), 345-350. http://dx.doi.org/10.1136/jnnp.54.4.345

Strong, K., Mathers, C., & Bonita, R. (2007). Preventing stroke: saving lives around the world. *The Lancet Neurology, 6*(2), 182-187. http://dx.doi.org/10.1016/S1474-4422(07)70031-5

Swanson, J. (2005). The Delis-Kaplan Executive Function System: A review. *Canadian Journal of School Psychology, 20*(1/2), 117-128. http://dx.doi.org/10.1177/0829573506295469

van Swieten, J. C., Koudstaal, P. J., Visser, M. C., Schouten, H. J., & van Gijn, J. (1988). Interobserver agreement for the assessment of handicap in stroke patients. *Stroke, 19*(5), 604-607. http://dx.doi.org/10.1161/01.str.19.5.604

Vogel, K. (2003). A comparison of headway and time to collision as safety indicators. *Accident Analysis & Prevention, 35*(3), 427-433. http://dx.doi.org/http://dx.doi.org/10.1016/S0001-4575(02)00022-2

Wechsler, D. (2008). *Wechsler Adult Intelligence Scale–Fourth Edition (WAIS–IV)*. San Antonio, Texas, USA: NCS Pearson.

Wolf, T. J., & Rognstad, M. C. (2013). Changes in cognition following mild stroke. *Neuropsychological Rehabilitation, 23*(2), 256-266. http://dx.doi.org/10.1080/09602011.2012.748672

Chapter Five: Investigating cognitive ability and self-reported driving performance of post-stroke adults in a driving simulator

Chapter Outline and Rationale

The purpose of this chapter was to further address objectives one (assess the relationship between deficits in cognition, executive function and driving behaviour in post-stroke drivers and non-stroke drivers) and three (assess the off-road driving performance of post-stroke drivers compared with the performance of healthy controls), and start addressing objectives five (compare the perceived level of task demand involved in different driving scenarios in post-stroke drivers to that of a comparison group of healthy controls), six (assess self-perception of driving behaviour and observed driving behaviour (calibration) and how it relates to cognition) and seven (assess compensation strategies for deficits in cognition that enable driving in post-stroke adults). This chapter also bridges the findings reported in Chapter Four and Chapter Six by beginning the investigation into task demand, calibration and driving performance, as assessed in an off-road repeatable environment (i.e., a driving simulator). Finally, this chapter further develops the findings reported in Chapter Four by investigating the relationship between driving performance, task demand and calibration with attention and executive function

The chapter is written as a manuscript, however it is formatted in line with the rest of the thesis, and outlines the background to the study, the methodologies used and the results. The chapter concludes with discussing how attention, executive function, task demand and calibration as assessed in a driving simulator may be useful for assessment and training of recently diagnosed post-stroke drivers who wish to return to driving.

Abstract

Safe driving is a highly complex metacognitive activity that requires calibration, i.e., the ability of the driver to accurately assess the level of task demand required to complete a task alongside an accurate evaluation of their own capabilities. There is much debate on the ability of post-stroke drivers to reliably and accurately assess and calibrate their own driving performance. Therefore, the aim of this study was to assess cognition, self-rated performance and estimations of task demand in a driving simulator with post-stroke drivers compared to a control group of similar age older drivers. Two groups were observed driving in two scenarios in a driving simulator and asked to complete the NASA Task Load Index Form following each scenario. Participants also completed a battery of psychometric tasks to assess cognition. Results suggested that there was no difference in the amount of task demand required to complete the driving task, and despite impairments in cognitive ability the post-stroke drivers were no-more likely than controls to be over-estimators when providing driving self-assessments. On-average, the post-stroke drivers rated themselves more poorly than the controls and this rating was related to cognitive ability. This study suggests that post-stroke drivers may be more aware of their deficits and adjust their driving behaviour more than previously thought. Furthermore, using self-performance and evaluation measurements alongside cognitive assessments and a driving simulator may provide complementary fitness-to-drive assessment and rehabilitation tools during post-stroke recovery.

Keywords: Attention, Australia, Calibration, Cognition, Executive Function, Task Demand

Introduction

Currently in Australia, returning to driving using a private vehicle license after a cerebrovascular accident (stroke) requires the affected person to wait a minimum of between two – four weeks following the stroke (Austroads & National Transport Commision Australia, 2016). This time can be significantly longer depending on the type and severity (Austroads & National Transport Commision Australia, 2016). It is also a requirement that all post-stroke adults inform the relevant state transport licensing authority of their stroke and obtain medical clearance prior to driving on the road (Austroads & National Transport Commision Australia, 2016). If the medical professional believes it necessary, the post-stroke adult may be required to attend a driving assessment or undertake further rehabilitation before returning to driving. These driving assessments normally consist of an on-road and off road assessment (Austroads & National Transport Commision Australia, 2016; Murie-Fernandez, Iturralde, Cenoz, Casado, & Teasell, 2014), however post-stroke drivers' experiences of return-to-driving assessments vary (Lister, 1999) and the guidelines available to medical professionals are limited (Murie-Fernandez et al., 2014).

As driving a is complex metacognitive and physical activity of daily living (Anstey, Wood, Lord, & Walker, 2005; Dickerson, Reistetter, Davis, & Monahan, 2011), the off-road assessment is normally comprised of a selection of cognitive tasks, reaction time tasks and physical ability tasks (Dickerson et al., 2011; Murie-Fernandez et al., 2014). Performance on these tasks provides the assessor with an indication of the post-stroke adults' on-road driving capability; however, often from the point of view of the post-stroke adult, the assessments are seen to be both novel and unfamiliar (McKay, 2007). Furthermore, it can be difficult for clients to understand the link between these assessments and on-road driving performance (McKay, 2007). Client awareness of their own deficits and the subsequent estimation of performance is vital for successful rehabilitation, otherwise it is difficult to improve upon an unseen and poorly understood problem (McKay, Rapport, Bryer, & Casey, 2011). Accurate self-assessment, as well as accurate estimation of the level of demand required to complete a driving task is important for the safety of the driver and road users. This is because reliable self-perception and evaluation results in improved driver calibration (Fuller, 2005; Heikkilä, Korpelainen, Turkka, Kallanranta, & Summala, 1999).

Driver calibration is ability of the driver to accurately assess the level of demand required for a task, alongside accurately evaluating their own ability to adjust the level of demand (i.e., the necessary amount of cognitive resources) required for the driving task to be manageable (Horrey, Lesch, Mistopolous-Rubens, & Lee, 2015). For example, increased difficulty with driving at night will result in a person self-regulating their driving to avoid driving during these times or reducing their speed when driving to compensate for slower processing speed (Baldock, Mathias, McLean, & Berndt, 2006). Thus, inaccurate self-assessment of performance ability can result in driving calibration errors (Fuller, 2005; Horrey et al., 2015). These errors become problematic if they result in drivers overrating their performance and therefore overestimating their abilities, leading to drivers taking increased risks on the road through exposure to situations they are unable to manage. Alternatively, drivers may underrate their abilities, which may lead to premature cessation of driving (Fuller, 2005) and can cause increased depression and reduced quality of life (Fonda, Wallace, & Herzog, 2001; Marottoli, Mendes de Leon, Glass, & Williams, 1997; Ragland, Satariano, & MacLeod, 2005).

There is much debate with varied conclusions on the ability of post-stroke drivers to reliably and accurately assess their own driving performance. Previous research has suggested that alongside post-stroke drivers taking greater risks on the road (Heikkilä et al., 1999), they generally over-estimate their driving performance (Heikkilä et al., 1999; Scott et al., 2009) or alternatively that there is no relation between self-rated performance and actual performance (e.g., Blane, Falkmer, Lee, Parsons, & Lee, 2016; Riendeau, Maxwell, Patterson, Weaver, & Bédard, 2016). However, it has also been suggested that older adults, regardless of the presence of a pathology, are unreliable when rating their own driving performance (Crizzle, Myers, & Almeida, 2013; Scott et al., 2009). Yet, research by Blane, Lee, Falkmer, and Dukic Willstrand (under review), found that post-stroke drivers, when compared to healthy matched controls were no more likely to overestimate their driving performance. Similarly, the self-assessed driving ratings in post-stroke adults have been found to correlate with the ratings assigned to them by a nominated proxy (Stapleton, Connolly, & O'Neill, 2012). Although some post-stroke adults have a tendency to overestimate their capacity to perform everyday activities, awareness of deficits and improvements in self-estimation can be improved using targeted rehabilitation techniques (Hartman-Maeir, Soroker, Oman, & Katz, 2003).

On-road assessments remain the ‘gold standard’ for driving assessments, however they are expensive, time consuming and stressful for the client (Lee, Cameron, & Lee, 2003; Lee & Lee, 2005). Therefore there is much debate on the use of simulators for driving assessments and rehabilitation (Stedmon, Young, & Hasseldine, 2009), particularly regarding the ability to predict on-road performance. The research is conflicted with some driving simulator research suggesting no correlation with crash risk (Kotterba, Widdig, Brylak, & Orth, 2005) or on-road classification (Lundqvist, Gerdle, & Rönnberg, 2000), however other studies report the opposite with simulators predicting both crash risk (Lee & Lee, 2005) and on-road performance in older drivers, as well as those with pathologies (e.g., brain injured patients (Lew et al., 2005)).

Despite these inconsistencies, a strong argument remains for using driving simulators in training and rehabilitation, as they provide a safe, replicable environment (Bédard, Parkkari, Weaver, Riendeau, & Dahlquist, 2010; Stedmon et al., 2009) with the added benefit of reporting immediate feedback (McKay, 2007). Driving simulators have previously been implemented as training and rehabilitation tools with mixed results (Pollatsek, Vlakveld, Kappé, Pradhan, & Fisher, 2011). Research in the post-stroke domain has focussed on unlicensed post-stroke drivers and similarly, when assessing driving calibration in driving simulators. Discrepancies in the results may stem from the use of unlicensed drivers without first assessing licensed drivers as a baseline to determine the usefulness of the assessments. Therefore, the aim of this research was to assess self-rated performance and estimations of task demand in a driving simulator in post-stroke drivers and age matched controls. Further aims of the study were to investigate self-rated performance and task demand in relation to driving simulator performance and cognitive performance.

Method

Design

A quasi-experimental comparison group design was used to assess the differences between community dwelling post-stroke drivers and a control group consisting of adults of the same age and gender matched at group level.

Participants

To be included in the study, all participants had to hold a driver's licence valid within Australia, have at least one year of overall driving experience, and drive at least twice a week. Further criteria for the post-stroke group were that they had previously been diagnosed with a stroke (either ischemic, haemorrhagic or a transient ischemic attack) and had been cleared to drive by a medical professional. Group selection was based on self-reported data, however medical records provided by the participant were sighted when possible. Participants were excluded if they had been diagnosed with hemianopia, any neurodegenerative disease, such as Parkinson's disease or dementia and if they required a wheelchair for mobility. One participant was excluded from the study based on a post-assessment notification of a fontal-lobe dementia diagnosis.

Participants were recruited and assessed between April 2015 and March 2016. Recruitment of both participant groups was achieved using purposive sampling techniques, including speaking at local community and post-stroke support groups, advertisements placed in community halls, advertising through local driving support organisations, community newspapers and local radio stations.

The total sample consisted of 82 participants and included 40 post-stroke drivers (male = 32) and 42 controls (male = 35). The mean age for the post-stroke group was 66 years (SD = 9), with the ages ranging from 37 – 81 years. The mean age for the controls was 67 years (SD = 8) with the ages ranging from 49 – 81 years. Driving exposure was reported as annual millage with post-stroke drivers reporting slightly more kilometres per year than controls i.e., 16,512km (SD = 12,946km) and 15,341 (SD=8,066km) respectively. There were no statistically significant differences between groups for age, gender distribution, licence length or driving exposure, therefore based on previously researched driving criteria (Evans, 2004), both groups were considered well-matched.

Measurements

Self-estimation of performance and task demand in the driving simulator. Self-estimation of task demand and self-rated performance were assessed using the NASA Task Load Index (TLX; Hart & Staveland, 1988). The TLX is a paper-based self-report questionnaire that assessed the participants' perceived amount of effort required on six different levels: mental demand, physical demand, temporal demand, performance, effort and frustration. Each level is presented as a 21 point Likert scale and participants were asked to rate their perceived level of workload and performance by drawing a circle or cross on the appropriate level on the scale. The TLX has been shown to be reliable and valid (Rubio, Diaz, Martin, & Puente, 2004) and has previously been utilised in driving research with older age groups (Bunce, Young, Blane, & Khugputh, 2012; Young & Stanton, 2004) and in drivers with cerebral lesions (Lundqvist et al., 1997).

Driving simulator

Driving performance was assessed using the Curtin University, School of Occupational Therapy, STISIM Driving Simulator. The simulator is a fixed-base car driving simulator that has mid-level physical fidelity and consists of a driving console with three ASUS display screens (Figure 14), onto which the forward facing and peripheral driving scenes are displayed. The driving console is made up of an adjustable sedan style seat, a fully functioning steering wheel and a fully-interactive pedal block consisting of clutch, acceleration and brake pedals. To accommodate all participants, including those post-stroke drivers with adaptive steering control vehicles, the acceleration function was programmed as either the right-hand side pedal (as in traditional cars) or the left-hand side pedal (traditionally the clutch pedal) and had the option of a spinmaster quick release steering spinner knob that was used as required to assist the post-stroke adults with reduced upper limb function. The simulator was configured for automatic transmission and provided driving related auditory feedback, such as traffic and engine noise. The simulator has previously been validated for use on older adults (Lee, Lee, & Cameron, 2003) and has good reported transference to real-world driving performance (Devos et al., 2009).

Figure 14. The Curtin University STISIM Driving Simulator

Driving scenarios

Two driving scenarios were programmed using the STISIM© driving software (Allen, Stein, Aponso, Rosenthal, & Hogue, 1990). These consisted of a lead-car scenario and a hazard perception (HP) scenario. The scenarios involved various traffic-based events to test the participants' driving performance, hazard perception skills, and knowledge of road rules and regulations. The scenarios were dressed to include other road users (cyclists, pedestrians, cars etc.), traffic lights, intersections and stop-signs. A 10 minute practice scenario that involved a dual-lane road was utilised for each participant, in order familiarise them with the driving console controls and visual stimuli.

The lead-car scenario consisted of a two-lane urban-residential road (i.e., one lane in each direction, with no median lane partition), which was 4.5 km and took approximately five minutes to complete. Once the participant had driven 500m, a blue Subaru sedan car appeared in the lane 180m in front of them, travelling at 60km per hour. Participants were instructed to maintain a safe and comfortable distance behind the lead-car. Unknown to the participant, the lead-car was programmed to maintain its speed without variation. The road was completely straight although the horizontal elevation of the road varied throughout the run, causing participants to vary the amount of power required to maintain the distance between them and the lead vehicle. There was no other traffic in the driver's lane, although there was traffic in the opposing direction provide a more realistic transport environment.

The HP scenario consisted of a four lane dual-carriageway (two lanes in each direction with a median lane partition) set within an urban-city environment. The road was 7.9km long, the speed limit 60km an hour and the scenario took between 10 – 15 minutes to complete. The scenario included several hazards, to which the participants had to perceive and respond accordingly to avoid a crash and to complete the drive. These included right turns, traffic lights, pedestrians, cyclists, other vehicles and roadworks. An emergency stop-style task was also implemented as part of the scenario in order to assess braking reaction and stopping times.

Performance in driving simulator

There were a number of variables recorded to assess driving performance. For the lead-car scenario, the variables included both the mean speed and mean headway (defined as distance to the car in front), as well as a recording of the moment to moment (2Hz) measurement of speed (speed variability), lateral lane position (LLP variability), and steering input (steering variability). As part of the hazard perception scenario, the variables included: simulator speed variability and LLP variability, as well as the mean braking reaction time, braking total stopping time, braking distance from reaction and total braking distance. The total number of crashes and speed exceedances were recorded for both scenarios. In the event a crash occurred, participants were instructed to wait until the cracked screen graphic that indicated the crash disappeared before continuing driving.

Calculating the moment-to-moment instability of each driving dependent variable (headway, speed, lateral lane position, steering input) consisted of performing a standard error regression with each driving variable listed as the dependent variable and the time recorded in 0.5 second increments as the independent variable. This technique was used to provide a collated moment-to-moment measure of instability consisting of residuals for the target driving variable (Bloomfield & Carroll, 1996). This process of calculating the residual data to be used as a dependent variable in the final analysis was conducted using a Microsoft Excel©-based macro, programmed using Visual Basic for Applications (Microsoft Office, 2010).

All participants completed the lead-car scenario, however a number of participants did not complete the hazard perception scenario for reasons including time-restrictions on participation day or the onset of simulator sickness. Specifically, 32 participants failed to complete the emergency stop task either due to the onset of simulator sickness (11 controls, 11 post-stroke), limited time availability of the participant (four controls and one post-stroke driver) or failure to stop within the allocated time (three controls, two post-stroke drivers).

Cognitive Measures

A battery of cognitive measures were utilised to assess executive function, processing speed, divided and selective attention.

Executive Function

Executive function was assessed using the Delis-Kaplan Trail Making Task© (Delis, Kaplan, & Kramer, 2001). The task included five components tasks that individually assessed different levels of cognition. Task one was a visual cancellation whereas tasks, two, three and five comprised of several connect the circle tasks, which were used to provide a baseline performance score of key components of cognition used within executive function, specifically: visual scanning, number sequencing, letter sequencing, and motor speed (Swanson, 2005). Task four was a number-letter switching task, which was used to assess executive function, specifically through assessing visuospatial thought flexibility (Swanson, 2005). Each task was paper-based and participants were timed to completion. The total time taken for each task was recorded and in order to control for the baseline functions represented in tasks one to three and five, contrast scores were calculated (Delis et al., 2001). The raw time-to-completion scores were scaled, in order to account for age effects (Delis et al., 2001). The tests have previously been used to assess cognitive performance in post-stroke participants, as well as being found to be sensitive to cognitive decline, particularly in frontal lobe function (Homack, Lee, & Riccio, 2005; Wolf & Rognstad, 2013).

Attention

Vision and attention, which can be impaired in post-stroke adults, are highly important to driving safely (Fisk, Owsley, & Mennemeier, 2002). Divided attention and selective attention were assessed using the Useful Field of View© task (UFOV) (Ball & Owsley, 1993). The UFOV, often used with post-stroke driving research, was presented using a Windows 7™ desktop and a 5:3 ratio screen (Fisk et al., 2002; George & Crotty, 2010). The UFOV requires the completion of three tasks that have been built on top of each other. The first assessed processing speed by asking participants to accurately name an object (either a car or truck) that is displayed on screen for varying amounts of time. The second task measured divided attention and required participants to accurately describe the periphery location of a second object whilst naming the object (i.e., a car or truck) in the centre of the screen, as in the first task.

The third task measured selective attention and followed the same procedure as the second task, however distractor triangles were also displayed on screen, requiring the participant to distinguish the appropriate information (i.e., distinguish the location of the second object in the periphery and name the primary object in the centre of the screen) from the display as quickly and accurately as possible. During each task, the objects are displayed for a range of durations (from 13.7ms – 500ms). The final score for each participant consisted of the fastest time the participant could accurately identify the object and location. Lower scores on the three subscales are indicative of better performance (Selander, Lee, Johansson, & Falkmer, 2011).

Data Collection and Procedure

Participants were given a participant information sheet and given the opportunity to ask questions before providing their informed consent. Once consent was given, participants were screened for minimum visual acuity within WA using the precision vision ETDRS visual acuity chart. Participants were then either allocated to the driving simulator or cognitive tasks first. The order of completion for the cognitive tasks was randomised for each participant using a Latin squares method. Participants completed the NASA TLX after both the lead-car scenario and the HP scenario in the driving simulator. The overall process took approximately 1.5 hours.

Statistical Analysis. Prior to analysis, all data were loaded, cleaned and checked using Microsoft Excel©. Data were then loaded into SPSS v22.0 (IBM Corporation, 2013) for analysis. Descriptive and univariate statistics were used to report the demographics of each group. Normality for all continuous data were assessed using histograms, boxplots, normal Q-Q plots, skewness and kurtosis, prior to calculating between groups descriptive data. A box-cox transformation was conducted on the UFOV data, DKEFS data, NASA TLX self-rated performance, lead-car steering input data and lead-car headway variability data to improve normality. Between groups analysis of the normally distributed cognitive data were analysed using an independent samples t-test. Between groups analysis of continuous non-normally distributed data (DKEFS TMT EF4, simulator braking tasks, HP LLP, HP speed) was analysed using a Mann-Whitney U-test.

Further analysis employed the use of general linear regression on the self-rated performance variable to identify whether any differences in cognition accounted for differences in self-rated driving performance.

The standardised difference value was calculated for cognitive variables and variation in performance simulator variables. For 40 participants in the smallest group, the standardised difference value was calculated as 0.63, with an α-level of 0.05 and a $1- \beta = 0.8$ (Cohen, 1988). For the braking reaction time task, due to significant drop out there were 21 participants in the smallest group, therefore the standardised difference value was calculated as 0.51, with an α-level of 0.05 and a 1-

$\beta = 0.8$ (Cohen, 1988). A p-value of <0.05 was taken to indicate a statistically significant association in all tests.

Ethical Considerations

This study and the associated protocols were approved by the Curtin University Human Research Ethics Committee – approval number: HR206-2014 and conformed to the principles of the Declaration of Helsinki. Participants were presented with an information sheet, given the opportunity to ask questions and each provided signed informed consent prior to participation. Participants were also informed that they could withdraw from the study at any time without the concern of incurring any negative consequences. Participants were offered a gift voucher worth $15 as thanks for their time and participation.

Results

Self-rated driving performance and task demand

In the lead-car scenario and the HP scenario, there were no significant differences between the post-stroke and comparison groups for the self-rated mental demand, physical demand, temporal demand, effort or frustration (Figures 15 -16). Also in both scenarios, when asked to rate their performance, the post-stroke drivers consistently and significantly rated themselves lower than the comparison group (Table 19).

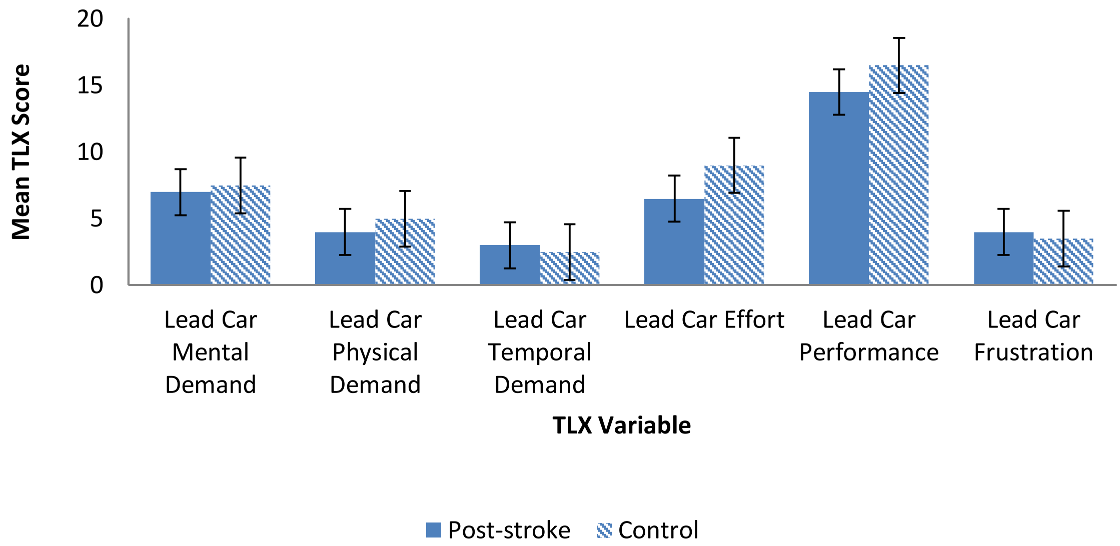

Figure 15. The mean self-rated score for both the post-stroke and comparison group on all TLX variables in lead-car scenario.

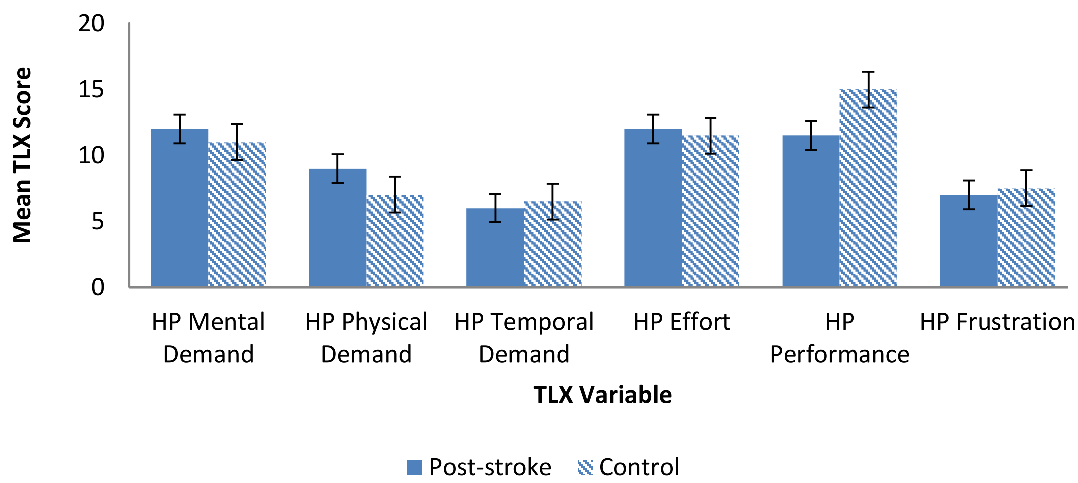

Figure 16. The mean self-rated score for both the post-stroke and comparison group on all TLX variables in the HP scenario.

Table 19.

Between groups analysis of self-rated simulator performance

Variables	Post-Stroke Driver			Controls			t-value	df	p-value
	n	Mean	SD	n	Mean	SD			
TLX – Lead-car Performance	40	14.48	4.46	42	16.26	3.60	-2.13	80	0.04*
TLX – HP Performance	35	11.38	4.56	39	14.88	3.98	-3.59	72	0.001**

*Significant data; p-value <0.05

*Significant data; p-value <0.001

Performance in driving simulator

Overall, in the lead-car scenario, the post-stroke drivers and the comparison group performed similarly with no significant differences observed. On-average the post-stroke drivers drove slower than the controls, however this difference was non-significant at group level and the amount of variation in vehicle speed, lateral lane and the amount of steering wheel input was also comparable in both groups (Table 20). Despite the lack of significant between group differences, on-average the post-stroke drivers maintained a greater distance between themselves and the lead-car than the control group. The post-stroke drivers also exhibited less variability in headway than the comparison group.

In the HP scenario there were no between group differences in braking reaction time in the lateral lane position, total braking time to stop, total braking distance, braking time to react or braking distance from reaction (Table 21). Despite there being no significant difference in reaction time when responding to the emergency stop stimulus, on-average the post-stroke drivers were slower in time and distance to stop the vehicle.

Table 20.

Between groups analysis of lead-car scenario variables

Variable	Post-Stroke Driver			Controls			df	t-value	p-value
	n	Mean	SD	n	Mean	SD			
Mean Speed	40	55.36	2.42	43	56.19	1.96	75	-1.71	0.09
Speed Variability	40	8.88	1.70	43	8.41	1.14	81	1.49	0.14
Headway	40	1.05	1.12	43	1.71	1.36	81	-2.44	0.02*
Lateral Lane Position	40	0.73	0.39	43	0.64	0.35	81	1.18	0.24
Steering Input	40	1.49	1.02	43	1.13	0.66	81	1.68	0.09
	n	Median	IQR	n	Median	IQR			p-value
Mean Headway	40	3.99	3.34	43	3.82	1.13			0.09

* p-value <0.05

Table 21.

Between groups analysis of HP scenario simulator variables

Variable	Post-Stroke Driver			Controls					p-value
	n	Median	IQR	n	Median	IQR			
HP Speed Variability	30	4.89	0.90	36	4.83	0.60			0.89
Braking Total Time to Stop	21	3.61	1.18	26	3.34	1.29			0.27
Braking Distance from Reaction	21	27.23	10.89	26	24.65	16.06			0.18
Total Breaking Distance	21	45.43	13.15	26	40.18	23.39			0.30
	n	Mean	SD	n	Mean	SD	t-value	df	p-value
Braking Reaction Time	21	1.07	0.32	26	1.05	0.27	0.25	45	0.79

Overall, there were 11 accidents observed in the HP scenario (Figure 17). Although non-significant, the post-stroke adults were less likely to have a crash than the comparison group with the latter hitting other vehicles (collisions) and pedestrians (pedestrian hits) more often. Only one post-stroke adult had an off-road crash that indicated they had steered too far off the specified road and one post-stroke participant had two collisions. Two control participants hit a pedestrian and had one and two collisions respectively; and seven other control participants either hit a pedestrian or had a collision.

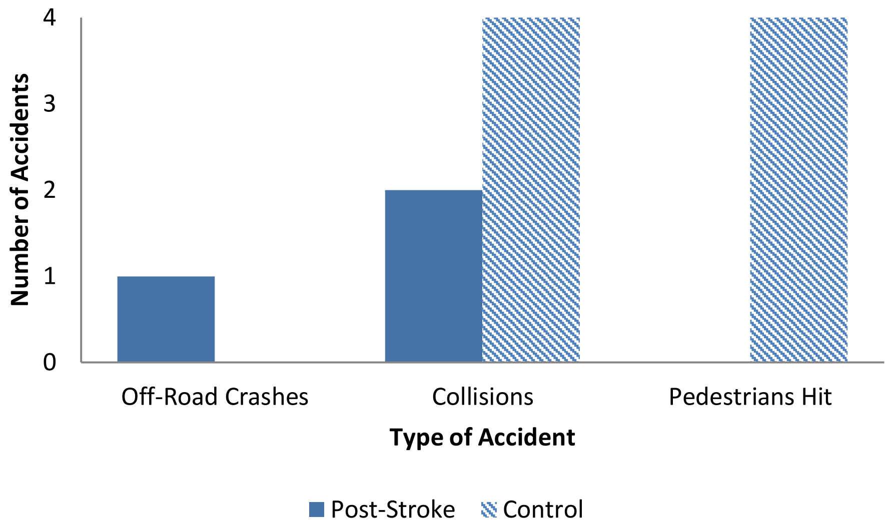

Figure 17. The total and type of crashes exhibited in hazard perception scenario by the post-stroke and comparison group

Association between self-rated performance and simulator performance

In the lead-car scenario, there was no correlation between self-rated performance and simulator performance in either group. In the HP scenario, there was a weak, but significant, negative correlation between the number of collisions with other vehicles and self-rated performance (Table 22), however there were also several participants, particularly in the post-stroke group, who rated themselves as poorer performing despite no collisions. No other correlations existed between self-rated performance and observed simulator driving performance in the HP scenario (Table 22).

Table 22.

Correlation coefficients for self-rated HP performance and HP performance variables

Variable	N	Correlation Coefficient	Sig. (2-tailed)
Speed	64	0.056	0.663
LLP	64	-0.245	0.051
Off-Road Crashes	64	-0.075	0.555
Collisions	64	-.256*	0.041
Pedestrians hit	64	0.077	0.545
Total Crashes	64	-0.183	0.147
Braking Total Time to Stop	47	-0.002	0.99
Braking Distance from Reaction	47	-0.015	0.923
Total Braking Distance	47	0.051	0.734
Braking Time to React	47	0.037¥	0.806

¥ - Pearson Correlation

* p-value <0.05

Cognitive performance

When assessed for cognitive ability, there were differences between the post-stroke and comparison groups. In the attention and executive function tasks, the post-stroke adults exhibited poorer performance than the comparison group as displayed by a higher mean score in the selective attention and divided attention UFOV tasks and lower mean scores in all D-KEFS TMT tasks (Table 23).

Table 23.

Between groups analysis of variables assessing and attention (UFOV) and executive function (D-KEFS trail making task)

Variables	Post-Stroke Driver			Controls			t-value	df	p-value
	n	Mean	SD	n	Mean	SD			
UFOV subtest 3	38	143.04	108.24	41	90.13	50.70	2.53	77.0	0.01*
UFOV subtest 2	38	80.23	108.93	42	36.29	38.84	2.03	78.	0.04*
DKEFS TMT 1	40	7.48	3.56	43	10.90	2.17	-5.26	63.6	0.001**
DKEFS TMT 2	40	9.20	3.69	43	11.47	3.01	-3.07	81.0	0.003*
DKEFS TMT 3	40	8.56	3.95	43	11.72	2.57	-4.30	66.1	0.001**
DKEFS TMT 4	40	8.3	4.36	43	11.65	2.35	-4.32	58.9	0.001**
DKEFS TMT 5	40	9.48	3.20	43	12.02	1.71	-4.48	58.7	0.001**
	n	Median	IQR	n	Median	IQR			p-value
UFOV subtest 1	38	13.75	0.10	42	13.8	0.10			0.98
DKEFS EF 4	40	1.0	2.50	43	1.00	0.001			0.02*

* p-value <0.05

** p-value <0.001

Cognitive performance as an explanation of between groups differences in the relationship between self-reported and actual performance

Lead-car scenario. Simulator performance was not found to account for between group differences in self-rated simulator performance in the lead-car scenario. When assessed with cognitive ability, only the D-KEFS TMT EF4 score accounted for any difference (Table 24). A small positive relationship between executive function and simulator performance was observed suggesting that as executive function performance increased, self-rated performance also increased.

Table 24.

General linear model assessing relationship of executive function with self-rated simulator lead-car driving performance (TLX performance score as dependent variable)

	Unstandardised coefficients		95% CI		p-value	Adjusted R^2
	B	SE	Lower Bound	Upper Bound		
Intercept	165.39	30.80	104.09	226.68	0.001**	
DKEFS EF 4	6.25	2.87	0.53	11.97	0.03*	0.04

* p-value <0.05

** p-value <0.001

HP scenario. In the HP scenario, as the more demanding scenario, there were some association with actual performance. The number of collisions committed partially accounted for the between group variance in self-rated performance (p=0.02, adjusted R^2 = 14%), however collisions were a rare event so the cognitive variables were also analysed as independent variables. The results indicated that the number of collisions across both groups along with selective attention in the post-stroke group accounted for 31% of the variance in self-rated performance in the HP scenario (Table 25). In the post-stroke group, as selective attention performance declined, self-rated performance declined, and, as number of collisions inclined, the level of self-rated performance declined in both groups.

Table 25.

General linear model assessing relationship of cognition with self-rated simulator hazard perception driving performance (TLX performance score as dependent variable)

	Unstandardised coefficients		95% CI		p-value	Adjusted R^2
	B	SE	Lower Bound	Upper Bound		
Intercept	23.46	3.43	16.58	30.34	0.001**	
Collisions	-6.79	2.20	-11.20	-2.37	0.003*	
Post-stroke x Selective Attention	-0.78	0.38	-1.54	-0.02	0.04*	
Control x Selective Attention	0.07	0.45	-0.82	0.97	0.87	31.3

* p-value <0.05

** p-value <0.001

Discussion

Summary of findings

The first and second aims of this study were to investigate the self-rated performance of post-stroke adults and controls in a driving simulation setting, as well as the influence of cognitive ability on the results. Despite little difference in actual driving performance, in both the simple lead-car scenario and the more demanding HP scenario, the post-stroke drivers rated themselves more poorly performing than their control group counterparts. Similar to previous research (e.g., Blane et al., 2016; Riendeau et al., 2016), there was no correlation in self-rated performance and actual driving performance in the simple lead-car scenario. Further analyses found that differences in self-rated performance were partially explained by variations in executive function, which suggested that in both groups, those with a higher scores in executive function tended to rate themselves as better performing in the driving task. In the more complex HP scenario, the number of collisions was associated with self-rated performance, with the small number of participants who had a collision with another vehicle, rating themselves as poorly performing. Interestingly, it was only the collisions with other vehicles, rather than any other type of crash, that was associated with poorer self-rated performance,. The number of pedestrians hit (zero in the post-stroke group, three in the control group) was not correlated with self-rated performance; however this may be a reflection of the participants' view of simulator fidelity (Ranney, 2011). As collisions were a rare event and more frequent in the control group, further analysis investigating the influence of cognitive deficits suggested that variations in selective attention in the post-stroke group in addition to the occurrence of a collision, explained the variance in the HP scenario. This suggests that those in the post-stroke group, who had higher performing scores on the selective attention tasks, were more likely to report themselves as better performing and vice versa. Taken together, these results may suggest that contrary to previous research (e.g., Lundqvist & Alinder, 2007), post-stroke adults are no more likely than controls to be over-estimators of their own ability, and have capacity for insight into their own performance. It is possible that this difference in results is due to the use of licensed post-stroke drivers, compared to non-drivers (Blane, Lee, Falkmer, & Dukic Willstrand, 2017), therefore these results may be viewed as a baseline for post-recovery.

The third aim of this study was to assess task demand in the driving simulator tasks. There was no between group difference in any form of task demand, which suggests that, similar levels of mental, physical and temporal demand, as well as similar amounts of frustration and effort were experienced by both groups. When viewed alongside the results that the post-stroke drivers scored more poorly in the attention and executive function tasks, which are known to be involved in driving (Anstey et al., 2005) the similarities in task demand and the similarities in levels of performance suggest that post-stroke adults must have some sort of awareness of their deficits to be able to employ compensatory behaviours, as suggested by the task capability model of Fuller (2005) and discussed in (Blane, Lee, Falkmer, & Dukic Willstrand, under review). This behaviour can be seen in the lead-car scenario, whereby the post-stroke drivers maintained on average a larger gap between themselves and the lead-car, and also were more consistent in their gap-keeping. This further suggests that the participants were aware of their deficits in these area and both amended their behaviour and ratings accordingly to compensate for level of task demand. These results have important implications for self-regulatory behaviour, which becomes an increasingly prominent compensatory strategy as drivers age (Gwyther & Holland, 2012). Specifically, understanding the mechanisms for self-rated performance and subsequent self-regulation is important as errors in calibration can provide greater risks to the driver and other road users (Fuller, 2005; Horrey et al., 2015).

As it is easier to objectively assess performance variables in a driving simulator, using off-road measures including cognitive tasks, a driving simulator and assessing the ability for calibration using self-performance measures may provide a useful means of assessment and rehabilitation post-stroke.

Limitations

The aim of the study was to investigate differences in self-rated performance, however there was no pass or fail element to the driving testing involved in the driving simulator, which can make it difficult to determine the accuracy of self-assessed performance. The driving performance variables differed between scenarios as moment-to-moment stability is difficult to determine when there are hazards and variations to the driving line, therefore only speed variation was calculated. Despite this, the driving performance results between both groups were comparably similar and reflected the fact that all participants were licensed drivers and therefore were of a sufficient standard to drive safely.

An assumption of the current research is that stroke status has influenced the presence of risk-taking behaviour. It is difficult and ethically questionable to determine whether the drivers were over- or under-estimators of their performance. It is possible to ask the participants how they feel that they have differed in their estimator status, however this is also subject to social desirability effects. Future research may consider assessing participants perception of change in estimation status, however it was considered beyond the scope of data for this study.

Although the sample size in this study has reasonable statistical power for between groups analysis, there was drop out in in the data due to simulator sickness, which is common in simulator research, particularly in the older population (Stoner, Fisher, & Mollenhauer, 2011). This was evident in the hazard perception scenario where the attrition rate rose, which increased the possibility for a type-II error and therefore the results should be interpreted with caution. Similarly, the R^2 values, particularly in the baseline regression, although significant are small, suggesting that further research is required to verify the finding, as well as to identify other factors affecting self-rated performance, e.g., working memory, visual acuity, global cognition, perception (Marshall et al., 2007), impulsivity (Cheng & Lee, 2012), driver confidence (McNamara, Walker, Ratcliffe, & George, 2014), age or gender (Gwyther & Holland, 2012).

As part of this research, multiple comparisons were applied which can cause statistical inflation of error rates, particularly when measuring variables assessing similar constructs. Were Bonferroni's adjustment to be applied, the results of much of the DKEFS data would remain the same, the UFOV 3 would remain significant and the UFOV 2 would become non-significant. These changes would not change the results or interpretation. Were Bonferroni's correction to be applied to the driving correlations, the statistical difference would be negated. However, with regard to the correlations, the rho and r values were considered more important than the p-values for interpretation.

As the aim of the study was to assess differences between post-stroke adults and controls in self-rated performance, similarity in the driving situations needed to be ensured. Consistency was achieved using a previously validated driving simulator. However, as with all driving simulator research, participants are aware that they are not driving on the road and that there are limited adverse consequences of their actions. Furthermore, as the simulator was static, there was limited vestibular feedback making the car movements less realistic.

Both groups were well matched for gender, age and driving exposure, however there was a clear gender disparity in both groups, which is due to the self-selection method of recruitment and a reflection of the propensity for older females to reduce the amount they drive (Siren, Hakamies-Blomqvist, & Lindeman, 2004). Further research with a larger and more evenly distributed sample size will help clarify.

Conclusion

This study suggests that despite impairments in cognitive ability, post-stroke drivers are no-more likely than controls to be over-estimators when providing driving self-assessments. Indeed, post-stroke drivers may be more conservative in their self-evaluation, and reported no differences in task demand that arguably relates to an awareness of their own cognitive deficits. Overall, this suggests that those licensed post-stroke drivers have the capability to safely regulate their own behaviour to compensate for cognitive deficits. Using self-performance and evaluation measurements alongside cognitive assessments and a driving simulator may provide complementary fitness-to-drive assessment and rehabilitation tools during post-stroke recovery.

Chapter Summary and Progression

This chapter has discussed post-stroke driver behaviour in a driving simulator and explored the relationship with calibration, task demand, self-rated rated performance and cognition. The proceeding section will further explore this themes on-road.

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Chapter Five References

Allen, R. W., Stein, C. A., Aponso, B. L., Rosenthal, T. J., & Hogue, J. R. (1990). *A low cost, part task driving simulator based on microcomputer technology.* Paper presented at the 69th Annual Meeting of the Transportation Research Board., Washington, DC.

Anstey, K. J., Wood, J., Lord, S., & Walker, J. G. (2005). Cognitive, sensory and physical factors enabling driving safety in older adults. *Clinical Psychology Review, 25*, 45-65. http://dx.doi.org/10.1016/j.cpr.2004.07.008

Austroads, & National Transport Commision Australia. (2016). Assessing fitness to drive for commercial and private vehicle drivers: Medical standards for licensing and clinical management guidelines., Retrieved from https://www.onlinepublications.austroads.com.au/items/AP-G56-16

Baldock, M. R. J., Mathias, J. L., McLean, A. J., & Berndt, A. (2006). Self-regulation of driving and its relationship to driving ability among older adults. *Accident Analysis & Prevention, 38*(5), 1038-1045. http://dx.doi.org/http://dx.doi.org/10.1016/j.aap.2006.04.016

Ball, K., & Owsley, C. (1993). The Useful Field of View test: A new technique for evaluating age-related declines in visual function. *Journal of the American Optometric Association, 64*(1), 71-79.

Bédard, M., Parkkari, M., Weaver, B., Riendeau, J., & Dahlquist, M. (2010). Assessment of driving performance using a simulator protocol: Validity and reproducibility. *American Journal of Occupational Therapy, 64*(2), 336-340. http://dx.doi.org/10.5014/ajot.64.2.336

Blane, A., Falkmer, T., Lee, M., Parsons, R., & Lee, H. C. (2016). The cognitive and socio-demographic influences on driving performance and driving cessation in post-stroke drivers. *Advances in Transportation Studies: An International Journal,*(38), 121-135.

Blane, A., Lee, H. C., Falkmer, T., & Dukic Willstrand, T. (2017). Assessing cognitive ability and simulator-based driving performance in post-stroke adults. *Behavioural Neurology, 2017* (Behavioural and Cognitive Effects of Cardiovascular Disease), 1-9. http://dx.doi.org/10.1155/2017/1378308

Blane, A., Lee, H. C., Falkmer, T., & Dukic Willstrand, T. (under review). Cognitive ability as a predictor of task demand and self-rated driving performance in post-stroke drivers – implications for self-regulation. *Journal of Transport and Health.*

Bloomfield, J. R., & Carroll, S. A. (1996). New measures of driving performance. In S. A. Robertson (Ed.), *Contemporary Ergonomics* (pp. 335-340). London: Taylor & Francis.

Bunce, D., Young, M. S., Blane, A., & Khugputh, P. (2012). Age and inconsistency in driving performance. *Accident Analysis & Prevention, 49*, 293-299. http://dx.doi.org/10.1016/j.aap.2012.01.001

Cheng, A. S., & Lee, H. C. (2012). Risk-taking behavior and response inhibition of commuter motorcyclists with different levels of impulsivity. *Transportation Research Part F: Traffic Psychology and Behaviour, 15*(5), 535-543. http://dx.doi.org/10.1016/j.trf.2012.05.005

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, New Jersey: L. Erlbaum Associates.

Crizzle, A. M., Myers, A. M., & Almeida, Q. J. (2013). Self-regulatory practices of drivers with Parkinson's disease: Accuracy of patient reports. *Parkinsonism & Related Disorders, 19*(2), 176-180. http://dx.doi.org/10.1016/j.parkreldis.2012.09.003

Delis, D. C., Kaplan, E., & Kramer, J. H. (2001). *Delis-Kaplan Executive Function System (D-KEFS) examiner’s manual*. San Antonio, Texas: The Psychological Corporation.

Devos, H., Akinwuntan, A. E., Nieuwboer, A., Tant, M., Truijen, S., De Wit, L., . . . De Weerdt, W. (2009). Comparison of the effect of two driving retraining programs on on-road performance after stroke. *Neurorehabilitation and*

Neural Repair, 23(7), 699-705. http://dx.doi.org/10.1177/1545968309334208

Dickerson, A. E., Reistetter, T., Davis, E. S., & Monahan, M. (2011). Evaluating driving as a valued instrumental activity of daily living. *American Journal of Occupational Therapy, 65*(1), 64-75. Retrieved from http://search.proquest.com.dbgw.lis.curtin.edu.au/docview/835030492?rfr_id=info%3Axri%2Fsid%3Aprimo

Evans, L. (2004). *Traffic safety*. Bloomfield Hills, Michigan: Science Serving Society.

Fisk, G. D., Owsley, C., & Mennemeier, M. (2002). Vision, attention, and self-reported driving behaviors in community-dwelling stroke survivors. *Archives of Physical Medicine and Rehabilitation, 83*(4), 469-477. http://dx.doi.org/10.1053/apmr.2002.31179

Fonda, S. J., Wallace, R. B., & Herzog, R. A. (2001). Changes in driving patterns and worsening depressive symptoms among older adults. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences, 56*(6), S343-S351.

Fuller, R. (2005). Towards a general theory of driver behaviour. *Accident Analysis & Prevention, 37*(3), 461-472. http://dx.doi.org/10.1016/j.aap.2004.11.003

George, S., & Crotty, M. (2010). Establishing criterion validity of the Useful Field of View assessment and Stroke Drivers' Screening Assessment: Comparison to the result of on-road assessment. *American Journal of Occupational Therapy, 64*(1), 114-122.

Gwyther, H., & Holland, C. (2012). The effect of age, gender and attitudes on self-regulation in driving. *Accident Analysis & Prevention, 45*, 19-28. http://dx.doi.org/http://dx.doi.org/10.1016/j.aap.2011.11.022

Hart, S. G., & Staveland, L. E. (1988). Development of the NASA-TLX (Task Load Index): Results of empirical and theoretical research. *Human Mental Workload, 1*(3), 139-183.

Hartman-Maeir, A., Soroker, N., Oman, S. D., & Katz, N. (2003). Awareness of disabilities in stroke rehabilitation-a clinical trial. *Disability and Rehabilitation, 25*(1), 35-44. http://dx.doi.org/10.1080/0963828021000007897

Heikkilä, V. M., Korpelainen, J., Turkka, J., Kallanranta, T., & Summala, H. (1999). Clinical evaluation of the driving ability in stroke patients. *Acta Neurologica Scandinavica, 99*(6), 349-355. http://dx.doi.org/10.1111/j.1600-0404.1999.tb07363.x

Homack, S., Lee, D., & Riccio, C. A. (2005). Test review: Delis-Kaplan Executive Function System. *Journal of Clinical and Experimental Neuropsychology, 27*(5), 599-609. http://dx.doi.org/http://dx.doi.org/10.1080/13803390490918444

Horrey, W. J., Lesch, M. F., Mistopolous-Rubens, E., & Lee, J. D. (2015). Calibration of skills and judgement in driving: Development of a conceptual framework and the implications for road safety. *Accident Analysis & Prevention, 76*, 25-33. http://dx.doi.org/http://dx.doi.org/10.1016/j.aap.2014.12.017

IBM Corporation. (2013). IBM SPSS Statistics for Windows, Version 22.0. Armonk, NY: IBM Corp.

Kotterba, S., Widdig, W., Brylak, S., & Orth, M. (2005). Driving after cerebral ischemia – a driving simulator investigation. *Wien Med Wochenschr, 155*(15), 348-353. http://dx.doi.org/10.1007/s10354-005-0191-3

Lee, H. C., Cameron, D., & Lee, A. H. (2003). Assessing the driving performance of older adult drivers: On-road versus simulated driving. *Accident Analysis & Prevention, 35*(5), 797-803. http://dx.doi.org/10.1016/S0001-4575(02)00083-0

Lee, H. C., & Lee, A. H. (2005). Identifying older drivers at risk of traffic violations by using a driving simulator: A 3-year longitudinal study. *The American Journal of Occupational Therapy, 59*(1), 97-100.

Lee, H. C., Lee, A. H., & Cameron, D. (2003). Validation of a driving simulator by measuring the visual attention skill of older adult drivers. *The American Journal of Occupational Therapy, 57*(3), 324-328. Retrieved from http://graphics.tx.ovid.com/ovftpdfs/FPDDNCLBAHJKIJ00/fs047/ovft/live/gv024/00000448/00000448-200305000-00010.pdf

Lew, H. L., Poole, J. H., Lee, E. H., Jaffe, D. L., Huang, H.-C., & Brodd, E. (2005). Predictive validity of driving-simulator assessments following traumatic brain injury: a preliminary study. *Brain Injury, 19*(3), 177-188. http://dx.doi.org/10.1080/02699050400017171

Lister, R. (1999). Loss of ability to drive following a stroke: The early experiences of three elderly people on discharge from hospital. *The British Journal of Occupational Therapy, 62*(11), 514-520. Retrieved from http://www.ingentaconnect.com/content/cot/bjot/1999/00000062/00000011/art00006

Lundqvist, A., & Alinder, J. (2007). Driving after brain injury: Self-awareness and coping at the tactical level of control. *Brain Injury, 21*(11), 1109-1117. http://dx.doi.org/10.1080/02699050701651660

Lundqvist, A., Alinder, J., Alm, H., Gerdle, B., Levander, S., & Ronnberg, J. (1997). Neuropsychological aspects of driving after brain lesion: Simulator study and on-road driving. *Applied Neuropsychology, 4*(4), 220-230. http://dx.doi.org/10.1207/s15324826an0404_3

Lundqvist, A., Gerdle, B., & Rönnberg, J. (2000). Neuropsychological aspects of driving after a stroke—in the simulator and on the road. *Applied Cognitive Psychology, 14*(2), 135-150. http://dx.doi.org/10.1002/(SICI)1099-0720(200003/04)14:2<135::AID-ACP628>3.0.CO;2-S

Marottoli, R. A., Mendes de Leon, C. F., Glass, T. A., & Williams, C. S. (1997). Driving cessation and increased depressive symptoms: Prospective evidence from the New Haven EPESE. *Journal of the American Geriatrics Society, 45*(2), 202-206. http://dx.doi.org/10.1111/j.1532-5415.1997.tb04508.x

Marshall, S. C., Molnar, F., Man-Son-Hing, M., Blair, R., Brosseau, L., Finestone, H. M., . . . Wilson, K. G. (2007). Predictors of driving ability following stroke: A systematic review. *Topics in Stroke Rehabilitation, 14*(1), 98-114. http://dx.doi.org/10.1310/tsr1401-98

McKay, C. (2007). *Self-evaluation of driving simulator performance in stroke patients.* PhD. University of Windsor. Retrieved from http://scholar.uwindsor.ca/etd/4687

McKay, C., Rapport, L., Bryer, R., & Casey, J. (2011). Self-evaluation of driving simulator performance after stroke. *Topics in Stroke Rehabilitation, 18*(5), 549-561. http://dx.doi.org/10.1310/tsr1805-549

McNamara, A., Walker, R., Ratcliffe, J., & George, S. (2014). Perceived confidence relates to driving habits post-stroke. *Disability & Rehabilitation, 37*(14), 1228-1233. http://dx.doi.org/10.3109/09638288.2014.95861

Microsoft Office. (2010). Visual Basic For Applications.

Murie-Fernandez, M., Iturralde, S., Cenoz, M., Casado, M., & Teasell, R. (2014). Driving ability after a stroke: Evaluation and recovery. *Neurología (English Edition), 29*(3), 161-167. http://dx.doi.org/http://dx.doi.org/10.1016/j.nrleng.2012.05.008

Pollatsek, A., Vlakveld, W., Kappé, B., Pradhan, A., & Fisher, D. L. (2011). Driving simulators as training and evaluation tools *Handbook of driving simulation for engineering, medicine, and psychology*: CRC Press. http://dx.doi.org/:10.1201/b10836-31

Ragland, D. R., Satariano, W. A., & MacLeod, K. E. (2005). Driving cessation and increased depressive symptoms. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences., 60*(3), 399-403.

Ranney, T. A. (2011). Psychological fidelity *Handbook of driving simulation for engineering, medicine, and psychology*: CRC Press. http://dx.doi.org/:doi:10.1201/b10836-10

Riendeau, J. A., Maxwell, H., Patterson, L., Weaver, B., & Bédard, M. (2016). Self-rated confidence and on-road driving performance among older adults. *Canadian Journal of Occupational Therapy, 83*(3), 177-183. http://dx.doi.org/10.1177/0008417416645912

Rubio, S., Diaz, E., Martin, J., & Puente, J. M. (2004). Evaluation of subjective mental workload: A comparison of SWAT, NASA-TLX, and workload profile methods. *Applied Psychology: An International Review, 53*(1), 61-86. http://dx.doi.org/10.1111/j.1464-0597.2004.00161.x

Scott, C. A., Rapport, L. J., Coleman Bryer, R., Griffen, J., Hanks, R., & McKay, C. (2009). Self-assessment of driving ability and the decision to resume driving following stroke. *Journal of Clinical and Experimental Neuropsychology, 31*(3), 353-362. http://dx.doi.org/10.1080/13803390802169067

Selander, H., Lee, H. C., Johansson, K., & Falkmer, T. (2011). Older drivers: On-road and off-road test results. *Accident Analysis & Prevention, 43* (4), 1348-1354. http://dx.doi.org/10.1016/j.aap.2011.02.007

Siren, A., Hakamies-Blomqvist, L., & Lindeman, M. (2004). Driving Cessation and Health in Older Women. *Journal of Applied Gerontology, 23*(1), 58-69. http://dx.doi.org/10.1177/0733464804263129

Stapleton, T., Connolly, D., & O'Neill, D. (2012). Exploring the relationship between self-awareness of driving efficacy and that of a proxy when determining fitness to drive after stroke. *Australian Occupational Therapy Journal, 59*(1), 63-70. http://dx.doi.org/10.1111/j.1440-1630.2011.00980.x

Stedmon, A., Young, M. S., & Hasseldine, B. (2009). Keeping it real or faking it: The trials and tribulations of real road studies and simulators in transport research. In P. D. Bust (Ed.), *Contemporary Ergonomics 2009: Proceedings of the International Conference on Contemporary Ergonomics 2009*, CRC Press, London, UK,

Stoner, H., Fisher, D., & Mollenhauer, J. M. (2011). Simulator and scenario factors influencing simulator sickness. In D. L. Fisher, M. Rizzo, J. K. Caird & J. D. Lee (Eds.), *Handbook of driving simulation for engineering, medicine, and psychology*. London. UK: CRC Press: Taylor and Francis. http://dx.doi.org/:doi:10.1201/b10836-15

Swanson, J. (2005). The Delis-Kaplan Executive Function System: A review. *Canadian Journal of School Psychology, 20*(1/2), 117-128. http://dx.doi.org/10.1177/0829573506295469

Wolf, T. J., & Rognstad, M. C. (2013). Changes in cognition following mild stroke. *Neuropsychological Rehabilitation, 23*(2), 256-266. http://dx.doi.org/10.1080/09602011.2012.748672

Young, M. S., & Stanton, N. A. (2004). Taking the load off: Investigations of how adaptive cruise control affects mental workload. *Ergonomics, 47*, 1014-1035. http://dx.doi.org/10.1080/00140130410001686348

Section Two

On-Road Driving Research

Chapter Six: Cognitive ability as a predictor of task demand and self-rated driving performance in post-stroke drivers – implications for self-regulation

Chapter Outline and Rationale

The purpose of this chapter was to address objective four (assess the on-road driving behaviour of post-stroke drivers, compared to healthy controls) and further address objectives one (assess the relationship between deficits in cognition, executive function and driving behaviour in post-stroke drivers and non-stroke drivers), five (compare the perceived level of task demand involved in different driving scenarios in post-stroke drivers to that of a comparison group of healthy controls), six (assess self-perception of driving behaviour and observed driving behaviour (calibration) and how it relates to cognition) and seven (assess compensation strategies for deficits in cognition that enable driving in post-stroke adult). In this chapter, on-road driving behaviour is explored using an on-road observation in the participants' own vehicle, and the relationship with task demand and cognition is examined.

The chapter is written as a submitted manuscript, formatted in line with the style of the thesis and outlines the background to the study, the methodologies used, the results found and discusses how attention, executive function, propensity for risk taking behaviour, task demand and calibration relate to on-road behaviour. The chapter concludes with further discussion regarding how the results may inform health practitioners regarding post-stroke driver behaviour and provide insight into likely self-regulation behaviours of post-stroke drivers who require post-diagnosis assessment.

Abstract

Driving is a highly complex task, requiring a number of cognitive and perceptual processes that can be detrimentally affected post-stroke. The ability of post-stroke adults to self-evaluate their driving performance is unclear and the impact of cognitive decline on this evaluation has not previously been investigated. The aim of this study was to investigate the perceived level of task demand involved in driving tasks for the post-stroke driver and control group, as well as investigate differences between their perceived and observed driving performance. A further aim of the research was to investigate the influence of cognition and risk propensity on self-rated driving performance. A total of 83 participants (40 post-stroke and 43 controls) were assessed using a series of cognitive tasks and observed whilst driving a specific driving route in their own vehicle. Participants were then asked to rate their own driving performance and the demand of driving tasks using the NASA Task Load Index. Between groups' analyses were conducted to determine differences in level of self-rated performance and task demand. Further analyses were conducted to investigate whether differences in cognition accounted for differences in task demand or self-rated performance. Overall, the results suggested that the post-stroke drivers exhibited deficits in cognition; however they did not report increased levels of task demand when driving. It was also found that post-stroke adults rated themselves more conservatively than the controls for on-road performance. Only propensity for risk accounted for variance in self-reported performance. This study suggests that awareness of cognitive deficits may influence post-stroke drivers with amending their driving behaviour, in order to bring the task demand within a manageable level. Understanding of the mechanisms involved in self-rated performance and estimations of task demand can help promote accurate self-regulated practices in post-stroke drivers. Furthermore, assessing propensity for risk, task demand and calibration may assist practitioners with assessing fitness-to-drive, as well as with tailoring post-stroke driving rehabilitation.

Keywords: Australia, Calibration, Cerebrovascular Accident, Cognitive Performance, Older Drivers, On-Road Driving, Workload

Introduction

A cerebrovascular accident is more generically referred to as a 'stroke' (Sacco et al., 2013). Although a stroke can occur at any time during a person's life, it is most prevalent within an older adult population (Australian Institute of Health and Welfare, 2013). The global incidence of stroke-related mortality is expected to reach 7.8 million by 2030 (Strong, Mathers, & Bonita, 2007) and between 30% - 50% of survivors will drive again post-stroke (Bryer, Rapport, & Hanks, 2006; Fisk, Owsley, & Pulley, 1997).

It is well established that driving is a highly cognitive and physical task that requires the use of a range of executive and cerebral abilities (Anstey, Wood, Lord, & Walker, 2005; Groeger, 2000). Following a stroke, survivors experience a decline in their cognitive abilities (Patel & Birns, 2015). Psychomotor speed, visuospatial function and executive function are frequently cited as heavily impaired in post-stroke adults (Leśniak, Bak, Czepiel, Seniów, & Członkowska, 2008; Middleton et al., 2014; Zinn, Bosworth, Hoenig, & Swartzwelder, 2007) and previous research has found that post-stroke drivers who show increased executive dysfunction perform significantly worse in simulated driving tasks when compared to controls (Motta, Lee, & Falkmer, 2014).

Older drivers have reported higher levels of task demand when completing a driving task (Bunce, Young, Blane, & Khugputh, 2012) and post-stroke drivers have exhibited longer cognitive reaction times, as well as increased cognitive demand during a driving task (Daly, Fang, Perepezko, Siemionow, & Yue, 2006), however the perceived task demand in driving has yet to be investigated in this pathology group.

Task demand is the amount of cognitive resources and task directed effort required to complete a given task (Dunn & Williamson, 2012). Perceived task demand (i.e., the self-assessment of the level of task-directed effort and resources required) is important when driving, as one of the key requirements for safe driving is the ability to reliably calibrate one's own competence through matching subjective and objective measures (Fuller, 2005; Heikkilä, Korpelainen, Turkka, Kallanranta, & Summala, 1999). Evidence suggests that some older adults implement compensatory cognitive processes (Andrews & Westerman, 2012) and that drivers alter their environment whilst driving in order to regulate their level of perceived demand. This allows the driver to align task demand with their perceived capabilities (Fuller, 2005), for example, by undertaking self-regulated driving to avoid high-stress traffic situations (Hakamies-Blomqvist & Wahlström, 1998; Molnar & Eby, 2008).

According to the task-capability interface model of Fuller (2005), drivers are able to adjust the difficulty of the driving task (self-regulating) by, for example, increasing or reducing the vehicle speed or by changing lane. Therefore, safe driving requires adjusting the task demand to the driver's own capabilities and this "calibration" or "self-regulation" activity involves matching the perceived task demand to the perceived capabilities of the driver. Safe driving requires the driver to continually risk assess situations (Charlton, Starkey, Perrone, & Isler, 2014), therefore there is a need for the driver to be aware of their own limitations in risk assessment ability in order to appropriately calibrate their behaviour. Older drivers, both with and without pathology, often lack the ability to realistically evaluate their own driving performance, having been found to overestimate their driving exposure (Crizzle, Myers, & Almeida, 2013) and exhibit positive self-bias when reporting on driving ability (Scott et al., 2009).

Errors in calibration can have a serious effect on safety and mobility (Fuller, 2005). If the calibration between the self- and the observed assessment is at odds and drivers overrate their abilities, they are over-estimators, whereas those who self-rate lower and perform well are under-estimators (Hassan, King, & Watt, 2015). Reduction in driving due to lack of confidence (McNamara, Walker, Ratcliffe, & George, 2014) or underestimated driving ability could mean those who are safe and capable of driving, experience a reduced quality of life due to lack of mobility and autonomy (Fristedt, Björklund, Wretstrand, & Falkmer, 2011). This can have serious consequences for health status and well-being (Fristedt et al., 2011; Fuller, 2005) particularly as driving is a highly relied upon activity of daily living, particularly in the older population (Poole, Chaudry, & Jay, 2008). Whereas those who overestimate their driving capability risk exposing themselves to situations that they are unable to safely negotiate and instead of ceasing or amending their driving, continue to use their car at a greater risk to all road users (Fuller, 2005; Hassan et al., 2015).

Subsequently the reliance on self-rated performance as a mechanism for self-regulation of on-road driving is unreliable and gaining an accurate insight into post-stroke driver perceptions of their own calibration capability and performance is important for understanding post-stroke driver behaviour and self-regulation practices.

The findings of currently available research appear conflicted. Specifically, drivers who have suffered a stroke and continue to drive were found to overestimate their driving capabilities (Heikkilä et al., 1999; Scott et al., 2009) and tended to take more risks on the roads when evaluated by health professionals (Heikkilä et al., 1999). This may be related to the effect of impaired cognition influencing self-rated performance (Rapoport et al., 2013). However, there is some evidence to suggest that the self-efficacy of driving ratings in post-stroke adults correlates with that of a nominated proxy (Stapleton, Connolly, & O'Neill, 2012) and that those with a brain injury are capable of realistic judgements of their own performance (Lundqvist & Alinder, 2007).

The aims of this study were to investigate the perceived level of task demand involved in driving tasks for the post-stroke driver and control group, as well investigate differences in their perceived level of performance and observed driving performance. A further aim of this study was to investigate the influence of cognition and risk propensity in any perceived driving performance.

Method

A quasi-experimental comparison group design was implemented, which involved a group of self-reported post-stroke drivers and an age and gender matched control group.

Participants

The inclusion criteria for study participation were that all participants held a driver’s licence valid within Australia, had at least one year of driving experience, drove at least twice a week and had access to a fully insured vehicle. Further criteria for the post-stroke group were that they had previously been diagnosed with a stroke (either ischemic, haemorrhagic or a transient ischemic attack) and had been cleared to drive by a medical professional. Where possible, participants were asked to bring in any medical documents relating to their stroke, for demographic verification purposes. Participants were excluded if they had been diagnosed with any neurodegenerative disease, such as Parkinson's disease or dementia or if they required a wheelchair for mobility. Participants were recruited using purposive sampling techniques including: speaking at and recruiting from local community groups and post-stroke support groups, as well as advertising in community newspapers and on local radio stations. The recruitment and assessment of participants took place between April 2015 and February 2016.

The total sample consisted of 83 participants including 40 post-stroke drivers (male = 32) and 43 controls (male = 35). The mean age of the post-stroke group was 66 years (SD = 9) and the ages ranged from 37 – 81 years. The mean age of the control group was slightly older at 67 years (SD =8), and ages ranged from 49 – 81 years. Driving exposure data were collected from each participant as an estimate of their annual millage in kilometres (km). The post-stroke group reported a mean of 16,512km per year (SD = 12,946), whereas the controls reported 15,341km per year (SD = 8,066km). The years of driving experience and the licence length of the post-stroke group was slightly shorter than control group with means of 48 years, (SD = 8) and 49 (SD = 8), respectively. No significant differences were found between groups for age, gender distribution, driving exposure or licence length, therefore the groups were considered well-matched (Evans, 2004).

Due to the self-nomination of participants in the study, the type and location of the stroke varied (Table 26). For the purposes of this research, participants who reported one or more transient ischemic attacks (TIA) were grouped with participants who reported an ischemic stroke. There was a greater proportion of ischemic strokes, to haemorrhagic stroke and females were more likely to report an ischemic stroke (n=6). Only one female reported a haemorrhagic stroke and one female participant reported that she was not sure of the type of stroke. Overall, 55% of participants reported an ischemic stroke, 28% reported a haemorrhagic stroke and 18% reported that they were not sure or could not remember. The total number of each type of stroke, as well as the approximate location of the stroke, is reported in Table 26.

Table 26.

Demographic data for type of stroke and stroke location

Stroke Type	Stroke Location				
	Left Hemisphere	Right Hemisphere	Brain Stem	Unknown	Total
Haemorrhagic	4	3	3	1	11
Ischemic	10	8	0	4	22
Unknown	2	2	0	3	7
Total	16	13	3	8	40

Measures

Demographic and screening measures. Demographic information for each participant, including driving exposure, driving habits, driving history and medical history was collected using a demographic questionnaire and selected questions from the Driving Habits Questionnaire (DHQ; Owsley, Stalvey, Wells, & Sloane, 1999). Age, gender, approximate location of stroke, annual millage and length of licence were also recorded.

In order to screen for potential confounding effects of poor visual acuity (VA), and to ensure compliance with the minimum VA for safe driving on-road in Western Australia, bilateral visual acuity for each participant was assessed using the Early Treatment Diabetic Retinopathy Study (ETDRS) chart. Specifically, the revised charts one to three from the 2000 ETDRS visual acuity chart (Precision Vision). All participants were required to achieve a bilateral score of at least 20/40 VA in order to participate and all participants met the minimum VA requirements.

Cognitive measures. Several cognitive measures made up a battery of assessments, which was utilised to assess different aspects of cognition including: psychomotor processing, attention, executive function, propensity for risk taking, spatial cognition and visuospatial function.

Psychomotor Processing. As psychomotor performance is known to be affected post-stroke (Leśniak et al., 2008), a simple reaction time task (SRT) measuring baseline processing, as well as two choice-based reaction time tasks, i.e., a two-choice reaction time task (2CRT) and a four-choice reaction time task (4CRT) were implemented. The SRT task required the participants to respond to a displayed target letter X by striking the space bar as quickly as possible. The 2CRT and 4CRT tasks involved the participants pressing the specified key corresponding to where the circle appeared spatially on screen, as quickly and as accurately as possible. Data recorded included hit, miss and false alarm (where appropriate), in order to adjust the data in post-processing (Bunce, Handley, & Gaines Jr, 2008; Bunce et al., 2012). All target letters, as well as the task order were presented randomly using the E-Prime 2.0 software (Schneider, Eschman, & Zuccolotto, 2012) and followed the criteria and procedures outlined in similar research investigating cognition and driving (Bunce et al., 2008; Bunce et al., 2012).

Attention and Executive Function. There were two types of attention measured as part of this study: selective attention and divided attention. The Useful Field of View© (UFOV) test was developed as a means of measuring visual, selective and divided attention (Ball & Owsley, 1993) and has been regularly implemented in post-stroke driving research (Fisk, Owsley, & Mennemeier, 2002; George & Crotty, 2010). A second simple selective attention task was administered using the E-Prime 2.0 software, which involved participants visually scanning for an embedded letter Q, within a 6x6 rectangular array of the letter O. Similar to the psychomotor processing task participants were asked to respond as quickly and as accurately as possible by pressing the key corresponding to "yes I saw a Q" (i.e., X) or "no I did not see a Q" (i.e., M). The task was designed following protocols reported in previous driving research (Bunce et al., 2012) and consisted of 64 randomly presented experimental trials.

As executive function is well-known to influence driving performance (Anstey et al., 2005) this was assessed using the Delis-Kaplan Trail Making Test© (DKEFS TMT;

Delis, Kaplan, & Kramer, 2001). The DKEFS TMT is an updated version of the Trail Making Task A and B and involved five individual component tasks that asses different levels of cognition (Kelly, 2003; Swanson, 2005), specifically, number sequencing and visual attention, letter sequencing and visual attention, and motor speed (Swanson, 2005). The four baseline tasks consisted of a visual cancellation task (DKEFS TMT 1) and several circle connection tasks (DKEFS TMT 2, DKEFS TMT 3, DKEFS TMT 5). The fourth task (DKEFS TMT 4) was a number-letter switching task, whereby the participant must repeatedly connect the circles from a number to a letter across two pages ultimately connecting all circles in order. This fourth task assessed executive function, specifically through assessing visuospatial thought flexibility (Swanson, 2005). This was achieved by calculating the participants score on the fourth task minus any baseline function from tasks one, two, three and five as a series of contrast scores (Delis et al., 2001). Each task was administered using paper and pencil and participants were timed to completion. The total time taken for each task was recorded before the timed score was scaled in order to account for age effects (Delis et al., 2001). The tests have previously been used to assess cognitive performance in post-stroke patients and found to be sensitive to cognitive decline, particularly in frontal lobe function (Homack, Lee, & Riccio, 2005; Wolf & Rognstad, 2013).

Propensity for Risk. The Balloon Analogue Risk Task (BART; Lejuez et al., 2002) is a measure of risk-taking and risk aversive behaviour. The task involved a digitised balloon, which was displayed using E-Prime© software and pumped up using specified computer keys (P to pump up the balloon and S to save the balloon). The aim of the task was to pump up the balloon to as sufficient size, without it bursting and collect the most points possible for each subsequent pump. The minimum number of pumps required before the balloon burst was one and the maximum allowed was 128, which is considered standard for the BART (Lejuez et al., 2002). The number of pumps that would cause the balloon to burst altered with each balloon and 10 points were awarded for each pump, providing that the participant saved the balloon prior to it bursting. The adjusted average of the number of pumps per balloon was recorded for each participant. Participants with lower scores and fewer burst balloons are considered to be risk aversive, whereas participants with higher scores and more burst balloons have a greater propensity for risk.

Spatial cognition and visuospatial function. Visuospatial function is often affected following the onset of a stroke (Kaplan & Hier, 1982; Stone et al., 1991; Treccani, Torri, & Cubelli, 2005), therefore the block design task (a subtask of the Wechsler Adult Intelligence Scale, (Wechsler, 2008)) and the Benton Judgement of Line Orientation Task (Benton, Hamsher, Varney, & Spreen, 1983) were used to measure non-verbal visuospatial reasoning, spatial cognition, perception and orientation ability. The Block Design task involved constructing a specified design made of out of a series of cuboid blocks as quickly and as accurately as possible. The difficulty of the design increased with each iteration and the time allowed also increased. Performance was scored based on the time taken to complete each design, with faster completion times yielding greater scores. The task was stopped once the participant had failed to complete the design within time for two consecutive designs. The Benton Judgement of Line Orientation Task (BJLOT) consisted of a series of reference lines arranged in a semi-circle format, from which participants had to identify specified target lines. The rotation and angle alteration of the target lines increased the difficulty of the task as the test progressed. The amount of correctly identified lines was recorded. Greater cumulative scores at the end of both the Block Design task and the BJLOT were indicative of greater performance. Both the BJLOT and the Block Design have previously been utilised in post-stroke driver research (Blane, Falkmer, Lee, Parsons, & Lee, 2016; Motta et al., 2014).

On-Road Driving. Participants were asked to undertake an observed drive on a pre-defined driving route around the Curtin University Campus and surrounding Bentley area. The route was 13 km and took approximately 20 minutes to complete. Participants were unaware of the route prior to the drive and were given directions by the first author. The route was specifically designed to include driving scenarios that require significant cognitive capacity, such as turning right, stop signs, pedestrian crossings, etc. The drive took place in the participants' own insured vehicle, which included any vehicle modifications, such as adaptive pedals or steering required as part of a conditional licence. All participants were asked to provide their licence for sighting prior to study commencement. The first author and a Research Assistant accompanied all participants on the drive for verification and safety purposes.

Observer rated driving performance. Observed driver behaviour was recorded using an adapted version of the Chee, Lee, Lee, and Falkmer (2013) driving behaviour checklist (DBC). The DBC is a researcher-administered tool comprised of a checklist of specific criteria that assess a driver's adherence to road rules, regulations and manoeuvring performance at specific areas of interest, e.g., intersections, stop signs, roundabouts. Criteria were ticked if a manoeuvre was correctly performed and crossed if not performed. Post-assessment, all criteria were coded based on type of driving-related process involved (attention, manoeuvring, speed adjustment, position, planning and interaction) inspired by the 'Be On Road' driving assessment protocol (Broberg & Dukic Willstrand, 2014). Analysis involved calculating the total number of errors committed, as well as calculating the number of each type of error (i.e., errors in attention, manoeuvring, speed adjustment, position, planning or interaction). Checklist data were collected whilst the on-road assessment took place and further confirmed post-assessment using the video recording taken using a head mounted eye-tracking camera. Participants were scored a one for an item if they performed the behaviour or the manoeuvre correctly, 0.5 if they partly performed the behaviour or manoeuvre (e.g., only checked one mirror or looked in one direction before completing a manoeuvre) and a zero if they did not perform the behaviour or manoeuvre at all. Due to technical faults and calibration issues of the eye-tracker, data were only collected for 52 participants using the DBC (25 controls and 27 post-stroke adults respectively). As the DBC is an observational tool and was being utilised to assess licensed drivers, a pass or fail score was not applied.

Self-Perception of driving performance and task demand. Overall self-rated performance in general driving situations was collected using the self-rated scale from the DHQ, prior to undertaking the assessments. Participants were asked compared to the general flow of traffic "how fast do you usually drive?" and "how would you rate the quality of your driving?" and were given a five point scale ranging from low to high on which to answer.

Perceived cognitive task demand and performance in a specific driving task was measured using the NASA Task Load Index (TLX; Hart & Staveland, 1988). This questionnaire assessed the participants' perceived amount of effort required on six different levels: mental demand, physical demand, temporal demand, performance, effort and frustration after the on-road assessment. The questionnaire is paper-based and required participants to indicate on a 21 point low-high scale how much demand the task required and how well they felt they performed.

Data Collection and Procedure

Participants were provided with a participant information sheet and screened for minimum VA. Participants were then allocated to the on-road driving or the cognitive tasks first. The order of completion for the cognitive tasks was randomised for each participant using the Latin squares method (Grant, 1948). Participants completed the NASA TLX after the on-road observation task. Overall, the process lasted approximately two hours.

Data Processing and Statistical Analysis. For the psychomotor tasks and visual search task, the data were screened for any accidental key presses and excessively fast or slow reaction latencies using data distributions in Microsoft Excel© and E-Data Aid© and any outliers found were trimmed, i.e., any RT trial scoring < 150ms or > mean RT (MRT) + three standard deviations (SD) (Bunce et al., 2012). Outlying RTs were eliminated without replacement and the MRT and SD recomputed the error rate recorded. For the 2CRT, 4CRT and visual search task, the baseline SRT's MRT was deducted from the target MRT to give a performance RT. For the BART, the participants' data were loaded into Microsoft Excel and the adjusted average number of pumps per balloon was calculated for the number of balloons saved. For all other measures, either the raw timed score or cumulative correct answer score was entered.

Prior to analysis, all data were loaded, cleaned and checked using Microsoft Excel©. Data were then loaded into SPSS v22.0 (IBM Corporation, 2013) for analysis. Descriptive and univariate statistics were used to report the demographics of each group. Normality of all continuous data was assessed using histograms, boxplots, normal Q-Q plots, skewness and kurtosis before between groups descriptive data were calculated. A box-cox transformation was conducted on the UFOV data, DKEFS data, visual search data, reaction time task data and TLX on-road self-rated performance score to improve normality. Between groups analysis of the normally distributed cognitive data were analysed using an independent samples t-test. Between groups analysis of continuous non-normally distributed data (DKEFS TMT EF4) was analysed using a Mann-Whitney U-test.

Further analyses employed the use of general linear regression on the self-rated performance variable to identify whether any differences in cognition accounted for differences in self-rated driving performance. With a total of 83 participants, the standardised difference value was calculated as 0.63, given an α-level of 0.05 and a $1-\beta = 0.8$ (Cohen, 1988). With 52 participants for the on-road calibration analysis the standardised difference value was calculated as 0.69, with an α-level of 0.05 and a $1-\beta = 0.8$ (Cohen, 1988). A p-value of <0.05 was taken to indicate a statistically significant association in all tests.

Ethical Considerations

This research and the associated study protocols were approved by the Curtin University Human Research Ethics Committee – approval number: HR206-2014 and conformed to the principles of the Declaration of Helsinki. Participants were presented with an information sheet, given the opportunity to ask questions and each provided signed informed consent prior to participation. Participants were also informed that they could leave the study at any time without incurring any negative consequences. Participants were informed prior to participation, should any behaviour or assessment results indicate an obvious driving difficulty or a medical issue then client benefit practices would be implemented, for example they would be offered the opportunity to undertake complementary driving counselling, as well as recommended to visit their regular medical practitioner. Participants were offered a gift voucher worth $15 as a token of appreciation for their time and travel costs..

Results

Cognitive Results

There were significant between groups' differences in several of the cognitive variables: BART, visual search, D-KEFS TMT 4 and UFOV (Tables 27 to 28). The post-stroke drivers saved more balloons in the BART and also had a lower average number of pumps per balloon, both of which indicated a greater tendency for risk averseness than those in the control group. In the UFOV 2 - Divided Attention, UFOV 3 - Selective Attention and Visual Search Task, the post-stroke drivers had significantly longer reaction times, all of which indicated poor performance. There were no statistically significant differences between groups on any of the following measures; BJLOT, Block Design, UFOV 1 – Processing Speed or any of the psychomotor tasks.

Table 27.

Between groups analysis of cognitive variables

Variables	Post-Stroke Driver			Controls			t-value	df	p-value
	n	Mean	SD	n	Mean	SD			
BART mean # pumps	40	20.70	10.33	43	27.49	17.78	-2.14	68.33	0.04*
BART mean # saved balloons	40	25	3.30	43	22.90	4.71	2.38	75.37	0.02*
BJLOT	39	24.67	4.95	43	25.44	9.93	-.78	72.45	0.44
Block Design	40	37.25	10.36	43	40.40	10.22	-1.39	81	0.17
SRT (milliseconds)	37	370.63	156.27	43	244.19	78.05	0.98	78	0.33
2CRT (milliseconds)	37	464.90	250.84	43	394.76	115.20	1.64	78	0.10
4CRT(milliseconds)	37	791.84	341.89	43	677.51	276.57	1.65	78	0.10
Simple visual search	37	678.71	409.42	43	494.11	150.96	2.61	78	0.01*
UFOV subtest 3	38	143.04	108.24	41	90.13	50.70	2.53	77	0.01*
UFOV subtest 2	38	80.23	108.93	42	36.29	38.84	2.03	78	0.04*
	n	Median	IQR	n	Median	IQR		U-value	p-value
UFOV subtest 1	38	13.75	0.10	42	13.80	0.10		795	0.98

*Significant data; p-value <0.05

Table 28.

Between groups differences (independent t-test and Mann-Whitney U test results) for DKEFS TMT

Variables	Post-Stroke Driver			Controls			t-value	df	p-value
	n	Mean	SD	n	Mean	SD			
DKEFS TMT 1	40	7.48	3.56	43	10.90	2.17	-5.26	63.56	0.001**
DKEFS TMT 2	40	9.20	3.69	43	11.47	3.01	-3.07	81	0.003*
DKEFS TMT 3	40	8.56	3.95	43	11.72	2.57	-4.30	66.12	0.001**
DKEFS TMT 4	40	8.3	4.36	43	11.65	2.35	-4.32	58.94	0.001**
DKEFS TMT 5	40	9.48	3.20	43	12.02	1.71	-4.48	58.71	0.001**
DKEFS TMT 2+ TMT3	40	9.23	3.92	43	12.35	2.89	-4.11	70.49	0.001**
DKEFS TMT EF-1	40	10.8	3.66	43	10.7	2.64	0.15	81	0.88
DKEFS TMT EF-2	40	9.25	3.72	43	10.20	2.26	-1.34	63.4	0.19
DKEFS TMT EF-3	40	9.83	3.69	43	9.93	2.41	-0.16	81	0.88
DKEFS TMT EF-5	40	8.95	4.34	43	9.63	2.57	-0.86	62.4	0.40
	n	Median	IQR	n	Median	IQR		U- value	p-value
DKEFS EF flexibility score	40	1.00	3.50	43	1.00	0.001		674.5	0.02*

*Significant data; p-value <0.05

**Significant data; p-value <0.001

Observer-Rated Driving Performance

Although the total performance score for positioning approached significance (p=0.07), there were no significant between group differences for total number of correct items or total score for each individual coded process suggesting that on average, both the post-stroke group and control group performed at a similar level across the driving route (Figure 18).

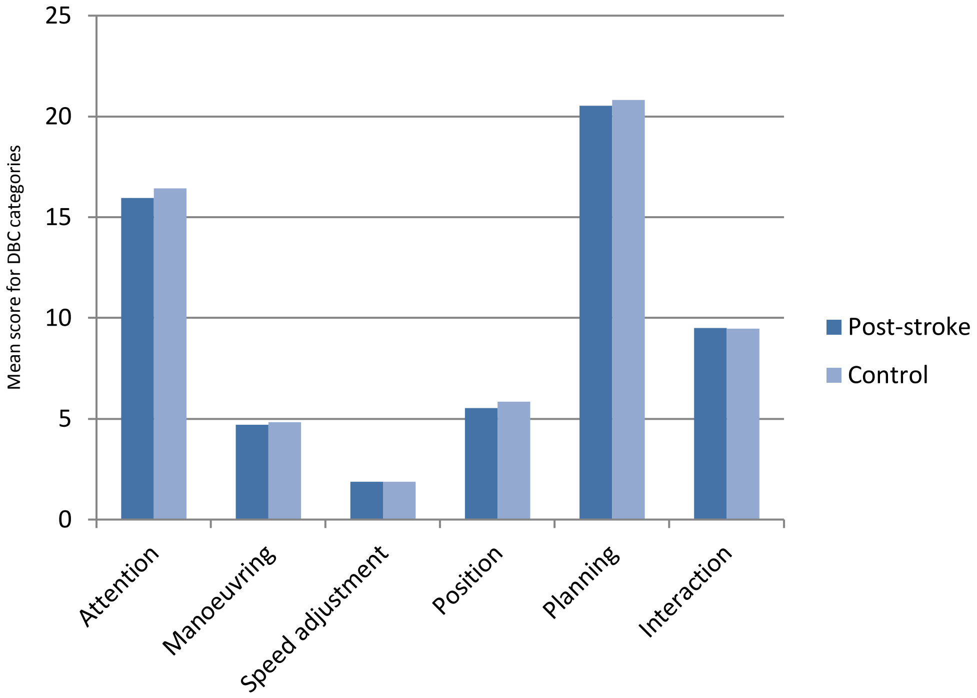

Figure 18. Grouped mean score values for DBC behaviour categories

Self-Rated Driving Performance

In the self-rated measures of everyday driving, measured prior to the cognitive and driving assessments, there were no significant differences between groups on self-ratings of driving performance or self-comparisons of driving speed estimation However, there was a tendency for controls to rate their driving quality as “excellent” than the post-stroke group (Table 29).

Table 29.

Between groups frequencies and chi-square analysis of self-rated everyday driving performance

Question	Post-Stroke	Control	df	χ^2	p-value
How would you rate the quality of your driving?			3	2.87	0.41
Excellent	16%	23%			
Good	76%	61%			
Average	8%	14%			
Fair	0%	2%			
How fast do you normally drive compared to the general flow of traffic?			2	0.85	0.65
Somewhat faster	10%	16%			
About the same	82%	79%			
Somewhat slower	8%	5%			
Total	38	43			

No significant differences were found between groups for self-rated estimations of mental demand, physical demand, temporal demand, effort or frustration in any scenario. This suggests that neither group found the task more difficult or required more task demand to complete.

In contrast, there were significant differences between groups based on self-estimations of performance (Table 30). Results indicated that the post-stroke drivers rated themselves more conservatively and as performing more poorly than the drivers in the control group.

Table 30.

Between groups analysis of self-rated driving performance scores

Variables	Post-Stroke Driver			Controls			z-value	df	p-value
	n	Mean	SD	n	Mean	SD			
TLX – On-Road Performance	39	16.76	3.21	41	18.26	1.49	-2.59	64.92	00.01*

*Significant data; p-value <0.05

Calibration between self-rated performance and observed driving performance

Bivariate correlations were run to assess the relationship between self-rated performance and observed driving performance and no significant correlations were reported for either group. This suggested that on average, the self-rated performance scores were not related to drivers' researcher observed performance score in either the post-stroke group r=0.29, p=0.14 or the control group r=0.08, p=0.72.

Cognition and propensity for risk as a predictor for self-rated driving performance

As self-rated performance between groups was significant, despite limited differences in observed driving performance, further analysis using multivariate regression was utilised to assess whether cognitive performance accounted for the between-groups differences in self-rated performance. The TLX self-rated performance score was entered as a dependent variable and the main effects of each cognitive variable entered as co-variates. Variables reported as significant for the on-road performance were the average number of pumps from the BART and the mean reaction time for the visual search task. Interactions between the independent variable and group (post-stroke or control) were then assessed.

The final model (Table 31) suggested that propensity for risk was the only variable to account for self-rated on-road performance F (1, 69)=6.95, p=0.01. Specifically, the greater the score on the BART, then higher was the reported performance score on the TLX. An interaction between participant group and selective attention as measured by the visual search task was also a significant predictive model, however became insignificant when analysed with the propensity for risk task and therefore is not reported as part of the final model.

Table 31.

General linear model assessing relationship of cognition with self-rated on-road driving performance (TLX performance score as dependent variable)

	Unstandardised coefficients		95% CI		p-value	Adjusted R^2
	B	SE	Lower Bound	Upper Bound		
Intercept	11128.95	337.85	456.34	1801.55	0.001**	
BART	255.97	110.39	36.20	475.73.49	0.02*	0.06

*Significant data; p-value <0.05

**Significant data; p-value <0.001

Discussion

Summary of findings

The first aim of the study was to investigate the perceived level of task demand required in driving tasks for post-stroke drivers, compared to controls. The study found that the difference between the groups in self-reported task demand for any of the driving tasks was not significant. It suggested that both groups experienced similar levels of mental, physical and temporal demand, as well as similar amounts of frustration and effort required. This was an interesting finding as the participants in the post-stroke group reported no greater task demand despite clear differences in cognitive ability. The current research showed similar results to previous research (e.g., Blane et al., 2016; Motta et al., 2014) whereby the post-stroke drivers exhibited slower reaction times and scored poorly in divided attention, selective attention and executive functioning assessments. As part of the cognitive battery, propensity for risk was measured and it was found that post-stroke drivers were more risk aversive than controls. i.e., post-stroke drivers saved more balloons and had a lower adjusted average of inflations per balloon. An interpretation for this is that post-stroke drivers amended their behaviour to adjust for the level of difficulty (Fuller, 2005). This suggests that the post-stroke drivers engaged in compensatory process, which may translate into on-road behaviour, such as speed increases or decreases in order to bring the level of effort required for driving within a range they consider comfortable. Therefore, it is possible that post-stroke adults adjust or normalise their perceived level of task demand in order to compensate for deficits in cognition, by self-regulating their driving behaviour, which is in line with previously reported findings (White et al., 2012). This is important to understand for health practitioners and policy makers as it provides insight into the self-regulation practices of this rapidly increasing demographic of the older population. Furthermore, health professionals may find that assessing task demand and propensity for risk provide a useful measurement when assessing fitness-to-drive.

The second aim of this study was to investigate differences in perceived level of performance and whether it relates to observed driving performance in post-stroke drivers and controls. When post-stroke drivers were asked to rate their perceived driving performance, compared to other on-road users there were no significant differences between groups, although the control group were more likely to rate their driving as excellent. However, when participants were asked to rate their own driving performance on a specific task, there was a statistically significant difference in the ratings, with the post-stroke group on average reporting lower self-ratings than the control group. This was an interesting finding, particularly when considering that there were no reported differences in the task demand requirements for either group, as it suggests that the post-stroke drivers were more conservative in their judgements of their driving performance, which was possibly as a result of an awareness of cognitive decline. This further suggested that post-stroke adults may have a greater sense of self-efficacy than previously thought (Lundqvist & Alinder, 2007) and as found in the Fuller (2005) task-capability interface model, used this to regulate their driving behaviour based upon their perceived level of task demand.

The calibration of self-perception and it's relation to driving performance appears consistent with previous research in both older drivers and post-stroke drivers where self-rated driving performance poorly resembles actual driving performance (Blane et al., 2016; Riendeau, Maxwell, Patterson, Weaver, & Bédard, 2016). However, the current study appears to contradict previously reported positive bias and overestimation in post-stroke drivers (Heikkilä et al., 1999; Scott et al., 2009), as the post-stroke group were no more likely to report above average scores in everyday driving when compared to age-matched controls and were more likely to rate themselves lower in specific driving tasks, despite little difference in actual driving performance. This is important for health practitioners and policy makers to understand as it is contrary to reports that cognitive deficits in post-stroke adults cause an overestimation of driving performance. It further suggests that some post-stroke drivers may have increased insight into their own limitations and adjust their responses accordingly when driving (Fuller, 2005; Hassan et al., 2015). Understanding the level of insight and subsequent calibration is important for health practitioners to be aware of when assessing fitness-to-drive as driving is so heavily relied upon by the older post-stroke population for independence (White et al., 2012) and the consequences of poor calibration are so high (Fuller, 2005; Hassan et al., 2015). Therefore, assessing cognition and calibration is vitally important so that healthcare practitioners are able to reliably assess who has the capacity to adapt to the road environment.

The final aim of this research was to investigate how much cognition and propensity for risk explained the differences in self-perceived levels of driving performance. It was found that propensity for risk was the variable most strongly associated with of levels of self-rated performance in the on-road task. That is, a positive relationship between the propensity for risk and self-rated performance was observed. Specifically, the greater the number of pumps for each balloon (i.e., indicating a higher propensity for risk), the greater the participant would rate their performance. This relationship was evident across both groups, although a slightly stronger relationship was displayed in the post-stroke group. This suggests that cognitive deficits per se did not account for between group estimations of self-rated driving performance however those who were more risk aversive in both the post-stroke and controls group were more likely to rate themselves lower on the performance scale. This may suggest that those who are more risk aversive have a lower perception of task demand and lower threshold for self-considered self-assessed risk (Fuller, 2005). This is important for practitioners, as the measures used in this study have the potential to form a baseline to assess risk averseness, self-awareness and driving calibration during post-stroke drivers' fitness-to-drive assessment, as well as during their physical and cognitive rehabilitation. Understanding the self-awareness of the post-stroke adult's calibration ability can enable practitioners to effectively tailor rehabilitation (Ekstam, Uppgard, Kottorp, & Tham, 2007) and therefore provide proper support during the transition back to driving.

Limitations

Although this research was investigating self-reported performance in post-stroke drivers and an age and gender matched control group, no pass or fail score was provided for the on-road test, therefore it can be difficult to assess the accuracy of the self-reported assessment of driving performance. However, all participants were licensed drivers and a large proportion of the post-stroke group had previously undertaken a post-stroke driving assessment, therefore it can be assumed that all performed at a standard considered sufficient to drive. It is also possible that the results reflect tendencies of post-stroke adults to lose confidence and become more risk averse following their stroke (McNamara et al., 2014), due to their increased awareness of the consequences of poor performance and the loss of independence associated with losing a their driver's licence. However, this is not within the scope of this research to determine.

In the final analysis, the regression model was significant, however the R^2 statistic was small suggesting that the amount of variance explained was minimal, therefore further in-depth research is required to account for the between group differences in self-rating. Similarly, although the sample size was sufficient for between groups analysis, it was still relatively small and is likely to have limited the generalisability of the regression model. This is partly due to difficulties associated with sampling and recruitment.

Although the groups were well matched for age, gender and driving exposure, there were fewer females in both groups and it is possible that this impacted on the results as there are well-documented differences in the driving behaviours related to each gender (Evans, 2004; Oltedal & Rundmo, 2006). Further research should include a more even gender distribution, however it is also possible that due to the self-selection method of sampling, the gender distribution reflects the tendency for older female drivers to give up their licence or demonstrate increased self-regulation and driving cessation (Siren, Hakamies-Blomqvist, & Lindeman, 2004), as well as the fact that there is a higher incidence of age-related stroke in men and that the outcomes for women tend to be more severe (Katsiki, Ntaios, & Vemmos, 2011) . Similarly, participants were self-selected from within the post-stroke population of Western Australia, therefore there are the biases inherent within this type of sampling, which can make it difficult to generalise beyond the target population.

There was a wide distribution of stroke type and location, as well as a higher proportion of ischemic strokes compared to haemorrhagic strokes, which is possibly a reflection of the commonality of ischemic stroke and the low life expectancy and disability following a haemorrhagic stroke (Brønnum-Hansen, Davidsen, & Thorvaldsen, 2001; Dennis et al., 1993; Sacco, Wolf, Kannel, & McNamara, 1982). This is a potential confounder when considering cognitive differences in post-stroke adults (Munsch et al., 2016), however when investigating the demographic distribution of the dependent and independent variables, the demographic profile was relatively well distributed.

Conclusion

This study presents an alternative assessment for understanding self-evaluation of driving performance and contrary to previous research suggests that post-stroke adults are more conservative in their self-evaluations of their driving performance. The results also suggest that although post-stroke drivers exhibit poorer cognitive performance, they report similar levels of self-reported task demand to that of age and gender matched adults. Finally, with the exception of measurements of propensity for risk, it was found that cognitive performance accounted little for differences in self-reported driving performance. Together these results suggest that post-stroke adults have a lower threshold for acceptable demand and that awareness of their cognitive deficits prompts post-stroke drivers to amend their driver behaviour to within a manageable level of acceptable demand.

Chapter Summary and Progression

This chapter has discussed the on-road behaviour of post-stroke drivers compared to healthy controls, with a particular focus on task demand, calibration, self-rated performance and cognition. The proceeding chapter will discuss the compensatory behaviours, particularly the scanning patterns post-stroke drivers employ to compared for cognitive deficits and reduce task demand on-road.

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Chapter Six References

Andrews, E. C., & Westerman, S. J. (2012). Age differences in simulated driving performance: Compensatory processes. *Accident Analysis & Prevention, 45*, 660-668. http://dx.doi.org/http://dx.doi.org/10.1016/j.aap.2011.09.047

Anstey, K. J., Wood, J., Lord, S., & Walker, J. G. (2005). Cognitive, sensory and physical factors enabling driving safety in older adults. *Clinical Psychology Review, 25*, 45-65. http://dx.doi.org/10.1016/j.cpr.2004.07.008

Australian Institute of Health and Welfare. (2013). *Stroke*. Canberra: Retrieved from http://www.aihw.gov.au/WorkArea/DownloadAsset.aspx?id=60129543611

Ball, K., & Owsley, C. (1993). The Useful Field of View test: A new technique for evaluating age-related declines in visual function. *Journal of the American Optometric Association, 64*(1), 71-79.

Benton, A. L., Hamsher, K., Varney, N. R., & Spreen, O. (1983). *Judgment of line orientation*. New York: Oxford University Press

Blane, A., Falkmer, T., Lee, M., Parsons, R., & Lee, H. C. (2016). The cognitive and socio-demographic influences on driving performance and driving cessation in post-stroke drivers. *Advances in Transportation Studies: An International Journal,*(38), 121-135.

Broberg, T., & Dukic Willstrand, T. (2014). Safe mobility for elderly drivers: Considerations based on expert and self-assessment. *Accident Analysis & Prevention, 66*, 104-113. http://dx.doi.org/http://dx.doi.org/10.1016/j.aap.2014.01.014

Brønnum-Hansen, H., Davidsen, M., & Thorvaldsen, P. (2001). Long-term survival and causes of death after stroke. *Stroke, 32*(9), 2131-2136.

Bryer, R. C., Rapport, L. J., & Hanks, R. A. (2006). Determining fitness to drive: Neuropsychological and psychological considerations In J. M. Pellerito (Ed.), *Driver Rehabilitation and Community Mobility* (pp. 165-184). Saint Louis, USA: Mosby. http://dx.doi.org/:http://dx.doi.org/10.1016/B978-032302937-7.50013-7

Bunce, D., Handley, R., & Gaines Jr, S. O. (2008). Depression, anxiety, and within-person variability in adults aged 18 to 85 years. *Psychology and Aging, 23*(4), 848-858.

Bunce, D., Young, M. S., Blane, A., & Khugputh, P. (2012). Age and inconsistency in driving performance. *Accident Analysis & Prevention, 49*, 293-299. http://dx.doi.org/10.1016/j.aap.2012.01.001

Charlton, S. G., Starkey, N. J., Perrone, J. A., & Isler, R. B. (2014). What's the risk? A comparison of actual and perceived driving risk. *Transportation Research Part F: Traffic Psychology and Behaviour, 25, Part A*, 50-64. http://dx.doi.org/http://dx.doi.org/10.1016/j.trf.2014.05.003

Chee, D. Y., Lee, H. C., Lee, A. H., & Falkmer, T. (2013). Performance of drivers with Parkinson's Disease under the effect of cognitive overloading: insinuation for assessment and training. *Advances in Transportation Studies: An International Journal,*(29), 5-17.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, New Jersey: L. Erlbaum Associates.

Crizzle, A. M., Myers, A. M., & Almeida, Q. J. (2013). Self-regulatory practices of drivers with Parkinson's disease: Accuracy of patient reports. *Parkinsonism & Related Disorders, 19*(2), 176-180. http://dx.doi.org/10.1016/j.parkreldis.2012.09.003

Daly, J. J., Fang, Y., Perepezko, E. M., Siemionow, V., & Yue, G. H. (2006). Prolonged cognitive planning time, elevated cognitive effort, and relationship to coordination and motor control following stroke. *IEEE Transactions on Neural Systems and Rehabilitation Engineering: a publication of the IEEE Engineering in Medicine and Biology Society, 14*(2), 168-171.

Delis, D. C., Kaplan, E., & Kramer, J. H. (2001). *Delis-Kaplan Executive Function System (D-KEFS) examiner's manual*. San Antonio, Texas: The Psychological Corporation.

Dennis, M. S., Burn, J., Sandercock, P., Bamford, J. M., Wade, D. T., & Warlow, C. P. (1993). Long-term survival after first-ever stroke: The Oxfordshire Community Stroke Project. *Stroke, 24*(6), 796-800.

Dunn, N., & Williamson, A. (2012). Driving monotonous routes in a train simulator: the effect of task demand on driving performance and subjective experience. *Ergonomics, 55*(9), 997-1008. http://dx.doi.org/10.1080/00140139.2012.691994

Ekstam, L., Uppgard, B., Kottorp, A., & Tham, K. (2007). Relationship between awareness of disability and occupational performance during the first year after a stroke. *American Journal of Occupational Therapy, 61*(5), 503-511.

Evans, L. (2004). *Traffic safety*. Bloomfield Hills, Michigan: Science Serving Society.

Fisk, G. D., Owsley, C., & Mennemeier, M. (2002). Vision, attention, and self-reported driving behaviors in community-dwelling stroke survivors. *Archives of Physical Medicine and Rehabilitation, 83*(4), 469-477. http://dx.doi.org/10.1053/apmr.2002.31179

Fisk, G. D., Owsley, C., & Pulley, L. V. (1997). Driving after stroke: Driving exposure, advice, and evaluations. *Archives of Physical Medicine and Rehabilitation, 78*(12), 1338-1345. http://dx.doi.org/http://dx.doi.org/10.1016/S0003-9993(97)90307-5

Fristedt, S., Björklund, A., Wretstrand, A., & Falkmer, T. (2011). Continuing mobility and occupational participation outside the home in old age is an act of negotiation. *Activities, Adaptation & Aging, 35*(4), 275-297. http://dx.doi.org/10.1080/01924788.2011.625213

Fuller, R. (2005). Towards a general theory of driver behaviour. *Accident Analysis & Prevention, 37*(3), 461-472. http://dx.doi.org/10.1016/j.aap.2004.11.003

George, S., & Crotty, M. (2010). Establishing criterion validity of the Useful Field of View assessment and Stroke Drivers’ Screening Assessment: Comparison to the result of on-road assessment. *American Journal of Occupational Therapy, 64*(1), 114-122.

Grant, D. A. (1948). The latin square principle in the design and analysis of psychological experiments. *Psychological Bulletin, 45*(5), 427-442. http://dx.doi.org/10.1037/h0053912

Groeger, J. A. (2000). Understanding driving: Applying cognitive psychology to a complex everyday task. Hove, East Sussex, UK: Psychology Press.

Hakamies-Blomqvist, L., & Wahlström, B. (1998). Why do older drivers give up driving? *Accident Analysis & Prevention, 30*(3), 305-312. http://dx.doi.org/http://dx.doi.org/10.1016/S0001-4575(97)00106-1

Hart, S. G., & Staveland, L. E. (1988). Development of the NASA-TLX (Task Load Index): Results of empirical and theoretical research. *Human Mental Workload, 1*(3), 139-183.

Hassan, H., King, M., & Watt, K. (2015). The perspectives of older drivers on the impact of feedback on their driving behaviours: a qualitative study. *Transportation Research Part F: Traffic Psychology and Behaviour, 28*, 25-39. http://dx.doi.org/10.1016/j.trf.2014.11.003

Heikkilä, V. M., Korpelainen, J., Turkka, J., Kallanranta, T., & Summala, H. (1999). Clinical evaluation of the driving ability in stroke patients. *Acta Neurologica Scandinavica, 99*(6), 349-355. http://dx.doi.org/10.1111/j.1600-0404.1999.tb07363.x

Homack, S., Lee, D., & Riccio, C. A. (2005). Test review: Delis-Kaplan Executive Function System. *Journal of Clinical and Experimental Neuropsychology, 27*(5), 599-609. http://dx.doi.org/http://dx.doi.org/10.1080/13803390490918444

IBM Corporation. (2013). IBM SPSS Statistics for Windows, Version 22.0. Armonk, NY: IBM Corp.

Kaplan, J., & Hier, D. B. (1982). Visuospatial deficits after right hemisphere stroke. *American Journal of Occupational Therapy, 36*(5), 314-321.

Katsiki, N., Ntaios, G., & Vemmos, K. (2011). Stroke, obesity and gender: A review of the literature. *Maturitas, 69*(3), 239-243. http://dx.doi.org/http://dx.doi.org/10.1016/j.maturitas.2011.04.010

Kelly, T. P. (2003). Book review of Delis-Kaplan Executive Function System. *Pediatric Rehabilitation, 6*(2), 125-126. http://dx.doi.org/10.1080/1363849031000149756-1

Lejuez, C., Read, J. P., Kahler, C. W., Richards, J. B., Ramsey, S. E., Stuart, G. L., . . . Brown, R. A. (2002). Evaluation of a behavioral measure of risk taking: the Balloon Analogue Risk Task (BART). *Journal of Experimental Psychology: Applied, 8*(2), 75-84. http://dx.doi.org/10.1037/1076-898X.8.2.75

Leśniak, M., Bak, T., Czepiel, W., Seniów, J., & Członkowska, A. (2008). Frequency and prognostic value of cognitive disorders in stroke patients. *Dementia and Geriatric Cognitive Disorders, 26*(4), 356-363. http://dx.doi.org/10.1159/000162262

Lundqvist, A., & Alinder, J. (2007). Driving after brain injury: Self-awareness and coping at the tactical level of control. *Brain Injury, 21*(11), 1109-1117. http://dx.doi.org/10.1080/02699050701651660

McNamara, A., Walker, R., Ratcliffe, J., & George, S. (2014). Perceived confidence relates to driving habits post-stroke. *Disability & Rehabilitation, 37*(14), 1228-1233. http://dx.doi.org/10.3109/09638288.2014.958619

Middleton, L. E., Lam, B., Fahmi, H., Black, S. E., McIlroy, W. E., Stuss, D. T., . . . Turner, G. R. (2014). Frequency of domain-specific cognitive impairment in sub-acute and chronic stroke. *Neurorehabilitation, 34*(2), 305-312. http://dx.doi.org/10.3233/NRE-131030

Molnar, L. J., & Eby, D. W. (2008). The relationship between self-regulation and driving-related abilities in older drivers: an exploratory study. *Traffic Injury Prevention, 9*(4), 314-319. Retrieved from http://www.tandfonline.com/doi/pdf/10.1080/15389580801895319

Motta, K., Lee, H. C., & Falkmer, T. (2014). Post-stroke driving: Examining the effect of executive dysfunction. *Journal of Safety Research, 49*, 33.e31. http://dx.doi.org/10.1016/j.jsr.2014.02.005

Munsch, F., Sagnier, S., Asselineau, J., Bigourdan, A., Guttmann, C. R., Debruxelles, S., . . . Tourdias, T. (2016). Stroke location is an independent predictor of cognitive outcome. *Stroke, 47*(1), 66-73. http://dx.doi.org/10.1161/strokeaha.115.011242

Oltedal, S., & Rundmo, T. (2006). The effects of personality and gender on risky driving behaviour and accident involvement. *Safety Science, 44*(7), 621-628. http://dx.doi.org/10.1016/j.ssci.2005.12.003

Owsley, C., Stalvey, B., Wells, J., & Sloane, M. E. (1999). Older drivers and cataract: driving habits and crash risk. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 54*(4), M203-M211. http://dx.doi.org/10.1093/gerona/54.4.M203

Patel, B., & Birns, J. (2015). Post-stroke cognitive impairment. In A. Bhalla & J. Birns (Eds.), *Management of post-stroke complications* (pp. 277-306). Cham, Germany: Springer International Publishing. http://dx.doi.org/:10.1007/978-3-319-17855-4_12

Poole, D., Chaudry, F., & Jay, W. M. (2008). Stroke and driving. *Topics in Stroke Rehabilitation, 15*(1), 37-41. http://dx.doi.org/10.1310/tsr1501-37

Precision Vision. 2000 Series Revised ETDRS Charts. La Salle, Illinois: (Precision Vision).

Rapoport, M. J., Naglie, G., Weegar, K., Myers, A., Cameron, D., Crizzle, A., . . . Marshall, S. (2013). The relationship between cognitive performance, perceptions of driving comfort and abilities, and self-reported driving restrictions among healthy older drivers. *Accident Analysis & Prevention, 61*, 288-295. http://dx.doi.org/10.1016/j.aap.2013.03.030

Riendeau, J. A., Maxwell, H., Patterson, L., Weaver, B., & Bédard, M. (2016). Self-rated confidence and on-road driving performance among older adults. *Canadian Journal of Occupational Therapy, 83*(3), 177-183. http://dx.doi.org/10.1177/0008417416645912

Sacco, R., Wolf, P. A., Kannel, W., & McNamara, P. (1982). Survival and recurrence following stroke. The Framingham study. *Stroke, 13*(3), 290-295.

Sacco, R. L., Kasner, S. E., Broderick, J. P., Caplan, L. R., Connors, J. J., Culebras, A., . . . Vinters, H. V. (2013). An updated definition of stroke for the 21st century. *Stroke, 44*(7), 2064-2089. http://dx.doi.org/10.1161/STR.0b013e318296aeca

Schneider, W., Eschman, A., & Zuccolotto, A. (2012). E-Prime (Version 2.0). Pittsburgh: Psychology Software Tools, Inc.

Scott, C. A., Rapport, L. J., Coleman Bryer, R., Griffen, J., Hanks, R., & McKay, C. (2009). Self-assessment of driving ability and the decision to resume driving following stroke. *Journal of Clinical and Experimental Neuropsychology, 31*(3), 353-362. http://dx.doi.org/10.1080/13803390802169067

Siren, A., Hakamies-Blomqvist, L., & Lindeman, M. (2004). Driving Cessation and Health in Older Women. *Journal of Applied Gerontology, 23*(1), 58-69. http://dx.doi.org/10.1177/0733464804263129

Stapleton, T., Connolly, D., & O'Neill, D. (2012). Exploring the relationship between self-awareness of driving efficacy and that of a proxy when determining fitness to drive after stroke. *Australian Occupational Therapy Journal, 59*(1), 63-70. http://dx.doi.org/10.1111/j.1440-1630.2011.00980.x

Stone, S., Wilson, B., Wroot, A., Halligan, P., Lange, L., Marshall, J., & Greenwood, R. (1991). The assessment of visuo-spatial neglect after acute stroke. *Journal of Neurology, Neurosurgery & Psychiatry, 54*(4), 345-350. http://dx.doi.org/10.1136/jnnp.54.4.345

Strong, K., Mathers, C., & Bonita, R. (2007). Preventing stroke: saving lives around the world. *The Lancet Neurology, 6*(2), 182-187. http://dx.doi.org/10.1016/S1474-4422(07)70031-5

Swanson, J. (2005). The Delis-Kaplan Executive Function System: A review. *Canadian Journal of School Psychology, 20*(1/2), 117-128. http://dx.doi.org/10.1177/0829573506295469

Treccani, B., Torri, T., & Cubelli, R. (2005). Is judgement of line orientation selectively impaired in right brain damaged patients? *Neuropsychologia, 43*(4), 598-608. http://dx.doi.org/http://dx.doi.org/10.1016/j.neuropsychologia.2004.07.008

Wechsler, D. (2008). *Wechsler Adult Intelligence Scale–Fourth Edition (WAIS–IV)*. San Antonio, Texas, USA: NCS Pearson.

White, J. H., Miller, B., Magin, P., Attia, J., Sturm, J., & Pollack, M. (2012). Access and participation in the community: a prospective qualitative study of driving post-stroke. *Disability and Rehabilitation, 34*(10), 831-838. http://dx.doi.org/10.3109/09638288.2011.623754

Wolf, T. J., & Rognstad, M. C. (2013). Changes in cognition following mild stroke. *Neuropsychological Rehabilitation, 23*(2), 256-266. http://dx.doi.org/10.1080/09602011.2012.748672

Zinn, S., Bosworth, H. B., Hoenig, H. M., & Swartzwelder, H. S. (2007). Executive function deficits in acute stroke. *Archives of Physical Medicine and Rehabilitation, 88*(2), 173-180. http://dx.doi.org/http://dx.doi.org/10.1016/j.apmr.2006.11.015

Chapter Seven: On-road visual scanning in post-stroke drivers in relation to their cognitive functioning

Chapter Outline and Rationale

This penultimate chapter concludes the results documentation of the thesis. The purpose of the chapter was to address objectives one (assess the relationship between deficits in cognition, executive function and driving behaviour in post-stroke drivers and non-stroke drivers), four (assess the on-road driving behaviour of post-stroke drivers, compared to healthy controls) and seven (assess compensation strategies for deficits in cognition that enable driving in post-stroke adults), with deference to the foundations laid in the preceding chapters. The chapter investigates on-road behaviour of post-stroke adults compared to healthy controls, with particular focus on visual scanning patterns using eye-tracking technology and how these patterns relate to cognition. The findings relate to task demand and calibration and outline clear directions for future research investigating these areas in post-stroke drivers.

The chapter is written as a manuscript, formatted in line with the remainder of the thesis, and outlines the background to the study, the methodologies used, and the results found. The chapter concludes with discussing how post-stroke drivers compensate for deficits in attention and executive function by amending their scanning patterns and discusses the potential for post-stroke drivers to amend their physical on-road behaviour, to accommodate task demand and increase task calibration.

Abstract

Driving is an important task for the older population as it is relied upon for their independence. Safe driving is dependent on several cognitive processes, including attention and executive function, which can be impaired post-stroke. As post-stroke drivers are able to return to driving following a stroke, despite deficits in cognitive processes, it stands to reason that post-stroke drivers employ compensation strategies. This study aimed to investigate the visual scanning patterns of post-stroke drivers in order to provide insight in to their cognitive processing while driving. Attention and executive function were assessed in 23 licensed post-stroke drivers and in 26 controls, before they were taken on-road in their own vehicle wearing a head-mounted eye-tracker to assess their visual scanning patterns. Post-stroke drivers had shorter fixation durations, increased spread of horizontal and vertical fixations, as well as on average a greater number of fixations spread evenly across both traffic relevant and non-relevant objects. The findings were indicative of increased task demand in safety critical driving scenarios. The increased spread and total number of fixations were also related to executive function performance. The implications for rehabilitation, as well as fitness to drive assessments in post-stroke adults are discussed.

Keywords: Australia, Attention, Compensation Strategies, Executive Function, Driving, Eye-Tracking, Traffic Relevant Fixations

Introduction

Driving is a fundamental task of daily living, which is increasingly integral for independence, particularly in the ageing population (Mazer et al., 2003). As the population ages, the incidence of a stroke increases (Australian Institute of Health and Welfare, 2013; Sacco et al., 1997). Therefore it is not surprising that the proportion of stroke survivors who wish to continue driving is significant given the demand among older people to use the car as a means of independent transportation (Ellaway, Macintyre, Hiscock, & Kearns, 2003; Marottoli et al., 2000). Previously, research has provided estimates of between 30% - 50% of post-stroke adults will return to driving (Bryer, Rapport, & Hanks, 2006; Fisk, Owsley, & Pulley, 1997). This has significant implications for medical professionals who must ensure that post-stroke adults are safe to drive before they return to driving.

It is well-established that driving utilises a range of visual, cognitive and cerebral processes, including executive function and attention (Anstey, Wood, Lord, & Walker, 2005; Groeger, 2000; Motta, Lee, & Falkmer, 2014) and that attentional processing in humans is fluid (i.e., divisible across tasks), however the overall capacity is limited (Kahneman, 1973). The ability to correctly identify traffic relevant stimuli from visual scanning is crucial for driving safely and is dependent upon several types of perceptual and cognitive processes (Jonassen, 2000; Tabibi & Pfeffer, 2003). Furthermore, it is also well-established that these cognitive processes can decline post-stroke. For example, executive function (involving goal-orientated behaviour, planning and cognitive flexibility) can be negatively affected, which impacts upon decision making (Zinn, Bosworth, Hoenig, & Swartzwelder, 2007). In addition, attentional deficits can occur, which result in longer reaction times, require increased cognitive workload in order to complete a task (Daly, Fang, Perepezko, Siemionow, & Yue, 2006) and increased demand for attentional resources (Kahneman, 1973). Attention and executive function have been found to be the most significant predictors of fitness-to-drive post-stroke (Marshall et al., 2007) and both are crucial to the process of visual scanning and performing safe behaviour on the road (Anstey et al., 2005).

When driving, target and environmental information is obtained through the fovea into the optic system before being processed and interpreted using multiple cognitive processes in the brain (Falkmer, Dahlman, Dukic, Bjällmark, & Larsson, 2008). Therefore understanding eye-movements and scanning patterns offers a useful insight into cognitive processes whilst driving (Falkmer et al., 2008). Investigating visual scanning behaviour on the road is normally achieved using head-mounted eye-tracking cameras (e.g., Dukic & Broberg, 2012; Falkmer & Gregersen, 2001). These cameras record eye-movements and overlay them onto a recording of the external environment visible within the field of view. From this, researchers can infer what the participant was looking at and for how long (Falkmer et al., 2008; Schütz, Braun, & Gegenfurtner, 2011). For example, eye-tracking research investigating older and younger drivers has found that older drivers tend to focus on areas associated with safe positioning in traffic when at intersections, whereas younger drivers tend to focus on areas posing potential threats e.g., other vehicles (Dukic & Broberg, 2012). Other research investigating novice and experienced drivers found that novice drivers tend to focus more within the vehicle and straight ahead on the road (Underwood, 2007; Underwood, Chapman, Brocklehurst, Underwood, & Crundall, 2003), whereas more experienced drivers tend to have a wider spread of fixations as they have learned to assess for potential hazards (Underwood, 2007). Similar findings are reported with novice drivers displaying reduced scanning patterns and longer durations than experienced drivers in high-demand situations (Falkmer & Gregersen, 2001; Underwood, 2007). These findings are useful as they can result in targeted training to assist with on-road visual scanning techniques (Chapman, Underwood, & Roberts, 2002).

In the post-stroke population, eye-tracking research has found that hemianopic persons engage in compensatory behaviours by increasing the frequency with which they look, and widening the distribution of their spread of fixations (Bahnemann et al., 2015). Interestingly, in this particular study, it was not the amount of visual field loss that predicted the ability of the driver, more the ability of the driver to compensate for the deficit. Older adults have been found to have the capacity to undertake compensatory processes when driving (Andrews & Westerman, 2012). Not all post-stroke adults experience hemianopia as a result of their stroke, however they generally experience at least some deficit in cognitive processing (Jokinen et al., 2015). As there are post-stroke adults who return to driving despite the cognitive deficits they experience (Blane, Falkmer, Lee, Parsons, & Lee, 2016), it stands to reason that these drivers employ compensatory behaviours to counteract these deficits. Previous research has suggested that post-stroke adults undertake compensatory behaviours to assist with bringing the demands of driving to within their own specified and manageable level (Blane, Lee, Falkmer, & Dukic Willstrand, under review). Understanding the compensatory strategies employed by post-stroke drivers is important to help inform rehabilitation programmes and to understand how post-stroke adults are able to safely undertake the driving process. Previous research investigating scanning behaviours and compensation strategies in this area has primarily focused on older and younger drivers (Pradhan et al., 2005), novice and experienced drivers who have not had a stroke (Underwood, 2007) or on drivers with hemianopia or visual field loss as a result of a stroke (Bahnemann et al., 2015). At present there is little to no empirical evidence to investigate strategies employed by post-stroke adults without hemianopia to compensate for cognitive deficits.

The aim of this study was to investigate the visual scanning behaviour of post-stroke drivers, with a particular focus on the relationship between cognitive function and visual scanning patterns on road. It was hypothesised that post-stroke adults would amend their scanning patterns to compensate for cognitive deficits; specifically, that the spread of the fixations would be higher for post-stroke drivers than for controls as a compensation strategy for impaired cognitive function. In addition, the number of fixations on non-traffic relevant objects would be higher for post-stroke drivers than controls, since it may be expected that their selective attentional processes are less efficient.

Method

Design

A quasi-experimental, on-road comparison group study design was employed.

Participants

Inclusion criteria for participation were that all participants held a driver's licence valid within Australia, had at least one year of overall driving experience, drove at least twice a week and had access to a fully insured vehicle. Further criteria for the post-stroke group were that they had previously been diagnosed with a stroke (either ischemic or haemorrhagic) and had been cleared to drive by a medical professional. Participants were excluded if they had been diagnosed with hemianopia, any neurodegenerative disease, such as Parkinson's disease or dementia, and if they required a wheelchair for mobility. One control participant's data was excluded based on a post-assessment notification of frontal lobe dementia. Participants were recruited using purposive sampling techniques including: using local community groups, post-stroke support groups, community newspapers and local radio stations. The post-stroke participants were recruited first and the control participants were recruited second with the age, gender and demographics monitored to ensure comparability between groups.

The total sample consisted of 48 participants and included 23 post-stroke drivers (male = 20) and 25 controls (male = 20). The mean age of the post-stroke group was 64 years (SD = 10). The control participants were slightly older with a mean age of 70 years (SD = 6). Similarly, post-stroke drivers reported a slightly shorter licence length than controls; 48 years (SD = 9), and 50 years (SD = 12), respectively. The mean recovery time since stroke was 3.6 years (SD = 3) with recovery times ranging from six months -15 years. Post-stroke drivers reported greater annual millage measured in kilometres (km) with a mean of 18,350 KM (SD= 15,072km) than controls who reported a mean of 16,460km (SD = 13,002km). No statistically significant difference was found between groups for age, gender distribution, licence length or driving exposure, therefore the groups were considered well-matched (Evans, 2004). Participants were asked to report their country of birth and although both groups were above the national percentage for residents born overseas (28.1 %; Australian Bureau of Statistics, 2016) there was no statistically significant difference between group for country of birth distribution as both groups reported 47% of participants born overseas.

Measurements

Visual Acuity. In order to screen for potential confounding effects of poor visual acuity (VA), and to ensure compliance with the minimum VA for safe driving in Western Australia, bilateral visual acuity (with corrective lenses if required) for each participant was assessed using the Early Treatment Diabetic Retinopathy Study (ETDRS) chart (Precision Vision). All participants were required to achieve a bilateral score of 20/40 VA in order to participate, and all participants met the minimum requirements. One post-stroke participant had a diagnosis of quadrantopia, but was included as he had been cleared to drive.

Visual Scanning, Attention and Executive Function. Visual scanning, attention and executive functioning were measured using the Delis-Kaplan Trail-Making Task (Delis, Kaplan, & Kramer, 2001), which is comprised of a visual cancellation task (DKEFS TMT 1) and several circle connection tasks (DKEFS TMT 2, DKEFS TMT 3, DKEFS TMT 5). The fourth task (DKEFS TMT 4) was a number-letter switching task, whereby the participant was asked to connect the circles from a number to a letter across two pages ultimately connecting all circles in order. This fourth task assessed executive function, specifically through assessing visuospatial thought flexibility (Swanson, 2005). Participants were timed to completion for each task and slower time-to-completion results were taken as an indication of poorer performance and displayed increased difficulty with the respective cognitive process. The time-to-completion scores were scaled to account for age effects and to contrast scores to assess executive function independent of baseline processes calculated (Delis et al., 2001). Higher scaled scores were indicative of better cognitive function.

Eye-Tracking Glasses. Visual scanning patterns were assessed for each group using either a monocular (Arrington) or binocular Sensomotoric Instruments (SMI) head-mounted portable eye-trackers. The two different eye-trackers used as part of this study were the Arrington ViewPoint^{TM} eye-tracking glasses (Figure 19 - left) and the (SMI) eye-tracking glasses (Figure 19 - right). During assessments, the units were controlled using a laptop.

Figure 19 .The two different head-mounted eye-trackers used in the study. Left - the Arrington ViewPoint eye-tracker. Right - the SMI head-mounted eye-tracker. Reprinted from http://www.businesswire.com/news/home/20141219005468/en/SMI-Eye-Tracking-Glasses-Set-Industry-Standard

Data Collection and Processing

Prior to the on-road assessment, participants completed the participant information sheet and were screened using the ETDRS. The eye-tracker was fitted onto the participant's head and calibrated. The Arrington ViewPoint eye-tracker was calibrated using a 16-point procedure, by following a laser pointed dot against a projector screen placed three metres from the participants in the driving laboratory. The SMI eye-tracker was calibrated using a three point chart placed one meter in front of the participant. In both cases, calibration was confirmed once in the vehicle by asking the participant to follow the finger of the researcher who traced a shape in by the researcher in the air just in front of the car. Eye-tracking data were collected during a supervised on-road driving assessment. The assessment took place in the participants' own vehicles, was approximately 13km in length and took approximately 20 minutes to complete. The route (Figure 20) was pre-defined and designed to cover safety critical challenges, i.e., those that required the most cognitive capacity, such as turning right (in left hand traffic) and negotiating pedestrian crossings (Figure 20). These scenarios were also chosen as they tend to be the scenarios that require the most cognitive demand and are considered most challenging by the older population

(Oxley, Fildes, Corben, & Langford, 2006). Participants were unaware of the route prior to the drive and were given directions by the researcher. There were two researchers present in each of the on-road driving assessments, for safety and logistical purposes. One researcher managed the eye-tracking equipment, whilst the other provided directions and conducted the on-road observation.

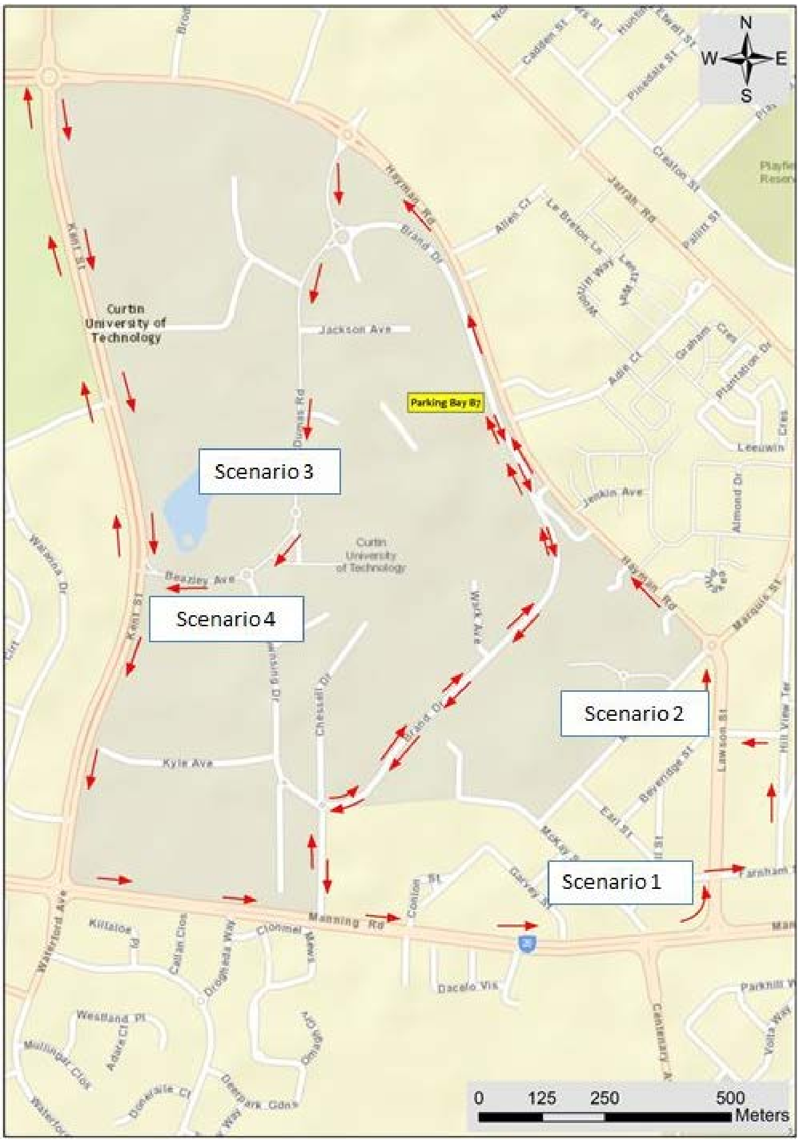

Figure 20. Map of driving route including the four driving scenarios. Adapted from Google Maps (2017a). Retrieved from https://www.google.com.au/maps/@-32.0066262,115.8927424,15.75z

Driving Scenarios

There were four driving scenarios investigated, a diagram of which is outlined in Figure 21:

- Scenario one included turning right across a dual lane road into a minor road
- Scenario two involved stopping at a stop sign before turning right from a minor road into a major road
- Scenario three involved the participant safely driving across a raised zebra crossing with zig zag lines.
- Scenario four involved turning right at a give-way sign and crossing a dual-lane major road with opposing traffic and safely negotiating an intersection gap in the median strip.

Figure 21. Graphic outline of the route for driving scenarios. Adapted from Google Maps (2017b). Retrieved from *https://www.google.com/maps/@32.0076663,115.89098,1491m/data=!3m1!1e3*

Data Analyses

Eye-Tracking. The eye-trackers recorded a real-time moment-to-moment recording of both the visual stimuli through a video-recording of the surrounding environment, and the eye movement data, including accumulated measures of fixation-based information. Data were recorded in 60 Hz. The number of fixations and duration of fixations were recorded for each participant and these data were overlaid with the video recording of the environment, in order to code each fixation for traffic relevancy. The variation in position for each fixation, recorded in degrees, was measured in each scenario by calculating the standard deviation of fixation along the horizontal (X) and vertical (Y) axes (Konstantopoulos, Chapman, & Crundall, 2010). Based on previous eye-tracking research, (e.g., Falkmer & Gregersen, 2005) a fixation was defined as the mean of the X,Y fixation coordinates within a 1° x 1° area and ≥100ms in duration.

Data collected using the Arrington ViewPoint eye-tracker were processed and analysed using the ViewPoint data analysis program (Arrington Research, 2006). Data recorded using the SMI eye-tracker were processed and raw measurements computed using the SMI BeGaze 3.5 software (SensoriMotoric Instruments, 2011) before the fixation data were calculated using a customised Matlab-based fixation generation interface. Fixations for both Arrington and SMI collected data were generated using the centroid-mode algorithm (Falkmer et al., 2008).

All generated fixations for each defined area of interest were reviewed using either the ViewPoint program or Microsoft Excel© to distinguish fixations and then manually coded frame by frame as traffic relevant (e.g., the road, other road users, traffic signs) or non-relevant (e.g., pavement, sky, landscape) using a coding matric (Appendix 14).

Eye-tracking data quality. All fixation data coding was assessed for quality assurance by the lead author (AB) through double checking and double data entry of 20% of each participant's fixations, which were selected at random. For each scenario there was 26% missing data in the post-stroke group, due to issues with glare, technological issues with the eye-tracker or due to road closures. There was no data loss in any scenario for the control group. Although there was data loss during the data recording phase, the data collected were of sufficient quality for processing and to determine between group differences in visual scanning behaviours. With respective group sample sizes of 21:25 (due to data loss), there was 80% power to detect an effect size of 0.85 between the post-stroke drivers and controls (Cohen, 1988).

Statistical Analyses. Descriptive and univariate statistics were used to characterise each group and all data were analysed using the Statistical Package for the Social Sciences (SPSS) v.23 (IBM Corporation, 2013). Normality of all variables were assessed using a histogram, Q-Q plots, and measures of skewness and kurtosis. The visual scanning variables and the total number of fixations and traffic relevant fixations were found to be normally distributed, therefore between groups differences were assessed using independent samples t-tests. Between groups assessment of proportion of traffic relevant fixations was assessed using a generalised estimating equation (GEE) analysis. This particular model was used so that correlation between observations on the same participant could be taken into account. All other variables were assessed using the Mann-Whitney U test. A p-value of < 0.05 was taken to indicate a statistically significant association in all tests.

Ethical Considerations

This research and the associated study protocols conformed to the Declaration of Helsinki and were approved by the Curtin University Human Research Ethics Committee – approval number: HR206-2014. Participants were presented with an information sheet, given the opportunity to ask questions and each provided signed informed consent prior to participation. Participants were also informed that they could leave the study at any time without incurring any negative consequences. They were offered a $15 (Australian) gift voucher as a token of appreciation for their time and travel costs.

Results

Cognition

There were significant differences in scaled cognitive performance between groups. The post-stroke drivers performed more poorly, as shown by lower mean scaled scores, indicating slower reaction times in all of the baseline trail-making tasks, however there were no significant differences in the higher order functions measured by the contrast scaled scores (Table 32).

Table 32.

Group based differences in cognitive variables (independent samples t-tests)

Variables	Post-Stroke Driver			Controls			t-value	df	p-value
	n	Mean	SD	n	Mean	SD			
DKEFS TMT 1	23	8.10	3.41	25	11.60	2.08	-4.36	35.8	0.001*
DKEFS TMT 2	23	9.40	3.41	25	11.84	2.99	-2.65	46	0.01*
DKEFS TMT 3	23	9.08	3.72	25	12.04	2.26	-3.29	35.8	0.002*
DKEFS TMT 4	23	8.56	4.35	25	11.60	2.96	-2.85	46	0.007*
DKEFS TMT 5	23	9.30	3.61	25	12.52	1.71	-3.89	30.8	0.001**
DKEFS TMT EF1	23	18.48	6.47	25	23.88	4.85	1.63	46	0.001**
DKEFS TMT EF2	23	9.26	3.98	25	9.92	2.89	-0.66	46	0.51
DKEFS TMT EF3	23	9.61	4.29	25	9.56	2.22	0.05	32.4	0.96
DKEFS TMT EF4	23	9.17	3.93	25	8.8	2.46	0.31	46	0.76
DKEFS TMT EF5	23	9.39	4.54	25	9.08	2.93	0.28	37.1	0.78

*Significant difference between group means; p-value <0.05

**Significant difference between group means; p-value <0.001

Eye-tracking

Number of Fixations. Overall, the post-stroke drivers had a higher number of fixations compared to control participants during scenario one and scenario three (Table 33) however, there was no difference in the number of fixations between groups during either scenario three or four (Table 34). When assessing the number of traffic relevant fixations and traffic non-relevant fixations, it was found there were no between groups differences in any of the driving scenarios (Table 35), suggesting that the proportion of traffic relevant fixations was comparable between groups. As the eye-tracking took place on-road in real-time traffic, there is the possibility for traffic to affect the duration of each scenario. In order to control for this, dwell time (i.e., the ∑ duration of all fixations) for each scenario was assessed. It was found that, on average there were no significant differences displayed, suggesting that the amount of time spent at each scenario between groups was comparable (Table 36).

Table 33.

Group based differences in number of fixations per driving scenario (independent samples t-test)

Scenario	1		3	
	Post-Stroke	Control	Post-Stroke	Control
n	21	25	21	25
# fixations	1293	1065	802	734
Mean	52.10	38.14	38.19	27.72
SD	22.92	17.13	13.25	14.46
t value	2.24		2.54	
df	44		44	
p-value	0.03*		0.02*	

*Significant difference between group means; p-value <0.05

Table 34.

Group based differences in number of fixations per driving scenario (Mann-Whitney U test)

Scenario	2		4	
	Post-Stroke	Control	Post-Stroke	Control
n	21	25	21	25
# fixations	936	1229	952	1018
Median	39	41	31	34
IQR	23	25	52	15
p-value	0.51		0.63	

Table 35.

GEE analysis group based difference in number of traffic relevant fixations in each driving scenario

Scenario	Group	Traffic Relevant	Not Traffic Relevant	Odds Ratio	95% CI		p-value
					Lower	Upper	
Scenario 1	Post-stroke	39%	61%	0.84	0.47	1.50	0.55
	Control	39%	61%				
Scenario 2	Post-stroke	43%	57%	0.88	0.51	1.52	0.65
	Control	47%	53%				
Scenario 3	Post-stroke	48%	52%	0.89	0.47	1.67	0.71
	Control	56%	44%				
Scenario 4	Post-stroke	41%	59%	0.82	0.49	1.35	0.42
	Control	51%	49%				

Table 36.

Group based differences dwell time (independent samples t-test)

Scenario	1		2		3		4	
	Post-stroke	Control	Post-stroke	Control	Post-stroke	Control	Post-stroke	Control
n	21	25	21	25	21	25	21	25
Mean	10.00	8.33	8.41	10.87	7.6	6.24	7.79	8.60
SD	3.85	3.9	6.09	6.04	2.73	3.69	5.19	4.48
t value	1.45		-1.37		1.4		-0.58	
df	44		44		44		44	
p-value	0.15		0.18		0.17		0.57	

Spread of fixations. Both the horizontal spread and vertical spread of fixations were assessed through computing the standard deviation of fixation placement on either the X or the Y axis. On the horizontal axis, on average the post-stroke drivers displayed a larger standard deviation, indicating increased horizontal scanning in all scenarios (Table 37). Similarly, on the vertical axis, on average the post-stroke drivers displayed a larger standard deviation in fixation location in all scenarios (Table 37), suggesting that the post-stroke drivers had a larger vertical spread of fixations than controls. A graphical representation of total fixation spread in all scenarios is displayed in Figure 22.

Table 37.

Group based differences spread (independent samples t-test)

Variable	Scenario	Post-stroke			Control			t-value	df	p-value
		n	Mean	SD	n	Mean	SD			
Horizontal Spread	1	21	5.80	2.42	25	2.96	3.74	3.132	41.5	0.003*
	2	21	8.44	4.80	25	5.03	5.89	2.16	44.0	0.04*
	3	21	5.91	2.80	25	2.46	3.04	3.97	44.0	0.001**
	4	21	9.57	4.30	25	5.86	6.95	2.21	40.7	0.04*
Vertical Spread	1	21	3.15	1.42	25	1.45	1.90	3.38	44.0	0.002*
	2	21	4.34	1.88	25	1.75	2.07	4.42	44.0	0.001**
	3	21	3.77	1.94	25	2.04	2.82	2.38	44.0	0.02*
	4	21	4.08	1.59	25	2.03	2.49	3.23	41.2	0.002*

*Significant data; p-value <0.05

**Significant data; p-value <0.001

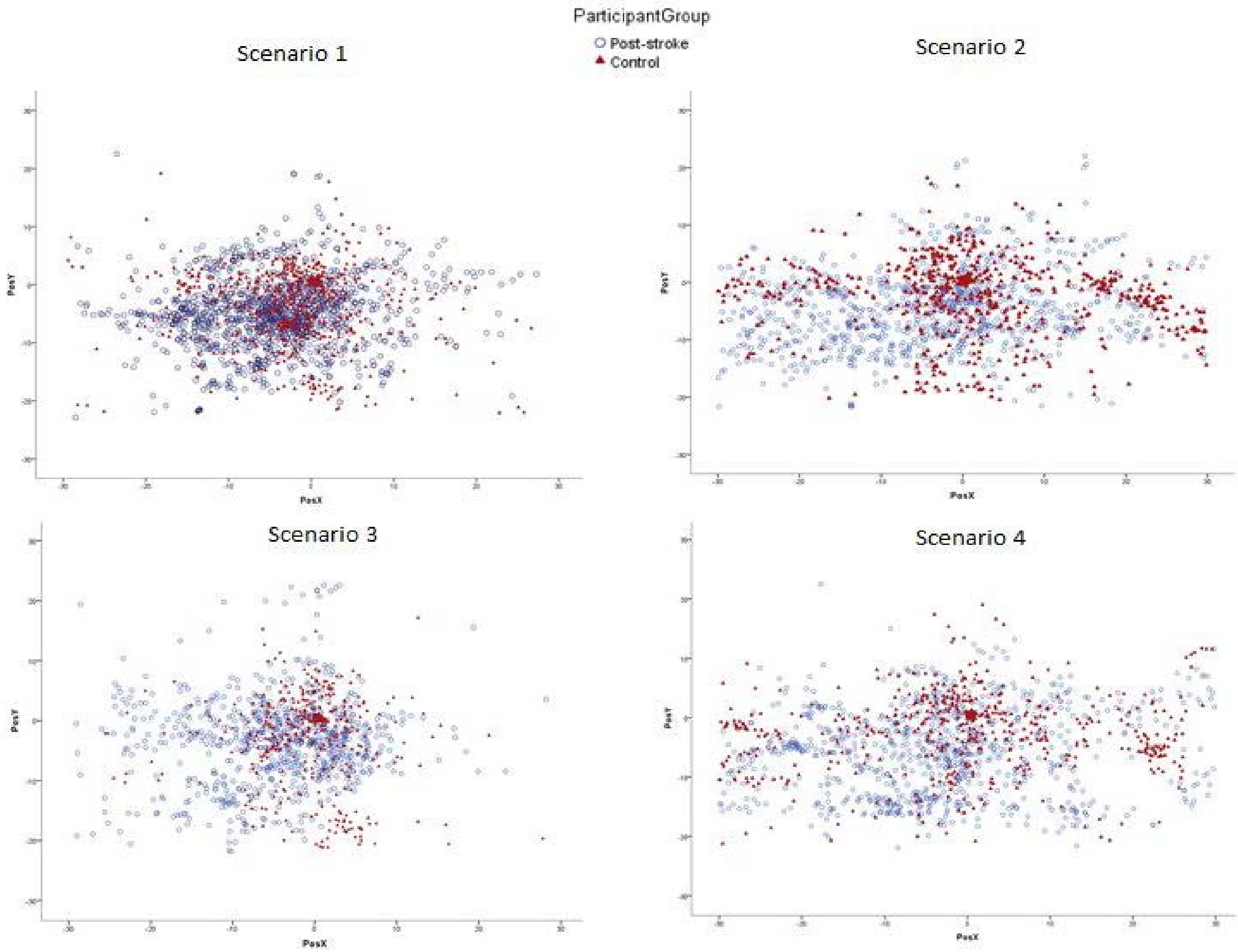

Figure 22. Scatter graphs of the variation in position of total fixations in each scenario.

Fixation Duration. Significant differences in fixation duration between groups were observed in scenarios two, three and four, as the post-stroke drivers displayed shorter fixations than controls (Table 38).

Table 38.

Group based differences in traffic relevant fixation duration in each driving scenario (Mann-Whitney U Test)

Scenario	1		2		3		4	
	Post-stroke	Control	Post-stroke	Control	Post-stroke	Control	Post-stroke	Control
n	21	25	21	25	21	25	21	25
# Fixations	506	412	402	573	381	407	391	524
Median	0.17	0.17	0.15	0.17	0.15	0.17	0.13	0.17
IQR	0.13	0.10	0.12	0.15	0.12	0.13	0.10	0.10
Mean	0.20	0.21	0.19	0.25	0.19	0.22	0.17	0.25
p-value	0.07		0.001**		0.001**		0.001**	

**Significant difference between group medians; p-value <0.001

Cognition and Eye-tracking

Further analyses were conducted to assess whether deficits in cognitive ability, specifically executive function and visual attention accounted for visual scanning in the post-stroke drivers (i.e., spread and number of fixations). General linear models were built with the standard deviation of the X coordinates, standard deviation of the Y coordinates and total number of fixations entered as dependent variables respectively, and using only data belonging to the post-stroke group.

The final model for total fixations in each scenario (Table 39) suggested that post-stroke drivers who had higher scores in executive function, independent of their visual attention score, were more likely to have greater numbers of fixations in tasks one and four and although the executive function score independent of visual scanning was not significantly associated with total fixations in scenario two and three, both results were approaching significance. The final model for vertical spread in each scenario (Table 40) suggested that visual attention alone accounted for variance in vertical spread in scenario one and the relationship in scenario two approached significance. Interestingly, the post-stroke drivers who had poorer scores in executive function independent of visual scanning ability in scenarios one and four were more likely to have increased numbers of fixations. Interestingly, it appeared that in scenario one, the post-stroke drivers who had impaired executive function, appeared to display greater numbers of fixations and have a smaller spread of fixations, however those who performed well in the executive function scenario had fewer fixations and increased spread of vertical fixations. No cognitive variable accounted for differences in any scenario on the horizontal axis.

Table 39.

General linear models assessing relationship of executive function contrast score (IV) with total number of fixations (DV).

Scenario	DV	Unstandardized Coefficients		95% CI		Adjusted R^2	p-value
		B	SE	Lower Bound	Upper Bound		
Scenario 1	Total Fixations	-2.66	0.97	-4.68	-0.64	0.25	0.01*
Scenario 2	Total Fixations	-3.23	1.59	-6.54	0.09	0.14	0.06
Scenario 3	Vertical Spread	0.24	0.12	0.001	0.48	0.14	0.05
	Total Fixations	-1.16	0.68	-2.58	0.25	0.09	0.09
Scenario 4	Total Fixations	-4.93	1.56	-8.18	-1.68	0.31	0.005*

*Significant data; p-value <0.05

Table 40.

General linear models assessing relationship of visual scanning and attention score (IV) with spread of fixations (DV).

Scenario	DV	Unstandardized Coefficients		95% CI		Adjusted R^2	p-value
		B	SE	Lower Bound	Upper Bound		
Scenario 1	Vertical Spread	-0.29	0.08	-0.46	-0.12	0.36	0.002*
Scenario 2	Vertical Spread	-0.23	0.11	-0.47	0.009	0.13	0.06
Scenario 3	Vertical Spread	-0.13	0.14	-0.42	0.15	0.004	0.35
Scenario 4	Vertical Spread	-0.13	0.11	-0.35	0.09	0.02	0.24

*Significant data; p-value <0.05

Discussion

Summary of findings

When cognitive ability was tested, as expected and similar to previous research findings (e.g., Blane et al., 2016; Jokinen et al., 2015), the post-stroke adults performed more poorly on the tests of cognitive ability. Despite this, the differences appeared to only be present at the baseline functioning as there were no differences for contrast scores, which provide insight into higher order functioning independent of baseline scores (Swanson, 2005). This is an important finding as it has previously been found that declines in the visuo-cognitive system account for the accident rates in older adults, rather than purely visual processing (Ball & Owsley, 1991; Ball, Owsley, Sloane, Roenker, & Bruni, 1993). However, this result appears to support the hypothesis that brains of older adults show over-activation of higher order processes (i.e., higher order processes work harder) to compensate for declining function (Reuter-Lorenz & Cappell, 2008). This is particularly relevant given that post-stroke drivers trended towards higher scaled scores in the executive functioning contrast calculations.

There were several dependent variables assessed as part of visual scanning behaviour, i.e., number of total fixations, proportion of traffic relevant and non-relevant fixations, fixation duration, horizontal and vertical spread of fixations. As the study was completed on-road, there is always the issue of traffic causing increased time at intersections however, as there was no significant difference in dwell time (i.e., the total time spent at each scenario), differences observed were considered as resulting from the group membership rather than influenced by the time spent fixating in the traffic environment.

During scenarios one and three, the post-stroke adults displayed a greater number of overall fixations and although the post-stroke drivers generally looked less at traffic relevant information, overall there was no significant difference in the proportion of traffic relevant and non-relevant fixations for any scenario. This suggested that overall the post-stroke drivers looked more at both traffic relevant and non-relevant information during these scenarios. This is a surprising finding and contrary to the hypothesis for the study, as it was expected that the post-stroke drivers would look more at non-relevant information. It suggests that the greater number of fixations may be a compensation strategy. This result is in line with previous research, which has suggested that visual scanning behaviour increases in more cognitively demanding situations (Underwood, 2007), as it can be argued that post-stroke drivers find the driving task more challenging due to deficits in cognitive function (Blane et al., under review).

The pattern of greater numbers of fixations in the post-stroke group was not seen in scenarios two and four, and there were no between group differences for proportion of traffic relevant and non-relevant fixations. As both these scenarios involve turning right across multiple lanes and bi-directional traffic, these scenarios are arguably the most cognitively demanding for the older driver (McGwin & Brown, 1999). Therefore, one possible suggestion for this is that both groups were comparable in their view of the task demand and therefore their fixations reflect the work required to process the visual stimuli (Falkmer & Gregersen, 2001; Underwood, 2007).

There appeared to be several between group differences in fixation duration for each scenario. There was no between groups difference in fixation duration for scenario one, whereas there were differences in scenarios two, three and scenario four with the post-stroke drivers displaying shorter fixation durations than the controls. This corroborates with previous research that has suggested that drivers decrease their fixation duration and increase the number of fixations as scenario demands increase (Crundall & Underwood, 1998).

When investigating the spread of fixations there were several significant between group differences. On the both the vertical and horizontal axes, the post-stroke drivers had a wider spread of fixations, suggesting that they scan their outlook more widely on both axes than the control participants in all scenarios. These results provide further support for the theory that as the post-stroke drivers increase their level of scanning to manage the increased level of difficulty required to complete the driving scenario (Crundall & Underwood, 1998) in compensation for their cognitive deficits, albeit with a previously defined inefficient scanning strategy (Young, 2000). The authors hypothesised that these increases in scanning were a compensation strategy, therefore the cognitive variables were entered into the analyses to investigate the degree to which cognitive ability accounted for deficits in the post-stroke group. The final models indicated that executive function accounted for the most variance in the post-stroke drivers in scenario three for vertical spread, and for the total number of fixations in scenarios one and four, with scenarios two and three approaching significance. Visual scanning and attention accounted for the most variance in the vertical spread for scenario one, although the scenario two also approached significance.

Specifically, in scenario one, which was turning right from a major road to a minor road, it appeared that as performance in executive function increased, the horizontal and vertical spread increased. Conversely, where the performance in executive function was poor, the post-stroke adults increased their total number of fixations. In scenario four, the total number of fixations was explained by deficits in executive function and the same pattern emerged as in scenario one where post-stroke adults who performed poorly on the executive function task, in general had a larger number of fixations. This again corroborates previous literature suggesting that drivers will compensate for deficits in high demand situations by amending scanning patterns (Crundall & Underwood, 1998). What is more difficult to explain are the results in scenario three. Although the total number of fixations was significantly different between groups, deficits in cognition did not account for increased fixations in the post-stroke group, however the result did approach significance. In Scenario three the pedestrian crossing is safety critical, however compared a right turn the level of cognitive demand is not as high, as indicated by the similarity in the medians duration between groups. It is therefore possible that the increase horizontal spread and number of fixations is an indication of a cautious approach of post-stroke adults to driving in this scenario (Blane, Lee, Falkmer, & Dukic Willstrand, 2017; Blane et al., under review).

It is difficult to determine whether the post-stroke adults are actively amending their scanning patterns as a compensatory mechanism, or whether it is an automatic process as a result of an inability to quickly process the information. However, as the post-stroke drivers were licensed and had been cleared to drive by a medical professional (many of whom had passed a driving reassessment, in order to return to driving), and as similar research has also found that licensed post-stroke drivers were of comparable driving standards to controls (Blane et al., 2017), it was concluded that the visual scanning patterns observed in the post-stroke group were indicative of compensation strategies for poor cognitive function. These results are similar to previous research in older drivers, and in post-stroke hemianopic patients, who amend their eye-movements to compensate for the visual and cognitive deficits (Szlyk, Seiple, & Viana, 1997) and subsequent increased task demand, either through increasing their amount of fixations or increasing their visual scanning on the x and y axis to compensate.

The present study results highlight the need to identify a method to evaluate fitness-to-drive after a stroke involving investigating the visual scanning behaviours. The diagnosis of a stroke itself may have little impact on the ability to drive safe, rather the ability to compensate for the subsequent deficits is important. Utilising these results will help inform rehabilitation programmes and will allow post-stroke adults to return to driving. Improving post-stroke driving outcomes is crucial to prevent isolation, a decrease of well-being and the increase of costs for society (Fonda, Wallace, & Herzog, 2001; Marottoli et al., 2000).

Limitations

As is common in eye-tracking research in the older population, there were difficulties with calibration of the equipment due to spectacle use, which ultimately limited the sample size in both groups. Although the sample size was sufficient for statistical power there were two different eye-trackers used, which potentially introduces bias. This bias was minimised through using the same fixation generation methodology, however it was not statistically possible to assess whether the differences in fixations were affected by type of eye-tracker the majority of the use of the Arrington eye-tracker was mostly confined to the control group. It is possible that the quality of data may differ between eye-trackers, despite having the same resolution accuracy of 0.2 degrees in the visual field, therefore future research should use a larger sample utilising the same eye-tracking equipment.

The final general linear models were calculated using the post-stroke group only, which had 21 participants, therefore the possibility for type II errors increase. Furthermore, there were multiple low-to-moderate adjusted R^2 scores in the final analysis investigating the association between cognition and scenario fixation total and spread, which are from separate models. Statistically there is a higher potential for type I errors when running multiple general linear models, however it did not make theoretical sense to combine the total number and spread of fixations (Field, 2013), therefore although the results are indicative, they should be interpreted with caution. Furthermore, the explained variance ranged between a quarter to a third of the total variance, suggesting that other factors not measured as part of the present study may be of high relevance. Previous research has found that head and body movement restrictions, which is possible following a stroke (Handley, Medcalf, Hellier, & Dutta, 2009), impacts on the ability of drivers to process on-road information due to a restricted field of view (Isler, Parsonson, & Hansson, 1997).

The groups were well matched for age, gender and driving exposure, however there were fewer females in both groups, which makes the results difficult to generalise to the female population, particularly as there are acknowledged differences between genders with regard to driving behaviour (Evans, 2004; Gwyther & Holland, 2012; Oltedal & Rundmo, 2006). In this study, it is likely that the small number of female drivers is a reflection of the propensity for older females to partake in increased driving self-regulation and self-imposed driving cessation (Siren, Hakamies-Blomqvist, & Lindeman, 2004), and the tendency for older women to have more severe outcomes following a stroke (Katsiki, Ntaios, & Vemmos, 2011). However, further research should attempt to equalise the gender distribution as the pattern of older females ceasing driving is likely to lessen as current generations age (Hjorthol, Levin, & Sirén, 2010), and with females in general having greater longevity than males (Austad, 2006). Similarly, the recruitment techniques employed in this study meant that participants self-selected into the study, and although where possible, information regarding health-status, particularly in the post-stroke group were sighted, the demographic results are heavily reliant on self-report. In addition, there are inherent biases within self-selection and those who chose to participate in research but, it was not practical or feasible to employ more robust forms of sampling for this study.

Generalisability of the on-road data is always problematic as there is no control over traffic and the environment. Future research should investigate whether the results are the same in a simulated driving environment, which may then be used for training and rehabilitation purposes. Furthermore, it may be useful to investigate the level of generalisability in post-stroke drivers with less driving experience as visual scanning patterns alter depending on experience (Chapman et al., 2002; Falkmer & Gregersen, 2001), since this may impact on those post-stroke adults who have less driving experience or those who have not driven for a long time, and who may require further support and specific driving training and rehabilitation.

Further research in this area would benefit from assessing driving behaviour as part of a formalised assessment. Although these groups have previously been found to be comparable in driving performance (Blane et al., 2017; Blane et al., under review) and all participants were licensed therefore assumed to be of a sufficient standard, no formalised assessment has taken place, which can make definitive comparisons difficult. Similarly, it would be useful as part of the on-road driving assessment to monitor speed and lane changes to determine whether post-stroke adults amend their behaviour on-road to assist with the compensation strategies found in this study.

Conclusion

Post-stroke drivers amend their visual scanning patterns depending on their levels of executive function. Those with better executive function have an increase in spread, whereas those with poorer executive function increase their number of fixations. Understanding the compensation strategies adapted by post-stroke drivers are important to share with the medical community as it will help inform rehabilitation programmes to assist post-stroke adults return to driving. This will increase confidence for post-stroke adults that there may be the option to return to driving and prevent them from the isolation which can accompany driving cessation in the older population.

Chapter Summary and Progression

This final results chapter has developed the findings discussed in earlier chapters and outlined the visual scanning patterns that post-stroke drivers use on-road and how they relate to cognition. The chapter outlined how post-stroke drivers, compared to healthy controls, exhibit the same strategies used by other drivers in high demand situations and discussed how these strategies appear to be a compensatory mechanism for cognitive deficits

The final chapter will discuss the overall results and conclusions in context, as well as outline the recommendations that can be drawn from the thesis findings.

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Chapter Seven References

Andrews, E. C., & Westerman, S. J. (2012). Age differences in simulated driving performance: Compensatory processes. *Accident Analysis & Prevention, 45*, 660-668. http://dx.doi.org/http://dx.doi.org/10.1016/j.aap.2011.09.047

Anstey, K. J., Wood, J., Lord, S., & Walker, J. G. (2005). Cognitive, sensory and physical factors enabling driving safety in older adults. *Clinical Psychology Review, 25*, 45-65. http://dx.doi.org/10.1016/j.cpr.2004.07.008

Arrington Research. (2006). ViewPoint EyeTracker®. Retrieved from http://www.arringtonresearch.com/viewpoint.html

Austad, S. N. (2006). Why women live longer than men: Sex differences in longevity. *Gender Medicine, 3*(2), 79-92. http://dx.doi.org/http://dx.doi.org/10.1016/S1550-8579(06)80198-1

Australian Bureau of Statistics. (2016). *Migration, Australia, 2014-2015*. Canberra: Australian Bureau of Statistics. .Retrieved from http://www.abs.gov.au/ausstats/abs@.nsf/mf/3412.0

Australian Institute of Health and Welfare. (2013). *Stroke*. Canberra: Retrieved from http://www.aihw.gov.au/WorkArea/DownloadAsset.aspx?id=60129543611

Bahnemann, M., Hamel, J., De Beukelaer, S., Ohl, S., Kehrer, S., Audebert, H., . . . Brandt, S. A. (2015). Compensatory eye and head movements of patients with homonymous hemianopia in the naturalistic setting of a driving simulation. *Journal of Neurology, 262*(2), 316-325. http://dx.doi.org/10.1007/s00415-014-7554-x

Ball, K., & Owsley, C. (1991). Identifying correlates of accident involvement for the older driver. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 33*(5), 583-595. http://dx.doi.org/10.1177/001872089103300509

Ball, K., Owsley, C., Sloane, M. E., Roenker, D. L., & Bruni, J. R. (1993). Visual attention problems as a predictor of vehicle crashes in older drivers. *Investigative Ophthalmology & Visual Science, 34*(11), 3110-3123.

Blane, A., Falkmer, T., Lee, M., Parsons, R., & Lee, H. C. (2016). The cognitive and socio-demographic influences on driving performance and driving cessation in post-stroke drivers. *Advances in Transportation Studies: An International Journal,*(38), 121-135.

Blane, A., Lee, H. C., Falkmer, T., & Dukic Willstrand, T. (2017). Assessing cognitive ability and simulator-based driving performance in post-stroke adults. *Behavioural Neurology, 2017* (Behavioural and Cognitive Effects of Cardiovascular Disease), 1-9. http://dx.doi.org/10.1155/2017/1378308

Blane, A., Lee, H. C., Falkmer, T., & Dukic Willstrand, T. (under review). Cognitive ability as a predictor of task demand and self-rated driving performance in post-stroke drivers – implications for self-regulation.

Bryer, R. C., Rapport, L. J., & Hanks, R. A. (2006). Determining fitness to drive: Neuropsychological and psychological considerations In J. M. Pellerito (Ed.), *Driver Rehabilitation and Community Mobility* (pp. 165-184). Saint Louis, USA: Mosby. http://dx.doi.org/:http://dx.doi.org/10.1016/B978-032302937-7.50013-7

Business Wire (2017).[image] Retrieved from http://www.businesswire.com/news/home/20141219005468/en/SMI-Eye-Tracking-Glasses-Set-Industry-Standard

Chapman, P., Underwood, G., & Roberts, K. (2002). Visual search patterns in trained and untrained novice drivers. *Transportation Research Part F: Traffic Psychology and Behaviour, 5*(2), 157-167. http://dx.doi.org/http://dx.doi.org/10.1016/S1369-8478(02)00014-1

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, New Jersey: L. Erlbaum Associates.

Crundall, D. E., & Underwood, G. (1998). Effects of experience and processing demands on visual information acquisition in drivers. *Ergonomics, 41*(4), 448-458. http://dx.doi.org/10.1080/001401398186937

Daly, J. J., Fang, Y., Perepezko, E. M., Siemionow, V., & Yue, G. H. (2006). Prolonged cognitive planning time, elevated cognitive effort, and relationship to coordination and motor control following stroke. *IEEE Transactions on Neural Systems and Rehabilitation Engineering: a publication of the IEEE Engineering in Medicine and Biology Society, 14*(2), 168-171.

Delis, D. C., Kaplan, E., & Kramer, J. H. (2001). *Delis-Kaplan Executive Function System (D-KEFS) examiner's manual*. San Antonio, Texas: The Psychological Corporation.

Dukic, T., & Broberg, T. (2012). Older drivers' visual search behaviour at intersections. *Transportation Research Part F: Traffic Psychology and Behaviour, 15*(4), 462-470. http://dx.doi.org/10.1016/j.trf.2011.10.001

Ellaway, A., Macintyre, S., Hiscock, R., & Kearns, A. (2003). In the driving seat: Psychosocial benefits from private motor vehicle transport compared to public transport. *Transportation Research Part F: Traffic Psychology and Behaviour, 6*(3), 217-231. http://dx.doi.org/http://dx.doi.org/10.1016/S1369-8478(03)00027-5

Evans, L. (2004). *Traffic safety*. Bloomfield Hills, Michigan: Science Serving Society.

Falkmer, T., Dahlman, J., Dukic, T., Bjällmark, A., & Larsson, M. (2008). Fixation identification in centroid versus start-point modes using eye-tracking data. *Perceptual and Motor Skills, 106*(3), 710-724.

Falkmer, T., & Gregersen, N. (2001). Fixations among experienced drivers and apprentices with and without cerebral palsy, in real traffic environments. *Transportation Research Part F: Traffic Psychology and Behaviour, 4*, 171-185.

Falkmer, T., & Gregersen, N. P. (2005). A comparison of eye movement behavior of inexperienced and experienced drivers in real traffic environments. *Optometry & Vision Science, 82*(8), 732-739.

Field, A. (2013). Discovering statistics using IBM SPSS statistics (4th ed.). London: Sage.

Fisk, G. D., Owsley, C., & Pulley, L. V. (1997). Driving after stroke: Driving exposure, advice, and evaluations. *Archives of Physical Medicine and Rehabilitation, 78*(12), 1338-1345. http://dx.doi.org/http://dx.doi.org/10.1016/S0003-9993(97)90307-5

Fonda, S. J., Wallace, R. B., & Herzog, R. A. (2001). Changes in driving patterns and worsening depressive symptoms among older adults. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences, 56*(6), S343-S351.

Google Maps (2017a) [image] Retrieved from https://www.google.com.au/maps/@-32.0066262,115.8927424,15.75z

Google Maps (2017b) [image] Retrieved from https://www.google.com/maps/@32.0076663,115.89098,1491m/data=!3m1!1e3

Groeger, J. A. (2000). Understanding driving: Applying cognitive psychology to a complex everyday task. Hove, East Sussex, UK: Psychology Press.

Gwyther, H., & Holland, C. (2012). The effect of age, gender and attitudes on self-regulation in driving. *Accident Analysis & Prevention, 45*, 19-28. http://dx.doi.org/http://dx.doi.org/10.1016/j.aap.2011.11.022

Handley, A., Medcalf, P., Hellier, K., & Dutta, D. (2009). Movement disorders after stroke. *Age and Ageing, 38*(3), 260-266. http://dx.doi.org/10.1093/ageing/afp020

Hjorthol, R. J., Levin, L., & Sirén, A. (2010). Mobility in different generations of older persons: The development of daily travel in different cohorts in Denmark, Norway and Sweden. *Journal of Transport Geography, 18*(5), 624-633. http://dx.doi.org/http://dx.doi.org/10.1016/j.jtrangeo.2010.03.011

IBM Corporation. (2013). IBM SPSS Statistics for Windows, Version 22.0. Armonk, NY: IBM Corp.

Isler, R. B., Parsonson, B. S., & Hansson, G. J. (1997). Age related effects of restricted head movements on the useful field of view of drivers. *Accident Analysis & Prevention, 29*(6), 793-801. http://dx.doi.org/10.1016/S0001-4575(97)00048-1

Jokinen, H., Melkas, S., Ylikoski, R., Pohjasvaara, T., Kaste, M., Erkinjuntti, T., & Hietanen, M. (2015). Post-stroke cognitive impairment is common even after successful clinical recovery. *European Journal of Neurology, 22*(9), 1288-1294. http://dx.doi.org/10.1111/ene.12743

Jonassen, D. (2000). Toward a design theory of problem solving. *Educational Technology Research and Development, 48*(4), 63-85. http://dx.doi.org/10.1007/BF02300500

Kahneman, D. (1973). *Attention and effort*. Englewood Cliffs, New Jersey: Prentice-Hall Inc.

Katsiki, N., Ntaios, G., & Vemmos, K. (2011). Stroke, obesity and gender: A review of the literature. *Maturitas, 69*(3), 239-243. http://dx.doi.org/http://dx.doi.org/10.1016/j.maturitas.2011.04.010

Konstantopoulos, P., Chapman, P., & Crundall, D. (2010). Driver's visual attention as a function of driving experience and visibility. Using a driving simulator to explore drivers' eye movements in day, night and rain driving. *Accident Analysis & Prevention, 42*(3), 827-834. http://dx.doi.org/10.1016/j.aap.2009.09.022

Marottoli, R. A., Mendes de Leon, C. F., Glass, T. A., Williams, C. S., Cooney, L. M., & Berkman, L. F. (2000). Consequences of driving cessation: Decreased out-of-home activity levels. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences, 55*(6), S334-S340. http://dx.doi.org/10.1093/geronb/55.6.S334

Marshall, S. C., Molnar, F., Man-Son-Hing, M., Blair, R., Brosseau, L., Finestone, H. M., . . . Wilson, K. G. (2007). Predictors of driving ability following stroke: A systematic review. *Topics in Stroke Rehabilitation, 14*(1), 98-114. http://dx.doi.org/10.1310/tsr1401-98

Mazer, B. L., Sofer, S., Korner-Bitensky, N., Gelinas, I., Hanley, J., & Wood-Dauphinee, S. (2003). Effectiveness of a visual attention retraining program on the driving performance of clients with stroke. *Archives of Physical Medicine and Rehabilitation, 84*(4), 541-550. http://dx.doi.org/http://dx.doi.org/10.1053/apmr.2003.50085

McGwin, J. G., & Brown, D. B. (1999). Characteristics of traffic crashes among young, middle-aged, and older drivers. *Accident Analysis & Prevention, 31*(3), 181-198. http://dx.doi.org/http://dx.doi.org/10.1016/S0001-4575(98)00061-X

Motta, K., Lee, H. C., & Falkmer, T. (2014). Post-stroke driving: Examining the effect of executive dysfunction. *Journal of Safety Research, 49*, 33.e31. http://dx.doi.org/10.1016/j.jsr.2014.02.005

Oltedal, S., & Rundmo, T. (2006). The effects of personality and gender on risky driving behaviour and accident involvement. *Safety Science, 44*(7), 621-628. http://dx.doi.org/10.1016/j.ssci.2005.12.003

Oxley, J., Fildes, B., Corben, B., & Langford, J. (2006). Intersection design for older drivers. *Transportation Research Part F: Traffic Psychology and Behaviour, 9*(5), 335-346. http://dx.doi.org/http://dx.doi.org/10.1016/j.trf.2006.06.005

Pradhan, A. K., Hammel, K. R., DeRamus, R., Pollatsek, A., Noyce, D. A., & Fisher, D. L. (2005). Using eye movements to evaluate effects of driver age on risk perception in a driving simulator. *Human Factors, 47*(4), 840-852. http://dx.doi.org/10.1518/001872005775570961

Precision Vision. 2000 Series Revised ETDRS Charts. La Salle, Illinois: (Precision Vision).

Reuter-Lorenz, P. A., & Cappell, K. A. (2008). Neurocognitive aging and the compensation hypothesis. *Current Directions in Psychological Science, 17*(3), 177-182. http://dx.doi.org/doi:10.1111/j.1467-8721.2008.00570.x

Sacco, R. L., Benjamin, E. J., Broderick, J. P., Dyken, M., Easton, J. D., Feinberg, W. M., . . . Wolf, P. A. (1997). Risk factors. *Stroke, 28*(7), 1507-1517. http://dx.doi.org/10.1161/01.str.28.7.1507

Schütz, A. C., Braun, D. I., & Gegenfurtner, K. R. (2011). Eye movements and perception: A selective review. *Journal of Vision, 11*(5), 1-30. http://dx.doi.org/10.1167/11.5.9

SensoriMotoric Instruments. (2011). SMI BeGaze™ Eye Tracking Analysis Software (Version 3.6). Retrieved from http://twiki.cis.rit.edu/twiki/pub/MVRL/SmiTracker/begaze2.pdf

Siren, A., Hakamies-Blomqvist, L., & Lindeman, M. (2004). Driving Cessation and Health in Older Women. *Journal of Applied Gerontology, 23*(1), 58-69. http://dx.doi.org/10.1177/0733464804263129

Swanson, J. (2005). The Delis-Kaplan Executive Function System: A review. *Canadian Journal of School Psychology, 20*(1/2), 117-128. http://dx.doi.org/10.1177/0829573506295469

Szlyk, J. P., Seiple, W., & Viana, M. (1997). Relative effects of age and compromised vision on driving performance. *Human Factors, 37*(2), 430–436. http://dx.doi.org/http://dx.doi.org/10.1016/0022-4375(97)90034-7

Tabibi, Z., & Pfeffer, K. (2003). Choosing a safe place to cross the road: the relationship between attention and identification of safe and dangerous road-crossing sites. *Child: Care, Health and Development, 29*(4), 237-244. http://dx.doi.org/10.1046/j.1365-2214.2003.00336.x

Underwood, G. (2007). Visual attention and the transition from novice to advanced driver. *Ergonomics, 50*(8), 1235-1249. http://dx.doi.org/10.1080/00140130701318707

Underwood, G., Chapman, P., Brocklehurst, N., Underwood, J., & Crundall, D. (2003). Visual attention while driving: sequences of eye fixations made by experienced and novice drivers. *Ergonomics, 46*(6), 629-646. http://dx.doi.org/10.1080/0014013031000090116

Young, M. S. (2000). Attention, automaticity, and automation: New perspectives on mental underload and performance. PhD. University of Southampton.

Zinn, S., Bosworth, H. B., Hoenig, H. M., & Swartzwelder, H. S. (2007). Executive function deficits in acute stroke. *Archives of Physical Medicine and Rehabilitation, 88*(2), 173-180. http://dx.doi.org/http://dx.doi.org/10.1016/j.apmr.2006.11.015

Chapter Eight: Discussion, Recommendations and Conclusion

Chapter Outline and Rationale

The purpose of this final chapter is to outline the findings of each study included as part of this thesis and to summarise the results in context, as well as draw together how the research answers the aims outlined in Chapter One. The penultimate section of this chapter will discuss the recommendations for future research, recommendations for post-stroke adults wishing to return to driving, as well as recommendations for clinicians and policy makers. The final section will outline the conclusion of the project.

Discussion

Summary of findings

This section will summarise and discuss the main findings of this thesis, as well as outlining the significance of each. The overall aim of this thesis was to develop a post-stroke driver profile exploring the factors affecting driving behaviour in post-stroke adults.

Chapter Three provided the grounding for the thesis by addressing objectives one (assess the relationship between deficits in cognition, executive function and driving behaviour in post-stroke drivers and non-stroke drivers) and two (assess the socio-demographic factors influencing driving behaviour in post-stroke drivers and post-stroke non-drivers). Specifically, Chapter Three investigated the influence of demographic and socioeconomic factors, as well as cognition on the decision to continue with or to cease driving post-stroke. The final results indicated that the decision to drive post-stroke was influenced by multiple factors, including finances, education and cognition, all of which were independent of actual driving performance. This suggested that the decision to continue or cease driving was multifactorial and it was concluded that screening tools for post-stroke drivers should consider finances, education, social support and cognitive factors during assessment and rehabilitation. This study was also the first in the thesis to investigate whether post-stroke adults were accurate in their self-assessment of their driving performance, with the findings suggesting that, similar to previous research, self-assessment was poorly related to actual driving performance. These results laid the foundation for assessing calibration in post-stroke adults and determining to what extent self-perceived performance influenced driving behaviour. It was interesting to note that the post-stroke drivers who continued to drive despite declining performance had fewer social supports available, potentially indicating an increased need to drive for social mobility. This finding corroborates previous research suggesting that better education is required for post-stroke drivers (Austroads & National Transport Commision Australia, 2016), as well as a need for a universal and comprehensive support framework for those no-longer able to drive (Marin-Lamellet & Haustein, 2015).

The following chapter investigated licensed post-stroke drivers. The aim of Chapter Four was to address objective three (assess the off-road driving performance of post-stroke drivers compared with the performance of healthy controls). Specifically, a series of cognitive tasks and a driving simulator were used to assess off-road driving performance and driving related-cognition in licensed post-stroke adults, compared to healthy controls.

There has been much research in the area of assessing the safety of post-stroke drivers, but the research has primarily focused on those that are looking to return to driving. Therefore, the concept of this chapter included assessing licensed post-stroke drivers, investigating the cognitive variables that were associated with driving and using these results as a baseline measurement for assessment and rehabilitation tools.

The results indicated that assessing propensity for risk, executive function and attention as part of an off-road assessment may be useful. This was in line with previous research, which also found that measures of attention and executive function were significant predictors of post-stroke driving (Marshall et al., 2007). Furthermore, the chapter also addressed the psychometric tools often used for assessing aspects of cognition (e.g., visuospatial function, processing speed) and how they may useful as part of driver screening or assessment as they appeared to have little relationship with simulated driving performance.

The use of the relevant associated cognitive assessments, as well as a driving simulator as a toolbox for training and rehabilitation post-stroke was discussed. Specifically, that using the simulator and cognitive assessments as a screening and rehabilitation tool prior to fitness-to-drive assessments would be useful in reducing the burden on practitioners, as well as potentially reducing the costs and risk associated with on-road driving assessments (Lew et al., 2005).

When investigating the difference between driving performance in the simulator, the results showed that there was little difference in the actual driving performance of post-stroke adults and controls. However, in both the propensity for risk task and in the driving simulator tasks, the post-stroke drivers were more cautious as they displayed greater and more consistent headway. These results were in contrast to previous research, which suggested that post-stroke drivers were more likely to overestimate their performance and taken more risks on the road (e.g., Heikkilä, Korpelainen, Turkka, Kallanranta, & Summala, 1999; Scott et al., 2009). Although not-hypothesised, this was not an unexplained finding when considering that the post-stroke drivers lower propensity for risk-taking behaviour scores. This is not just important for practitioners and policy makers to understand, but also important for the families of the post-stroke adult to understand, as previous research has shown that familial advice and early post-stroke education are important factors for determining who in the post-stroke adult population returns to driving. Specifically, post-stroke adults may be capable of driving but choose not to due to the advice of family or a lack of education of the rules and regulations or the adaptations available to them (Blane, Falkmer, Lee, Parsons, & Lee, 2016; Tan, O'Driscoll, & O'Neill, 2011) This may preclude the post-stroke adult from engaging with community life following their stroke, therefore increasing their chances of social isolation and depression. Therefore it is crucial that the evidence upon which the family or practitioner makes their decision is up-to-date, and that they know that post-stroke adults are capable of cautious driving behaviour. As the findings were contrary to previous research investigating risk taking and cautious behaviour on the road, these results added to the foundation laid in Chapter Three and suggested that understanding whether the cautious behaviour was due to post-stroke drivers' awareness of their own limitations i.e., calibration was worth investigating.

Chapters' five to seven developed this idea of calibration and followed a common theme of investigating cognition, task demand and driving performance with a particular focus on the compensation strategies for licensed post-stroke drivers.

In Chapter Five, task demand, cognition and calibration were assessed in a controlled environment by using a driving simulator. Using a safe and replicable driving environment, the aim was to investigate the calibration (i.e., how well the driver was able to assess their own performance) of post-stroke drivers and whether cognition or task demand influenced calibration and any subsequent driving behaviour, i.e., address objectives five (compare the perceived level of task demand involved in different driving scenarios in post-stroke drivers to that of a comparison group of healthy controls) and six (assess self-perception of driving behaviour and observed driving behaviour (calibration) and how it relates to cognition). The results showed that despite limited differences in driving performance and no difference in task demand, the post-stroke drivers, on average, rated themselves more conservatively in performance than the controls. These results were partially explained by variance in executive function ability and selective attention ability, i.e., that those with higher executive function and selective attention rated themselves more favourably and vice versa. Due to the poorer performance of the post-stroke drivers compared to the controls and the lack of difference in estimates of task demand, the results suggested that the post-stroke drivers had a greater awareness of their own deficits, which was also a finding contrary to previous research (e.g., Lundqvist & Alinder, 2007). The results were explained with reference to the Task Capability Framework of Fuller (2005). Using this framework, the results also suggested that post-stroke drivers were able to amend their driving behaviour by taking a more conservative approach to driving (leaving a greater and more consistent gap) to compensate for deficits in driving-related cognition and to bring the task demand within a manageable level. Together, these finding suggest that post-stroke drivers undertake some form of calibration activity and that this is important to know for practitioners.

The next stage of the project was to investigate task demand and calibration on-road, the results of which were reported in Chapter Six, therefore addressing objectives four (assess the on-road driving behaviour of post-stroke drivers, compared to healthy controls), five (compare the perceived level of task demand involved in different driving scenarios in post-stroke drivers to that of a comparison group of healthy controls) and six (assess self-perception of driving behaviour and observed driving behaviour (calibration) and how it relates to cognition). Similar to the findings reported in Chapter Five, the post-stroke drivers scored lower than controls on the cognitive assessments and rated themselves more conservatively than the controls, despite no differences in actual on-road behaviour. The difference in self-rated performance results were partially explained by the participant's propensity for risk score, which saw that post-stroke drivers had lower propensity for risk and as such a lower level of acceptable risk than the controls. As in Chapter Five, the results were discussed in relation to the Task Capability Framework of Fuller (2005) with the outcome suggesting that post-stroke drivers regulate their behaviour through calibration of their actions to their perceived level of performance and task demand in order to compensate for deficits. This research has further demonstrated the importance of accurate self-awareness, upon which calibration is based in post-stroke drivers for effective self-regulation practices. Furthermore, the results of both Chapters Five and Six suggest that using an assessment of self-awareness and calibration as part of the fitness-to-drive test, and / or as part of the post-stroke rehabilitation process may provide insight into the ability of post-stroke drivers to self-regulate. This is becoming increasingly important as the population ages, as self-regulation is highly relied upon for driver safety.

The penultimate thesis chapter and final results-based chapter concluded the investigation into task demand, cognition and compensatory practices in post-stroke adults. The results in Chapter Seven further developed the results reported in chapters five and six, which suggested that post-stroke drivers were aware at some level of their cognitive deficits and engaged in calibration activities. Therefore Chapter Seven addressed objectives four (assess the on-road driving behaviour of post-stroke drivers, compared to healthy controls using:, using eye-tracking) and seven (assess compensation strategies for deficits in cognition that enable driving in post-stroke adults), specifically by investigating cognition and on-road visual scanning in post-stroke drivers.

Chapter Seven involved observing two groups of drivers' on-road in their own vehicle using an eye-tracking camera, and also assessed off-road for cognitive function using a series of cognitive assessments. There was no significant difference between the groups for driving behaviour, however there were differences in cognition and in eye-tracking search strategies. The results indicated that post-stroke drivers implemented several strategies including increasing their number of fixations, as well as amending the spread of their both their horizontal and visual scanning.

Similar patterns have been reported for other participant groups (e.g., novice vs. experienced drivers, Underwood, 2007), and were suggested to be an indication of increased task demand. As the total number of fixations, and the vertical spread were related to deficits in cognitive function, the results suggested that these scanning patterns in the post-stroke drivers were to compensate for deficits in executive function and attention, as a strategy to decrease task demand to a comfortable level. The results suggest that these strategies could be further implemented as part of rehabilitation programs for post-stroke adults. Specifically, if visual scanning was assessed on-road, it may be feasible to provide feedback in a safe, repeatable and supportive environment, whilst rehabilitating post-stroke adults. This also may assist with developing transport policy for an increasingly diverse range of drivers on the road, as knowing how they will react to and interpret on-road information, and how they adapt behaviours will allow further research to determine ways of making road design cues more inclusive for drivers who need assistance.

Similar to the findings reported in the earlier chapters, assessing visual scanning, attention and executive function will reduce the burden on practitioners for on-road tests, limit the risk of on-road tests and can provide increased possibility for post-stroke adults to improve their compensatory mechanisms and return to driving.

In summary, as found in previous research, there is no one test or group of tests that can determine fitness to drive, however, similar to findings from previous research, assessing the cognitive factors; specifically and attention and executive function, socio-demographic factors and calibration activity, as well as making use of simulated driving, may provide a helpful indication of fitness-to-drive and should be investigated further to verify their usefulness as tools for assessment and rehabilitation purposes following a stroke.

With the findings provided in this post-stroke driver profile, practitioners and policy makers will be able to start developing a standardised procedure to assess and develop in-depth rehabilitation programmes. Providing this support through assessment and rehabilitation will not only assist post-stroke drivers with an improved quality of life, but will help to create a safer environment for all road users.

Significance of findings

Although there is much research investigating post-stroke drivers and cognition (e.g., Marshall et al., 2007), there has previously been a dearth of information investigating licensed post-stroke drivers, which may explain the mixed results found when formulating assessment protocols. This research has investigated cognitive ability in licensed post-stroke drivers and has provided a baseline when using cognitive assessments as part of future research protocols. Furthermore, to the author's knowledge, this project represents the first set of studies to investigate task demand and calibration whilst driving in the post-stroke driver population. This has broadened the knowledge of the post-stroke driver literature, through exploration their capabilities and the compensation strategies. It is also an important finding as drivers are known to make judgements regarding driving situations (Charlton, Starkey, Perrone, & Isler, 2014), and these judgements related to their own ability are important for maintaining safety and avoiding collisions (Fuller, 2005). Finally, although eye-tracking has frequently been used as measure of cognitive workload in driving performance (Harbluk, Noy, & Eizenman, 2002; Son, Oh, & Park, 2013; Young & Hulleman, 2013), and there has been some research investigating the scanning patterns in hemianopic post-stroke adults, this research is the first to assess eye-tracking in non-hemianopic post-stroke adults. This provides an important step in understanding the compensation strategies in the broader post-stroke population and provides development in the literature related to task demand and driving self-regulation practices for this cohort of drivers.

Limitations

Many of this project's limitations have been addressed in each chapter and it is not the aim of this section to repeat each limitation, but to provide an overview of the major methodology limitations for the project.

In Chapter Three, a driving simulator was utilised, however the outcome measures were generic (e.g., number of traffic tickets, number of accidents, number of lane deviations) and lacked the sensitivity of using variables, such as the standard deviation or standard error of lane positioning, speed maintenance, headway distance, which has been argued to better emulate real-world driving (Bloomfield & Carroll, 1996; Mullen, Charlton, Devlin, & Bedard, 2011). Therefore, it is possible that had more specific outcome measures been used, there may have been greater correlations with driving status and with the cognitive and socio-demographic variables. Similarly, the self-assessment tool used in Chapter Three was generic and had not been validated however, this situation was rectified in Chapter Four and Chapter Five through the use of the NASA Task Load Index.

Furthermore, although more specific measures were used in Chapters Four and Five, there is always the question of external and ecological validity with driving simulator research, particularly as the simulator is static and lacks vestibular feedback (Kaptein, Theeuwes, & Horst, 1996). However, the benefits associated with a moving driving simulator were outweighed by the costs for this project (Jamson, 2011), particularly as older adults are more prone to simulator sickness (Brooks et al., 2010; Kawano et al., 2012), the occurrence of which is increasingly likely in moving-based simulators if calibration is not absolute (Reason & Brand, 1975; Stoner, Fisher, & Mollenhauer, 2011). As mid-level fixed based-simulators do achieve respectable validity (Kaptein et al., 1996) and the simulator has previously been validated (Lee, Lee, & Cameron, 2003), the simulator was considered sufficient.

The propensity for simulator sickness was seen in all studies included in this thesis. In Chapter Three, 4% of participants reported some simulator sickness, however despite this there was no drop out in participation. In Chapter Four and Chapter Five, 27%-28% respectively reported some simulator sickness, which led to participation drop out and data loss. Although the simulator scenarios were split to try to minimise simulator sickness, future research should consider splitting scenarios further to maximise data collection and minimise sickness.

There was further data loss in the hazard perception scenario due to data logging errors, which made it impossible to analyse steering, headway and lateral lane position. The study would have benefited from a pilot to ensure data recording was correct.

When driving on-road, the participants were assessed using an amended checklist that has been previously utilised in driving research (Chee, Lee, Lee, & Falkmer, 2013; Chee, Lee, Patomella, & Falkmer, 2017) and it was coded based on a frequently used and clinically relevant assessment tool (Broberg & Dukic Willstrand, 2014), however, as of yet, the DBC has not been formally validated. Furthermore, the assessor in each study was not a Driving Assessment-Trained Occupational Therapist; therefore future research should include validation of the on-road assessment tool. Assessments may also benefit from video recording or the presence of a Driving Assessment-Trained Occupational Therapist for verification purposes.

The major methodological limitation in Chapter Seven was the use of two different eye-trackers. There were several equipment breakdowns of the SMI eye-tracker, which required the device to be returned to Germany for repair. In many cases it was difficult to reschedule assessments, so in order to avoid asking participants to return or repeat on-road assessments and risk associated practice effects, the back-up Arrington eye-tracker was used. The SMI eye-tracker was binocular and required post-processing of fixations, whereas the Arrington eye-tracker was monocular and did not require post-processing of fixations. Although the fixation generation used the same method (centroid dispersion), there is the possibility of inherent differences causing bias. Furthermore, there were limitations in sample size due to difficulties with the eye-tracker. Initially, there were 83 participants enrolled in the study, however due to errors with the eye-tracker, which included glare, overheating of the equipment and difficulty with calibration due to type of daily corrective lenses used in the participants' spectacles at the recording phase, the total amount of data collected was reduced to 48 participants. Likewise, there is the general observation that there was a great deal of variation in the sample sizes across the studies included. Future research should improve confidence in conclusion by using a larger sample size to equalise the gender disparity in both groups, particularly as the gender gap in driving cessation is likely to lessen in future populations. In Chapter Seven, despite the drop in sample size, a further limitation is that the analysis for the eye-tracking data was time-consuming, particularly as the on-road driving scenario lasted on average 20 minutes and for every hour of data, 30 hours of analyses were required.

There is the limitation in Chapter Three, whereby there is only a small number of cognitive assessments used and a collective score provided. There is also the lack of assessment investigating attention, particularly divided and selective attention, which have previously been implicated in post-stroke driving performance (Marshall et al., 2007). This limitation was rectified in the subsequent results chapters.

A limitation that is applicable for all chapters that investigate cognition is the lack of assessment of memory, particularly working memory, which has been shown to be impaired in post-stroke adults (van Geldorp, Kessels, & Hendriks, 2013), a significant predictor of on and off-road driving in post-stroke adults (Marshall et al., 2007), as well as to be related to risk-taking behaviour in male drivers (Starkey & Isler, 2016). This is an oversight, particularly due to the integral and functional relationship that working memory shares with executive function and attentional processing (Baddeley, 2000), therefore, future research should also include assessments of working memory.

An observation for all of the driving-based assessments included in this thesis was that there was no pass or fail element, which can make calibration between self-assessment and performance difficult to determine. Again, future research may benefit from a Driving Assessment-Trained Occupational Therapist being involved in the assessment, however as this research primarily investigated licensed drivers, the decision was taken to assume at least a baseline standard for all participants and that pass or fail would be inappropriate. It is also possible that in all of the situations the participants may have felt observed (Ranney, 2011) and the data were reliant on observer interpretation (Eby, 2011). Furthermore, the driving time on-road and in the simulator was limited (between 10 and 25 minutes). In the simulator, this timing is recommended to minimise simulator sickness (Stoner et al., 2011), however limited time spent on road can limit the validity of the on-road research therefore in future research these points may be addressed using a more naturalistic driving methodology (Eby, 2011).

There is some debate on the generalisability of the results, as the participants were recruited using non-probability sampling methods, i.e., an opt-in volunteer basis. Due to altruistic nature of these participants, the results may have been skewed, particularly as the post-stroke drivers appeared to be particularly cognitively healthy compared to post-stroke adults reported in previous research (e.g., Fisk, Owsley, & Mennemeier, 2002). Although the results suggest that this may be due to all participants being licensed drivers rather than post-stroke adults looking to reobtain their licence, it is of course possible that there is inherent bias in the participants who volunteered being of a higher standard and more confident disposition than other post-stroke drivers who did not volunteer. In addition, the post-stroke status was self-reported, as were the measures of driving habits and of socio-demographic data, both of which are prone to social desirability effects and recall bias. This may be particularly problematic in the post-stroke group who may have been more sensitive to the possibility of losing their licence and subsequent threat to their independence and community integration (Griffen, Rapport, Coleman Bryer, & Scott, 2009; White et al., 2012). Finally, although it was beyond the scope of this research, future research should determine whether the results vary by stroke location, type and time since stroke, particularly as these variables are known to impact on the type of deficits experienced (Munsch et al., 2016).

Recommendations

To complement the recommendations listed in the summary and findings and limitations sections, the following section will outline directions for future research, as well as recommendations for practitioners and recommendations for policy makers.

Recommendations for future research

Further development is required for the factors investigated as part of Chapter Three, specifically, a more in-depth investigation of the motivation of post-stroke adults to continue or cease driving. Future research should utilise some qualitative techniques, e.g., a post-assessment interview or survey, which would help limit the speculation for driving cessation (i.e., whether the psychosocial, cognitive, visual, physical or economic).

One of the limitations of the current research is the relatively small sample size and mixed demographic in the post-stroke drivers (e.g., gender disparity and mixture of stroke type, location and duration since recovery). As there are previously reported differences in the deficits following different types of stroke (Munsch et al., 2016), and driving behaviours in gender (Evans, 2004; Oltedal & Rundmo, 2006), future research should consider a more consistent demographic and investigate the influence of gender, type and location of stroke on compensation strategies, task demand and calibration.

Although assessing visual scanning on-road had high levels of validity, it is almost impossible whilst on-road to ensure consistency across assessment, therefore assessing visual scanning in a repeatable, consistent driving simulator scenario may be beneficial to further verify results. This would also provide grounding for using driving simulation and visual scanning assessment during post-stroke driving limitations. Furthermore, one of the limitations of Chapter Seven was that although executive function and attention explained between a quarter to a third of the variance of visual scanning behaviours, there were other factors not measured that need to be identified. Some suggestions for further investigation are the influence of restricted head and or body movement, as well the impact of working memory.

When assessing calibration and visual scanning as part of the on-road assessment, objectively assessing speed was beyond the scope of this study. Therefore future research should utilise modern driver-tracking methodologies e.g., using a GPS tracker or using an instrumented vehicle with integrated recording devices such eye-tracking, GPS and vehicle positioning. This will help develop the literature and explore visual scanning, calibration and task demand on-road, by assessing whether post-stroke drivers amend their driving behaviour (e.g., speed) to compensate for increased difficulty with cognition and driving and to provide extra time for fixations.

Recommendations for practitioners

There are a number of implications for practitioners identified as part of this thesis. Firstly, practitioners should consider a multitude of factors when discussing the possibility of returning to driving with post-stroke adults. Although this is already the case in some areas, as there is no set procedure, medical practitioners should consider cognition and socio-demographic factors to be included as part of a medical return-to-drive assessment.

Secondly, a recurring result as part of this thesis was that attention and executive function were associated with driving behaviour. This is important as it suggests that tools that assess these functions are useful when assessing fitness-to-drive in the post-stroke population. In addition, assessing propensity for risk may also prove a useful indicator. In the same line of reasoning, practitioners should consider that assessing visuospatial function and spatial perception may not be a beneficial use of time, as it appeared to have a limited relationship with driver behaviour.

Furthermore, assessing calibration of a post-stroke driver's self-rated performance with their driving behaviour may also prove useful when considering the need for self-awareness when managing everyday driving. Assessing calibration using a driving simulator may be useful, as there are fewer risks attached.

Finally, this research has demonstrated that post-stroke adults without hemianopia have been shown to amend their scanning patterns on the road, partly as a compensatory response to cognitive deficits. Therefore, it may be useful to incorporate assessment of visual scanning behaviours as part of assessment and rehabilitation strategies for post-stroke adults.

Recommendations for policy makers

The recommendations for policy makers involve recognising that post-stroke adults have the potential and capability to return to driving when given the proper support. Therefore, changing Australian policy to provide a unified approach to post-stroke driving assessments, as well as providing universal post-stroke driver education, will help improve the disparity of knowledge and improve traffic safety. Furthermore, understanding the profile of post-stroke drivers as contained within this thesis (e.g., the self-regulation and compensatory strategies), will help inform transport design and traffic safety policy.

Conclusion

There are multiple factors involved in post-stroke driving, including cognition and socio-demographic variables. Despite cognitively based deficits, post-stroke adults are able to exhibit similar driving performance and behaviours to healthy controls. Therefore it is clear that some post-stroke adults are able to safely return to the driving. This has huge implications for post-stroke adults who may feel that a stroke diagnosis precludes them from driving, and they may subsequently have a reduced quality of life having lost their independence.

The findings also provide insight for health professionals and policy makers, as they suggest that socio-demographic information, including education, social support and economics, as well as cognitively based information including risk-taking behaviour, attention, executive function and drivers' ability to accurately calibrate their perceived task demand with their performance, are useful to test as part of a post-stroke driving assessment. Furthermore visuo-spatial function and psychomotor processing do not provide as much insight, therefore should not be used as part of an assessment.

The findings also afford an understanding of the compensation strategies employed by licensed post-stroke drivers on the road. These strategies are to amend their visual scanning behaviour, as well as their physical on-road behaviour, in response to cognitively based deficits, therefore they should be tested for in post-stroke driving assessments and incorporated into post-stroke driving rehabilitation programmes.

Chapter Eight References

Austroads, & National Transport Commision Australia. (2016). Assessing fitness to drive for commercial and private vehicle drivers: Medical standards for licensing and clinical management guidelines., Retrieved from https://www.onlinepublications.austroads.com.au/items/AP-G56-16

Baddeley, A. (2000). The episodic buffer: a new component of working memory? *Trends in Cognitive Sciences, 4*(11), 417-423. http://dx.doi.org/10.1016/S1364-6613(00)01538-2

Blane, A., Falkmer, T., Lee, M., Parsons, R., & Lee, H. C. (2016). The cognitive and socio-demographic influences on driving performance and driving cessation in post-stroke drivers. *Advances in Transportation Studies: An International Journal,*(38), 121-135.

Bloomfield, J. R., & Carroll, S. A. (1996). New measures of driving performance. In S. A. Robertson (Ed.), *Contemporary Ergonomics* (pp. 335-340). London: Taylor & Francis.

Broberg, T., & Dukic Willstrand, T. (2014). Safe mobility for elderly drivers: Considerations based on expert and self-assessment. *Accident Analysis & Prevention, 66*, 104-113. http://dx.doi.org/http://dx.doi.org/10.1016/j.aap.2014.01.014

Brooks, J. O., Goodenough, R. R., Crisler, M. C., Klein, N. D., Alley, R. L., Koon, B. L., . . . Wills, R. F. (2010). Simulator sickness during driving simulation studies. *Accident Analysis & Prevention, 42*(3), 788-796. http://dx.doi.org/http://dx.doi.org/10.1016/j.aap.2009.04.013

Charlton, S. G., Starkey, N. J., Perrone, J. A., & Isler, R. B. (2014). What's the risk? A comparison of actual and perceived driving risk. *Transportation Research Part F: Traffic Psychology and Behaviour, 25, Part A*, 50-64. http://dx.doi.org/http://dx.doi.org/10.1016/j.trf.2014.05.003

Chee, D. Y., Lee, H. C., Lee, A. H., & Falkmer, T. (2013). Performance of drivers with Parkinson's Disease under the effect of cognitive overloading: insinuation for assessment and training. *Advances in Transportation Studies: An International Journal,*(29), 5-17.

Chee, D. Y., Lee, H. C., Patomella, A. H., & Falkmer, T. (2017). Performance of drivers with Parkinson's disease under the effect of cognitive overloading: insinuation for assessment and training. *Journal of Autism and Developmental Disorders* (in press)

Eby, D. W. (2011). Naturalistic observational field techniques for traffic psychology research In B. E. Porter (Ed.), *Handbook of traffic psychology* (pp. 61-72). San Diego: Academic Press. http://dx.doi.org/:http://dx.doi.org/10.1016/B978-0-12-381984-0.10005-0

Evans, L. (2004). *Traffic safety*. Bloomfield Hills, Michigan: Science Serving Society.

Fisk, G. D., Owsley, C., & Mennemeier, M. (2002). Vision, attention, and self-reported driving behaviors in community-dwelling stroke survivors. *Archives of Physical Medicine and Rehabilitation, 83*(4), 469-477. http://dx.doi.org/10.1053/apmr.2002.31179

Fuller, R. (2005). Towards a general theory of driver behaviour. *Accident Analysis & Prevention, 37*(3), 461-472. http://dx.doi.org/10.1016/j.aap.2004.11.003

Griffen, J. A., Rapport, L. J., Coleman Bryer, R., & Scott, C. A. (2009). Driving Status and Community Integration After Stroke. *Topics in Stroke Rehabilitation, 16*(3), 212-221. http://dx.doi.org/10.1310/tsr1603-212

Harbluk, J. L., Noy, Y. I., & Eizenman, M. (2002). *The impact of cognitive distraction on driver visual behaviour and vehicle control* (00942271). Ontario, Canada: T. R. Board. Retrieved from http://www.tc.gc.ca/roads.../tp13889/pdf/tp13889es.pdf

Heikkilä, V. M., Korpelainen, J., Turkka, J., Kallanranta, T., & Summala, H. (1999). Clinical evaluation of the driving ability in stroke patients. *Acta Neurologica Scandinavica, 99*(6), 349-355. http://dx.doi.org/10.1111/j.1600-0404.1999.tb07363.x

Jamson, H. (2011). Cross-platform validation issues. In D. L. Fisher, M. Rizzo, J. K. Caird & J. D. Lee (Eds.), *Handbook of driving simulation for engineering, medicine, and psychology*. London, UK: CRC Press: Taylor and Francis. http://dx.doi.org/:10.1201/b10836-13

Kaptein, N., Theeuwes, J., & Horst, R. V. D. (1996). Driving simulator validity: Some considerations. *Transportation Research Record: Journal of the Transportation Research Board, 1550*, 30-36. http://dx.doi.org/10.3141/1550-05

Kawano, N., Iwamoto, K., Ebe, K., Aleksic, B., Noda, A., Umegaki, H., . . . Ozaki, N. (2012). Slower adaptation to driving simulator and simulator sickness in older adults. *Aging Clinical and Experimental Research, 24*(3), 285-289. http://dx.doi.org/10.1007/bf03325260

Lee, H. C., Lee, A. H., & Cameron, D. (2003). Validation of a driving simulator by measuring the visual attention skill of older adult drivers. *The American Journal of Occupational Therapy, 57*(3), 324-328. Retrieved from http://graphics.tx.ovid.com/ovftpdfs/FPDDNCLBAHJKIJ00/fs047/ovft/live/gv024/00000448/00000448-200305000-00010.pdf

Lew, H. L., Poole, J. H., Lee, E. H., Jaffe, D. L., Huang, H.-C., & Brodd, E. (2005). Predictive validity of driving-simulator assessments following traumatic brain injury: a preliminary study. *Brain Injury, 19*(3), 177-188. http://dx.doi.org/10.1080/02699050400017171

Lundqvist, A., & Alinder, J. (2007). Driving after brain injury: Self-awareness and coping at the tactical level of control. *Brain Injury, 21*(11), 1109-1117. http://dx.doi.org/10.1080/02699050701651660

Marin-Lamellet, C., & Haustein, S. (2015). Managing the safe mobility of older road users: How to cope with their diversity? *Journal of Transport & Health, 2*(1), 22-31. http://dx.doi.org/10.1016/j.jth.2014.07.006

Marshall, S. C., Molnar, F., Man-Son-Hing, M., Blair, R., Brosseau, L., Finestone, H. M., . . . Wilson, K. G. (2007). Predictors of driving ability following stroke: A systematic review. *Topics in Stroke Rehabilitation, 14*(1), 98-114. http://dx.doi.org/10.1310/tsr1401-98

Mullen, N., Charlton, J., Devlin, A., & Bedard, M. (2011). Simulator validity: Behaviors observed on the simulator and on the road. In D. L. Fisher, M. Rizzo, J. K. Caird & J. D. Lee (Eds.), *Handbook of driving simulation for engineering, medicine and psychology*. United States: CRC Press, Taylor and Francis. http://dx.doi.org/:10.1201/b10836-14

Munsch, F., Sagnier, S., Asselineau, J., Bigourdan, A., Guttmann, C. R., Debruxelles, S., . . . Tourdias, T. (2016). Stroke location is an independent predictor of cognitive outcome. *Stroke, 47*(1), 66-73. http://dx.doi.org/10.1161/strokeaha.115.011242

Oltedal, S., & Rundmo, T. (2006). The effects of personality and gender on risky driving behaviour and accident involvement. *Safety Science, 44*(7), 621-628. http://dx.doi.org/10.1016/j.ssci.2005.12.003

Ranney, T. A. (2011). Psychological fidelity *Handbook of driving simulation for engineering, medicine, and psychology*: CRC Press. http://dx.doi.org/:doi:10.1201/b10836-10

Reason, J. T., & Brand, J. J. (1975). *Motion sickness* New York, USA: Academic Press.

Scott, C. A., Rapport, L. J., Coleman Bryer, R., Griffen, J., Hanks, R., & McKay, C. (2009). Self-assessment of driving ability and the decision to resume driving following stroke. *Journal of Clinical and Experimental Neuropsychology, 31*(3), 353-362. http://dx.doi.org/10.1080/13803390802169067

Son, J., Oh, H., & Park, M. (2013). Identification of driver cognitive workload using support vector machines with driving performance, physiology and eye movement in a driving Simulator. *International Journal of Precision Engineering Manufacturing, 14*(8), 1321-1327. http://dx.doi.org/10.1007/s12541-013-0179-7

Starkey, N. J., & Isler, R. B. (2016). The role of executive function, personality and attitudes to risks in explaining self-reported driving behaviour in adolescent and adult male drivers. *Transportation Research Part F: Psychology and Behaviour, 38*, 127-136. http://dx.doi.org/10.1016/j.trf.2016.01.013

Stoner, H., Fisher, D., & Mollenhauer, J. M. (2011). Simulator and scenario factors influencing simulator sickness. In D. L. Fisher, M. Rizzo, J. K. Caird & J. D. Lee (Eds.), *Handbook of driving simulation for engineering, medicine, and psychology*. London. UK: CRC Press: Taylor and Francis. http://dx.doi.org/:doi:10.1201/b10836-15

Tan, K. M., O'Driscoll, A., & O'Neill, D. (2011). Factors affecting return to driving post-stroke. *Irish Journal of Medical Science, 180*(1), 41-45. http://dx.doi.org/10.1007/s11845-010-0528-9

Underwood, G. (2007). Visual attention and the transition from novice to advanced driver. *Ergonomics, 50*(8), 1235-1249. http://dx.doi.org/10.1080/00140130701318707

van Geldorp, B., Kessels, R. P. C., &Hendriks, M. P. H. (2013). Single-item and associative working memory in stroke patients. *Behavioural Neurology, 26*(3), 199-201. http://dx.doi.org/10.3233/BEN-2012-129010

White, J. H., Miller, B., Magin, P., Attia, J., Sturm, J., & Pollack, M. (2012). Access and participation in the community: a prospective qualitative study of driving post-stroke. *Disability and Rehabilitation, 34*(10), 831-838. http://dx.doi.org/10.3109/09638288.2011.623754

Young, A. H., & Hulleman, J. (2013). Eye movements reveal how task difficulty moulds visual search. *Journal of Experimental Psychology: Human Perception and Performance, 39*(1), 168-190. http://dx.doi.org/10.1037/a0028679

Thesis Reference List

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Adler, G., & Rottunda, S. (2006). Older adults' perspectives on driving cessation. *Journal of Aging Studies, 20*(3), 227-235. http://dx.doi.org/http://dx.doi.org/10.1016/j.jaging.2005.09.003

Akinwuntan, A. E., Devos, H., Verheyden, G., Baten, G., Kiekens, C., Feys, H., & De Weerdt, W. (2010). Retraining moderately impaired stroke survivors in driving-related visual attention skills. *Topics in Stroke Rehabilation, 17*(5), 328-336. http://dx.doi.org/10.1310/tsr1705-328

Akinwuntan, A. E., Feys, H., De Weerdt, W., Baten, G., Arno, P., & Kiekens, C. (2006). Prediction of driving after stroke: a prospective study. *Neurorehabilitation and Neural Repair, 20*(3), 417-423. http://dx.doi.org/10.1177/1545968306287157

Allen, R. W., Stein, C. A., Aponso, B. L., Rosenthal, T. J., & Hogue, J. R. (1990). *A low cost, part task driving simulator based on microcomputer technology.* Paper presented at the 69th Annual Meeting of the Transportation Research Board., Washington, DC.

Allen, Z. A., Halbert, J., & Huang, L. (2007). Driving assessment and rehabilitation after stroke. *The Medical Journal of Australia, 187*(10), 599.

Alila Medical Media, (2017) Shutterstock illustration ID: 78690082 [image]. Retrieved from https://www.shutterstock.com

Alvarez, J. A., & Emory, E. (2006). Executive function and the frontal lobes: A meta-analytic review. *Neuropsychology Review, 16*(1), 17-42. http://dx.doi.org/10.1007/s11065-006-9002-x

Andrews, E. C., & Westerman, S. J. (2012). Age differences in simulated driving performance: Compensatory processes. *Accident Analysis & Prevention, 45*, 660-668. http://dx.doi.org/http://dx.doi.org/10.1016/j.aap.2011.09.047

Anstey, K. J., Wood, J., Lord, S., & Walker, J. G. (2005). Cognitive, sensory and physical factors enabling driving safety in older adults. *Clinical Psychology Review, 25*, 45-65. http://dx.doi.org/10.1016/j.cpr.2004.07.008

Ardila, A., Ostrosky-Solis, F., Rosselli, M., & Gómez, C. (2000). Age-related cognitive decline during normal aging: The complex effect of education. *Archives of Clinical Neuropsychology, 15*(6), 495-513. http://dx.doi.org/http://dx.doi.org/10.1016/S0887-6177(99)00040-2

Arenaza-Urquijo, E. M., Landeau, B., La Joie, R., Mevel, K., Mézenge, F., Perrotin, A., . . . Chételat, G. (2013). Relationships between years of education and gray matter volume, metabolism and functional connectivity in healthy elders. *Neuroimage, 83*, 450-457. http://dx.doi.org/10.1016/j.neuroimage.2013.06.053

Arrington Research. (2006a). Eye Tracking News, Head Mounted EyeTracker Systems. Retrieved from http://www.arringtonresearch.com/

Arrington Research. (2006b). ViewPoint EyeTracker®. Retrieved from http://www.arringtonresearch.com/viewpoint.html

Austad, S. N. (2006). Why women live longer than men: Sex differences in longevity. *Gender Medicine, 3*(2), 79-92. http://dx.doi.org/http://dx.doi.org/10.1016/S1550-8579(06)80198-1

Australian Bureau of Statistics. (2009). *Profiles of Disability, Astralia*. (44290.0). Australian Bureau of Statistics.

Australian Bureau of Statistics. (2016). *Migration, Australia, 2014-2015*. Canberra: Australian Bureau of Statistics. .Retrieved from http://www.abs.gov.au/ausstats/abs@.nsf/mf/3412.0

Australian Institute of Health and Welfare. (2013). *Stroke*. Canberra: Retrieved from http://www.aihw.gov.au/WorkArea/DownloadAsset.aspx?id=60129543611

Austroads, & National Transport Commision Australia. (2016). Assessing fitness to drive for commercial and private vehicle drivers: Medical standards for licensing and clinical management guidelines., Retrieved from https://www.onlinepublications.austroads.com.au/items/AP-G56-16

Baddeley, A. (2000). The episodic buffer: a new component of working memory? *Trends in Cognitive Sciences, 4*(11), 417-423. http://dx.doi.org/10.1016/S1364-6613(00)01538-2

Bahnemann, M., Hamel, J., De Beukelaer, S., Ohl, S., Kehrer, S., Audebert, H., . . . Brandt, S. A. (2015). Compensatory eye and head movements of patients with homonymous hemianopia in the naturalistic setting of a driving simulation. *Journal of Neurology, 262*(2), 316-325. http://dx.doi.org/10.1007/s00415-014-7554-x

Baldock, M. R. J., Mathias, J. L., McLean, A. J., & Berndt, A. (2006). Self-regulation of driving and its relationship to driving ability among older adults. *Accident Analysis & Prevention, 38*(5), 1038-1045. http://dx.doi.org/http://dx.doi.org/10.1016/j.aap.2006.04.016

Ball, K., & Owsley, C. (1991). Identifying correlates of accident involvement for the older driver. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 33*(5), 583-595. http://dx.doi.org/10.1177/001872089103300509

Ball, K., & Owsley, C. (1993). The Useful Field of View test: A new technique for evaluating age-related declines in visual function. *Journal of the American Optometric Association, 64*(1), 71-79.

Ball, K., Owsley, C., Sloane, M. E., Roenker, D. L., & Bruni, J. R. (1993). Visual attention problems as a predictor of vehicle crashes in older drivers. *Investigative Ophthalmology & Visual Science, 34*(11), 3110-3123.

Ball, K., Owsley, C., Stalvey, B., Roenker, D. L., Sloane, M. E., & Graves, M. (1998). Driving avoidance and functional impairment in older drivers. *Accident Analysis & Prevention, 30*(3), 313-322. http://dx.doi.org/http://dx.doi.org/10.1016/S0001-4575(97)00102-4

Bédard, M., Parkkari, M., Weaver, B., Riendeau, J., & Dahlquist, M. (2010). Assessment of driving performance using a simulator protocol: Validity and reproducibility. *American Journal of Occupational Therapy, 64*(2), 336-340. http://dx.doi.org/10.5014/ajot.64.2.336

Belagaje, S. R., & Butler, A. J. (2013). Poststroke Recovery. In K. M. Barrett, J. F. Meschia & I. ebrary (Eds.), *Stroke* (1st ed., pp. 119-136). Chichester, West Sussex: John Wiley & Sons. http://dx.doi.org/:10.1002/9781118560730.ch7

Benton, A. L., Hamsher, K., Varney, N. R., & Spreen, O. (1983). *Judgment of line orientation*. New York: Oxford University Press

Beydoun, M. A., Beydoun, H. A., Gamaldo, A. A., Teel, A., Zonderman, A. B., & Wang, Y. (2014). Epidemiologic studies of modifiable factors associated with cognition and dementia: Systematic review and meta-analysis. *BMC Public Health, 14*(1)Retrieved from http://www.scopus.com/inward/record.url?eid=2-s2.0-84904348791&partnerID=40&md5=ab0ae83513049f49163b68e5d30d60f4

Blane, A., Falkmer, T., Lee, M., Parsons, R., & Lee, H. C. (2016). The cognitive and socio-demographic influences on driving performance and driving cessation in post-stroke drivers. *Advances in Transportation Studies: An International Journal,*(38), 121-135.

Blane, A., Lee, H. C., Falkmer, T., & Dukic Willstrand, T. (2017). Assessing cognitive ability and simulator-based driving performance in post-stroke adults. *Behavioural Neurology, 2017* (Behavioural and Cognitive Effects of Cardiovascular Disease), 1-9. http://dx.doi.org/10.1155/2017/1378308

Blane, A., Lee, H. C., Falkmer, T., & Dukic Willstrand, T. (under review). Cognitive ability as a predictor of task demand and self-rated driving performance in post-stroke drivers – implications for self-regulation.

Bloomfield, J. R., & Carroll, S. A. (1996). New measures of driving performance. In S. A. Robertson (Ed.), *Contemporary Ergonomics* (pp. 335-340). London: Taylor & Francis.

Braitman, K. A., & Williams, A. F. (2011). Changes in self-regulatory driving among older drivers over time. *Traffic Injury Prevention, 12*(6), 568-575. http://dx.doi.org/10.1080/15389588.2011.616249

Broberg, T., & Dukic Willstrand, T. (2014). Safe mobility for elderly drivers: Considerations based on expert and self-assessment. *Accident Analysis & Prevention, 66*, 104-113. http://dx.doi.org/http://dx.doi.org/10.1016/j.aap.2014.01.014

Brønnum-Hansen, H., Davidsen, M., & Thorvaldsen, P. (2001). Long-term survival and causes of death after stroke. *Stroke, 32*(9), 2131-2136.

Brooks, J. O., Goodenough, R. R., Crisler, M. C., Klein, N. D., Alley, R. L., Koon, B. L., . . . Wills, R. F. (2010). Simulator sickness during driving simulation studies. *Accident Analysis & Prevention, 42*(3), 788-796. http://dx.doi.org/http://dx.doi.org/10.1016/j.aap.2009.04.013

Brouwer, W. H., Waterink, W., Van Wolffelaar, P. C., & Rothengatter, T. (1991). Divided attention in experienced young and older drivers: Lane tracking and visual analysis in a dynamic driving simulator. *Human Factors, 33*(5), 573-582. http://dx.doi.org/10.1177/001872089103300508

Bryer, R. C., Rapport, L. J., & Hanks, R. A. (2006). Determining fitness to drive: Neuropsychological and psychological considerations In J. M. Pellerito (Ed.), *Driver Rehabilitation and Community Mobility* (pp. 165-184). Saint Louis, USA: Mosby. http://dx.doi.org/:http://dx.doi.org/10.1016/B978-032302937-7.50013-7

Bunce, D., Handley, R., & Gaines Jr, S. O. (2008). Depression, anxiety, and within-person variability in adults aged 18 to 85 years. *Psychology and Aging, 23*(4), 848-858.

Bunce, D., Young, M. S., Blane, A., & Khugputh, P. (2012). Age and inconsistency in driving performance. *Accident Analysis & Prevention, 49*, 293-299. http://dx.doi.org/10.1016/j.aap.2012.01.001

Burns, P. C. (1999). Navigation and the mobility of older drivers. The Journals of Gerontology Series B: Psychological Sciences and Social Sciences, 54(1), S49-S55.

Business Wire (2017).[image] Retrieved from http://www.businesswire.com/news/home/20141219005468/en/SMI-Eye-Tracking-Glasses-Set-Industry-Standard

Carsten, O., & Jamson, A. H. (2011). Driving simulators as research tools in traffic psychology. In B. E. C. Porter (Ed.), *Handbook of traffic psychology* (pp. 87-96). Burlington: Elsevier Science.

Chapman, P., Underwood, G., & Roberts, K. (2002). Visual search patterns in trained and untrained novice drivers. *Transportation Research Part F: Traffic Psychology and Behaviour, 5*(2), 157-167. http://dx.doi.org/http://dx.doi.org/10.1016/S1369-8478(02)00014-1

Charlton, S. G., Starkey, N. J., Perrone, J. A., & Isler, R. B. (2014). What's the risk? A comparison of actual and perceived driving risk. *Transportation Research Part F: Traffic Psychology and Behaviour, 25, Part A*, 50-64. http://dx.doi.org/http://dx.doi.org/10.1016/j.trf.2014.05.003

Chee, D. Y., Lee, H. C., Lee, A. H., & Falkmer, T. (2013). Performance of drivers with Parkinson's Disease under the effect of cognitive overloading: insinuation for assessment and training. *Advances in Transportation Studies: An International Journal,*(29), 5-17.

Chee, D. Y., Lee, H. C., Patomella, A. H., & Falkmer, T. (2017). Performance of drivers with Parkinson's disease under the effect of cognitive overloading: insinuation for assessment and training. *Journal of Autism and Developmental Disorders* (in press)

Cheng, A. S., & Lee, H. C. (2012). Risk-taking behavior and response inhibition of commuter motorcyclists with different levels of impulsivity. *Transportation Research Part F: Traffic Psychology and Behaviour, 15*(5), 535-543. http://dx.doi.org/10.1016/j.trf.2012.05.005

Choi, M., Adams, K. B., & Kahana, E. (2012). The impact of transportation support on driving cessation among community-dwelling older adults. *Journals of Gerontology Series B: Psychological Sciences and Social Sciences, 67B*(3), 392-400. http://dx.doi.org/10.1093/geronb/gbs035

Chua, M., McCluskey, A., & Smead, J. M. (2012). Retrospective analysis of factors that affect driving assessment outcomes after stroke. *Australian Occupational Therapy Journal, 59*(2), 121-130. http://dx.doi.org/10.1111/j.1440-1630.2012.01005.x

Classen, S., Bewernitz, M., & Shechtman, O. (2011). Driving simulator sickness: An evidence-based review of the literature. *American Journal of Occupational Therapy, 65*(2), 179-188. http://dx.doi.org/10.5014/ajot.2011.000802

Classen, S., Wang, Y., Crizzle, A. M., Winter, S. M., & Lanford, D. N. (2012). Gender differences among older drivers in a comprehensive driving evaluation. *Accident Analysis & Prevention, 61*, 146-152. http://dx.doi.org/10.1016/j.aap.2012.10.010

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, New Jersey: L. Erlbaum Associates.

Cordell, R., Lee, H. C., Granger, A., Vieira, B., & Lee, A. H. (2008). Driving assessment in Parkinson's disease—A novel predictor of performance? *Movement Disorders, 23*(9), 1217-1222. http://dx.doi.org/10.1002/mds.21762

Coyne, P. H. (2007). *Roadcraft: the essential police driver's handbook*. London, United Kingdom: The Stationary Office.

Craik, F. I. M., & Byrd, M. (1982). Aging and cognitive deficits. In F. I. M. Craik & S. Trehub (Eds.), *Aging and cognitive processes (advances in the study of communication and affect)* (Vol. 8, pp. 191-211). New York: Plenum Press.

Crizzle, A. M., Myers, A. M., & Almeida, Q. J. (2013). Self-regulatory practices of drivers with Parkinson's disease: Accuracy of patient reports. *Parkinsonism & Related Disorders, 19*(2), 176-180. http://dx.doi.org/10.1016/j.parkreldis.2012.09.003

Crundall, D. E., & Underwood, G. (1998). Effects of experience and processing demands on visual information acquisition in drivers. *Ergonomics, 41*(4), 448-458. http://dx.doi.org/10.1080/001401398186937

D'Ambrosio, L. A., Donorfio, L. K., Coughlin, J. F., Mohyde, M., & Meyer, J. (2008). Gender differences in self-regulation patterns and attitudes toward driving among older adults. *Journal of Women & Aging, 20*(3-4), 265-282. http://dx.doi.org/10.1080/08952840801984758

Daigneault, G., Joly, P., & Frigon, J.-Y. (2002). Executive functions in the evaluation of accident risk of older drivers. *Journal of Clinical and Experimental Neuropsychology, 24*(2), 221-238. Retrieved from http://www.tandfonline.com/doi/pdf/10.1076/jcen.24.2.221.993

Daly, J. J., Fang, Y., Perepezko, E. M., Siemionow, V., & Yue, G. H. (2006). Prolonged cognitive planning time, elevated cognitive effort, and relationship to coordination and motor control following stroke. *IEEE Transactions on Neural Systems and Rehabilitation Engineering: a publication of the IEEE Engineering in Medicine and Biology Society, 14*(2), 168-171.

Decarlo, D. K., Scilley, K., Wells, J., & Owsley, C. (2003). Driving habits and health-related quality of life in patients with age-related maculopathy. *Optometry & Vision Science, 80*(3), 207-213. Retrieved from http://journals.lww.com/optvissci/Fulltext/2003/03000/Driving_Habits_and_Health_Related_Quality_of_Life.10.aspx

Delis, D. C., Kaplan, E., & Kramer, J. H. (2001a). *Delis-Kaplan Executive Function System (D-KEFS) examiner's manual*. San Antonio, Texas: The Psychological Corporation.

Delis, D. C., Kaplan, E., & Kramer, J. H. (2001b). *Delis-Kaplan Executive Function System (D-KEFS) technical manual*. San Antonio, Texas: The Psychological Corporation. .

Dennis, M. S., Burn, J., Sandercock, P., Bamford, J. M., Wade, D. T., & Warlow, C. P. (1993). Long-term survival after first-ever stroke: The Oxfordshire Community Stroke Project. *Stroke, 24*(6), 796-800.

Devos, H., Akinwuntan, A. E., Nieuwboer, A., Tant, M., Truijen, S., De Wit, L., . . . De Weerdt, W. (2009). Comparison of the effect of two driving retraining programs on on-road performance after stroke. *Neurorehabilitation and Neural Repair, 23*(7), 699-705. http://dx.doi.org/10.1177/1545968309334208

Devos, H., Akinwuntan, A. E., Nieuwboer, A., Truijen, S., Tant, M., & De Weerdt, W. (2011). Screening for fitness to drive after stroke A systematic review and meta-analysis. *Neurology, 76*(8), 747-756.

Dickerson, A. E., Reistetter, T., Davis, E. S., & Monahan, M. (2011). Evaluating driving as a valued instrumental activity of daily living. *American Journal of Occupational Therapy, 65*(1), 64-75. Retrieved from http://search.proquest.com.dbgw.lis.curtin.edu.au/docview/835030492?rfr_id=info%3Axri%2Fsid%3Aprimo

Donorfio, L. K., D'Ambrosio, L. A., Coughlin, J. F., & Mohyde, M. (2009). To drive or not to drive, that isn't the question—the meaning of self-regulation among older drivers. *Journal of Safety Research, 40*(3), 221-226. http://dx.doi.org/10.1016/j.jsr.2009.04.002

Dukic, T., & Broberg, T. (2012). Older drivers' visual search behaviour at intersections. *Transportation Research Part F: Traffic Psychology and Behaviour, 15*(4), 462-470. http://dx.doi.org/10.1016/j.trf.2011.10.001

Dunn, N., & Williamson, A. (2012). Driving monotonous routes in a train simulator: the effect of task demand on driving performance and subjective experience. *Ergonomics, 55*(9), 997-1008. http://dx.doi.org/10.1080/00140139.2012.691994

Eby, D. W. (2011). Naturalistic observational field techniques for traffic psychology research In B. E. Porter (Ed.), *Handbook of traffic psychology* (pp. 61-72). San

Diego: Academic Press. http://dx.doi.org/:http://dx.doi.org/10.1016/B978-0-12-381984-0.10005-0

Edwards, J. D., Vance, D. E., Wadley, V. G., Cissell, G. M., Roenker, D. L., & Ball, K. K. (2005). Reliability and validity of Useful Field of View test scores as administered by personal computer. *Journal of Clinical and Experimental Neuropsychology, 27*(5), 529-543. http://dx.doi.org/10.1080/13803390490515432

Ekstam, L., Uppgard, B., Kottorp, A., & Tham, K. (2007). Relationship between awareness of disability and occupational performance during the first year after a stroke. *American Journal of Occupational Therapy, 61*(5), 503-511.

Ellaway, A., Macintyre, S., Hiscock, R., & Kearns, A. (2003). In the driving seat: Psychosocial benefits from private motor vehicle transport compared to public transport. *Transportation Research Part F: Traffic Psychology and Behaviour, 6*(3), 217-231. http://dx.doi.org/http://dx.doi.org/10.1016/S1369-8478(03)00027-5

Evans, D. A., Beckett, L. A., Albert, M. S., Hebert, L. E., Scherr, P. A., Funkenstein, H. H., & Taylor, J. O. (1993). Level of education and change in cognitive function in a community population of older persons. *Annals of Epidemiology, 3*(1), 71-77. http://dx.doi.org/10.1016/1047-2797(93)90012-S

Evans, K. K., Horowitz, T. S., Howe, P., Pedersini, R., Reijnen, E., Pinto, Y., & Wolfe, J. M. (2011). Visual attention. *Wiley Interdisciplinary Reviews. Cognitive Science, 2*(5), 503-514. http://dx.doi.org/10.1002/wcs.127

Evans, L. (2004). *Traffic safety*. Bloomfield Hills, Michigan: Science Serving Society.

Eysenck, M. W. (1982). *Attention and arousal: Cognition and performance*. Berlin: Springer-Verlag.

Falkmer, T., Dahlman, J., Dukic, T., Bjällmark, A., & Larsson, M. (2008). Fixation identification in centroid versus start-point modes using eye-tracking data. *Perceptual and Motor Skills, 106*(3), 710-724.

Falkmer, T., & Gregersen, N. (2001). Fixations among experienced drivers and apprentices with and without cerebral palsy, in real traffic environments. *Transportation Research Part F: Traffic Psychology and Behaviour, 4*, 171-185.

Falkmer, T., & Gregersen, N. P. (2005). A comparison of eye movement behavior of inexperienced and experienced drivers in real traffic environments. *Optometry & Vision Science, 82*(8), 732-739.

Feigin, V. L., Forouzanfar, M. H., Krishnamurthi, R., Mensah, G. A., Connor, M., Bennett, D. A., . . . Murray, C. (2014). Global and regional burden of stroke during 1990–2010: findings from the Global Burden of Disease Study 2010. *The Lancet, 383*(9913), 245-255. http://dx.doi.org/http://dx.doi.org/10.1016/S0140-6736(13)61953-4

Field, A. (2013). Discovering statistics using IBM SPSS statistics (4th ed.). London: Sage.

Fisher, D. L., Rizzo, M., Caird, J., & Lee, J. D. (2011). *Handbook of driving simulation for engineering, medicine, and psychology*. Hoboken: Taylor and Francis.

Fisk, G. D., Owsley, C., & Mennemeier, M. (2002). Vision, attention, and self-reported driving behaviors in community-dwelling stroke survivors. *Archives of Physical Medicine and Rehabilitation, 83*(4), 469-477. http://dx.doi.org/10.1053/apmr.2002.31179

Fisk, G. D., Owsley, C., & Pulley, L. V. (1997). Driving after stroke: Driving exposure, advice, and evaluations. *Archives of Physical Medicine and Rehabilitation, 78*(12), 1338-1345. http://dx.doi.org/http://dx.doi.org/10.1016/S0003-9993(97)90307-5

Fonda, S. J., Wallace, R. B., & Herzog, R. A. (2001). Changes in driving patterns and worsening depressive symptoms among older adults. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences, 56*(6), S343-S351.

Foster, J. K., Black, S., Buck, B. H., & Bronskill, M. J. (1997). Ageing and executive functions: A neuroimaging perspective. In P. Rabbitt (Ed.), *Methodology of frontal and executive function* (pp. 177-190). Hove, Sussex, UK: Psychology Press.

Freund, B., Colgrove, L. A., Burke, B. L., & McLeod, R. (2005). Self-rated driving performance among elderly drivers referred for driving evaluation. *Accident Analysis & Prevention, 37*(4), 613-618. http://dx.doi.org/10.1016/j.aap.2005.03.002

Fristedt, S., Björklund, A., Wretstrand, A., & Falkmer, T. (2011). Continuing mobility and occupational participation outside the home in old age is an act of negotiation. *Activities, Adaptation & Aging, 35*(4), 275-297. http://dx.doi.org/10.1080/01924788.2011.625213

Fuller, R. (2005). Towards a general theory of driver behaviour. *Accident Analysis & Prevention, 37*(3), 461-472. http://dx.doi.org/10.1016/j.aap.2004.11.003

Galski, T., Bruno, R. L., & Ehle, H. T. (1992). Driving after cerebral damage: A model with implications for evaluation. *American Journal of Occupational Therapy, 46*(4), 324-332.

Galski, T., Ehle, H. T., McDonald, M. A., & Mackevich, J. (2000). Evaluating fitness-to-drive after cerebral injury: Basic issues and recommendations for medical and legal communities. *The Journal of Head Trauma Rehabilitation, 15*(3), 895-908.

George, S., & Crotty, M. (2010). Establishing criterion validity of the Useful Field of View assessment and Stroke Drivers' Screening Assessment: Comparison to the result of on-road assessment. *American Journal of Occupational Therapy, 64*(1), 114-122.

Glisky, E. L. (2007). Changes in cognitive function in human aging. In D. R. Riddle (Ed.), *Brain aging* (pp. 3-20). Boca Raton, Florida: CRC Press. http://dx.doi.org/:doi:10.1201/9781420005523.sec1

Go, A. S., Mozaffarian, D., Roger, V. L., Benjamin, E. J., Berry, J. D., Blaha, M. J., . . . Turner, M. B. (2014). Heart disease and stroke statistics-2014 update: a report from the American Heart Association. *Circulation, 129*(3), e28. http://dx.doi.org/10.1161/01.cir.0000441139.02102.80

Google Maps (2017a) [image] Retrieved from https://www.google.com.au/maps/@-32.0066262,115.8927424,15.75z

Google Maps (2017b) [image] Retrieved from https://www.google.com/maps/@32.0076663,115.89098,1491m/data=!3m1!1e3

Gottesman, R. F., & Hillis, A. E. (2010). Predictors and assessment of cognitive dysfunction resulting from ischaemic stroke. *The Lancet Neurology, 9*(9), 895-905. http://dx.doi.org/http://dx.doi.org/10.1016/S1474-4422(10)70164-2

Grant, D. A. (1948). The latin square principle in the design and analysis of psychological experiments. *Psychological Bulletin, 45*(5), 427-442. http://dx.doi.org/10.1037/h0053912

Green, J., Siddall, H., & Murdoch, I. (2002). Learning to live with glaucoma: a qualitative study of diagnosis and the impact of sight loss. *Social Science & Medicine, 55*(2), 257-267. http://dx.doi.org/10.1016/S0277-9536(01)00169-1

Griffen, J. A., Rapport, L. J., Coleman Bryer, R., & Scott, C. A. (2009). Driving Status and Community Integration After Stroke. *Topics in Stroke Rehabilitation, 16*(3), 212-221. http://dx.doi.org/10.1310/tsr1603-212

Groeger, J. A. (2000). Understanding driving: Applying cognitive psychology to a complex everyday task. Hove, East Sussex, UK: Psychology Press.

Groth-Marnat, G., & Teal, M. (2000). Block Design as a measure of everyday spatial ability: A study of ecological validity. *Perceptual and Motor Skills, 90*(2), 522-526. http://dx.doi.org/10.2466/pms.2000.90.2.522

Gwyther, H., & Holland, C. (2012). The effect of age, gender and attitudes on self-regulation in driving. *Accident Analysis & Prevention, 45*, 19-28. http://dx.doi.org/http://dx.doi.org/10.1016/j.aap.2011.11.022

Hakamies-Blomqvist, L. (1998). Older drivers' accident risk: Conceptual and methodological issues. *Accident Analysis & Prevention, 30*(3), 293-297. http://dx.doi.org/http://dx.doi.org/10.1016/S0001-4575(97)00120-6

Hakamies-Blomqvist, L., & Wahlström, B. (1998). Why do older drivers give up driving? *Accident Analysis & Prevention, 30*(3), 305-312. http://dx.doi.org/http://dx.doi.org/10.1016/S0001-4575(97)00106-1

Handley, A., Medcalf, P., Hellier, K., & Dutta, D. (2009). Movement disorders after stroke. *Age and Ageing, 38*(3), 260-266. http://dx.doi.org/10.1093/ageing/afp020

Harbluk, J. L., Noy, Y. I., & Eizenman, M. (2002). *The impact of cognitive distraction on driver visual behaviour and vehicle control* (00942271). Ontario, Canada:

T. R. Board. Retrieved from http://www.tc.gc.ca/roads.../tp13889/pdf/tp13889es.pdf

Harrison, A., & Ragland, D. (2003). Consequences of driving reduction or cessation for older adults. *Transportation Research Record: Journal of the Transportation Research Board, 1843*, 96-104. http://dx.doi.org/doi:10.3141/1843-12

Hart, S. G., & Staveland, L. E. (1988). Development of the NASA-TLX (Task Load Index): Results of empirical and theoretical research. *Human Mental Workload, 1*(3), 139-183.

Hartman-Maeir, A., Soroker, N., Oman, S. D., & Katz, N. (2003). Awareness of disabilities in stroke rehabilitation-a clinical trial. *Disability and Rehabilitation, 25*(1), 35-44. http://dx.doi.org/10.1080/0963828021000007897

Haselkorn, J. K., Mueller, B. A., & Rivara, F. A. (1998). Characteristics of drivers and driving record after traumatic and nontraumatic brain injury. *Archives of Physical Medicine and Rehabilitation, 79*(7), 738-742. http://dx.doi.org/http://dx.doi.org/10.1016/S0003-9993(98)90349-5

Hassan, H., King, M., & Watt, K. (2015). The perspectives of older drivers on the impact of feedback on their driving behaviours: a qualitative study.

Transportation Research Part F: Traffic Psychology and Behaviour, 28, 25-39. http://dx.doi.org/10.1016/j.trf.2014.11.003

Heikkilä, V. M., Korpelainen, J., Turkka, J., Kallanranta, T., & Summala, H. (1999). Clinical evaluation of the driving ability in stroke patients. *Acta Neurologica Scandinavica, 99*(6), 349-355. http://dx.doi.org/10.1111/j.1600-0404.1999.tb07363.x

Hird, M. A., Vesely, K. A., Christie, L. E., Alves, M. A., Pongmoragot, J., Saposnik, G., & Schweizer, T. A. (2015). Is it safe to drive after acute mild stroke? A preliminary report. *Journal of the Neurological Sciences, 354*(1), 46-50. http://dx.doi.org/10.1016/j.jns.2015.04.043

Hird, M. A., Vetivelu, A., Saposnik, G., & Schweizer, T. A. (2014). Cognitive, on-road, and simulator-based driving assessment after stroke. *Journal of Stroke and Cerebrovascular Diseases, 23*(10), 2654-2670. http://dx.doi.org/10.1016/j.jstrokecerebrovasdis.2014.06.010

Hjorthol, R. J., Levin, L., & Sirén, A. (2010). Mobility in different generations of older persons: The development of daily travel in different cohorts in Denmark, Norway and Sweden. *Journal of Transport Geography, 18*(5), 624-633. http://dx.doi.org/http://dx.doi.org/10.1016/j.jtrangeo.2010.03.011

Homack, S., Lee, D., & Riccio, C. A. (2005). Test review: Delis-Kaplan Executive Function System. *Journal of Clinical and Experimental Neuropsychology, 27*(5), 599-609. http://dx.doi.org/http://dx.doi.org/10.1080/13803390490918444

Horrey, W. J., Lesch, M. F., Mistopolous-Rubens, E., & Lee, J. D. (2015). Calibration of skills and judgement in driving: Development of a conceptual framework and the implications for road safety. *Accident Analysis & Prevention, 76*, 25-33. http://dx.doi.org/http://dx.doi.org/10.1016/j.aap.2014.12.017

Horswill, M. S., Anstey, K. J., Hatherly, C., Wood, J. M., & Pachana, N. A. (2011). Older drivers' insight into their hazard perception ability. *Accident Analysis & Prevention, 43*(6), 2121-2127. http://dx.doi.org/http://dx.doi.org/10.1016/j.aap.2011.05.035

IBM Corporation. (2012). IBM SPSS Statistics for Windows, Version 21.0. Armonk, NY: IBM Corp.

IBM Corporation. (2013). IBM SPSS Statistics for Windows, Version 22.0. Armonk, NY: IBM Corp.

Isler, R. B., Parsonson, B. S., & Hansson, G. J. (1997). Age related effects of restricted head movements on the useful field of view of drivers. *Accident Analysis &*

Prevention, 29(6), 793-801. http://dx.doi.org/10.1016/S0001-4575(97)00048-1

Jamson, H. (2011). Cross-platform validation issues. In D. L. Fisher, M. Rizzo, J. K. Caird & J. D. Lee (Eds.), *Handbook of driving simulation for engineering, medicine, and psychology*. London, UK: CRC Press: Taylor and Francis. http://dx.doi.org/:10.1201/b10836-13

Jokinen, H., Melkas, S., Ylikoski, R., Pohjasvaara, T., Kaste, M., Erkinjuntti, T., & Hietanen, M. (2015). Post-stroke cognitive impairment is common even after successful clinical recovery. *European Journal of Neurology, 22*(9), 1288-1294. http://dx.doi.org/10.1111/ene.12743

Jonassen, D. (2000). Toward a design theory of problem solving. *Educational Technology Research and Development, 48*(4), 63-85. http://dx.doi.org/10.1007/BF02300500

Kahneman, D. (1973). *Attention and effort*. Englewood Cliffs, New Jersey: Prentice-Hall Inc.

Kaplan, J., & Hier, D. B. (1982). Visuospatial deficits after right hemisphere stroke. *American Journal of Occupational Therapy, 36*(5), 314-321.

Kaptein, N., Theeuwes, J., & Horst, R. V. D. (1996). Driving simulator validity: Some considerations. *Transportation Research Record: Journal of the Transportation Research Board, 1550*, 30-36. http://dx.doi.org/10.3141/1550-05

Katsiki, N., Ntaios, G., & Vemmos, K. (2011). Stroke, obesity and gender: A review of the literature. *Maturitas, 69*(3), 239-243. http://dx.doi.org/http://dx.doi.org/10.1016/j.maturitas.2011.04.010

Kaufman, A. S. (1983). Test Review: Wechsler, D. Manual for the Wechsler Adult Intelligence Scale, Revised. New York: Psychological Corporation, 1981. *Journal of Psychoeducational Assessment, 1*(3), 309-313. http://dx.doi.org/10.1177/073428298300100310

Kawano, N., Iwamoto, K., Ebe, K., Aleksic, B., Noda, A., Umegaki, H., . . . Ozaki, N. (2012). Slower adaptation to driving simulator and simulator sickness in older adults. *Aging Clinical and Experimental Research, 24*(3), 285-289. http://dx.doi.org/10.1007/bf03325260

Kelland, D. Z., & Lewis, R. F. (1996). The Digit Vigilance Test: reliability, validity, and sensitivity to diazepam. *Archives of Clinical Neuropsychology, 11*(4), 339-344. http://dx.doi.org/10.1093/arclin/11.4.339

Kelly, T. P. (2003). Book review of Delis-Kaplan Executive Function System. *Pediatric Rehabilitation, 6*(2), 125-126. http://dx.doi.org/10.1080/1363849031000149756-1

Konstantopoulos, P., Chapman, P., & Crundall, D. (2010). Driver's visual attention as a function of driving experience and visibility. Using a driving simulator to explore drivers' eye movements in day, night and rain driving. *Accident Analysis & Prevention, 42*(3), 827-834. http://dx.doi.org/10.1016/j.aap.2009.09.022

Kostyniuk, L. P., & Shope, J. T. (2003). Driving and alternatives: Older drivers in Michigan. *Journal of Safety Research, 34*(4), 407-414. http://dx.doi.org/http://dx.doi.org/10.1016/j.jsr.2003.09.001

Kotterba, S., Widdig, W., Brylak, S., & Orth, M. (2005). Driving after cerebral ischemia – a driving simulator investigation. *Wien Med Wochenschr, 155*(15), 348-353. http://dx.doi.org/10.1007/s10354-005-0191-3

Kramer, A. F., & Madden, D. J. (2011). Attention. In F. I. M. Craik & T. A. Salthouse (Eds.), *The handbook of aging and cognition* (pp. 189-249). London, UK: Taylor and Francis. Retrieved from http://ebookcentral.proquest.com/lib/curtin/detail.action?docID=672429

Kulikov, E. (2010). The social and policy predictors of driving mobility among older adults. *Journal of Aging & Social Policy, 23*(1), 1-18. http://dx.doi.org/10.1080/08959420.2011.531991

Lee, H. C., Cameron, D., & Lee, A. H. (2003). Assessing the driving performance of older adult drivers: On-road versus simulated driving. *Accident Analysis & Prevention, 35*(5), 797-803. http://dx.doi.org/10.1016/S0001-4575(02)00083-0

Lee, H. C., Drake, V., & Cameron, D. (2002). Identification of appropriate assessment criteria to measure older adults' driving performance in simulated driving. *Australian Occupational Therapy Journal, 49*(3), 138-145. http://dx.doi.org/10.1046/j.1440-1630.2002.00314.x

Lee, H. C., & Lee, A. H. (2005). Identifying older drivers at risk of traffic violations by using a driving simulator: A 3-year longitudinal study. *The American Journal of Occupational Therapy, 59*(1), 97-100.

Lee, H. C., Lee, A. H., & Cameron, D. (2003). Validation of a driving simulator by measuring the visual attention skill of older adult drivers. *The American Journal of Occupational Therapy, 57*(3), 324-328. Retrieved from http://graphics.tx.ovid.com/ovftpdfs/FPDDNCLBAHJKIJ00/fs047/ovft/live/gv024/00000448/00000448-200305000-00010.pdf

Lee, H. C., Lee, A. H., Cameron, D., & Li-Tsang, C. (2003). Using a driving simulator to identify older drivers at inflated risk of motor vehicle crashes. *Journal of Safety Research, 34*(4), 453-459. http://dx.doi.org/http://dx.doi.org/10.1016/j.jsr.2003.09.007

Lejuez, C., Read, J. P., Kahler, C. W., Richards, J. B., Ramsey, S. E., Stuart, G. L., . . . Brown, R. A. (2002). Evaluation of a behavioral measure of risk taking: the Balloon Analogue Risk Task (BART). *Journal of Experimental Psychology: Applied, 8*(2), 75-84. http://dx.doi.org/10.1037/1076-898X.8.2.75

Leśniak, M., Bak, T., Czepiel, W., Seniów, J., & Członkowska, A. (2008). Frequency and prognostic value of cognitive disorders in stroke patients. *Dementia and Geriatric Cognitive Disorders, 26*(4), 356-363. http://dx.doi.org/10.1159/000162262

Lew, H. L., Poole, J. H., Lee, E. H., Jaffe, D. L., Huang, H.-C., & Brodd, E. (2005). Predictive validity of driving-simulator assessments following traumatic brain injury: a preliminary study. *Brain Injury, 19*(3), 177-188. http://dx.doi.org/10.1080/02699050400017171

Lewis, R., & Rennick, P. (1979). Manual for the repeatable cognitive-perceptual-motor battery. *Gross Point, MI: Axon,* Lincoln, N., & Fanthome, Y. (1994). Reliability of the stroke drivers screening assessment. *Clinical Rehabilitation, 8*(2), 157-160.

Lister, R. (1999). Loss of ability to drive following a stroke: The early experiences of three elderly people on discharge from hospital. *The British Journal of Occupational Therapy, 62*(11), 514-520. Retrieved from http://www.ingentaconnect.com/content/cot/bjot/1999/00000062/00000011/art00006

Logan, P. A., Dyas, J., & Gladman, J. R. (2004). Using an interview study of transport use by people who have had a stroke to inform rehabilitation. *Clinical Rehabilitation, 18*(6), 703-708. http://dx.doi.org/10.1191/0269215504cr742oa

Lundberg, C., Caneman, G., Samuelsson, S. M., Hakamies-Blomqvist, L., & Almkvist, O. (2003). The assessment of fitness-to-drive after a stroke: The Nordic Stroke Driver Screening Assessment. *Scandinavian Journal of Psychology, 44*(1), 23-30. http://dx.doi.org/10.1111/1467-9450.00317

Lundqvist, A. (2001). Neuropsychological aspects of driving characteristics. *Brain Injury, 15*(11), 981-994. http://dx.doi.org/doi:10.1080/02699050110065637

Lundqvist, A., & Alinder, J. (2007). Driving after brain injury: Self-awareness and coping at the tactical level of control. *Brain Injury, 21*(11), 1109-1117. http://dx.doi.org/10.1080/02699050701651660

Lundqvist, A., Alinder, J., Alm, H., Gerdle, B., Levander, S., & Ronnberg, J. (1997). Neuropsychological aspects of driving after brain lesion: Simulator study and on-road driving. *Applied Neuropsychology, 4*(4), 220-230. http://dx.doi.org/10.1207/s15324826an0404_3

Lundqvist, A., Gerdle, B., & Rönnberg, J. (2000). Neuropsychological aspects of driving after a stroke—in the simulator and on the road. *Applied Cognitive Psychology, 14*(2), 135-150. http://dx.doi.org/10.1002/(SICI)1099-0720(200003/04)14:2<135::AID-ACP628>3.0.CO;2-S

Luu, S., Lee, A. W., Daly, A., & Chen, C. S. (2010). Visual field defects after stroke: A practical guide for gps. *Australian Family Physician, 39*(7), 499-503.

MacGregor, J. M., Freeman, D. H., & Zhang, D. (2001). A traffic sign recognition test can discriminate between older drivers who have and have not had a motor vehicle crash. *Journal of the American Geriatrics Society, 49*(4), 466-469. http://dx.doi.org/10.1046/j.1532-5415.2001.49095.x

Marin-Lamellet, C., & Haustein, S. (2015). Managing the safe mobility of older road users: How to cope with their diversity? *Journal of Transport & Health, 2*(1), 22-31. http://dx.doi.org/10.1016/j.jth.2014.07.006

Marottoli, R. A., Mendes de Leon, C. F., Glass, T. A., & Williams, C. S. (1997). Driving cessation and increased depressive symptoms: Prospective evidence from the New Haven EPESE. *Journal of the American Geriatrics Society, 45*(2), 202-206. http://dx.doi.org/10.1111/j.1532-5415.1997.tb04508.x

Marottoli, R. A., Mendes de Leon, C. F., Glass, T. A., Williams, C. S., Cooney, L. M., & Berkman, L. F. (2000). Consequences of driving cessation: Decreased out-of-home activity levels. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences, 55*(6), S334-S340. http://dx.doi.org/10.1093/geronb/55.6.S334

Marshall, S. C., Molnar, F., Man-Son-Hing, M., Blair, R., Brosseau, L., Finestone, H. M., . . . Wilson, K. G. (2007). Predictors of driving ability following stroke: A systematic review. *Topics in Stroke Rehabilitation, 14*(1), 98-114. http://dx.doi.org/10.1310/tsr1401-98

Mathias, J. L., & Lucas, L. K. (2009). Cognitive predictors of unsafe driving in older drivers: A meta-analysis. *International Psychogeriatrics, 21*(04), 637-653. http://dx.doi.org/10.1017/S1041610209009119

Mathworks, T. (1998). MATLAB User's Guide. In *Natick, Inc., MA* (Vol. 5.

Mazer, B. L., Sofer, S., Korner-Bitensky, N., Gelinas, I., Hanley, J., & Wood-Dauphinee, S. (2003). Effectiveness of a visual attention retraining program on the driving performance of clients with stroke. *Archives of Physical Medicine and Rehabilitation, 84*(4), 541-550. http://dx.doi.org/http://dx.doi.org/10.1053/apmr.2003.50085

McGwin, J. G., & Brown, D. B. (1999). Characteristics of traffic crashes among young, middle-aged, and older drivers. *Accident Analysis & Prevention, 31*(3), 181-198. http://dx.doi.org/http://dx.doi.org/10.1016/S0001-4575(98)00061-X

McKay, C. (2007). *Self-evaluation of driving simulator performance in stroke patients.* PhD. University of Windsor. Retrieved from http://scholar.uwindsor.ca/etd/4687

McKay, C., Rapport, L., Bryer, R., & Casey, J. (2011). Self-evaluation of driving simulator performance after stroke. *Topics in Stroke Rehabilitation, 18*(5), 549-561. http://dx.doi.org/10.1310/tsr1805-549

McNamara, A., McCluskey, A., White, J., & George, S. (2014). The need for consistency and equity in driver education and assessment post-stroke. *Journal of Transport & Health, 1*(2), 95-99. http://dx.doi.org/http://dx.doi.org/10.1016/j.jth.2014.02.002

McNamara, A., Walker, R., Ratcliffe, J., & George, S. (2014). Perceived confidence relates to driving habits post-stroke. *Disability & Rehabilitation, 37*(14), 1228-1233. http://dx.doi.org/10.3109/09638288.2014.958619

Meuleners, L., & Fraser, M. (2015). A validation study of driving errors using a driving simulator. *Transportation Research Part F: Psychology and Behaviour, 29*, 14-21. http://dx.doi.org/10.1016/j.trf.2014.11.009

Meuleners, L. B., Harding, A., Lee, A. H., & Legge, M. (2006). Fragility and crash over-representation among older drivers in Western Australia. *Accident Analysis & Prevention, 38*, 1006-1010.

Michon, J. A. (1985). A critical view of driver behavior models: what do we know, what should we do? USA: Springer.

Microsoft Office. (2010). Visual Basic For Applications.

Middleton, L. E., Lam, B., Fahmi, H., Black, S. E., McIlroy, W. E., Stuss, D. T., . . . Turner, G. R. (2014). Frequency of domain-specific cognitive impairment in sub-acute and chronic stroke. *Neurorehabilitation, 34*(2), 305-312. http://dx.doi.org/10.3233/NRE-131030

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology, 41*(1), 49-100. http://dx.doi.org/http://dx.doi.org/10.1006/cogp.1999.0734

Molnar, L. J., & Eby, D. W. (2008). The relationship between self-regulation and driving-related abilities in older drivers: an exploratory study. *Traffic Injury Prevention, 9*(4), 314-319. Retrieved from http://www.tandfonline.com/doi/pdf/10.1080/15389580801895319

Scheffer, M,., Monteiro, J. K., & De Almeida, R. M. M. (2011). Frontal stroke: problem solving, decision making, impulsiveness, and depressive symptoms in men and women. *Psychology & Neuroscience, 4*(2), 267-278. http://dx.doi.org/10.3922/j.psns.2011.2.012

Motta, K., Lee, H. C., & Falkmer, T. (2014). Post-stroke driving: Examining the effect of executive dysfunction. *Journal of Safety Research, 49*, 33.e31. http://dx.doi.org/10.1016/j.jsr.2014.02.005

Mullen, N., Charlton, J., Devlin, A., & Bedard, M. (2011). Simulator validity: Behaviors observed on the simulator and on the road. In D. L. Fisher, M. Rizzo, J. K. Caird & J. D. Lee (Eds.), *Handbook of driving simulation for* *engineering, medicine and psychology*. United States: CRC Press, Taylor and Francis. http://dx.doi.org/:10.1201/b10836-14

Munsch, F., Sagnier, S., Asselineau, J., Bigourdan, A., Guttmann, C. R., Debruxelles, S., . . . Tourdias, T. (2016). Stroke location is an independent predictor of cognitive outcome. *Stroke, 47*(1), 66-73. http://dx.doi.org/10.1161/strokeaha.115.011242

Murie-Fernandez, M., Iturralde, S., Cenoz, M., Casado, M., & Teasell, R. (2014). Driving ability after a stroke: Evaluation and recovery. *Neurología (English Edition), 29*(3), 161-167. http://dx.doi.org/http://dx.doi.org/10.1016/j.nrleng.2012.05.008

Nasreddine, Z. S., Phillips, N. A., Bédirian, V., Charbonneau, S., Whitehead, V., Collin, I., . . . Chertkow, H. (2005). The Montreal Cognitive Assessment, MoCA: A brief screening tool for mild cognitive impairment. *Journal of the American Geriatrics Society, 53*(4), 695-699. http://dx.doi.org/10.1111/j.1532-5415.2005.53221.x

National Stroke Foundation. (2013). Driving after stroke. February 2013 Retrieved from https://strokefoundation.com.au/~/media/strokewebsite/resources/factsheets/fs01_driving_web.ashx?la=en

Nouri, F. M., & Lincoln, N. B. (1992). Validation of a cognitive assessment: Predicting driving performance after stroke. *Clinical Rehabilitation, 6*(4), 275-281. http://dx.doi.org/10.1177/026921559200600402

Odenheimer, G. L. (2011). Which patients are fit to drive after a stroke? *Journal Watch. Neurology,* http://dx.doi.org/10.1056/JN201103150000001

Odenheimer, G. L., Beaudet, M., Jette, A. M., Albert, M. S., Grande, L., & Minaker, K. L. (1994). Performance-based driving evaluation of the elderly driver: Safety, reliability, and validity. *Journal of Gerontology, 49*(4), M153-M159. Retrieved from http://geronj.oxfordjournals.org/content/49/4/M153.full.pdf

Oltedal, S., & Rundmo, T. (2006). The effects of personality and gender on risky driving behaviour and accident involvement. *Safety Science, 44*(7), 621-628. http://dx.doi.org/10.1016/j.ssci.2005.12.003

Ott, B. R., Papandonatos, G. D., Davis, J. D., & Barco, P. P. (2012). Naturalistic validation of an on-road driving test of older drivers. *Human Factors, 54*(4), 663-674. http://dx.doi.org/10.1177/0018720811435235

Owsley, C., Ball, K., McGwin, Jr, G., & et al. (1998). Visual processing impairment and risk of motor vehicle crash among older adults. *JAMA, 279*(14), 1083-1088. http://dx.doi.org/10.1001/jama.279.14.1083

Owsley, C., Stalvey, B., Wells, J., & Sloane, M. E. (1999). Older drivers and cataract: driving habits and crash risk. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 54*(4), M203-M211. http://dx.doi.org/10.1093/gerona/54.4.M203

Oxley, J., Fildes, B., Corben, B., & Langford, J. (2006). Intersection design for older drivers. *Transportation Research Part F: Traffic Psychology and Behaviour, 9*(5), 335-346. http://dx.doi.org/http://dx.doi.org/10.1016/j.trf.2006.06.005

Patel, B., & Birns, J. (2015). Post-stroke cognitive impairment. In A. Bhalla & J. Birns (Eds.), *Management of post-stroke complications* (pp. 277-306). Cham, Germany: Springer International Publishing. http://dx.doi.org/:10.1007/978-3-319-17855-4_12

Patomella, A.-H., Johansson, K., & Tham, K. (2009). Lived experience of driving ability following stroke. *Disability & Rehabilitation, 31*(9), 726-733. http://dx.doi.org/10.1080/09638280802306539

Patomella, A.-H., Kottorp, A., & Tham, K. (2008). Awareness of driving disability in people with stroke tested in a simulator. *Scandinavian Journal of Occupational Therapy, 15*(3), 184-192. http://dx.doi.org/10.1080/11038120802087600

Pendlebury, S. T., Cuthbertson, F. C., Welch, S. J. V., Mehta, Z., & Rothwell, P. M. (2010). Underestimation of cognitive impairment by Mini-Mental State Examination versus the Montreal Cognitive Assessment in patients with transient ischemic attack and stroke: A population-based study. *Stroke, 41*(6), 1290-1293. http://dx.doi.org/10.1161/strokeaha.110.579888

Perrier, M.-J., Korner-Bitensky, N., & Mayo, N. E. (2010). Patient factors associated with return to driving poststroke: Findings from a multicenter cohort study. *Archives of Physical Medicine and Rehabilitation, 91*(6), 868-873. http://dx.doi.org/10.1016/j.apmr.2010.03.009

Perrier, M.-J., Korner-Bitensky, N., Petzold, A., & Mayo, N. (2010). The risk of motor vehicle crashes and traffic citations post-stroke: A structured review. *Topics in Stroke Rehabilitation, 17*(3), 191-196. http://dx.doi.org.dbgw.lis.curtin.edu.au/10.1310/tsr1703-191

Persson, D. (1993). The elderly driver: Deciding when to stop. *The Gerontologist, 33*(1), 88-91. http://dx.doi.org/10.1093/geront/33.1.88

Plainis, S., & Murray, I. J. (2002). Reaction times as an index of visual conspicuity when driving at night. *Ophthalmic and Physiological Optics, 22*(5), 409-415. http://dx.doi.org/10.1046/j.1475-1313.2002.00076.x

Pollatsek, A., Vlakveld, W., Kappé, B., Pradhan, A., & Fisher, D. L. (2011). Driving simulators as training and evaluation tools *Handbook of driving simulation for engineering, medicine, and psychology*: CRC Press. http://dx.doi.org/:10.1201/b10836-31

Ponsford, A. S., Viitanen, M., Lundberg, C., & Johansson, K. (2008). Assessment of driving after stroke-a pluridisciplinary task. *Accident Analysis & Prevention, 40*(2), 452-460. http://dx.doi.org/10.1016/j.aap.2007.07.015

Poole, D., Chaudry, F., & Jay, W. M. (2008). Stroke and driving. *Topics in Stroke Rehabilitation, 15*(1), 37-41. http://dx.doi.org/10.1310/tsr1501-37

Pradhan, A. K., Hammel, K. R., DeRamus, R., Pollatsek, A., Noyce, D. A., & Fisher, D. L. (2005). Using eye movements to evaluate effects of driver age on risk perception in a driving simulator. *Human Factors, 47*(4), 840-852. http://dx.doi.org/10.1518/001872005775570961

Precision Vision. 2000 Series Revised ETDRS Charts. La Salle, Illinois: (Precision Vision).

Precision Vision. Snellen Visual Acuity Chart. La Salle, Illinois: (Precision Vision).

Qualls, C. E., Bliwise, N. G., & Stringer, A. Y. (2000). Short forms of the Benton Judgment of Line Orientation test: Development and psychometric properties. *Archives of Clinical Neuropsychology, 15*(2), 159-163. http://dx.doi.org/http://dx.doi.org/10.1016/S0887-6177(98)00043-2

Qualtrics. (2015). Qualtrics. Provo, Utah, USA.

Radford, K. A., & Lincoln, N. B. (2004). Concurrent validity of the stroke drivers screening assessment. *Archives of Physical Medicine and Rehabilitation, 85*(2), 324-328. http://dx.doi.org/10.1016/S0003-9993(03)00765-2

Ragland, D. R., Satariano, W. A., & MacLeod, K. E. (2004). Reasons given by older people for limitation or avoidance of driving. *The Gerontologist, 44*(2), 237-244.

Ragland, D. R., Satariano, W. A., & MacLeod, K. E. (2005). Driving cessation and increased depressive symptoms. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences., 60*(3), 399-403.

Rankin, J. (1957). Cerebral vascular accidents in patients over the age of 60: II. Prognosis. *Scottish Medical Journal, 2*(5), 200-215.

Ranney, T. A. (1994). Models of driving behavior: A review of their evolution. *Accident Analysis & Prevention, 26*(6), 733-750. http://dx.doi.org/http://dx.doi.org/10.1016/0001-4575(94)90051-5

Ranney, T. A. (2011). Psychological fidelity *Handbook of driving simulation for engineering, medicine, and psychology*: CRC Press. http://dx.doi.org/:doi:10.1201/b10836-10

Rapoport, M. J., Naglie, G., Weegar, K., Myers, A., Cameron, D., Crizzle, A., . . . Marshall, S. (2013). The relationship between cognitive performance, perceptions of driving comfort and abilities, and self-reported driving restrictions among healthy older drivers. *Accident Analysis & Prevention, 61*, 288-295. http://dx.doi.org/10.1016/j.aap.2013.03.030

Reason, J. T., & Brand, J. J. (1975). *Motion sickness* New York, USA: Academic Press.

Reitan, R. M., & Wolfson, D. (1985). The Halstead-Reitan Neuropsychological Test Battery: Theory and clinical interpretation. Tucson, Arizona, USA: Neuropsychology Press.

Reuter-Lorenz, P. A., & Cappell, K. A. (2008). Neurocognitive aging and the compensation hypothesis. *Current Directions in Psychological Science, 17*(3), 177-182. http://dx.doi.org/doi:10.1111/j.1467-8721.2008.00570.x

Riccio, C. A., & Hynd, G. W. (1992). Validity of Benton's Judgement of Line Orientation Test. *Journal of Psychoeducational Assessment, 10*(3), 210-218. http://dx.doi.org/10.1177/073428299201000301

Riendeau, J. A., Maxwell, H., Patterson, L., Weaver, B., & Bédard, M. (2016). Self-rated confidence and on-road driving performance among older adults. *Canadian Journal of Occupational Therapy, 83*(3), 177-183. http://dx.doi.org/10.1177/0008417416645912

Rubio, S., Diaz, E., Martin, J., & Puente, J. M. (2004). Evaluation of subjective mental workload: A comparison of SWAT, NASA-TLX, and workload profile methods. *Applied Psychology: An International Review, 53*(1), 61-86. http://dx.doi.org/10.1111/j.1464-0597.2004.00161.x

Rudman, D. L., Friedland, J., Chipman, M., & Sciortino, P. (2006). Holding on and letting go: The perspectives of pre-seniors and seniors on driving self-regulation in later life. *Canadian Journal on Aging, 25*(1), 65-76.

Sacco, R., Wolf, P. A., Kannel, W., & McNamara, P. (1982). Survival and recurrence following stroke. The Framingham study. *Stroke, 13*(3), 290-295.

Sacco, R. L., Benjamin, E. J., Broderick, J. P., Dyken, M., Easton, J. D., Feinberg, W. M., . . . Wolf, P. A. (1997). Risk factors. *Stroke, 28*(7), 1507-1517. http://dx.doi.org/10.1161/01.str.28.7.1507

Sacco, R. L., Kasner, S. E., Broderick, J. P., Caplan, L. R., Connors, J. J., Culebras, A., . . . Vinters, H. V. (2013). An updated definition of stroke for the 21st century.

Stroke, 44(7), 2064-2089. http://dx.doi.org/10.1161/STR.0b013e318296aeca

Scheffer, M., Monteiro, J. K., & Almeida, R. M. M. d. (2011). Frontal stroke: problem solving, decision making, impulsiveness, and depressive symptoms in men and women. *Psychology & Neuroscience, 4*(2), 267-278. http://dx.doi.org/10.3922/j.psns.2011.2.012

Schneider, W., Eschman, A., & Zuccolotto, A. (2012). E-Prime (Version 2.0). Pittsburgh: Psychology Software Tools, Inc.

Schneider, W., & Shiffrin, R. M. (1977). Controlled and automatic human information processing: II. Perceptual learning, automatic attending and a general theory. *Psychological Review, 84*(2), 127-190. http://dx.doi.org/10.1037/0033-295X.84.2.127

Schütz, A. C., Braun, D. I., & Gegenfurtner, K. R. (2011). Eye movements and perception: A selective review. *Journal of Vision, 11*(5), 1-30. http://dx.doi.org/10.1167/11.5.9

Scott, C. A., Rapport, L. J., Coleman Bryer, R., Griffen, J., Hanks, R., & McKay, C. (2009). Self-assessment of driving ability and the decision to resume driving following stroke. *Journal of Clinical and Experimental Neuropsychology, 31*(3), 353-362. http://dx.doi.org/10.1080/13803390802169067

Scott, J. G., & Schoenberg, M. R. (2011). Deficits in visuospatial/visuoconstructional skills and motor praxis. In M. R. Schoenberg & J. G. Scott (Eds.), *The little black book of neuropsychology: A syndrome-based approach* (pp. 201-218). Boston, Massachusetts, USA: Springer USA. http://dx.doi.org/:10.1007/978-0-387-76978-3_9

Selander, H., Lee, H. C., Johansson, K., & Falkmer, T. (2011). Older drivers: On-road and off-road test results. *Accident Analysis & Prevention, 43* (4), 1348-1354. http://dx.doi.org/10.1016/j.aap.2011.02.007

SensoriMotoric Instruments. (2011). SMI BeGaze™ Eye Tracking Analysis Software (Version 3.6). Retrieved from http://twiki.cis.rit.edu/twiki/pub/MVRL/SmiTracker/begaze2.pdf

Siren, A., Hakamies-Blomqvist, L., & Lindeman, M. (2004). Driving Cessation and Health in Older Women. *Journal of Applied Gerontology, 23*(1), 58-69. http://dx.doi.org/10.1177/0733464804263129

Son, J., Oh, H., & Park, M. (2013). Identification of driver cognitive workload using support vector machines with driving performance, physiology and eye movement in a driving Simulator. *International Journal of Precision Engineering Manufacturing, 14*(8), 1321-1327. http://dx.doi.org/10.1007/s12541-013-0179-7

Song, C.-S., Chun, B.-Y., & Chung, H.-S. (2015). Test-retest reliability of the driving habits questionnaire in older self-driving adults. *Journal of Physical Therapy Science, 27*(11), 3597-3599. http://dx.doi.org/10.1589/jpts.27.3597

Stanton, N. A., & Marsden, P. (1996). From fly-by-wire to drive-by-wire: Safety implications of automation in vehicles. *Safety Science, 24*(1), 35-49. http://dx.doi.org/http://dx.doi.org/10.1016/S0925-7535(96)00067-7

Stapleton, T., Connolly, D., & O'Neill, D. (2012). Exploring the relationship between self-awareness of driving efficacy and that of a proxy when determining fitness to drive after stroke. *Australian Occupational Therapy Journal, 59*(1), 63-70. http://dx.doi.org/10.1111/j.1440-1630.2011.00980.x

Starkey, N. J., & Isler, R. B. (2016). The role of executive function, personality and attitudes to risks in explaining self-reported driving behaviour in adolescent and adult male drivers. *Transportation Research Part F: Psychology and Behaviour, 38*, 127-136. http://dx.doi.org/10.1016/j.trf.2016.01.013

Stedmon, A., Young, M. S., & Hasseldine, B. (2009). Keeping it real or faking it: The trials and tribulations of real road studies and simulators in transport research. In P. D. Bust (Ed.), *Contemporary Ergonomics 2009: Proceedings of the International Conference on Contemporary Ergonomics 2009*, CRC Press, London, UK, Stone, S., Wilson, B., Wroot, A., Halligan, P., Lange, L., Marshall, J., & Greenwood, R. (1991). The assessment of visuo-spatial neglect after acute stroke. *Journal of Neurology, Neurosurgery & Psychiatry, 54*(4), 345-350. http://dx.doi.org/10.1136/jnnp.54.4.345

Stoner, H., Fisher, D., & Mollenhauer, J. M. (2011). Simulator and scenario factors influencing simulator sickness. In D. L. Fisher, M. Rizzo, J. K. Caird & J. D. Lee (Eds.), *Handbook of driving simulation for engineering, medicine, and psychology*. London. UK: CRC Press: Taylor and Francis. http://dx.doi.org/:doi:10.1201/b10836-15

Strong, K., Mathers, C., & Bonita, R. (2007). Preventing stroke: saving lives around the world. *The Lancet Neurology, 6*(2), 182-187. http://dx.doi.org/10.1016/S1474-4422(07)70031-5

Swanson, J. (2005). The Delis-Kaplan Executive Function System: A review. *Canadian Journal of School Psychology, 20*(1/2), 117-128. http://dx.doi.org/10.1177/0829573506295469

Szlyk, J. P., Seiple, W., & Viana, M. (1997). Relative effects of age and compromised vision on driving performance. *Human Factors, 37*(2), 430–436. http://dx.doi.org/http://dx.doi.org/10.1016/0022-4375(97)90034-7

Tabibi, Z., & Pfeffer, K. (2003). Choosing a safe place to cross the road: the relationship between attention and identification of safe and dangerous road-crossing sites. *Child: Care, Health and Development, 29*(4), 237-244. http://dx.doi.org/10.1046/j.1365-2214.2003.00336.x

Tan, K. M., O'Driscoll, A., & O'Neill, D. (2011). Factors affecting return to driving post-stroke. *Irish Journal of Medical Science, 180*(1), 41-45. http://dx.doi.org/10.1007/s11845-010-0528-9

Thrift, A. G., Cadilhac, D. A., Thayabaranathan, T., Howard, G., Howard, V. J., Rothwell, P. M., & Donnan, G. A. (2014). Global stroke statistics. *International Journal of Stroke: Official Journal of The International Stroke Society, 9*(1), 6-18. http://dx.doi.org/10.1111/ijs.12245

Treccani, B., Torri, T., & Cubelli, R. (2005). Is judgement of line orientation selectively impaired in right brain damaged patients? *Neuropsychologia, 43*(4), 598-608. http://dx.doi.org/http://dx.doi.org/10.1016/j.neuropsychologia.2004.07.008

Uc, E., & Rizzo, M. (2011). Driving in Alzheimer's disease, Parkinson's disease and stroke. In D. L. Fisher, M. Rizzo, J. K. Caird & J. D. Lee (Eds.), *Handbook of driving simulation for engineering, medicine, and psychology*. Boca Raton, Florida, USA: CRC Press: Taylor and Francis. http://dx.doi.org/:doi:10.1201/b10836-49

Underwood, G. (2007). Visual attention and the transition from novice to advanced driver. *Ergonomics, 50*(8), 1235-1249. http://dx.doi.org/10.1080/00140130701318707

Underwood, G., Chapman, P., Brocklehurst, N., Underwood, J., & Crundall, D. (2003). Visual attention while driving: sequences of eye fixations made by experienced and novice drivers. *Ergonomics, 46*(6), 629-646. http://dx.doi.org/10.1080/0014013031000090116

Unsworth, C. A., Wells, Y., Browning, C., Thomas, S. A., & Kendig, H. (2007). To continue, modify or relinquish driving: Findings from a longitudinal study of healthy ageing. *Gerontology, 53*(6), 423-431. Retrieved from http://www.karger.com/DOI/10.1159/000111489

van Geldorp, B., Kessels, R. P. C., &Hendriks, M. P. H. (2013). Single-item and associative working memory in stroke patients. *Behavioural Neurology, 26*(3), 199-201. http://dx.doi.org/10.3233/BEN-2012-129010

van Swieten, J. C., Koudstaal, P. J., Visser, M. C., Schouten, H. J., & van Gijn, J. (1988). Interobserver agreement for the assessment of handicap in stroke patients. *Stroke, 19*(5), 604-607. http://dx.doi.org/10.1161/01.str.19.5.604

van Zomeren, A. H., & Brouwer, W. H. (1994). *Clinical neuropsychology of attention*. New York: Oxford University Press

Vogel, K. (2003). A comparison of headway and time to collision as safety indicators. *Accident Analysis & Prevention, 35*(3), 427-433. http://dx.doi.org/http://dx.doi.org/10.1016/S0001-4575(02)00022-2

Wechsler, D. (2008). *Wechsler Adult Intelligence Scale–Fourth Edition (WAIS–IV)*. San Antonio, Texas, USA: NCS Pearson.

White, J. H., Miller, B., Magin, P., Attia, J., Sturm, J., & Pollack, M. (2012). Access and participation in the community: a prospective qualitative study of driving post-stroke. *Disability and Rehabilitation, 34*(10), 831-838. http://dx.doi.org/10.3109/09638288.2011.623754

Wolf, T. J., & Rognstad, M. C. (2013). Changes in cognition following mild stroke. *Neuropsychological Rehabilitation, 23*(2), 256-266. http://dx.doi.org/10.1080/09602011.2012.748672

Xiao, Y. M., Wang, Z. M., Wang, M. Z., & Lan, Y. J. (2005). The appraisal of reliability and validity of subjective workload assessment technique and NASA-task load index. *Chinese Journal of Industrial Hygience and Occupational Disease, 23*(3), 178-181.

Yamin, S., Stinchcombe, A., & Gagnon, S. (2016). Deficits in attention and visual processing but not global cognition predict simulated driving errors in drivers diagnosed with mild Alzheimer's disease. *American Journal of Alzheimer's Disease & Other Dementias, 31*(4), 351-360. http://dx.doi.org/10.1177/1533317515618898

Yochim, B., Baldo, J., Nelson, A., & Delis, D. C. (2007). D-KEFS Trail Making Test performance in patients with lateral prefrontal cortex lesions. *Journal of the International Neuropsychological Society, 13*(04), 704-709. http://dx.doi.org/10.1017/S1355617707070907

Young, A. H., & Hulleman, J. (2013). Eye movements reveal how task difficulty moulds visual search. *Journal of Experimental Psychology: Human Perception and Performance, 39*(1), 168-190. http://dx.doi.org/10.1037/a0028679

Young, M. S. (2000). Attention, automaticity, and automation: New perspectives on mental underload and performance. PhD. University of Southampton.

Young, M. S., Brookhuis, K. A., Wickens, C. D., & Hancock, P. A. (2015). State of science: mental workload in ergonomics. *Ergonomics, 58*(1), 1-17. http://dx.doi.org/10.1080/00140139.2014.956151

Young, M. S., & Stanton, N. A. (2002). Attention and automation: new perspectives on mental underload and performance. *Theoretical Issues in Ergonomics Science, 3*(2), 178-194. http://dx.doi.org/10.1080/14639220210123789

Young, M. S., & Stanton, N. A. (2004). Taking the load off: Investigations of how adaptive cruise control affects mental workload. *Ergonomics, 47*, 1014-1035. http://dx.doi.org/10.1080/00140130410001686348

Zinn, S., Bosworth, H. B., Hoenig, H. M., & Swartzwelder, H. S. (2007). Executive function deficits in acute stroke. *Archives of Physical Medicine and Rehabilitation, 88*(2), 173-180. http://dx.doi.org/http://dx.doi.org/10.1016/j.apmr.2006.11.015

Appendix 1: Statement of Author Contribution

Alison Blane
School of Occupational Therapy and Social Work
Curtin University
GPO Box U1987
Pert, WA, 6845

14th March 2017

Dear Sir or Madam,

Re. Paper authorship contribution confirmation

This letter is to confirm that I, Alison Blane, as lead author was the major contributor to the conceptualisation, coordination and implementation of the following paper.

Blane, A., Falkmer, T., Lee, M., Parsons, R., & Lee, H. (2016). The cognitive and socio-demographic influences on driving performance and driving cessation in post-stroke drivers. *Advances in Transportation Studies* (38), 121-135.

I contributed to the conceptualisation, drafting, analysis, interpretation and proof-reading of the abovementioned paper. This paper involved assessment, analysis and interpretation of data previously collected by Megan Lee. All authors have agreed the author order and have provided permission for this paper to be used as part of my PhD thesis, subject to receiving the appropriate copyright permissions.

Yours sincerely,

Alison Blane

I, as Co-Author endorse that the level of contribution by the candidate and is appropriate for that of lead author and provide permission for the paper to be used as part of the candidate's PhD thesis, subject to appropriate copyright conditions.

Torbjörn Falkmer: ______________________________

Megan Lee: ______________________________

Richard Parsons: ______________________________

Hoe C. Lee: ______________________________

Curtin University

Alison Blane
School of Occupational Therapy and Social Work
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GPO Box U1987
Perth, WA, 6845

14th March 2017

Dear Sir or Madam,

Re. Paper authorship contribution confirmation

This letter is to confirm that I, Alison Blane, as lead author was the major contributor to the conceptualisation, coordination and implementation of the following paper in press.

Blane, A., Lee, H. C., Falkmer, T., & Dukic Willstrand, T. (*in press*). Assessing cognitive ability and simulator-based driving performance in post-stroke adults. *Behavioural Neurology,* ([Special Issue] Behavioural and Cognitive Effects of Cerebrovascular Diseases).

This abovementioned paper involved assessment, analysis and interpretation of data collected by me and I contributed to the conceptualisation, drafting, analysis, interpretation and proof-reading of the final manuscript. All authors have agreed the author order and have provided permission for this paper to be used as part of my PhD thesis, subject to receiving the appropriate copyright permissions.

Yours sincerely,

Alison Blane

I, as Co-Author endorse that the level of contribution by the candidate and is appropriate for that of lead author and provide permission for the paper to be used as part of the candidate's PhD thesis, subject to appropriate copyright conditions.

Torbjorn Falkmer: ____________________

Hoe C. Lee: ____________________

Tania Dukic Willstrand: ____________________

Alison Blane
School of Occupational Therapy and Social Work
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Perth, WA, 6845

14th March 2017

Dear Sir or Madam,

Re. Paper authorship contribution confirmation

This letter is to confirm that I, Alison Blane, as lead author was the major contributor to the conceptualisation, coordination and implementation of the following paper under review.

Blane, A., Lee, H. C., Falkmer, T., & Dukic Willstrand, T. (*under review*). Investigating cognitive ability and self-reported driving performance of post-stroke adults in a driving simulator

This abovementioned paper involved assessment, analysis and interpretation of data collected by me and I contributed to the conceptualisation, drafting, analysis, interpretation and proof-reading of the final manuscript. All authors have agreed the author order and have provided permission for this paper to be used as part of my PhD thesis, subject to receiving the appropriate copyright permissions.

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Alison Blane

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Torbjorn Falkmer: ______________________________

Hoe C. Lee: ______________________________

Tania Dukic Willstrand: ______________________________

Curtin University

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School of Occupational Therapy and Social Work

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Perth, WA, 6845

14th March 2017

Dear Sir or Madam,

Re. Paper authorship contribution confirmation

This letter is to confirm that I, Alison Blane, as lead author was the major contributor to the conceptualisation, coordination and implementation of the following paper under review.

Blane, A., H.C., Falkmer, T., & Dukic Willstrand, T. (under review). *Cognitive ability as a predictor of task demand and self-rated driving performance in post-stroke drivers – implications for self-regulation*.

This abovementioned paper involved assessment, analysis and interpretation of data collected by me and I contributed to the conceptualisation, drafting, analysis, interpretation and proof-reading of the final manuscript. All authors have agreed the author order and have provided permission for this paper to be used as part of my PhD thesis, subject to receiving the appropriate copyright permissions.

Yours sincerely,

Alison Blane

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Torbjorn Falkmer: ______________________________

Hoe C. Lee: ______________________________

Tania Dukic Willstrand: ______________________________

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14th March 2017

Dear Sir or Madam,

Re. Paper authorship contribution confirmation

This letter is to confirm that I, Alison Blane, as lead author was the major contributor to the conceptualisation, coordination and implementation of the following paper under review.

Blane, A., Lee, H. C., Falkmer, T., & Dukic Willstrand, T. (*under review*). On-road visual scanning in post-stroke drivers in relation to their cognitive functioning

This abovementioned paper involved assessment, analysis and interpretation of data collected by me and I contributed to the conceptualisation, drafting, analysis, interpretation and proof-reading of the final manuscript. All authors have agreed the author order and have provided permission for this paper to be used as part of my PhD thesis, subject to receiving the appropriate copyright permissions.

Yours sincerely,

Alison Blane

I, as Co-Author endorse that the level of contribution by the candidate and is appropriate for that of lead author and provide permission for the paper to be used as part of the candidate's PhD thesis, subject to appropriate copyright conditions.

Torbjorn Falkmer: ______________________________

Hoe C. Lee: ______________________________

Tania Dukic Willstrand: ______________________________

Appendix 2: Demographic Questionnaire

Curtin University

Demographic Questionnaire and Driving History

Questionnaire Information

This questionnaire contains some questions regarding your driving, and demographic information. Please select the response that best describes your situation.

- Section 1: Driver Screening
- Section 2: Demographic Information and Driving History

Statement of Confidentiality

All of the information collected through this questionnaire will be kept strictly confidential. Such information will only be used for the purpose of this research study and will not be released without prior consent, except when required by law.

Participant Signature: ______________________________

Participant Name (*please print*) ______________________________

Date: (DD/MM/YYYY) ______________________________

Part A. – Driver Screening

1. Have you previously been diagnosed as having a stroke?

❍ Yes (go to question 1a)

❍ No (go to question 2)

1a. When was your stroke diagnosed? (MM/YYYY)

____

1b. In which area of the brain did you stroke occur?

(e.g., *left hemisphere/ right hemisphere/ frontal lobe / midbrain etc*.)

____

____

1c. Have you been cleared to drive by a medical professional?

❍ Yes

❍ No

1d. Have you declared your stroke to the WA Department of Transport?

❍ Yes

❍ No

2. Are you aged over 60 years old?

❍ Yes

❍ No

3. Do you have normal or corrected-to-normal (i.e. with glasses or contact lenses) vision?

- ❍ Yes
- ❍ No

4. Do you possess a full driving license that is valid within Australia?

- ❍ Yes
- ❍ No

5. Do you drive at least twice a week?

- ❍ Yes
- ❍ No

6. Do you require a wheelchair to get around?

- ❍ Yes (please review study guidelines)
- ❍ No

7. Have you been diagnosed with any of the following (select all that apply):

- ❑ Hemianopia
- ❑ Quadrantopia
- ❑ Hemispheric Neglect
- ❑ Parkinson's Disease
- ❑ Alzheimer's Disease
- ❑ Dementia
- ❑ Any other neurodengerative disease
- ❑ None of the above

8. Do you require a modified car to drive?

❍ Yes (go to Q8b)

❍ No (go to Q9)

Q8b. What modifications have been installed into your car to assist you with driving?

____

____

____

Q9. Have you previously taken part in our older driver research at Curtin University?

❍ Yes

❍ No

Part B - Demographic Details and Driving Experience

Q1. What is your full name?

____

____

Q2. What is your gender?

❍ Male

❍ Female

Q3. What is your date of birth? (DD/MM/YYYY)

____

Q4. Were you born in Australia?

❍ Yes (go to Q4b)

❍ No (go to Q4a)

Q4a. What is your country of birth?

____

Q4b. What do you consider to be your ethnicity?

____

____

Q5. Which of the following statements best describes you?

- ❍ Never Married
- ❍ Married
- ❍ In a de-facto partnership
- ❍ Separated / Widowed / Divorced

Q6. Do you live alone?

- ❍ Yes
- ❍ No

Q7. What is the highest level of education you have completed?

- ❍ Did not attend school
- ❍ Primary School
- ❍ Secondary School
- ❍ TAFE / Other Certificate
- ❍ University Degree

Q8. Are you currently any of the following?

- ❍ Employed (go to Q9)
- ❍ Unemployed (go to Q10)
- ❍ Retired (go to Q10)

Q9. Do you work...?

- ❍ Full Time
- ❍ Part Time

Q10. What is / was your most recent profession?

____

____

Q11. Do you wear glasses or contact lenses when you drive?

❍ Yes (go to Q11a)

❍ No (go to Q12)

Q11a. What is your most up to date glasses prescription?

____

Q12. Do you have a diagnosis of a medical condition such as epilepsy, diabetes or heart disease etc.? If yes, please give details

____

____

Q13 Are you currently taking any prescribed medications? If yes, please give details.

____

____

Q14. What types of vehicles are you currently licensed to drive?

(please tick all that apply)

- ❑ Car (Manual)
- ❑ Car (automatic)
- ❑ Van
- ❑ Bus
- ❑ Taxi
- ❑ Truck
- ❑ Motorcycle
- ❑ Emergency Vehicle

Q15. When did you first receive your driving license (MM/YYYY)

____

Q16. What is your approximate annual mileage?

____

Q17. Please indicate the amount of time (in hours) you normally spend a week of the following types of roads?

_______ Urban (City / Suburbs)

_______ Rural

_______ Freeway

Appendix 3: STISIM Programming

- Lead-Car Scenario Code
- Hazard Perception Code

Scenario: Lead Car

```
METRIC
0ROAD122110.335.5130.330.330000100100200200
0BSAV10.5STROKE1234567891011121314181922223
0SIGN100457.2C:\STISIM3\Data\EuroSigns\SpeedLimit\Speed_Limit_60.mka
0Tree250*1~15;-2;-7;-10-62.484{0}-74.676{0}
0BLDG487.6817.67H*1;2
0BLDG502.9218.67H*1;3;2
2BLDG502.92-20.67H*1;2
5BLDG487.68-19.67H*1;2
100A4510006*1~4
150SIGN100457.2C:\STISIM3\Data\EuroSigns\SpeedLimit\Speed_Limit_60.mka
200LS600
200BLDG457.219.67H*1;2;
200BLDG472.4420.67H*1;3;2
200BLDG487.6817.67H*1;2
200BLDG502.9218.67H*1;3;2
202BLDG502.92-20.67H*1;2
205BLDG472.44-19.67H*1;3;2
205BLDG487.68-19.67H*1;2
300A45100066
365.76TREE250*1~15;-2;-7;-1022.1921.76
463.04TREE250*1~15;-2;-7;-1028.1919.76
500FLLW16.6666741.667-5.75{0}233001802100
500PRG:\ALB-StrokeDriving\VoiceInstructions\Audacity\FollowTheLeadCar1.wav110
500A45100063
500BLDG457.219.67H*1;2;
500BLDG472.4420.67H*1;3;2
500BLDG487.6817.67H*1;2
500BLDG502.9218.67H*1;3;2
502BLDG502.92-20.67H*1;2
505BLDG472.44-19.67H*1;3;2
505BLDG487.68-19.67H*1;2
650BLDG457.219.67H*1;2;
650BLDG472.4420.67H*1;3;2
650BLDG487.6817.67H*1;2
650BLDG502.9218.67H*1;3;2
652BLDG502.92-20.67H*1;2
655BLDG472.44-19.67H*1;3;2
655BLDG487.68-19.67H*1;2
680SIGN100457.2C:\STISIM3\Data\EuroSigns\SpeedLimit\Speed_Limit_60.mka
700A4510006*1~4
800BLDG457.219.67H*1;2;
800BLDG472.4420.67H*1;3;2
800BLDG487.6817.67H*1;2
800BLDG502.9218.67H*1;3;2
802BLDG502.92-20.67H*1;2
805BLDG472.44-19.67H*1;3;2
805BLDG487.68-19.67H*1;2
838I07620000
900A45100068
914.4TREE00*1~15;-2;-7;-1019.1916.76
950BLDG487.6817.67H*1;2
950BLDG502.9218.67H*1;3;2
952BLDG502.92-20.67H*1;2
955BLDG487.68-19.67H*1;2
975.36TREE250*1~15;-2;-7;-1023.1917.76
1000SIGN100457.2C:\STISIM3\Data\EuroSigns\SpeedLimit\Speed_Limit_60.mka
1000A5010006*1~4
1000BLDG457.219.67H*1;2;
1000BLDG472.4420.67H*1;3;2
1000BLDG487.6817.67H*1;2
1000BLDG502.9218.67H*1;3;2
1002BLDG502.92-20.67H*1;2
1005BLDG472.44-19.67H*1;3;2
1005BLDG487.68-19.67H*1;2
1075A45100063
1200BLDG487.6817.67H*1;2
1200BLDG502.9218.67H*1;3;2
1202BLDG502.92-20.67H*1;2
1205BLDG487.68-19.67H*1;2
1219.2VC152.40.01
1250A4510006*1~4
1310.64TREE00*1~15;-2;-7;-1019.1917.76
1400A4510006*1~4
1438I17620000
```

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1450BLDG487.6817.67H*1;2
1450BLDG502.9218.67H*1;3;2
1452BLDG502.92-20.67H*1;2
1455BLDG487.68-19.67H*1;2
1500SIGN100457.2C:\STISIM3\Data\EuroSigns\SpeedLimit\Speed_Limit_60.mka
1535.14ROAD122110.335.5130.330.3319.812000100100200200
1600A55100064
1600BLDG487.6817.67H*1;2
1600BLDG502.9218.67H*1;3;2
1602BLDG502.92-20.67H*1;2
1605BLDG487.68-19.67H*1;2
1664.86ROAD122110.335.5130.330.3319.812000100100200200
1676.4VC152.4-0.01
1738StaticObject76259.055118560791{1}0000C:\STISIM3\Data\Miscellaneous\TelephonePole.Mka
1767.84TREE00*1~15;-2;-7;-1027.1923.76
1800SIGN100457.2C:\STISIM3\Data\EuroSigns\SpeedLimit\Speed_Limit_60.mka
1800A4010006*1~4
1800BLDG487.6817.67H*1;2
1800BLDG502.9218.67H*1;3;2
1802BLDG502.92-20.67H*1;2
1805BLDG487.68-19.67H*1;2
1889.76TREE250*1~15;-2;-7;-1025.1919.76
2000SIGN100457.2C:\STISIM3\Data\EuroSigns\SpeedLimit\Speed_Limit_60.mka
2000A5010006*1~4
2000BLDG457.219.67H*1;2;
2000BLDG472.4420.67H*1;3;2
2000BLDG487.6817.67H*1;2
2000BLDG502.9218.67H*1;3;2
2002BLDG502.92-20.67H*1;2
2005BLDG472.44-19.67H*1;3;2
2005BLDG487.68-19.67H*1;2
2100A4510006*1~4
2135.14ROAD122110.335.5130.330.3319.812000100100200200
2175BLDG487.6817.67H*1;2
2175BLDG502.9218.67H*1;3;2
2177BLDG502.92-20.67H*1;2
2180BLDG487.68-19.67H*1;2
2264.86ROAD122110.335.5130.330.3319.812000100100200200
2300A45100066
2338I07621
2500SIGN100457.2C:\STISIM3\Data\EuroSigns\SpeedLimit\Speed_Limit_60.mka
2500A45100063
2500BLDG487.6817.67H*1;2
2500BLDG502.9218.67H*1;3;2
2502BLDG502.92-20.67H*1;2
2505BLDG487.68-19.67H*1;2
2700A4510006*1~4
2900SIGN100457.2C:\STISIM3\Data\EuroSigns\SpeedLimit\Speed_Limit_60.mka
2900A45100068
2971.8VC152.4-0.01
3000BLDG457.219.67H*1;2;
3000BLDG472.4420.67H*1;3;2
3000BLDG487.6817.67H*1;2
3000BLDG502.9218.67H*1;3;2
3002BLDG502.92-20.67H*1;2
3005BLDG472.44-19.67H*1;3;2
3005BLDG487.68-19.67H*1;2
3035.14ROAD122110.335.5130.330.3319.812000100100200200
3100A5010006*1~4
3164.86ROAD122110.335.5130.330.3319.812000100100200200
3200BLDG457.219.67H*1;2;
3200BLDG472.4420.67H*1;3;2
3200BLDG487.6817.67H*1;2
3200BLDG502.9218.67H*1;3;2
3202BLDG502.92-20.67H*1;2
3205BLDG472.44-19.67H*1;3;2
3205BLDG487.68-19.67H*1;2
3300SIGN100457.2C:\STISIM3\Data\EuroSigns\SpeedLimit\Speed_Limit_60.mka
3375A45100063
3438I07621
3500BLDG457.219.67H*1;2;
3500BLDG472.4420.67H*1;3;2
3500BLDG487.6817.67H*1;2
3500BLDG502.9218.67H*1;3;2
3502BLDG502.92-20.67H*1;2
3505.2VC152.40.01
3505BLDG472.44-19.67H*1;3;2
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3505BLDG487.68-19.67H*1;2
3550A4510006*1~4
3700A4510006*1~4
3800SIGN100457.2C:\STISIM3\Data\EuroSigns\SpeedLimit\Speed_Limit_60.mka
3810VC304.80.01
3900A55100064
4067.2VC304.8-0.01
4135.14ROAD122110.335.5130.330.3319.812000100100200200
4200A4010006*1~4
4264.86ROAD122110.335.5130.330.3319.812000100100200200
4400SIGN100457.2C:\STISIM3\Data\EuroSigns\SpeedLimit\Speed_Limit_60.mka
4400A5010006*1~4
4400BLDG457.219.67H*1;2;
4400BLDG472.4420.67H*1;3;2
4400BLDG487.6817.67H*1;2
4400BLDG502.9218.67H*1;3;2
4402BLDG502.92-20.67H*1;2
4405BLDG472.44-19.67H*1;3;2
4405BLDG487.68-19.67H*1;2
4500ES
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Scenario: Hazard Perception

```
METRIC
0,ROAD,6.66,4,2,2,0.3,3.05,3.05,0.12,0.12,0,-1,-1,0,3.05,0,3.05,0,3.05,0,3.05,0
0,BSAV,1,0.5,STROKE,1,2,3,4,5,6,7,8,9,10,11,12,13,14,18,19,22,23,24,25,26,27,28,29,32,33,34,35,36,
37,38,39,44,45,47,48,50,51,52,
0,TREE,100,50,0,16.67,30.48
0,SIGN,100,60.96,C:\STISIM3\Data\EuroSigns\SpeedLimit\Speed_Limit_60.mka
0,V,10,550,-11.5,1,36
0,BLDG,435.86,-16.67,G4
0,BLDG,435.86,16.67,G4
0,BLDG,478.54,-16.67,G5
0,BLDG,478.54,16.67,G5
0,I,0,304.8,1,1,1
0,SL,-304.8,7,6.5,5,0,-4.88,6
0,SL,-6070,8,0,0,0,-4.88,6,1,1,,1,
1,ONCOMINGTRAFFIC
61.96,PED,256.03,4,3.59,13.01,R,11,26.75
61.96,PED,256.03,0,0,-13.72,L,*4~5
100,A,45,1000,6,*1~4
200,LS,60,0
262.720000574951,ROAD,6.66,4,2,2,0.3,3.05,3.05,0.12,0.12,19.8119998488464,0,0,0,3.05,0,3.05,0,
3.05,0,3.05,0
275.96,PED,256.64,0,0,-15.72,L,*4~5
300,A,45,1000,6,6
304.8,SIGN,4,396.24,0,1
304.8,SIGN,100,457.2,C:\STISIM3\Data\EuroSigns\SpeedLimit\Speed_Limit_60.mka
347.279999425049,ROAD,6.66,4,2,2,0.3,3.05,3.05,0.12,0.12,19.8119998488464,-1,-
1,0,3.05,0,3.05,0,3.05,0,3.05,0
400,BLDG,435.86,-16.7,H2
400,BLDG,435.86,16.67,H5
400,PED,39,15{0},*2,-13{0},L,*1~8,0,
426.72,TREE,0,0,0,0,0
450,BLDG,435.86,-14.67,H3
450,BLDG,435.86,16.67,H5
490,BLDG,435.86,16.67,H2
500,A,45,1000,6,3
500,BLDG,435.86,-16.67,H13
500,PED,1500,10{0},4,-15,F,*1~9,0
500,PED,1500,10{0},5,-15,F,*2~10,0
530,BLDG,435.86,16.67,H2
548.64,TREE,75,50,0,14.67,30.48
550,BLDG,435.86,-16.67,H2
560,BLDG,435.86,-17.67,H7
590,BLDG,435.86,16.67,H6
609.6,BLDG,435.86,-16.67,H9
609.6,BLDG,435.86,16.67,H9
609.6,BLDG,478.54,-16.67,H2
609.6,BLDG,478.54,16.67,H2
700,A,45,1000,6,*1~4
700.6,BLDG,478.54,-15.67,H13
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750,PED,1515,10{0},6.5,16,B,*1~9,0
779.48,BSAV,1,.1,TrafficMerge,1,4,7,16,17
779.48,SIGN,24,200,,1,0,,
779.48,BARL,304.8,0,0,3,0,0,0,0,-12.31,1,1
783.48,BARL,304.8,0,0,3,0,0,0,0,-11.71,1,1
787.48,BARL,304.8,0,0,3,0,0,0,0,-11.03,1,1
792.48,BARL,304.8,0,0,3,0,0,0,0,-10.71,1,1
792.72,StaticObject,304.8,-
33.1364860534668{0},0,0,0,0,C:\STISIM\Data\Construction\GravelPile.Lmm,
795.53,BARL,304.8,0,0,3,0,0,0,0,-10.25,1,1
798.58,BARL,304.8,0,0,3,0,0,0,0,-9.49,1,1
801.62,BARL,304.8,0,0,3,0,0,0,0,-9.03,1,1
804.67,BARL,304.8,0,0,3,0,0,0,0,-8.27,1,1
807.72,BARL,304.8,0,0,3,0,0,0,0,-8.27,1,14
810.77,BARL,304.8,0,0,3,0,0,0,0,-8.27,1,1
813.82,BARL,304.8,0,0,3,0,0,0,0,-8.27,1,1
816.86,BARL,304.8,0,0,3,0,0,0,0,-8.27,1,1
820.48,BARL,304.8,0,0,3,0,0,0,0,-9.03,1,1
824.53,BARL,304.8,0,0,3,0,0,0,0,-9.49,1,1
828.58,BARL,304.8,0,0,3,0,0,0,0,-10.25,1,1
832.62,BARL,304.8,0,0,3,0,0,0,0,-10.71,1,1
836.62,BARL.304.8,0,0,3,0,0,0,0,-11.03,1,1
853.44,C,0,0,152.4,0,-8.20E-03
900,A,45,1000,6,8
990.6,TREE,0,0,0,0,0
1000,PED,1530,10{0},6,15,F,*2~10,0
1066.8,SIGN,100,457.2,C:\STISIM3\Data\EuroSigns\SpeedLimit\Speed_Limit_60.mka
1100,A,50,1000,6,*1~4
1143,TREE,50,50,0,14.67,30.48
1219.2,VC,152.4,0.03
1250,A,45,1000,6,*1~4
1250,BLDG,435.86,-16.67,H14
1250,PED,1540,10{0},4,-16,B,*1~9,0
1400,A,45,1000,6,*1~4
1400,PED,1550,10{0},6,16.5,F,*2~10,0
1502.66,BLDG,457.2,16.67,G4
1502.66,BLDG,457.2,-17.67,G4
1550,PED,1500,10{0},6,-14.5,F,*1~9,0
1600,A,55,1000,6,4
1615.44,BLDG,457.2,17.67,G15
1615.44,BLDG,457.2,-17.67,G16
1676.4,VC,152.4,-0.03
1730,PED,1500,10{0},6,-14.5,F,*2~10,0
1730,PED,1515,10{0},3,15,B,*1~11,0
1775.5,BLDG,457.2,-17.67,G36
1780.44,BLDG,457.2,17.67,G34
1800,A,40,1000,6,*1~4
1800.32,BLDG,457.2,17.67,G12
1800.32,BLDG,457.2,-17.67,H15
1828.05,BLDG,457.2,17.67,U7
1828.8,SIGN,100,457.2,C:\STISIM3\Data\EuroSigns\SpeedLimit\Speed_Limit_60.mka
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1830.32,BLDG,457.2,17.67,G10
1905,TREE,0,0,0,0,0
1908.05,BLDG,457.2,-17.67,H1
2000,A,50,1000,6,*1~4
2040,PED,1530,10{0},6,15,F,*2~10,0
2103.12,SIGN,4,457.2,0,1
2133.6,BLDG,457.2,19.67,H*1;2;
2133.6,BLDG,472.44,20.67,H*1;3;2
2138.6,BLDG,472.44,-19.67,H*1;3;2
2200,A,45,1000,6,*1~4
2375,A,45,1000,6,3
2423.16,TREE,75,50,0,14.67,30.48
2499.36,BLDG,487.68,17.67,H*1;2
2500,A,45,1000,6,*1~4
2504.36,BLDG,487.68,-19.67,H*1;2
2575.56,TREE,0,0,0,0,0
2590.8,SIGN,100,457.2,C:\STISIM3\Data\EuroSigns\SpeedLimit\Speed_Limit_60.mka
2600,PED,1540,10{0},4,-16,B,*1~9,0
2667,TREE,50,50,0,14.67,30.48
2699.36,BLDG,466.34,-17.67,B2
2699.36,BLDG,487.68,17.67,B8
2712.72,C,0,0,152.4,0,-9.84E-03
2743.2,SIGN,5,457.2,0,1
2750,A,45,1000,6,6
2926.08,TREE,0,0,0,0,0
2971.8,VC,152.4,-0.03
3000,A,45,1000,6,8
3000.36,BLDG,487.68,-17.67,H2
3000.36,BLDG,487.68,17.67,H2
3000,PED,1550,10{0},6,14.5,F,*2~10,0
3030.88,V,*-9.14,243.84,-1.83,1,*1~59,5,1,6.05,5,-3,-3.66,0,5,
3048,ROAD,6.66,4,2,2,0.3,3.05,3.05,0.1,0.1,152.4,-1,-1,-3,3.05,-3,3.05,25,10.67,25,10.67,0
3048,TREE,75,50,0,14.67,30.48
3100,A,50,1000,6,*1~4
3330.88,V,*14.67,-182.88,-1.83,1,*1~59
3352.8,C,0,0,304.8,0,2.46E-03
3352.8,SIGN,100,457.2,C:\STISIM3\Data\EuroSigns\SpeedLimit\Speed_Limit_60.mka
3375,A,45,1000,6,3
3429,V,0,457.2,-12.75,1,5
3449,V,0,466.34,-12.75,1,45
3500,PED,1500,10{0},6,-14.5,F,*1~9,0
3505.2,VC,152.4,0.03
3505.2,SIGN,4,457.2,0,1
3550,A,45,1000,6,3
3600.36,BLDG,487.68,-17.67,H3
3700,PED,1500,10{0},6,-14.5,F,*2~10,0
3775,A,45,1000,6,3
3810,VC,304.8,0.02
3950,PED,1515,10{0},4.2,15,B,*1~9,0
4000,A,45,1000,6,*1~4
4000,PED,1530,10{0},3,12,F,*1~10,0
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4028.8344,Pedestrian,762,3.5,1.8288,-12.9248{0},L,4
4114.8,C,0,0,304.8,0,-2.46E-03
4250,PED,1540,10{0},6,-14.5,B,*2~9,0
4267.2,VC,304.8,-0.02
4267.2,SIGN,100,457.2,C:\STISIM3\Data\EuroSigns\SpeedLimit\Speed_Limit_60.mka
4375,A,45,1000,6,3
4444,PED,1550,10{0},6,15,F,*1~10,0
4500,A,45,1000,6,*1~4
4572,ROAD,6.66,4,2,2,0.3,3.05,3.05,0.12,0.12,152.4,-1,-1,0,3.05,0,3.05,0,3.05,
4572,BLDG,457.2,19.67,H*1;2;
4572,BLDG,457.2,-20.67,H*1;2;3
4572,BLDG,472.44,20.67,H*1;3;2
4572,BLDG,487.68,17.67,H*1;2
4572,BLDG,502.92,18.67,H*1;3;2
4572,BLDG,1000,-5{2},G21
4574,BLDG,502.92,-20.67,H*1;2
4577,BLDG,472.44,-19.67,H*1;3;2
4577,BLDG,487.68,-19.67,H*1;2
4599,PED,1500,10{0},6,-15,F,*2~10,0
4790,A,45,1000,6,3
4790,Vehicles,475.488,-12.62{0},0{0},1,T30,1,0
4790,Vehicles,490.728,-12.62{0},.03048{0},1,S19,1,0,2,1,2.7432{7},20,2.5,{25},2,4.572{0},,,2.5
4790,Vehicles,499.872,-12.62{0},0{0},1,F13,1,0
4790,Vehicles,509.9304,-12.62{0},0{0},1,F5,1,0
4876.8,SIGN,100,457.2,C:\STISIM3\Data\EuroSigns\SpeedLimit\Speed_Limit_60.mka
4876.8,BLDG,487.68,17.67,H*1;2
4876.8,BLDG,502.92,18.67,H*1;3;2
4878.8,BLDG,502.92,-20.67,H*1;2
4881.8,BLDG,487.68,-19.67,H*1;2
4900,A,45,1000,6,3
4953,TREE,0,0,0,0,0
5000,A,55,1000,6,4
5000,PED,1500,10{0},6,-14.5,F,*1~9,0
5048.496,Pedestrian,762,7,1.524,-15.4112{0},F,*1~8;-4;-5
5048.496,Pedestrian,762,7,1.524,-16.0208{0},F,*1~8;-4;-5
5100,BLDG,487.68,17.67,B8
5167.2,SIGN,100,457.2,C:\STISIM3\Data\EuroSigns\SpeedLimit\Speed_Limit_60.mka
5239,TREE,75,50,0,14.67,30.48
5255,PED,1515,10{0},5,15,B,*2~10,0
5260,PED,1530,10{0},4,14.5,F,*1~11,0
5275,A,45,1000,6,3
5308,I,0,762,2,1,1,1,G:\ALB-StrokeDriving\VoiceInstructions\Audacity\TurnRight.WAV,1,10
5376.8,SIGN,100,457.2,C:\STISIM3\Data\EuroSigns\SpeedLimit\Speed_Limit_60.mka
5410.2,TREE,75,50,0,14.67,30.48
5471.16,BLDG,457.2,17.67,H14
5490.64,Vehicles,379.476,-12.7536{0},0{0},1,E2,1,0
5490.64,Vehicles,388.62,-12.5156{0},0{0},1,C17,1,0,3,1,3.9624{7},20,1,{25},2,3.048{0},,,1
5490.64,Vehicles,405.384,-12.3632{0},0{0},1,C17,1,0
5501.64,V,0,457.2,-14.67,1,46,2,5.18,/-1.52,5,2,0,60.96,10
5501.64,BLDG,457.2,-17.67,H14
5508.6,TREE,0,0,0,0,0
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5516.88,BLDG,457.2,19.67,H*1;2;
5516.88,BLDG,472.44,20.67,H*1;3;2
5516.88,BLDG,487.68,17.67,H*1;2
5516.88,BLDG,502.92,18.67,H*1;3;2
5518.88,BLDG,502.92,-20.67,H*1;2
5521.88,BLDG,472.44,-19.67,H*1;3;2
5521.88,BLDG,487.68,-19.67,H*1;2
5567.2,SIGN,100,457.2,C:\STISIM3\Data\EuroSigns\SpeedLimit\Speed_Limit_60.mka
5575,A,45,1000,6,3
5600,PR,G:\ALB-StrokeDriving\VoiceInstructions\Audacity\400MetersTurnRight.wav,1,10
5600,SIGN,8,365.76,0,1
5720.84,BLDG,457.2,19.67,H*1;2;
5720.84,BLDG,472.44,20.67,H*1;3;2
5720.84,BLDG,487.68,17.67,H*1;2
5725.84,BLDG,472.44,-19.67,H*1;3;2
5725.84,BLDG,487.68,-19.67,H*1;2
5740,PED,503.83,5,1.83,-13.92,L,4,0
5776.8,SIGN,100,457.2,C:\STISIM3\Data\EuroSigns\SpeedLimit\Speed_Limit_60.mka
5800,BLDG,457.2,19.67,H*1;2;
5800,BLDG,472.44,20.67,H*1;3;2
5800,BLDG,487.68,17.67,H*1;2
5800,BLDG,502.92,18.67,H*1;3;2
5802,BLDG,502.92,-20.67,H*1;2
5805,BLDG,472.44,-19.67,H*1;3;2
5805,BLDG,487.68,-19.67,H*1;2
5830,PED,1540,10{0},6,-14.5,B,*2~10,0
5850,SIGN,8,549.76,0,1,1,180
5850,A,26.82,304.8,1.83,*1~35;-8;-9;-16;-17;-3;-5,
5867.4,TREE,0,0,0,0,0
5870,BLDG,457.2,19.67,H*1;2;
5870,BLDG,472.44,20.67,H*1;3;2
5870,BLDG,487.68,17.67,H*1;2
5875,A,45,1000,6,3
5875,BLDG,472.44,-19.67,H*1;3;2
5875,BLDG,487.68,-19.67,H*1;2
5900,BLDG,457.2,19.67,H*1;2;
5900,BLDG,472.44,20.67,H*1;3;2
5900,BLDG,487.68,17.67,H*1;2
5905,BLDG,472.44,-19.67,H*1;3;2
5905,BLDG,487.68,-19.67,H*1;2
5950,PR,G:\ALB-StrokeDriving\VoiceInstructions\Audacity\TurnRightatIntersection.WAV,1,10
5951.36,A,26.82,304.8,1.83,*1~35;-8;-9;-16;-17;-3;-5
5952.36,A,26.82,335.28,5.49,*1~35;-8;-9;-16;-17;-3;-5,3,0,36.58,0.5
5952.36,A,26.82,375.76,1.83,*1~35;-8;-9;-16;-17;-3;-5
5952.36,A,26.82,399.24,5.49,*1~35;-8;-9;-16;-17;-3;-5,3,0,45.72,0.5
5952.36,A,22.86,457.2,5.49,*1~35;-8;-9;-16;-17;-3;-5,3,0,48.77,0.5
5952.36,A,22.86,518.16,1.83,*1~35;-8;-9;-16;-17;-3;-5,4,0,48.77,0.5
5952.36,A,22.86,589.12,5.49,*1~35;-8;-9;-16;-17;-3;-5,3,0,48.77,0.5
5952.36,A,22.86,609.6,1.83,*1~35;-8;-9;-16;-17;-3;-5,4,0,48.77,0.5
5952.36,A,22.86,640.08,5.49,*1~35;-8;-9;-16;-17;-3;-5,3,0,48.77,0.5
5955.36,A,22.86,457.2,5.49,*1~35;-8;-9;-16;-17;-3;-5,3,0,48.77,0.5
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5955.36,A,22.86,518.16,1.83,*1~35;-8;-9;-16;-17;-3;-5,4,0,48.77,0.5
5955.36,A,22.86,579.12,5.49,*1~35;-8;-9;-16;-17;-3;-5,3,0,48.77,0.5
5955.36,A,22.86,609.6,1.83,*1~35;-8;-9;-16;-17;-3;-5,4,0,48.77,0.5
5955.36,A,22.86,650.08,5.49,*1~35;-8;-9;-16;-17;-3;-5,3,0,48.77,0.5
5967.2,SIGN,100,457.2,C:\STISIM3\Data\EuroSigns\SpeedLimit\Speed_Limit_60.mka
5988,I,0,762,2,1,1,1,G:\ALB-StrokeDriving\VoiceInstructions\Audacity\TurnRight.wav,1,10
6000,TREE,100,50,0,14.67,30.48
6000,A,40,1000,6,*1~4
6000,PED,1550,10{0},5,15,F,*1~9,0
6027.72000057495,ROAD,6.66,4,2,2,0.3,3.05,3.05,0.12,0.12,19.8119998488464,0,0,0,3.05,0,3.05,0,
3.05,0,0,
6088,Building,762,-18.288{0},H*2;4~7;9;13
6112.27999942505,ROAD,6.66,4,2,2,0.3,3.05,3.05,0.12,0.12,19.8119998488464,-1,-
1,0,3.05,0,3.05,0,3.05,
6138,Building,762,-18.288{0},H*2;4~7;9;13
6176.8,SIGN,100,457.2,C:\STISIM3\Data\EuroSigns\SpeedLimit\Speed_Limit_60.mka
6238,Building,762,-18.288{0},H*2;4~7;9;13
6250.4,PED,51.82,6,1.62,-13.92,F,*1~10
6275,A,45,1000,6,3
6338,Building,762,18.288{0},H*2;4~7;9;13
6338,Building,762,-18.288{0},H*4;5
6340,PED,503.83,*5,1.83,-13.92,L,4,0
6350,BLDG,457.2,19.67,H*1;2;
6350,BLDG,472.44,20.67,H*1;3;2
6350,BLDG,487.68,17.67,H*1;2
6350,BLDG,502.92,18.67,H*1;3;2
6350,PR,G:\ALB-StrokeDriving\VoiceInstructions\Audacity\400MetersTurnRight.wav,1,10
6352,BLDG,502.92,-20.67,H*1;2
6355,BLDG,472.44,-19.67,H*1;3;2
6355,BLDG,487.68,-19.67,H*1;2
6367.2,SIGN,100,457.2,C:\STISIM3\Data\EuroSigns\SpeedLimit\Speed_Limit_60.mka
6400,A,50,1000,6,*1~4
6400,BLDG,457.2,19.67,H*1;2;
6400,BLDG,472.44,20.67,H*1;3;2
6400,BLDG,487.68,17.67,H*1;2
6400,BLDG,502.92,18.67,H*1;3;2
6402,BLDG,502.92,-20.67,H*1;2
6405,BLDG,472.44,-19.67,H*1;3;2
6405,BLDG,487.68,-19.67,H*1;2
6438,Building,762,18.288{0},H*2;4~7;9;13
6500,BLDG,457.2,19.67,H*1;2;
6500,BLDG,472.44,20.67,H*1;3;2
6500,BLDG,487.68,17.67,H*1;2
6505,BLDG,472.44,-19.67,H*1;3;2
6505,BLDG,487.68,-19.67,H*1;2
6575,A,45,1000,6,3
6576.8,SIGN,100,457.2,C:\STISIM3\Data\EuroSigns\SpeedLimit\Speed_Limit_60.mka
6600,SIGN,2,100,,1,0,
6650,SIGN,2,150,,1,1,180,
6650,A,26.82,304.8,1.83,*1~35;-8;-9;-16;-17;-3;-5,
6650.12,A,26.82,304.8,1.83,*1~35;-8;-9;-16;-17;-3;-5,4,0,45.72,0.5
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6651.36,A,26.82,304.8,1.83,*1~35;-8;-9;-16;-17;-3;-5
6652.36,A,26.82,335.28,5.49,*1~35;-8;-9;-16;-17;-3;-5,3,0,36.58,0.5
6652.36,A,26.82,365.76,1.83,*1~35;-8;-9;-16;-17;-3;-5
6652.36,A,26.82,396.24,5.49,*1~35;-8;-9;-16;-17;-3;-5,3,0,45.72,0.5
6652.36,A,22.86,457.2,5.49,*1~35;-8;-9;-16;-17;-3;-5,3,0,48.77,0.5
6652.36,A,22.86,518.16,1.83,*1~35;-8;-9;-16;-17;-3;-5,4,0,48.77,0.5
6652.36,A,22.86,579.12,5.49,*1~35;-8;-9;-16;-17;-3;-5,3,0,48.77,0.5
6652.36,A,22.86,609.6,1.83,*1~35;-8;-9;-16;-17;-3;-5,4,0,48.77,0.5
6652.36,A,22.86,640.08,5.49,*1~35;-8;-9;-16;-17;-3;-5,3,0,48.77,0.5
6659.36,A,22.86,457.2,5.49,*1~35;-8;-9;-16;-17;-3;-5,3,0,48.77,0.5
6659.36,A,22.86,518.16,1.83,*1~35;-8;-9;-16;-17;-3;-5,4,0,48.77,0.5
6659.36,A,22.86,579.12,5.49,*1~35;-8;-9;-16;-17;-3;-5,3,0,48.77,0.5
6659.36,A,22.86,609.6,1.83,*1~35;-8;-9;-16;-17;-3;-5,4,0,48.77,0.5
6659.36,A,22.86,640.08,5.49,*1~35;-8;-9;-16;-17;-3;-5,3,0,48.77,0.5
6665.36,A,22.86,457.2,5.49,*1~35;-8;-9;-16;-17;-3;-5,3,0,48.77,0.5
6667.36,A,22.86,518.16,1.83,*1~35;-8;-9;-16;-17;-3;-5,4,0,48.77,0.5
6670.36,A,22.86,750.6,1.83,*1~35;-8;-9;-16;-17;-3;-5,4,0,48.77,0.5
6670.36,A,22.86,840.08,5.49,*1~35;-8;-9;-16;-17;-3;-5,3,0,48.77,0.5
6675,A,45,1000,6,3
6690.36,A,22.86,800.2,5.49,*1~35;-8;-9;-16;-17;-3;-5,3,0,48.77,0.5
6690.36,A,22.86,700.16,1.83,*1~35;-8;-9;-16;-17;-3;-5,4,0,48.77,0.5
6690.36,A,22.86,712.12,5.49,*1~35;-8;-9;-16;-17;-3;-5,3,0,48.77,0.5
6700,PR,G:\ALB-StrokeDriving\VoiceInstructions\Audacity\TurnRightatIntersection.wav,1,10
6700,SIGN,2,100,,1,0,
6700.36,A,22.86,800.2,5.49,*1~35;-8;-9;-16;-17;-3;-5,3,0,48.77,0.5
6700.36,A,22.86,712.16,1.83,*1~35;-8;-9;-16;-17;-3;-5,4,0,48.77,0.5
6700.36,A,22.86,750.12,5.49,*1~35;-8;-9;-16;-17;-3;-5,3,0,48.77,0.5
6700.36,A,22.86,690.6,1.83,*1~35;-8;-9;-16;-17;-3;-5,4,0,48.77,0.5
6700.36,A,22.86,840.08,5.49,*1~35;-8;-9;-16;-17;-3;-5,3,0,48.77,0.5
6701.36,A,22.86,800.2,5.49,*1~35;-8;-9;-16;-17;-3;-5,3,0,48.77,0.5
6701.36,A,22.86,720.16,1.83,*1~35;-8;-9;-16;-17;-3;-5,4,0,48.77,0.5
6701.36,A,22.86,750.12,5.49,*1~35;-8;-9;-16;-17;-3;-5,3,0,48.77,0.5
6701.36,A,22.86,790.6,1.83,*1~35;-8;-9;-16;-17;-3;-5,4,0,48.77,0.5
6701.36,A,22.86,700.08,5.49,*1~35;-8;-9;-16;-17;-3;-5,3,0,48.77,0.5
6707.72000057495,ROAD,6.66,4,2,2,0.3,3.05,3.05,0.12,0.12,19.8119998488464,0,0,0,3.05,0,3.05,0,
3.05,0,0,
6730,BLDG,620,17.07,H3
6730,BLDG,550.44,-20.73,G15
6750,BLDG,350.36,18.29,G21
6750,BLDG,600.92,-18.29,H16
6767.2,SIGN,100,457.2,C:\STISIM3\Data\EuroSigns\SpeedLimit\Speed_Limit_60.mka
6770,BLDG,450.52,18.29,H1
6770,BLDG,608.5,-18.29,H14
6775,A,45,1000,6,3
6790,BLDG,600.1,18.29,H2
6790,BLDG,550.4,-18.29,H8
6792.27999942505,ROAD,6.66,4,2,2,0.3,3.05,3.05,0.12,0.12,19.8119998488464,-1,-
1,0,3.05,0,3.05,0,3.05,
6800,BLDG,487.68,-17.67,H2
6800,V,3.66,167.64,-12.5,1,36,4,1.83,1.52,2,2B,-1.83,3.66,2
6810,BLDG,502.92,17.67,H2

6825,BLDG,502.92,-17.67,H3
6840,BLDG,497.62,17.67,H3
6850,BLDG,497.62,17.67,H1
6875,BDLG,502.92,17.67,H14
6880,BDLG,502.92,-17.67,B5
6895,BDLG,497.62,-17.67,B2
6901.64,BLDG,457.2,17.67,B1
6920,BLDG,457.2,-17.67,U7
6950,Building,396.24,-18.288{0},H*2;4~7;9;13
6950,Vehicles,396.24,-16.9728{0},0{0},2,SP14,1,0,5,2,-
4.0864{0},,,2,{25},2,0{0},,,2,3{26},2,,,,2,{25},2,0{0},,,2
6976.8,SIGN,100,457.2,C:\STISIM3\Data\EuroSigns\SpeedLimit\Speed_Limit_60.mka
7000,Vehicles,574.548,-
13.9248{0},.03048{0},1,*S8;F4:F22,,1,0,7{0},11,1,2.3,1,6.096{7},20,2,{25},2,26.8224{0},,,2,-
3.2,1,0{7},20,4,{25},2,1.524{0},,,4,-2,1,0{7},20,2,{25},2,12.192{0},,,
7050,Building,396.24,18.288{0},H*2;4~7;9;13
7100,BLDG,457.2,17.67,H2
7105,BLDG,457.2,-17.67,H2
7125,BLDG,472.44,17.67,H1
7125,BLDG,472.44,-17.67,H3
7155,BLDG,487.68,17.67,H14
7167.2,SIGN,100,457.2,C:\STISIM3\Data\EuroSigns\SpeedLimit\Speed_Limit_60.mka
7175,BLDG,487.68,-17.67,H2
7180.16,Vehicles,228.6,-13.3632{0},0{0},1,*18~35,1,1,6{1},11,1,3{1},1,-
6.096{0},20,4,{25},11,0,{25},2,6.7056{0},,,4,1965.96{15},1,-10.3632{0},20,3,{25},2,0{0},,,3
7200,BLDG,502.92,17.67,H3
7200,BLDG,502.92,-17.67,H3
7200,BLDG,426.72,-13.29,H*4;5
7220,BLDG,457.2,17.67,H15
7245,BLDG,457.2,-17.67,H2
7250,BLDG,472.44,17.67,H2
7270,BLDG,472.44,-17.67,H1
7280,BLDG,487.68,17.67,H1
7285,BLDG,487.68,-17.67,H1
7310,BLDG,502.92,-17.67,H3
7340,BLDG,457.2,17.67,H3
7345,BLDG,457.2,-17.67,H13
7370,BLDG,472.44,17.67,H14
7376.8,SIGN,100,457.2,C:\STISIM3\Data\EuroSigns\SpeedLimit\Speed_Limit_60.mka
7390,BLDG,487.68,17.67,H1
7395,BLDG,472.44,-17.67,H15
7405,BLDG,487.68,-17.67,H1
7420,BLDG,502.92,17.67,H1
7445,BLDG,502.92,-17.67,H14
7450,BLDG,497.62,17.67,H15
7470,BLDG,502.92,-17.67,H*2~13;-10;-11;-8;-12;-3
7490,BLDG,497.62,17.67,H*2~13;-10;-11;-8;-12;-3
7500,BLDG,502.92,-17.67,H*2~13;-10;-11;-8;-12;-3
7540,BLDG,457.2,17.67,H*2~13;-10;-11;-8;-12;-3
7545,BLDG,457.2,-17.67,H*2~13;-10;-11;-8;-12;-3
7570,BLDG,472.44,17.67,H*2~13;-10;-11;-8;-12;-3

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7590,BLDG,487.68,17.67,H*2~13;-10;-11;-8;-12;-3
7590,BSAV,1,.04,Brakereactiondata#2:00(Timeuxax),1,4,6,13
7595,BLDG,472.44,-17.67,H*2~13;-10;-11;-8;-12;-3
7605,BLDG,487.68,-17.67,H*2~13;-10;-11;-8;-12;-3
7620,BLDG,502.92,17.67,H*2~13;-10;-11;-8;-12;-3
7645,BLDG,502.92,-17.67,H*2~13;-10;-11;-8;-12;-3
7650,BLDG,497.62,17.67,H*2~13;-10;-11;-8;-12;-3
7690,BLDG,502.92,-17.67,H*2~13;-10;-11;-8;-12;-3
7700,BLDG,497.62,17.67,H*2~13;-10;-11;-8;-12;-3
7711.92,RT,0,10
7742.4,ESAV
7850,ES
```

Appendix 4: On-Road Driving Behaviour Checklist

Round-about (Straight)	Code	✓
Approach with appropriate speed	*Planning*	
Approach left lane	*Planning*	
Head turn, check mirror	*Attention*	
Indicate/signal left before advancing	*Interaction*	
Exit in left lane after round-about	*Planning*	
Speed bump/pedestrian crossing		
Approach with appropriate speed	*Planning*	
Did not hit speed bump at high speed,	*Speed adjustment*	
Gave way to pedestrians (if applicable)	*Attention*	
Complied with km/hr rule	*Speed Adjustment*	
Round about (straight)		
Approach with appropriate speed	*Planning*	
Head turn, check mirror	*Attention*	
Manoeuvring around round about is smooth	*Manoeuvre*	
Round about (straight)		
Approach with appropriate speed	*Planning*	
Head turn, check mirror	*Attention*	
Manoeuvring around round about is smooth	*Manoeuvre*	
Give way (right turn) Tricky junction with constant flow of traffic		
Noticed and approached with appropriate speed at give way sign	*Planning*	
Signal right	*Interaction*	
Check oncoming traffic (head turns)	*Attention*	
Proceed with smooth manoeuvre when way is clear	*Manoeuvre*	
Check mirrors	*Attention*	

Dual lane round about (U-turn)	Code	✓
Approach with appropriate speed	*Planning*	
Head turns, check mirror	*Attention*	
Indicate right before entering	*Interaction*	
Appropriate signalling	*Interaction*	
Proceed when way is clear	*Planning*	
Maneuvering around round about is smooth	*Manoeuvre*	
Exit in correct lane	*Position*	
Check mirror after manoeuvre	*Attention*	
T-junction (turn left)		
Check mirror before entering lane	*Attention*	
Approach junction with appropriate speed	*Planning*	
Head turns, check traffic	*Attention*	
Appropriate signal	*Interaction*	
Proceed with smooth manoeuvre when way is clear	*Manoeuvre*	
Check mirror	*Attention*	
Traffic lights		
Approach with appropriate speed	*Planning*	
Stop at appropriate distance to car in front	*Position*	
Noticed lights; stopped (red)or go (green) as indicated	*Attention*	
Proceed with smooth manoeuvre when way is clear	*Manoeuvre*	
(moved into right hand lane before traffic light in preparation for next turning)	*Planning*	
Turning into small street		
Check mirrors	*Attention*	
Appropriate signal (turning right)	*Interaction*	
Moved into right hand lane	*Planning*	
Appropriate signal (turning right)	*Interaction*	

Turning into small street cont.	Code	✓
Stopped at appropriate position next to traffic island (not blocking oncoming traffic)	*Position*	
Check oncoming traffic (head turns)	*Attention*	
Proceed with smooth manoeuvre when way is clear	*Manoeuvre*	
Stop sign		
Noticed and approached stop sign with appropriate speed	*Planning*	
Come to a complete stop before proceeding	*Planning*	
Stopped before & close to the stop line	*Position*	
Check oncoming traffic (head turns)	*Attention*	
Appropriate signal (turning right)	*Interaction*	
Proceed with smooth manoeuvre when way is clear	*Manoeuvre*	
Check mirrors	*Attention*	
Round about (straight on Hayman Rd)		
Approach with appropriate speed	*Planning*	
Head turn, check mirror	*Attention*	
Manoeuvring around round about is smooth	*Manoeuvre*	
Exit in correct lane before merge	*Position*	
Round-about (turn left)		
Approach left lane	*Planning*	
Head turn,	*Attention*	
Check mirrors	*Attention*	
Indicate/signal left before advancing	*Interaction*	
Parking (Bay 7)		
Check for traffic behind using rear mirror	*Attention*	
Slow down	*Planning*	
Correct signalling	*Interaction*	
Apply handbrake	*Manoeuvre*	

Appendix 5: Recruitment Poster

We are currently recruiting **post-stroke** adults who **have returned to driving** to help with a new research study. As a participant, you will be required to complete some brain-training style tasks, as well as a run in the Curtin University Driving Simulator and undertake an on-road assessment (in your own vehicle). The assessments are for research only and are not a review of your ability to drive. Information collected will not be accessible by the Department of Transport for licencing purposes.

As a thank you for your time you will receive a $15 Coles/Myer voucher, but more importantly, you will be providing the vital information about driving post-stroke, which may ultimately help future survivors.

You can participate in the study if you have:

- a drivers licence valid in WA
- been cleared to drive by a medical professional
- declared your stroke to the Department of Transport; and
- access to an insured vehicle.

For more information, please contact:

Alison Blane
School of Occupational Therapy & Social Work
Tel: 9266 7681
Email: Alison.Blane@curtin.edu.au

This study has been approved by the Curtin University Research Ethics Committee: HR206/2014

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CRICOS Provider Code 00301J.

Appendix 6: Study Information Brochure

What if I don't want to take part in the study or want to withdraw later?

Participation in this study is **entirely voluntary**. It is completely up to you whether or not you participate. If you decide not to participate, or choose to withdraw from the study later, it will not result in any negative consequences. If you decide to withdraw from this study, please inform the researcher.

Will anyone else know the results?

Any identifiable information collected will remain strictly confidential and only authorised study staff will have access to these details. Analysis of any data collected will be on de-identified data only. Once the study has been completed, the data will be securely stored before being confidentially destroyed in line with Curtin University and Western Australian University Sector Disposal Authority Guidelines. A report of the study will be submitted for publication and we will also share some information about the tests used in this study to work out how useful they are in assessing driving behaviour post-stroke. Individual names will not be included in any study output and your details will remain confidential at all times.

Will the study benefit me?

Whilst we intend for this research study to further our knowledge and improve services for post-stroke drivers in the future, it may not be of direct benefit to you. As a thank you for your participation, you will receive a $15 Coles / Myer Voucher.

Contact **Alison Blane**

Tel | **+61 8 9266 7681**

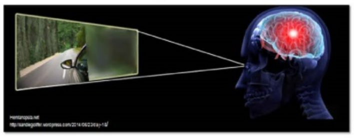
Email | alison.blane@curtin.edu.au

Are there any risks involved?

All measures involved in the study are non-invasive and have been previously used in Australia. As part of the study, if you are found to have eye sight below the legal standard to drive, or if you show severe difficulty with the driving tasks, we will recommend that you make a voluntary referral to your GP or Ophthalmologist or seek professional driving counsel. It is possible that any consequent medical review *may* lead to a legal review of your capacity to drive. However, please be aware that any assessment undertaken as part of this research alone does **not** constitute a legal review of your driving ability and it is **not** the aim of this study to terminate your driving licence.

What if I require further information?

If you would like to know more about this study please contact Alison Blane using the details listed below.



This study has been approved by the Curtin University Human Research Ethics Committee. Any person with concerns or complaints about the conduct of this study should contact the Curtin University Ethics coordinator:

Tel | **+61 8 9266 7681**

Email | alison.blane@curtin.edu.au

Web | **www.curtin.edu.au**

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CRICOS Provider Code 00301J (WA), 02637B (NSW)

Curtin University

Driving on the Brain: Investigating Driving Post-Stroke

Can **YOU** help us with exciting new driving research?

Participant Information (Post-Stroke Drivers)

Curtin University

Study Approval Reference Number: HR 206/2014

Participant Information

Curtin University

What is the research about?

You are invited to take part in an innovative research study investigating the impact of a stroke on driving performance and behaviour

A stroke can occur at any time during a person's life, although it is most prevalent in the older adult population. It is one of the most common causes of death in Australia, as well as in adults worldwide.

At present, it is unclear how the brain damage caused by a stroke affects driving performance and behaviour. This project is designed to use various assessments including: questionnaires, cognitive tasks (brain training games) and innovative driving measurements, such as an off-road driving simulator, as well as using GPS data from an on-road assessment to investigate the impact on driving caused by a stroke.

The results from this study will help us to make recommendations about how to assess driving behaviours in post-stroke adults and assist with rehabilitation, health and safety management, as well as driving policy.

Who is carrying out the research study?

The study is being conducted by a dedicated research team at Curtin University. The team includes experts in psychology, occupational therapy, spatial science and driving research. If you would like to know more about the project, **contact Alison Blane** using: alison.blane@curtin.edu.au or on 9266 7681.

Who can take part in this study?

Adults who have been previously diagnosed with a stroke, who also have been cleared to return to driving by a medical professional / who have declared their stroke to the WA Department of Transport...

AND

- Have normal or corrected-to-normal vision (i.e., corrected with glasses or contact lenses).
- Possess a full driving licence valid in Australia.
- Have access to an insured vehicle.
- Drive at least twice a week.
- Do not require a wheelchair to get around.
- Are not currently diagnosed with Hemianopia or Hemispheric Neglect.
- Have not been diagnosed with a separate traumatic brain injury or with Parkinson's disease, Alzheimer's disease or Dementia etc.

What does the study involve?

The study will run in 2 phases. Phase 1 will consist of completing a series of cognitive tasks, that are like brain-training games, on a laptop, as well as filling out questionnaires and undertaking a run on the Curtin University Driving Simulator.

This phase will also include an on-road driving assessment, which will take place at the Curtin University Bentley Campus and the surrounding Bentley area.

The on-road assessment will take place in your own vehicle and a GPS mapping device will be temporarily installed onto your car. During the on-road assessment and whilst in the driving simulator, you will be asked to wear an eye-tracking camera. Phase 2 will involve a focus group, which will explore the experiences and risk perceptions of post-stroke drivers.

Eye-Tracking Glasses

Curtin University Driving Simulator

How much time will the study take?

Phase 1 will last approximately 2.5 hours. This assessment will be conducted at a time suitable for you. If you are interested in taking part in the focus group this will take place on a different day to the driving assessments and you will be given a choice of dates that are available. Refreshments will be provided to you during all assessments.

Personal Information

We will request that you bring any relevant medical records relating to your stroke with you on assessment day. We will ask you to detail; when you were diagnosed with your stroke, as well as the type and location of the stroke. This is to help with analysis and all information will be kept strictly confidential.

Appendix 7: Ethical Approval Numbers

Curtin University

Memorandum

To	Dr Hoe C.Lee, Occupational Therapy
From	Professor Peter O'Leary, Chair Human Research Ethics Committee
Subject	Protocol Approval **HR 206/2014**
Date	30 October 2014
Copy	Alison Blane Occupational Therapy Professor Torbjorn Falkmer Occupational Therapy Prof Jonathan Foster Occupational Therapy

Office of Research and Development
Human Research Ethics Committee

TELEPHONE 9266 2784
FACSIMILE 9266 3793
EMAIL hrec@curtin.edu.au

Thank you for providing the additional information for the project titled "*Driving on the Brain: Investigating Cerebrovascular Accident and Driving Performance in Older Adults.*". The information you have provided has satisfactorily addressed the queries raised by the Committee. Your application is now **approved**.

- You have ethics clearance to undertake the research as stated in your proposal.
- The approval number for your project is **HR 206/2014.** *Please quote this number in any future correspondence.*
- Approval of this project is for a period of four years **30-10-2014** to **30-10-2018**.
- Your approval has the following conditions:
  i) Annual progress reports on the project must be submitted to the Ethics Office.
- **It is your responsibility, as the researcher, to meet the conditions outlined above and to retain the necessary records demonstrating that these have been completed. See: Western Australian University Sector Disposal Authority (WAUSDA).**

Applicants should note the following:

It is the policy of the HREC to conduct random audits on a percentage of approved projects. These audits may be conducted at any time after the project starts. In cases where the HREC considers that there may be a risk of adverse events, or where participants may be especially vulnerable, the HREC may request the chief investigator to provide an outcomes report, including information on follow-up of participants.

The attached **Progress Report** should be completed and returned to the Secretary, HREC, C/- Office of Research & Development annually.

Our website https://research.curtin.edu.au/guides/ethics/non_low_risk_hrec_forms.cfm contains all other relevant forms including:

- Completion Report (to be completed when a project has ceased)
- Amendment Request (to be completed at any time changes/amendments occur)
- Adverse Event Notification Form (If a serious or unexpected adverse event occurs)
- Western Australian University Sector Disposal Authority (WAUSDA)

Yours sincerely

Professor Peter O'Leary
Chair Human Research Ethics Committee

Curtin University

Memorandum

To	Dr Hoe Lee
From	Teena Bowman
Subject	Protocol Approval **OTSW-20-2011**
Date	15 November 2011
Copy	Ms Megan Yumin Lee

Office of Research and Development
Human Research Ethics Committee
Telephone 9266 2784
Facsimile 9266 3793
Email hrec@curtin.edu.au

Thank you for your Application for Approval of Research with Low Risk (Ethical Requirements) for the project titled **'An investigation into the reasons why individuals post-stroke continue to drive'.** On behalf of the Human Research Ethics Committee, I am authorised to inform you that the project is approved.

Approval of this project is for a period of twelve months **11 November 2011** to **11 November 2012**.

The approval number for your project is **OTSW-20-2011**. *Please quote this number in any future correspondence*. If at any time during the twelve months changes/amendments occur, or if a serious or unexpected adverse event occurs, please advise me immediately.

TBowman

Teena Bowman
Research Centre Administrator
School of Occupational Therapy and Social Work
Telephone: 9266 4651
Email: t.bowman@curtin.edu.au

Please Note: The following standard statement must be included in the information sheet to participants:
This study has been approved by the Curtin University Human Research Ethics Committee (Approval Number OTSW-20-2011). If needed, verification of approval can be obtained either by writing to the Curtin University Human Research Ethics Committee, c/- Office of Research and Development, Curtin University of Technology, GPO Box U1987, Perth, 6845 or by telephoning 9266 2784 or hrec@curtin.edu.au

CRICOS Provider Code 00301J

Appendix 8: Participant Information Sheet

PARTICIPANT INFORMATION SHEET (POST-STROKE PARTICIPANTS)

Study title: "Driving on the brain: Investigating cerebrovascular accident and driving performance"

You are invited to participate in this research study. It is important that you first take time to read through and understand the information provided in this sheet. This study will be explained to you and you will be given the chance to ask questions. After you are properly satisfied that you understand this study and you wish to participate, you will need to sign the consent form. You will be given a copy of this consent form to take home with you.

Purpose of the research study

A cerebrovascular accident is more commonly referred to as a stroke. Despite the increasing number of people who are diagnosed as having a stroke a year, there is not much information on how a stroke can impact driving performance and how we can help stroke patients return to driving. The results from this study will be used to improve the safety of post-stroke drivers as they continue to drive on Western Australia roads.

Who can take part?

We are looking for participants who have previously been diagnosed as having a stroke and have returned to driving. In order to participate you must fulfil the following criteria:

- You have previously been diagnosed as having had a stroke.
- You must also have been *cleared to drive by a medical professional / had your stroke declared to the department of transport*.

AND

- You have normal or corrected-to-normal (i.e. with glasses or contact lenses) vision.
- You possess a full driving license valid in Australia.
- You have access to an insured vehicle.
- You drive at least twice a week.
- You do not require a wheelchair to get around.
- You are not currently diagnosed with any of the following:
  - Hemianopia or Quadrantanopia,
  - Hemispheric Neglect,
- You have not been diagnosed with traumatic brain injury or a neurodengerative disease such as: Parkinson's disease, Alzheimer's disease, Dementia etc.

PARTICIPANT INFORMATION SHEET (CONTROL PARTICIPANT)

Study title: "Driving on the brain: Investigating cerebrovascular accident and driving performance"

You are invited to participate in this research study. It is important that you first take time to read through and understand the information provided in this sheet. This study will be explained to you and you will be given the chance to ask questions. After you are properly satisfied that you understand this study and you wish to participate, you will need to sign the consent form. You will be given a copy of this consent form to take home with you.

Purpose of the research study

A cerebrovascular accident is more commonly referred to as a stroke. Despite the increasing number of people who are diagnosed as having a stroke each year, there is not much information on how a stroke can impact driving performance and how we can help stroke patients return to driving. The results from this study will be used to improve the safety of post-stroke drivers as they continue to drive on Western Australia roads.

Who can take part?

We are currently looking for control participants to act as a comparison group therefore in order to take part you must fulfil the following criteria:

- You have not previously had a stroke.

AND

- You have normal or corrected-to-normal (i.e. with glasses or contact lenses) vision.
- You possess a full driving license valid in Australia.
- You have access to an insured vehicle.
- You drive at least twice a week.
- You do not require a wheelchair to get around.
- You are not currently diagnosed with any of the following:
    - Hemianopia or Quadrantanopia,
    - Hemispheric Neglect,
- You have not been diagnosed with traumatic brain injury or a neurodengerative disease such as: Parkinson's disease, Alzheimer's disease, Dementia etc.

Privacy and confidentiality

The information obtained during this study will be held in strict confidence and all the researchers who handle your information will comply with the Privacy Act 1988.

Information collected for this study will be kept strictly confidential and will not be released to a third party without your consent unless required by law. If the results of the trial are published in a medical journal, as is intended, no reader will be able to identify individual participant details. A summary of the study results will be made available to you upon request at the conclusion of the study.

What will happen to my information?

All research data will be stored in a stand-alone and password-protected computer at Curtin University. All hardcopies of the research data will be locked in a cupboard at the School of Occupational Therapy and Social Work. The research data will be retained for a period of seven years, after which the data will be safely destroyed in line with university guidelines.

This research study has been reviewed and given approval by Curtin University Human Research Ethics Committee (approval number HR 206/2014). The Curtin University Human Research Ethics Committee is comprised of members of the public, academics, lawyers, doctors and pastoral carers. If you have questions about your rights as a participant, or any complaints about the study, or if needed, verification of ethical approval can be obtained by either writing to the Human Research Ethics Committee, C/O Office of Research and Development, Curtin University, GPO Box U1987, Perth, 6845 or by telephoning 9266 9223 or emailing hrec@curtin.edu.au.

Who to contact if you have questions

Please feel free to contact the below researchers with any queries about this study and/or your participation and we will respond to you as soon as possible.

- **Ms Alison Blane (Primary Investigator):** *Alison.Blane@postgrad.curtin.edu.au*
- **Dr Hoe Lee (Primary Supervisor):** *H.Lee@curtin.edu.au*
- **Professor Torbjörn Falkmer:** *T.Falkmer@curtin.edu.au*

What is involved?

You will be invited to undergo a 2-phase study, which may take 2-4 hours to complete. Before the driving assessments, you will complete a series of computerised assessments and paper-pencil tests to measure your overall cognition. Next, you will be invited to participate in a driving simulator assessment in the Curtin University Driving Simulation Laboratory.

You will then be asked to complete a short driving route with a GPS device, which will be temporarily installed into your vehicle and which will monitor your on-road position. You will use your own vehicle for this part and petrol costs will be reimbursed. An eye tracking device to capture where you look during the driving assessments will be used. Throughout the session, you will be given regular breaks with refreshments.

Risks

A small number of participants may experience simulator sickness whilst using the driving simulator. These symptoms are similar to motion sickness and may include sweating, dizziness, headache or nausea. Precautionary measures will be put in place to minimize the chances of simulator sickness however, if you feel unwell during the simulation drive, we will stop the test immediately and attend to you.

This study is observational and not intended to assess your on road driving ability. By agreeing to take part in the study, you understand that results from the driving assessment observation will be used for research purposes only and will ***not*** be forwarded to any regulatory body.

If the researcher finds any indication that your health may impact your everyday driving, the researcher will inform you of the problem and advise you to seek professional medical advice. Any consequent professional or medical review may lead to a legal review of your capacity to drive, however please be aware that it is ***not*** the aim of this study to terminate your driving license.

Rights

Your participation in this study is entirely voluntary. When you have signed the consent form, the researcher will assume that you have agreed to participate and that you allow the use of your data in this research. You have the right to not participate in this study and to withdraw your participation at any time without reason or justification and without incurring any negative consequences. Should you have any queries or concerns regarding the study you may contact the researchers using the contact details below.

Curtin University

Participant Consent Form

Participant ID: ______________________

Please read the below statements and complete the signatory section below:

- I voluntarily consent to participate in this research study. I have fully understood the purpose and procedures of the research and I have been given the opportunity to ask questions, all of which have been answered to my satisfaction.
- I understand that all information collected from me is solely for the use of this study and will remain confidential. I understand that my information will not be released to a third party without my consent unless required by law.
- I understand that all personal identifying information will be removed from all research data or files once my information has been recorded and I agree that the results of this study may be published, provided that I cannot be identified.
- I acknowledge that I have the right to withdraw from this study at any time without any negative consequences.
- I understand that, in taking part in the research, I have read and fulfil the criteria outlined in the above participant information sheet above:
- I have been provided with the participant information sheet and consent form which I have read and understood.

______________________ ______________________ ____________

Name of Participant Signature Date

I, the undersigned, certify that I have explained the study to the participant and to the best of my knowledge the participant signing this consent form clearly understands his/ her participation in this study.

______________________ ______________________ ____________

Name of Researcher Signature Date

Thank you for your involvement in this research project. Your participation is greatly appreciated and will contribute to Curtin University of Technology's further research into disability and society.

4

Appendix 9: Risk Assessment

Health & Safety Risk Assessment

Curtin University

Activity / Task / Location:	Date:
PhD Project: Investigating Cerebrovascular Accident and Driving Performance – Phase 1 -3 Location: Curtin University Bentley Campus	30.07.2014

Developed by:	Approved By:
Alison Blane	Dr Hoe C. Lee

Hazard Identification		Risk Assessment			Control	Residual Risk Assessment				
Activity	Potential Hazards	Consequence	Likelihood	Risk Score	Risk Control Measures 1. **Eliminate,** eg: eliminate task, remove hazard 2. **Substitute** eg: replace with less hazardous process, material 3. **Isolate** eg: enclosures, restricted access; 4. **Engineering** eg: guarding, separation, redesign; 5. **Administrative** eg: Safe Work Procedure, training; 6. **Personal Protective Equipment (PPE)** eg: gloves, goggles	Consequence	Likelihood	Risk Score	Who is responsible to implement the changes	Date Finalised
Phase 1-3	Harm to Human Subjects	Moderate	Unlikely	Medium	An application for Ethical Approval of Research Involving Humans (Form A) will be submitted to the Curtin University Human Research Ethics Committee and research recruitment will not begin until approval has been granted.	Minor	Rare	Low	All researchers involved in the project.	01/08/2014

Health & Safety Risk Assessment

Curtin University

Phase 1: Cognitive Assessments including: computerised assessments, eye tracker and questionnaires	None	N/A			N/A	N/A			N/A	01/08/2014
Phase 1: Off-road driving simulator assessment	Simulator Sickness	Insignificant	Possible	Low	The researchers will make participants aware of the symptoms prior to the assessment and advise them to inform the researcher should they begin to feel any discomfort. Participants will be monitored for symptoms during each run. Should simulator sickness occur, the driving simulator assessment will be discontinued for that participant.	Insignificant	None	Low	PhD student Researcher	01/08/2014
Phase 2: On-road driving assessment	Driver Difficulty	Moderate	Possible	Medium	The driving simulator involved in phase 1 of the project will act as a screening tool. If participants present unsafe driving behaviours or experience driving difficulty then the on-road driving assessment will not be undertaken. If difficulty occurs during the on-road assessment then the assessment will be stopped, the participant informed of the decision and will be offered professional driving counselling with the primary supervisor.	Insignificant	Rare	Low	PhD Student Researcher	01/08/2014
Phase 2: On-road driving assessment using GPS device and eye-tracker	Traffic Collision	Moderate	Possible	Medium	Only participants who have a valid driving licence, an insured vehicle and who drive regularly will be invited to participate. These criteria will be confirmed by the participant prior to the commencement of the assessment e.g. by showing their driving licence. The participants will be shown a standardised route before being asked to drive the route themselves. The route consists of a number of main roads of which	Moderate	Rare	Low	PhD Student Researcher	01/08/2014

Version 2.0 Uncontrolled document when printed Health and Safety Page 2 of 4

Health & Safety Risk Assessment

Curtin University

					the maximum speed limit is 70km per hour and does not consist of any task that would be uncommon in a regular driving situation. On-road driving assessments will not take place before 9.00am or between 4.30pm and 6.30pm in order to minimise exposure to traffic congestion.					
Phase 3:	None	N/A			N/A	N/A			N/A	01/08/2014

Version 2.0 Uncontrolled document when printed Health and Safety Page 3 of 4

Health & Safety Risk Assessment

Curtin University

Health & Safety Risk Matrix

DETERMINING THE RISK LEVEL: Risk Level = Consequence Level x Likelihood Level

Maximum Foreseeable Exposure: For each risk, select the expected Consequence Level and the expected Likelihood Level assuming controls are either not in place or controls fail.

Residual Risk Exposure: For each risk, select the expected Consequence Level and the expected Likelihood Level given the type and effectiveness of the controls that are in place. **Risk Response:** Apply the appropriate response based on the assessed Risk Level

		LIKELIHOOD DESCRIPTION				
	LIKELIHOOD	The event may occur only in exceptional circumstances	Not expected but the event may occur at some time	The event could occur at some time	The event will probably occur in most circumstances	The event is expected to occur or has occurred and is continuing to impact
IMPACTS		Likelihood Level				
Health and Safety	Consequence Level	Rare	Unlikely	Possible	Likely	Almost Certain
Fatality Permanent Total Disability	Critical				Extreme	
Significant/extensive injury or illness. Permanent Partial Disability	Major			High		
Serious injury or illness. Lost time injury >10 days	Moderate		Medium			
Injury or illness requiring medical treatment Lost time injury <10 days	Minor	Low				
Injury or illness requiring First Aid treatment No lost time injury days	Insignificant					

CONSEQUENCE DESCRIPTION

RISK MANAGEMENT ACTION	
RISK LEVEL	**RESPONSE**
Extreme	Immediate action required to reduce exposure. A detailed mitigation plan must be developed, implemented and monitored by senior management to reduce the risk to as low as reasonably practicable.
High	A mitigation plan shall be developed and authorised by area manager or supervisor to reduce the risk to as low as reasonably practicable. The effectiveness of risk control strategies shall be monitored and reported to management and relevant committee.
Medium	A mitigation plan shall be developed. Control strategies are implemented and periodically monitored.
Low	Manage by documented routine processes and procedures, monitor periodically to determine situation changes which may affect the risk

Version 2.0 Uncontrolled document when printed Health and Safety Page 4 of 4

Appendix 10: Approval from Advances in Transportation Studies re. Copyright Permissions

Alison Blane
School of Occupational Therapy & Social Work
Curtin University
GPO Box U1987,
Perth, WA, 6845

Editor-in-Chief
Advances in Transportation Studies
Via Email

9th March 2017

Dear Dr Calvi

It is my understanding that Advances in Transportation Studies are the copyright holder for the following material: Blane, A., Falkmer, T., Lee, M., Parsons, R., & Lee, H. (2016). The cognitive and socio-demographic influences on driving performance and driving cessation in post-stroke drivers. *Advances in Transportation Studies* (38), 121-135.

I would like to reproduce an extract of this work in a doctoral/Master's thesis which I am currently undertaking at Curtin University in Perth, Western Australia. The subject of my research is **post-stroke driving.** I am carrying out this research in my own right and have no association with any commercial organisation or sponsor.

The specific material / extract that I would like to use for the purposes of the thesis is **the proofed manuscript of the paper.**

Once completed, the thesis will be made available in online form via Curtin University's Institutional Repository espace@Curtin (http://espace.library.curtin.edu.au). The material will be provided strictly for educational purposes and on a non-commercial basis.

I would be most grateful for your consent to the copying and communication of the work as proposed. If you are willing to grant this consent, please complete and sign the attached approval slip and return it to me at the address shown. Full acknowledgement of the ownership of the copyright and the source of the material will be provided with the material.

If you are not the copyright owner of the material in question, I would be grateful for any information you can provide as to who is likely to hold the copyright.

I look forward to hearing from you and thank you in advance for your consideration of my request.

Yours sincerely

Alison Blane

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Version date: 15/09/16

CRICOS Provider Code 00301J

Appendix 10: Approval from Advances in Transportation Studies re. Copyright Permissions

PERMISSION TO USE COPYRIGHT MATERIAL AS SPECIFIED BELOW:

Blane, A., Falkmer, T., Lee, M., Parsons, R., & Lee, H. (2016). The cognitive and socio-demographic influences on driving performance and driving cessation in post-stroke drivers. *Advances in Transportation Studies* (38), 121-135.

I hereby give permission for **Alison Blane** to include the abovementioned material(s) in his/her higher degree thesis for Curtin University, and to communicate this material via the espace@Curtin institutional repository. This permission is granted on a non-exclusive basis and for an indefinite period.

I confirm that I am the copyright owner of the specified material.

Signed Alessandro Calvi

Name: Alessandro Calvi

Position: Editor in Chief of Advances in Transportation Studies

Date: 13rd March, 2017

Please return signed form to **Alison Blane at Alison.Blane@curtin.edu.su**

Appendix 11: Author Proofed Manuscript from Advances in Transportation Studies

The cognitive and socio-demographic influences on driving performance and driving cessation in post-stroke drivers

A. Blane[1] H.C. Lee[1] M. Lee[1] R. Parsons[1] T. Falkmer[1,2,3]

[1]*School of Occupational Therapy and Social Work, Curtin University, Perth, Australia*
email: HoeLee@curtin.edu.au
[2]*Rehabilitation Medicine, Department of Medicine and Health Sciences (IMH), Faculty of Health Sciences, Linköping University & Pain and Rehabilitation Centre, UHL, County Council, Linköping, Sweden*
[3]*School of Occupational Therapy, La Trobe University, Melbourne, Victoria, Australia*

subm. 21st May 2015 *approv. after rev. 9th September 2015*

Abstract

Background: Driving is a complex activity requiring highly integrated cognitive and perceptual functions that can be negatively affected following a stroke. The decision to continue or cease with driving after a stroke may not be exclusively dependent on deficits in cognitive and motor abilities. Instead, it is possible that social supports, alternative means of transportation, education level, income, self-regulation ability and the awareness of personal health problems may also influence the decision.

Aim: The aim of this research was to explore the influence of personal and socioeconomic factors, in addition to existing cognitive impairment, on the decision of post-stroke adults to return to driving.

Method: A case control design was employed to compare driving performance of 48 individuals who had experienced a stroke and 22 volunteer healthy control participants. Half of the post-stroke cohort (N=24) had continued driving and the other half had ceased driving. Socio-demographic and driving-related cognitive performance data were collected to characterise the comparison groups before driving performance was assessed in a driving simulator.

Results: Overall, the post-stroke groups did not perform as well as the control participants in the cognitive and driving assessments. The perceived ability to drive after a stroke was not significantly correlated with participants' actual driving ability. Post-stroke adults were more likely to continue driving if they reported having a tertiary level education and a greater income.

Conclusion: The decision to return to driving after a stroke is a complicated, multifactorial process. This study confirms previous research, which found that cognition and driving performance are impaired post-stroke. The findings also suggest that post-stroke drivers' decision to return to driving was not linked to their ability to drive, but more to socio-demographic and environmental factors. Further screening tools and assessments to identify those at risk when returning to the road post-stroke are required.

Keywords – cognition, driving cessation, driving performance, driving simulator, post-stroke, socio-economic factors

1. Introduction

The ability to maintain driving is often considered a crucial part of an individual's identity [14, 21] and is a key element for functional mobility and autonomy, particularly in older age [9].

Driving is a complex and multifaceted activity requiring highly integrated functions, including: visual and motor functions, as well as, cognitive abilities (e.g., perceptual and executive functioning [4]), all of which can be affected following the onset of a stroke [2, 41]. Research has shown that up to 30% of stroke survivors will return to driving [18]. As the population ages, the risk of a stroke increases.

Therefore it is not surprising that the incidence of stroke survivors who wish to continue driving is significant given the necessity among older people to use the car as a means of independent transportation [53].

Safe driving regulation in the ageing population is a worldwide multifactorial problem. The decision to continue or cease with driving after a stroke may not be dependent on an individual's visual, motor or cognitive abilities. Regardless of substandard driving performance or ability, many older drivers are reluctant to relinquish their licenses [64], as driving cessation can lead to a decrease in out-of-home activity [40], a loss of independence [1] and cause increased feelings of loneliness, isolation and depression [19, 57, 59]. Reluctance to give up driving has been found to be particularly common in post-stroke drivers [36, 37, 49]. Previous literature investigating older drivers has reported that social supports, alternative means of transportation, education level, sense of identity, income, self-regulation ability, and the awareness of personal health problems can all influence the decision to continue or to cease with driving [1, 15, 27].

Screening assessments for post-stroke individuals at risk of unsafe driving are essential in order to maintain the safety of all road users.

In Australia, the process for post-stroke driving evaluation includes general road knowledge questionnaires and cognitive assessments, as well as an on-road driving assessment [45]. However, final clearance to drive is usually given by a medical practitioner and the experience of this process between drivers can vary [36]. Off-road assessments have previously been identified as useful for identifying those at-risk of failing a driving test [13], however many physicians are unfamiliar with off-road-based tests [47] and there is still potential for post-stroke drivers who have undertaken a driving evaluation to be unsafe drivers as "…the quality of driving evaluations…may not be sufficient to detect potential deficits in driving skills" [18]. Therefore assessments that incorporate screening of an individual's personal and socioeconomic profile may also assist in identifying those at-risk.

Currently there is limited research that investigates the socio-demographic factors influencing the decision of stroke patients to return to drive.

Available research consists of over-the-phone interviews [52], which failed to capture several personal and contextual factors.

The participants' level of insight into personal health, level of education, what, if any, advice they received regarding driving post-stroke, and to what alternative means of transportation they have regular access have not been investigated. Therefore, the aim of this study was to identify personal and socioeconomic factors, in addition to cognitive impairment that influence the decision of individuals to return to or cease driving post-stroke.

2. Methods

A case control design was applied to compare the cognitive performance and driving performance in post-stroke adults compared to healthy controls.

Further analysis was applied to investigate the socio-demographic variables associated with driving performance and driving cessation in post-stroke adults who continued with driving and those who had ceased driving.

2.1. Participants

Participants comprised 24 post-stroke adults (male = 24) who were driving (post-stroke drivers) aged between 56 – 78 years (Mean = 67, SD = 7.7), 24 post-stroke adults (male = 18) who had ceased driving (post-stroke non-drivers) aged between 30 and 83 years (Mean = 68, SD = 17.7) and 22 control participants (male = 17) aged between 53 and 79 years (Mean = 64, SD = 6.7).

2.2. Sampling and recruitment

Purposive sampling techniques were employed during the recruitment process, which was conducted during February, March, May and June 2013. Healthy controls were recruited through advertisements in the community, whereas recruitment of the post-stroke groups was accomplished with the assistance of Home and Driving Occupational Therapy Services and Osborne Park Hospital in Western Australia, as well as, through advertisements placed with several community-based organisations. Inclusion criteria were stipulated for all participants. These included: that participants were community-dwelling, held a current driving license valid in Western Australia, actively drove for a minimum of two hours a week (or had done so prior to stroke for post-stroke non-drivers) and had no further significant confounding comorbid condition, such as dementia or physical impairment. A further criterion for post-stroke adults was that they previously had been diagnosed with a stroke, at least 6 months prior to the assessment. Participants were screened for visual acuity using the Snellen Visual Acuity Chart. No participants were excluded based on the visual acuity (VA) score. All participants were able to read the chart at a distance equal to a VA score of 20/40 or better, which is the minimum VA score required in order to legally drive in Australia.

2.3. Performance measures and equipment

2.3.1. Cognitive measures

In order to obtain an overall measure of the cognitive and perceptual abilities of all participants, psychometric assessments were administered. The assessments included the Montreal Cognitive Assessment [44] Benton Judgment of Line Orientation Test [7], Digit Vigilance Test [34], Trail Making Test Part B [58], and a Road Sign Recognition Test [35].

The Montreal Cognitive Assessment (MoCA) [44] is a 30-item cognitive screening tool that has been validated for measuring mild cognitive impairment in older adults. Lower scores are indicative of increased cognitive decline. It has moderate test-retest reliability of 70%-92% [44]. The MoCA has previously been implemented in various pathology groups, including a stroke population [51]. The Benton Judgment of Line Orientation Task (BJLOT) [7] is a commonly used neuropsychological assessment to measure visuospatial function [54]. Spatial perception is a higher order cognitive function that affects driving ability and is predictive of driving continuation post-stroke [41, 46]. The test requires participants to correctly match two adjoining lines, to a pair of longer lines from within a semi-circular line set. The orientation of the target line pair alters with each test iteration. The assessment has been reported to have high test-retest reliability of 0.90 [38] and has been found a highly reliable predictor of simulated driving performance [42]. The Digit Vigilance Task (DVT) [34] is a reliable and valid neuropsychological assessment that is used to evaluate sustained attention and speed of cognitive processing [26].

The assessment requires participants to identify and put a cross through target numbers (6 or 9) as quickly and accurately as possible. Total time taken and errors / omissions were recorded for all participants. The Trail Making Test Part B (TMT-B) [58] is a highly utilized psychometric test that is used to asses an individual's higher order functioning, including divided attention, visual perception, and executive functioning. The test requires participants to draw lines alternating between letters and numbers as quickly and as accurately as possible. The test is widely used in driving assessments, and has been found to be a significant predictor of outcomes of on-road and off-road driving assessment in post-stroke drivers [41, 43, 55].

The Road Sign Recognition Test (RSRT) assesses knowledge of road signs, visual recognition, memory, and problem solving abilities [35, 55]. The test involves a series of road signs used in Western Australia and asks the participant to explain the meaning of the sign. The test has good face validity and requires the participants to demonstrate knowledge of common road rules and regulations required for safe driving. Similar tests have been previously utilized in driving research with valid and reliable results [35, 39, 55].

2.3.2. Driving performance measures

Each participant completed an off-road driving assessment using the interactive driving simulator located in the Driving Assessment Lab at Curtin University in Western Australia. The Curtin University Driving Simulator is a fixed-base simulator that has mid-level physical fidelity and consists of a driving console and three display screens (see Figure 1). The driving console is made up of an adjustable sedan style seat with acceleration, brake pedals and a fully functioning steering wheel.

Driving related auditory feedback, such as traffic and engine noise is provided through the digital auditory output system, therefore providing a more immersive experience. The simulator has previously been validated for use on older adults [32] and has good reported transference to real-world driving performance [12].

A specially designed driving scenario was programmed using the STISIM© driving software [3] and included various traffic scenarios that would assess participants' cognitive and perceptual abilities, as well as, knowledge of road rules and regulations. The variables recorded as a measure of driving performance included: the number of collisions, pedestrians hit, speed exceedances, traffic light violations, centreline crossings, road edge excursions and stops at traffic lights. The driving performance of the participants was gauged by a total driving score, based on these seven variables.

Fig. 1 - The STISIM driving simulator

The scenario was comprised of a mixture of urban 4-lane and 2-lane road each participant was afforded a 10 minute practice run in order to become familiar with the simulator visuals and with operating the driving console. The experimental trial was programmed to a distance of 8.25 kilometres and took approximately 15 minutes to complete.

2.4. Procedure

After completing the participant information sheet, participants were screened using the Snellen Visual Acuity Chart. Participants then completed the MoCA, BJLOT, the DVT and the TMT-B.

Following previous research by Perrier et al., [52], participants' personal and socioeconomic information was collected and included: driving exposure, medical history, level of education, availability of social supports, access to alternative means of transportation and if advice on driving post-stroke had been previously given. Participants were also asked to rate their own driving performance compared to other adults of their age group. This was in order to obtain an indication of the participants' perception and insight into their own driving ability. Participants rated their performance using a Likert scale that ranged from 1 (compared to others my own age, I am not a good driver), through 5 (compared to others my own age, I am an average driver) to 10 (compared to others my own age, I am a highly competent driver).

Finally, participants completed the driving assessment in the driving simulator. Instructions for the simulator were given prior to each simulator assessment. Overall, the assessment process lasted approximately two hours.

2.5. Ethical approval

The study was approved by Curtin University's Human Research Ethics Committee (HREC OTSW-20-2011). Written consent to participate was obtained from all participants and confidentiality of records was maintained in line with the Declaration of Helsinki and the Western Australian University Sector Disposal Authority.

All participants were informed that they could withdraw from the study at any time without incurring any negative consequences. Furthermore, in the event that participant performance indicated unsafe driving, a referral would be made for the participant to obtain complementary driver counselling and advice.

2.6. Statistical analysis

All collected data including the background and socio-demographic data, screening, psychometric assessments, and driving simulator were exported into Microsoft Excel© and analysed using SPSS version 21.0 [25]. Descriptive and univariate statistics were used to describe the demographics of each group. Normality of data was assessed for all continuous measures. Only the TMT-B presented with positively skewed data therefore statistical analysis was performed on the logarithm of this variable. Between groups analysis of cognitive performance was analysed using a one-way ANOVA with LSD post-hoc analysis. A cumulative score for overall cognitive performance and driving performance was calculated using PCA analysis on the individual cognitive variables and driving simulator outputs respectively.

The effect of cognitive decline on driving performance was then investigated using linear regression modelling; after adjusting for driving exposure (driving in hours per week), duration since diagnosis with stroke in months and changes in driving habits (frequency of using alternative means of transportation).

Binary logistic regression was employed to identify whether socio-economic factors (availability of carers / friends/ family members to drive participants around and their level of education and income) had an effect on the decision of post-stroke participants to continue driving. A p-value of < 0.05 was taken to indicate a statistically significant association in all tests.

3. Results

3.1. Demographic characteristics

Significant differences in the demographic profile (Table 1) were found in the following variables: years of driving, hours driven per week (Table 1), reported highest level of education (Table 2) and individual income (Table 3).

Hours driven per week became non-significant when post-stroke non-driving status was controlled for $t(44) = .643$, $p = .523$, 95% CI [-2.8, 5.42]. No significant differences were reported in gender distribution between the post-stroke and control groups $X^2 = 2.38$, $p > 0.05$ but there was a significant difference in gender distribution between the post-stroke cohorts as all post-stroke female participants had ceased driving $X^2 = 6.86$ $p = 0.009$. When comparing the overall demographic profile of post-stroke drivers and post-stroke non-drivers, no differences were found in age, years of driving or individual income.

A large proportion of post-stroke drivers reported having completed tertiary education $X^2 = 10.25$; $p = 0.02$ and fewer of them reported earning $85,000 or more. More post-stroke non-drivers had received advice regarding driving after their stroke compared to the post-stroke drivers (75% and 41% respectively).

In total, 58% of the post stroke group reported having declared their stroke to the appropriate medical and transport authorities and 41% percent of the post-stroke participants had not received advice on driving capacity. More than half of the post-stroke participants continued to drive without having consulted a medical or driving professional. Across the 48 post-stroke participants, the length of time since stroke diagnosis ranged from 6 months – 138 months. Although the reported distribution of the length of time since stroke diagnosis was positively skewed, there was no significant difference in length of time since stroke diagnosis between the post-stroke drivers and post-stroke non-drivers $t(46) = -.253$, $p > 0.05$, 95% CI [-32.99, 25.63].

Tab. 1 - Demographic information of post-stroke cohort and control groups

Variables	Controls (N = 22)		Post-Stroke Driver (N = 24)		Post-Stroke Non-Driver (N = 24)			p-value
	Mean	*SD*	Mean	*SD*	Mean	*SD*		
Age	64.8	6.7	67.8	17.7	68.2	7.8	0.555	0.577
License length in years	45.9	7.1	56.9	9.0	54.6	11.0	9.024	<0.005
Hours of driving per week	11.1	7.7	9.8	6.1	0	0		<0.005
Hours of Driving (weekly)	11.1	7.7	9.82	6.1	N/A			0.523
Recovery period (month)	N/A		48.6	52.6	44.9	48.3	t (46) = -0.25	>0.005
Declared stroke to authorities	N/A		Yes = 14 (58%)	No = 10 (42%)	Yes = 14 (58%)	No = 10 (42%)	$X^2 = 1.3$	>0.005
Received advice on driving	N/A		Yes = 14 (58%)	No = 10 (42%)	Yes = 18 (75%)	No = 6 (25%)	$X^2 = 5.49$	0.19

Tab. 2 - Education level information of post-stroke cohort and control groups

Education Level	Controls (N = 22)	Post-Stroke Driver (N = 24)	Post-Stroke Non-Driver (N = 24)		p-value
Tertiary	(14) 64%	(14) 58%	(4) 17%	$X^2 = 19.7$	0.003
Year 12	(2) 9%	(5) 21%	(6) 25%		
Year 10	(6) 27%	(3) 13%	(6) 25%		
Primary	0	(2) 8%	(8) 33%		

Tab. 3 - Income level information of post-stroke cohort and control groups

Income Level	Controls (N = 22)	Post-Stroke Driver (N = 24)	Post-Stroke Non-Driver (N = 24)		p-value
≤$5,000	0	(4) 17%	(2) 8.3%	$X^2 = 13.86$	0.008
$5,000 - $84,999	(3) 14%	(12) 50%	(8) 33.3%		
≥ $85,000	(19) 86%	(8) 33%	(14) 58.3%		

3.2. Between-groups analysis of cognition and driving performance

A one-way ANOVA with LSD post-hoc analysis was performed to assess cognitive performance between groups (Table 4). There was a significant between-group difference in performance on the MoCA. Both the post-stroke driver and post-stroke non-driver group obtained a mean score below the MoCA cut off >26. With the exception of the TMT-B and the DVT, higher cognitive scores are indicative of greater cognitive performance. In the TMT-B and the DVT, errors and reaction times are measured; therefore lower scores are indicative of greater cognitive performance.

There were also clear differences in the cognitive performance between the post-stroke groups, as the post-stroke drivers generally displayed greater cognitive performance than post-stroke non-drivers.

Assumptions of the current research were that the psychometric measures represented overall driving-related cognitive function and that the simulator measures represented driving performance. Principle component analysis (PCA) was conducted on the five psychometric measures (BJLOT, TMT-B, DVT errors, MoCA and RSRT).

Tab. 4 - Between groups analysis of psychometric task performance

Psychometric Task	**Control (N = 22)**		**Post-Stroke Driver (N = 24)**		**Post-Stroke Non-Driver (N = 24)**		***F*-value (df = 2, 67)**	***p*-value**
	Mean	SD	Mean	SD	Mean	SD		
MoCA	26.82	1.82	25.21	2.90	23.29	2.97	10.32	<0.001
Benton (# items Correct)	25.55	4.46	25.17	4.29	21.25	4.48	6.85	0.002
TMT-B	77.59	25.59	125.31	38.66	171.67	95.35	13.23	<0.001
RSRT (# items correct)	4.14	1.13	3.25	1.39	3.17	1.44	3.70	0.03
DVT (Errors)	4.77	6.57	10.08	5.038	15.00	23.47	2.84	0.065
DVT (Time)	437.09	92.53	529.71	142.00	656.08	144.59	16.62	<0.001

The first component (see equation 1) which explained 38.1% of the variance, was identified as an “overall cognitive score”, and was calculated for each participant in the following way:

** Overall cognition score = 0.87 *MoCA + 0.529 *Benton - .717 * TMT-B + .523 * RSRT -.249 * DVT (# errors) – .714 *DVT (# time)* (1)

All of the driving criteria measured as part of the simulator assessment were combined to form three variables: number of collisions (vehicle or roadway collisions, and pedestrians hit), driver errors (speed exceedances and traffic light tickets,) and unsafe driving manoeuvers (unsafe manoeuvring, centreline crossings, road edge excursions and inappropriate indicator use). A lower score indicated fewer errors and therefore better driving performance.

PCA analysis was employed to aggregate the individual driving variables into a single driving performance variable, which could be viewed as a total weighted average of all the assessment criteria. A lower overall driving performance score indicated fewer errors and therefore better driving performance. This procedure is based on the previous research by Lee et al., [30] and has been previously validated for use in older driver research [11, 33]. The first component of PCA explained 67.57% of the variance of the overall driving performance score; therefore it was adopted and calculated as shown in equation 2:

Overall driving performance = .7465 Number of Collisions + .905 * Driver Errors + .808 *Unsafe Driving Manoeuvres* (2)

A one-way ANOVA was applied to the controls, post-stroke drivers and post-stroke non-drivers. Significant differences were found between groups in overall driving performance $F(2) = 8.08$, $p < 0.01$ and overall cognitive performance $F(2) = 31.78$, $p < 0.0001$. Post-hoc LSD analysis revealed significant differences in overall cognitive performance between the controls and post-stroke drivers $p < 0.0001$, 95% CI [.43, 1.35], the controls and post-stroke non-drivers $p < 0.0001$, 95% CI [1.11, 2.02], and between the post-stroke drivers and post-stroke non-drivers $p < 0.005$, 95% CI [.23, 1.13].

Further post-hoc LSD analysis revealed significant differences in overall driving performance between the healthy controls and post-stroke non-drivers $p < 0.001$, 95% CI [-1.61, .57] and between the post-stroke drivers and post-stroke non-drivers $p < 0.05$, 95% CI [-1.12, -.72]. Differences between the controls and post-stroke drivers in overall driving performance were non-significant p = .079 CI [-1.02, .057].

In general, the post-stroke non-drivers scored worst among the three groups. In order to determine whether there was a relationship between overall cognitive performance and overall driving performance, general linear regression was conducted. Analysis was run on overall driving performance and overall cognitive performance in the post-stroke groups, whilst controlling for driving exposure, which is known confounder in driving research [17]. It was found that there was no significant relationship between the two variables $R^2= .063$, $F(4, 43) = .727$, $p = 0.579$ in the post-stroke group.

3.3. Predictive value of personal and socioeconomic criteria on return to driving post-stroke

Further analysis was conducted to identify the variables that post-stroke adults consider when making the decision on whether or not to continue driving. Forwards stepwise logistic regression analysis was applied to identify the main personal and socioeconomic factors attributed to the cessation of driving after stroke. Driving status of the post-stroke cohort (driver = 1, non-driver = 0) was entered as the dependent variable.

Tab. 5 - Logistic regression model predicting driving cessation in post-stroke adults (95% CI based on 48 samples)

	Odds Ratio	p-value	95% C.I. for Odds Ratio	
			Lower	Upper
Education		.011		
Primary	0.010	0.001	0.001	0.174
Year 10	0.064	0.019	0.006	0.634
High School	0.132	0.048	0.018	0.980
University/Diploma	1 (reference)			
Income (annual in $)		0.027		
50000	36.929	0.021	1.734	786.643
50,000 – 84,999	9.372	0.021	1.393	63.068
85,000 or above	1 (reference)			
Constant	1.785	0.354		

Nagelkerke $R^2 =$ 0.476; Cox & Snell R^2 = 0.357; pseudo $R^2 =$ 0.672

Education, the availability of other drivers, individual income, driving perception, whether the participant had been advised on their driving and whether or not the participant had reported their stroke to the authority, as well as, overall driving performance were included as independent variables. Control participants' data were excluded from this analysis and there was no missing data in any variable within the post-stroke cohort.

The model (Table 5) suggested that individuals who had a university education, had a significantly increased likelihood of continuing to drive post-stroke than their lower educated counterparts. Also the likelihood that individuals with annual earnings of $85,000 or above would continue to driving post stroke was significantly lower than those in lower income groups. Tests for multicollinearity and tolerance statistics were conducted with no violation of assumptions.

Interestingly, variables removed as non-significant in the analysis were the availability of the other drivers and perceived driving ability. This suggested that insight into driving ability does not influence driving cessation and that other factors have a greater impact on the decision to stop driving following a stroke. Figure 2 shows a scatter plot of the overall driving performance scores for both drivers and non-drivers in the post-stroke group. It can be seen that there were post-stroke adults who continued to drive despite having achieved similar or worse driving performance scores than the post-stroke adults who have ceased driving. For example while participant (A) performed best in the driving assessment and had stopped driving, participants (B, C and D) were ranked low in their performance during the driving assessment, yet they all continued to drive. When compared to figure 3, it can be seen that actual driving performance was also not correlated with perceived driving ability. Participants who rated themselves as most competent had ceased driving, while there were participants who scored poorly in the driving performance measures who rated themselves above average – highly competent and who were continuing to drive. Specifically, participants (E, F and G) rated their driving as very good (8/10) or excellent (9/10) and continued to drive, however they performed poorly during their driving assessment. Participants (H and I) rated their driving as above average and continued to drive however they also performed poorly in the driving assessment. Participant (J) rated her driving ability as average (6/10) had ceased driving, but performed very well during the driving assessment.

Participant (K) rated his driving ability as excellent (10/10), performed well in the driving assessment and yet had ceased driving. Finally, participant (L) rated his driving as just above average, performed well and continued to drive.

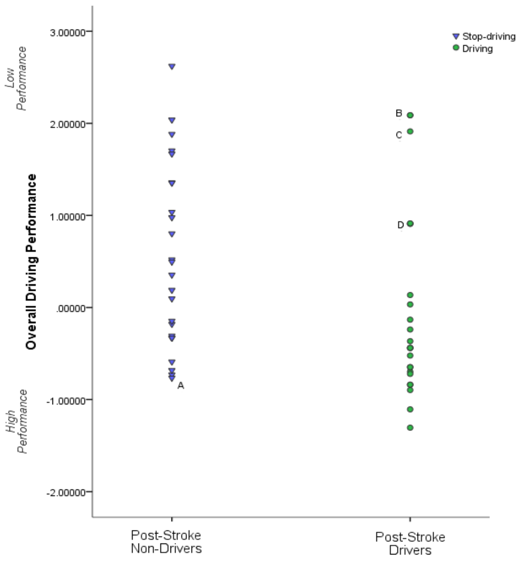

Fig. 2 - A scatter-plot outlining the individual scores of post-stroke drivers in each group

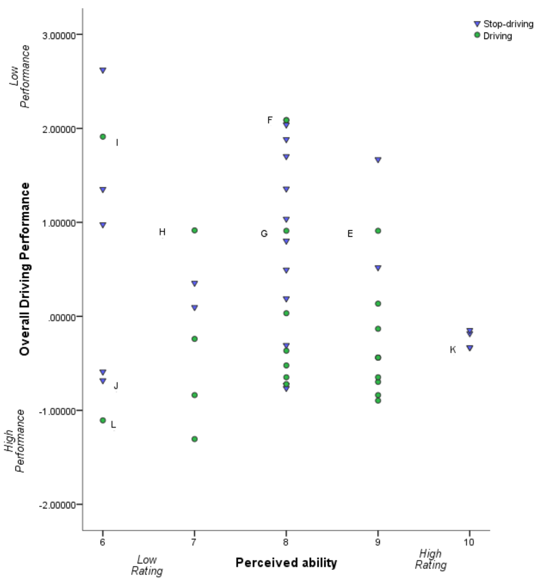

Fig. 3 - A scatterplot of the post-stroke cohort individual scores of driving performance compared to perceived driving ability and separated by driving status

Overall, this finding may suggest either a lack of insight in post-stroke drivers or a potential disregard for personal risk and has implications for reliance upon self-regulation practices. Although not included as significant in the final model, it is worth noting that an independent t-test suggested that post-stroke drivers had statistically fewer drivers available to assist them than post-stroke non-drivers $t(46) = 2.27$, $p > 0.05$, d = .33, 95% CI [.084, 1.42] and overall, statistically fewer social supports than post-stroke non-drivers $t(46) = 2.67$, $p = 0.01$, d = .41, 95% CI [.026, 1.91].

4. Discussion

4.1. Summary of findings

The primary aim for this study was to examine the personal and socioeconomic factors, in addition to cognitive impairment, that influence driving performance and driving cessation in post-stroke adults. As expected, the driving and cognitive performances of post-stroke adults were significantly poorer than for the controls [43]. The findings suggest that driving-related cognition including spatial, sustained and divided attention, visual perceptual and visuospatial ability, executive function, and the speed of cognitive processing [29, 41, 43], as measured by the cognitive variables (MoCA, DVT, BJLOT, RSRT and TMT-B), are impaired in a post-stroke cohort. However, in contrast to previous research (e.g. Marshall et al., [41]), which looked at individual aspects of cognition, this study found that overall cognitive performance was not a strong predictor of post-stroke driving performance.

In line with previous research investigating older post-stroke drivers, it was found that the level of perceived driving ability bore little resemblance to actual driving performance [20, 24, 50, 61]. Although the overall driving performance of the post-stroke driver cohort was better than post-stroke non-drivers, the individual scores suggest that some post-stroke adults who continued to drive performed on par, or in some cases, worse than post-stroke adults who had ceased driving. This is consistent with previous studies, which found that drivers who have suffered a stroke and continued to drive have been known to overestimate their driving capabilities and tend to be riskier on the roads as evaluated by health professionals [23]. These results suggest that some post-stroke adults lacked insight into their performance as evidenced by their bias in self-rating and poorer performance. However, whether the stroke-related cognitive deficit caused this lack of insight could not be determined. Alternatively, in the case of the post-stroke drivers, it is also possible that the participants' perceived need to drive outweighed their personal sense of risk, particularly as deficits in executive function often experienced by post-stroke adults can lead to an increase in impulsivity and risk-taking behaviour [60].

It is also important to consider that the driving performance of some of the post-stroke adults who had ceased driving was better than that of some post-stroke drivers, yet their perceived ability was less. Considering the negative health outcomes associated with the loss of independence due to driving cessation [22, 57], it is critical to ensure that unnecessary self-regulation is not relied upon for post-stroke driving management.

It appears that in the present study, the level of cognitive impairment, although significant in post-stroke drivers, was not the major influencing factor in the decision to return to, or cease with, driving post-stroke. Preliminary analysis suggested that level of education and individual income, accounted for much of the reasoning behind driving cessation. This corroborates the findings of previous research, which have investigated factors influencing older adult driving cessation or continuation [28, 56].

Further in-depth research is required to determine causality, for example, it is possible that those on a lower income were not able to afford the post-stroke driving assessment and were thus unaware of the driving modifications available, or they were unable to afford driving modifications required to drive following their stroke. All post-stroke females in the present study had ceased driving, regardless of actual driving ability, which is in line with previous older driver research that found that older female drivers, despite being less likely to fail an on-road test, are more likely to undertake driving avoidance behaviours [10]. Although social support in the form of other available drivers was excluded from the regression analysis, the post-hoc t-tests revealed that most of the post-stroke drivers did not have family available to help them with driving in day-to-day life, and this could partly explain why post-stroke adults felt an increased need to continue to drive. These results suggest that, although some post-stroke adults undertake voluntary driving self-regulation, some do not, and the deficits in driving performance are a cause for concern. Future research should focus on identifying reliable screening tools and rehabilitation programs to assist with identifying post-stroke adults who are at risk of unsafe driving.

4.2. Limitations

This study is not without limitations. There were significant differences between the control and post-stroke cohorts in length of license and driving exposure, although only the driving exposure was significantly different between the post-stroke groups. Data collected in the post-stroke driver cohort involved an all-male sample set, whereas the non-driver and control cohort contained data from both male and a small number of female participants, which is as a result of the sampling method used. It is therefore difficult to determine whether gender is a factor in the decision of post-stroke adults to cease driving, however it has been previously found that older females, particularly those with deteriorating health, are more likely to relinquish their driving licences [62]. Participants were recruited from a small section of the post-stroke community and therefore the results may not generalise beyond the study population. There was the additional limitation that no medical data were sighted in order to further confirm stroke diagnosis, therefore the experiment relied on self-report information and there is subsequent potential for differences in stroke type, locale and severity to further confound the results. The self-report nature of the research creates the possibility for social desirability bias. Focus groups with family members of post-stroke adults may be used to obtain unbiased information regarding participant insight or awareness of personal health status. Purposive sampling and volunteer sampling were the main sources of recruitment, creating the unavoidable potential for self-selection bias. Due to the nature of the research, more robust methods of sampling, such as random sampling, were not economically viable or practicable. The case control nature of the research means that it is ultimately difficult to determine causality. For example, the level of education, which was significantly different between post-stroke groups, is a known moderator of cognitive decline in older adults, i.e., older adults with higher levels of education tend to exhibit less cognitive decline [5, 6, 8, 16]. It is therefore difficult to determine whether education acted as a moderator in cognitive function in the post-stroke groups and thus impacted driving performance or whether education is an independent contributing factor. There has been much debate in transport research as to whether driving simulators are a valid predictor of on-road performance [29, 61, 63] with on-road assessments still being considered the ‘gold standard’ for driving research [29, 31, 41, 48]. However, it can be argued that the driving simulator may be a useful and more economical tool to assess on-road behaviour and identify those unsafe to drive on-road, in a reliable and safe environment before progressing to on-road assessments [29, 32, 63].

5. Conclusion

In conclusion, the results of this study support the finding that older post-stroke adults exhibit cognitive deficits and poorer driving performance than healthy adults of the same age. However, cognitive deficits and driving performance were not a direct contributing factor to post-stroke driving status. In addition, perceived ability of driving performance appears to have no impact on actual driving performance or post-stroke driving status. In contrast, personal and socio-economic factors including level of education and individual income appeared to influence driving status and self-regulation in post-stroke adults. Development of a screening tool that incorporates an individual's personal and socioeconomic profile may be beneficial in assisting health professionals to identify individuals who are safe to return to driving post-stroke.

References

1. Adler, G., Rottunda, S. (2006). Older Adults' Perspectives on Driving Cessation. Journal of Aging Studies. 20(3), pp. 227-35.
2. Akinwuntan, A.E., Feys, H., De Weerdt, W., Baten, G., Arno, P., Kiekens, C. (2006). Prediction of Driving after Stroke: A Prospective Study. Neurorehabilitation and Neural Repair. 20(3), pp. 417-23.
3. Allen, R.W., Stein, C.A., Aponso, B.L., Rosenthal, T.J., Hogue, J.R. (1990). A low cost, part task driving simulator based on microcomputer technology. Proceedings of the 69th Annual Meeting of the Transportation Research Board, Washington, DC.
4. Anstey, K.J., Wood, J., Lord, S., Walker, J.G. (2005). Cognitive, sensory and physical factors enabling driving safety in older adults. Clinical Psychology Review.
5. Ardila, A., Ostrosky-Solis, F., Rosselli, M., Gómez, C. (2000). Age-related cognitive decline during normal aging: the complex effect of education. Archives of Clinical Neuropsychology. 15(6), pp. 495-513.
6. Arenaza-Urquijo, E.M., Landeau, B., La Joie, R., Mevel, K., Mézenge, F., Perrotin, A., Desgranges, B., Bartrés-Faz, D., Eustache, F., Chételat, G. (2013). Relationships between years of education and gray matter volume, metabolism and functional connectivity in healthy elders. NeuroImage. 83, pp. 450-7.
7. Benton, A.L., Hamsher, K., Varney, N.R., Spreen, O. (1983) Judgment of Line Orientation: Oxford University Press, New York.
8. Beydoun, M.A., Beydoun, H.A., Gamaldo, A.A., Teel, A., Zonderman, A.B., Wang, Y. (2014), Epidemiologic studies of modifiable factors associated with cognition and dementia: a systematic review and meta-analysis. BMC Public Health. 14(1), pp. 643. doi:10.1186/1471-2458-14-643
9. Burns, P.C. (1999). Navigation and the mobility of older drivers. The Journals of Gerontology Series B: Psychological Sciences and Social Sciences. 54(1), pp. 49-S55.
10. Classen, S., Wang, Y., Crizzle, A.M., Winter, S.M., Lanford, D.N. (2012). Gender differences among older drivers in a comprehensive driving evaluation. Accident Analysis and Prevention. 61, pp. 146-152
11. Cordell, R., Lee, H.C., Granger, A., Vieira, B., Lee, A.H. (2008). Driving assessment in parkinson's disease—a novel predictor of performance? Movement Disorders. 23(9), pp. 1217-22.
12. Devos, H., Akinwuntan, A.E., Nieuwboer, A., Tant, M., Truijen, S., De Wit, L., Kiekens, C., De Weerdt, W. (2009). Comparison of the effect of two driving retraining programs on on-road performance after stroke. Neurorehabilitation and Neural Repair. 23(7), pp. 699-705.
13. Devos, H., Akinwuntan, A.E., Nieuwboer, A., Truijen, S., Tant, M., De Weerdt, W. (2011). Screening for fitness to drive after stroke a systematic review and meta-analysis. Neurology. 76(8), pp. 747-56.
14. Dickerson, A.E., Reistetter, T., Davis, E.S., Monahan, M. (2011). Evaluating Driving as a Valued Instrumental Activity of Daily Living. American Journal of Occupational Therapy. 65(1), pp. 64-75.
15. Donorfio, L.K., D'Ambrosio, L.A., Coughlin, J.F., Mohyde, M. (2009). To drive or not to drive, that< I> isn't</I> the question—the meaning of self-regulation among older drivers. Journal of Safety Research. 40(3), pp. 221-6.

16. Evans, D.A., Beckett, L.A., Albert, M.S., Hebert, L.E., Scherr, P.A., Funkenstein, H.H., Taylor, J.O. (1993). Level of education and change in cognitive function in a community population of older persons. Annals of Epidemiology. 3(1), pp. 71-7.
17. Evans, L. (2004) Traffic Safety. Bloomfield, Michigan: Science Serving Society.
18. Fisk, G.D., Owsley, C., Pulley, L.V. (1997). Driving after stroke: driving exposure, advice, and evaluations. Archives of Physical Medicine and Rehabilitation. 78(12), pp. 1338-45.
19. Fonda, S.J., Wallace, R.B., Herzog, R.A. (2001). Changes in driving patterns and worsening depressive symptoms among older adults. The Journals of Gerontology Series B: Psychological Sciences and Social Sciences. 56(6), pp. 343-51.
20. Freund, B., Colgrove, L.A., Burke, B.L., McLeod, R. (2005). Self-rated driving performance among elderly drivers referred for driving evaluation. Accident Analysis & Prevention. 37(4), pp. 613-8.
21. Griffen, J.A., Rapport, L.J., Bryer, R.C., Scott, C.A. (2009). Driving status and community integration after stroke. Topics in stroke rehabilitation. 16(3), pp. 212-21.
22. Harrison, A., Ragland, D. (2003). Consequences of driving reduction or cessation for older adults. Transportation Research Record: Journal of the Transportation Research Board. 1843, pp. 96-104.
23. Heikkilä, V.M., Korpelainen, J., Turkka, J., Kallanranta, T., Summala, H. (1999). Clinical evaluation of the driving ability in stroke patients. Acta Neurologica Scandinavica. 99(6), pp. 349-55.
24. Horswill, M.S., Anstey, K.J., Hatherly, C., Wood, J.M., Pachana, N.A. (2011). Older drivers' insight into their hazard perception ability. Accident Analysis & Prevention. 43(6), pp. 2121-7.
25. IBM Corporation. (2012) IBM SPSS Statistics for Windows, Version 21.0. Armonk, NY: IBM Corp.
26. Kelland, D.Z., Lewis, R.F. (1996). The Digit Vigilance Test: reliability, validity, and sensitivity to diazepam. Archives of Clinical Neuropsychology. 11(4), pp. 339-44.
27. Kostyniuk, L.P., Shope, J.T. (2003), Driving and alternatives: older drivers in Michigan. Journal of Safety Research. 34(4), pp. 407-14.
28. Kulikov, E. (2010). The social and policy predictors of driving mobility among older adults. Journal of Aging & Social Policy. 23(1), pp. 1-18.
29. Lee, H.C., Cameron, D., Lee, A.H. (2003). Assessing the driving performance of older adult drivers: on-road versus simulated driving. Accident Analysis & Prevention. 35(5), pp. 797-803.
30. Lee, H.C., Drake, V., Cameron, D. (2002). Identification of appropriate assessment criteria to measure older adults' driving performance in simulated driving. Australian Occupational Therapy Journal. 49(3), pp. 138-45.
31. Lee, H.C., Lee, A.H. (2005). Identifying Older drivers at risk of traffic violations by using a driving simulator: A 3-year longitudinal study. The American Journal of Occupational Therapy. 59(1), pp. 97-100.
32. Lee, H.C., Lee, A.H., Cameron, D. (2003). Validation of a driving simulator by measuring the visual attention skill of older adult drivers. The American Journal of Occupational Therapy. 57(3), pp. 324.
33. Lee, H.C., Lee, A.H., Cameron, D., Li-Tsang, C. (2003). Using a driving simulator to identify older drivers at inflated risk of motor vehicle crashes. Journal of Safety Research. 34(4), pp. 453-9.
34. Lewis, R., Rennick, P. (1979). Manual for the repeatable cognitive-perceptual-motor battery. Gross Point. MI: Axon.
35. Lincoln, N., Fanthome, Y. (1994). Reliability of the stroke drivers screening assessment. Clinical Rehabilitation. 8(2), pp. 157-60.
36. Lister, R. (1999). Loss of ability to drive following a stroke: the early experiences of three elderly people on discharge from hospital. The British Journal of Occupational Therapy. 62(11), pp. 514-20.
37. Logan, P.A., Dyas, J., Gladman, J.R. (2004). Using an interview study of transport use by people who have had a stroke to inform rehabilitation. Clinical Rehabilitation. 18(6), pp. 703-8.
38. Lundberg, C., Caneman, G., Samuelsson, S.M., Hakamies-Blomqvist, L., Almkvist, O. (2003). The assessment of fitness-to-drive after a stroke: The Nordic Stroke Driver Screening Assessment. Scandinavian Journal of Psychology. 44(1), pp. 23-30.
39. MacGregor, J.M., Freeman, D.H., Zhang, D. (2001). A traffic sign recognition test can discriminate between older drivers who have and have not had a motor vehicle crash. Journal of the American Geriatrics Society. 49(4), pp. 466-9.

40. Marottoli, R.A., de Leon, C.F.M., Glass, T.A., Williams, C.S., Cooney, L.M., Berkman, L.F. (2000). Consequences of driving cessation: decreased out-of-home activity levels. The Journals of Gerontology Series B: Psychological Sciences and Social Sciences. 55(6), pp. 334-40.
41. Marshall, S.C., Molnar, F., Man-Son-Hing, M., Blair, R., Brosseau, L., Finestone, H.M., Lamothe, C., Korner-Bitensky, N., Wilson, K.G. (2007). Predictors of driving ability following stroke: a systematic review. Topics in Stroke Rehabilitation. 14(1), pp. 98-114.
42. Mathias, J.L., Lucas, L.K. (2009). Cognitive predictors of unsafe driving in older drivers: a meta-analysis. International Psychogeriatrics. 21(04), pp. 637-53.
43. Motta, K., Lee, H., Falkmer, T. (2014). Post-stroke driving: examining the effect of executive dysfunction. Journal of Safety Research. 49(33), pp.33-38
44. Nasreddine, Z.S., Phillips, N.A., Bédirian, V., Charbonneau, S., Whitehead, V., Collin, I., Cummings, J.L., Chertkow, H. 2005; The Montreal Cognitive Assessment, MoCA: A brief screening tool for mild cognitive impairment. Journal of the American Geriatrics Society. 53(4), pp. 695-9.
45. National Stroke Foundation. (2013). Driving after Stroke. National Stroke Foundation Australia, https://strokefoundation.com.au/~/media/strokewebsite/resources/factsheets/fs01_driving_web.ashx?la=en.
46. Nouri, F.M., Lincoln, N.B. (1992). Validation of a cognitive assessment: predicting driving performance after stroke. Clinical Rehabilitation. 6(4), pp. 275-81.
47. Odenheimer, G.L. (2011). Which patients are fit to drive after a stroke? Journal Watch Neurology. DOI: 10.1056/JN201103150000001
48. Odenheimer, G.L., Beaudet, M., Jette, A.M., Albert, M.S., Grande, L., Minaker, K.L. (1994). Performance-based driving evaluation of the elderly driver: safety, reliability, and validity. Journal of Gerontology. 49(4), pp. 153-9.
49. Patomella, A.-H., Johansson, K., Tham, K. (2009). Lived experience of driving ability following stroke. Disability & Rehabilitation. 31(9), pp. 726-33.
50. Patomella, A.-H., Kottorp, A., Tham, K. (2008). Awareness of driving disability in people with stroke tested in a simulator. Scandinavian Journal of Occupational Therapy. 15(3), pp. 184-92.
51. Pendlebury, S.T., Cuthbertson, F.C., Welch, S.J.V., Mehta, Z., Rothwell, P.M. (2010). Underestimation of cognitive impairment by mini-mental state examination versus the montreal cognitive assessment in patients with transient ischemic attack and stroke: a population-based study. Stroke; A Journal of Cerebral Circulation. 41(6), pp. 1290-3.
52. Perrier, M.-J., Korner-Bitensky, N., Mayo, N.E. (2010). Patient factors associated with return to driving poststroke: findings from a multicenter cohort study. Archives of Physical Medicine and Rehabilitation. 91(6), pp. 868-73.
53. Ponsford, A.-S., Viitanen, M., Lundberg, C., Johansson, K. (2008). Assessment of driving after stroke—a pluridisciplinary task. Accident Analysis & Prevention. 40(2), pp. 452-60.
54. Qualls, C.E., Bliwise, N.G., Stringer, A.Y. (2000). Short forms of the Benton Judgment of Line Orientation Test: development and psychometric properties. Archives of Clinical Neuropsychology. 15(2), pp. 159-63.
55. Radford, K.A., Lincoln, N.B. (2004). Concurrent validity of the stroke drivers screening assessment. Archives of Physical Medicine and Rehabilitation. 85(2), pp. 324-8.
56. Ragland, D.R., Satariano, W.A., MacLeod, K.E. (2004). Reasons given by older people for limitation or avoidance of driving. The Gerontologist. 44(2), pp. 237-44.
57. Ragland, D.R., Satariano, W.A., MacLeod, K.E. (2005). Driving cessation and increased depressive symptoms. The Journals of Gerontology Series A: Biological Sciences and Medical Sciences. 60(3), pp. 399-403.
58. Reitan, R.M., Wolfson, D. (1985) The Halstead-Reitan Neuropsychological Test Battery: Theory and Clinical Interpretation: Neuropsychology Press Tucson, AZ.
59. Rudman, D.L., Friedland, J., Chipman, M., Sciortino, P. (2006). Holding on and letting go: the perspectives of pre-seniors and seniors on driving self-regulation in later life. Canadian Journal on Aging. 25(1), pp. 65-76.

60. Scheffer, M., Monteiro, J.K., Almeida, R.M.M.D. (2011). Frontal stroke: problem solving, decision making, impulsiveness, and depressive symptoms in men and women. Psychology & Neuroscience. 4(2), pp. 267-78.
61. Selander, H., Lee, H., Johansson, K., Falkmer, T. (2011). Older drivers: on-road and off-road test results. Accident Analysis and Prevention 43 (4), pp. 1348-54.
62. Siren, A., Hakamies-Blomqvist, L., Lindeman, M. (2004). Driving cessation and health in older women. Journal of Applied Gerontology. 23(1), pp. 58-69.
63. Stedmon, A., Young, M., Hasseldine, B. (2009). Keeping it real or faking it: the trials and tribulations of real road studies and simulators in transport research. Proceedings of the International Conference on Contemporary Ergonomics 2009: CRC Press.
64. Unsworth, C.A., Wells, Y., Browning, C., Thomas, S.A., Kendig, H. (2007). To continue, modify or relinquish driving: findings from a longitudinal study of healthy ageing. Gerontology. 53(6), pp. 423-31.

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Appendix 13: Final Manuscript from Behavioural Neurology

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Research Article

Assessing Cognitive Ability and Simulator-Based Driving Performance in Poststroke Adults

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Driving is an important activity of daily living, which is increasingly relied upon as the population ages. It has been well-established that cognitive processes decline following a stroke and these processes may influence driving performance. There is much debate on the use of off-road neurological assessments and driving simulators as tools to predict driving performance; however, the majority of research uses unlicensed poststroke drivers, making the comparability of poststroke adults to that of a control group difficult. It stands to reason that in order to determine whether simulators and cognitive assessments can accurately assess driving performance, the baseline should be set by licenced drivers. Therefore, the aim of this study was to assess differences in cognitive ability and driving simulator performance in licensed community-dwelling poststroke drivers and controls. Two groups of licensed drivers (37 poststroke and 43 controls) were assessed using several cognitive tasks and using a driving simulator. The poststroke adults exhibited poorer cognitive ability; however, there were no differences in simulator performance between groups except that the poststroke drivers demonstrated less variability in driver headway. The application of these results as a prescreening toolbox for poststroke drivers is discussed.

1. Introduction

It is well-established that safe driving, as an important activity for daily living, is heavily reliant on functioning cognitive processes [1, 2]. It is also well acknowledged that cognitive processes decline following a stroke and that this may impact on their ability to drive [3]. There is great debate regarding whether poststroke adults are at an increased risk of a crash, with much variation in the results. For example, some research has suggested that poststroke drivers are up to three times more likely to crash [4], whereas others have suggested there is no association with increased crash risk [5]. With this uncertainty and the knowledge that this population will only increase [6], knowing the extent of cognitive decline and the safe limit required in order to return to driving on the road is essential.

It has been estimated that between 30% and 50% of poststroke adults will return to driving [7, 8]. Currently, the Australian process for returning to driving after a stroke (using a private vehicle license) requires the affected person to wait a minimum of two weeks for a transient ischemic attack and four weeks for a fully ischemic stroke or haemorrhagic stroke [9]. All poststroke adults must also inform the relevant state transport-licensing authority of their stroke and obtain medical clearance prior to driving [9]. Only a medical professional (usually a general practitioner) can advise whether a person is safe to drive, and if the respective medical professional believes it is necessary, the poststroke adult may be required to attend a driving assessment or further driver training before returning to the road [9]. Ideally, poststroke adults with questionable driving capability should undertake a two-stage assessment process that involves a neurological examination and an on-road observation; however, limited guidelines are available to help doctors determine fitness-to-drive [10]. Although on-road driving tests remain the "gold standard" for driving assessments, they are arguably subjective, highly stressful, costly, and time consuming [11, 12], as well as carry inherent risks to safety [13]. Therefore, using off-road techniques to give an accurate estimate of the stage of recovery, as well as provide reliable information for targeted driver rehabilitation, is required. Neuropsychological assessments have regularly been implemented to assess cognition, and there is a strong correlation between the results and the client's driving performance; however, cognitive ability should be assessed alongside actual driving behaviour, rather than in isolation [3].

Driving simulation is one of the most heavily utilised alternative measures of driving performance [14]. This is due to its ability to reliably measure driving performance, whilst also ensuring driver safety and eliminating difficult to control extraneous variables, such as traffic density and weather conditions [11, 14]. The limited research using driving simulators to assess driving performance in a poststroke population has found varying results. Some studies have reported that poststroke adults performed significantly worse in a driving simulator assessment, having exhibited more errors when compared to controls [15–17]. Others have reported that although poststroke drivers exhibit difficulty with secondary tasks, such as listening span tasks whilst driving, there were no differences in actual driving performance variables [18]. Part of the reason for the discrepancy and subsequent predictive value of previous simulator-based research may be due to the fact that the majority of simulated driving research has focused on unlicensed poststroke drivers. It stands to reason that in order to determine whether simulators and cognitive assessments can accurately assess driving performance, the baseline should be set by those who are already licensed to drive. Therefore, the aim of this study was to assess differences in driving simulator performance in licensed community-dwelling poststroke drivers and controls, as well as to assess whether differences in cognition account for differences in driving performance.

2. Method

2.1. Design. A quasi-experimental comparison group design, involving a group of licensed poststroke drivers and a control group of licensed drivers of similar ages and of the same gender, was utilised to perform the assessments.

2.2. Participants. The inclusion criteria for study participation were that all participants held a driving license valid within Australia, had at least one year of overall driving experience, drove at least twice a week, and had access to a fully insured vehicle. Further criteria for the poststroke group were that they had previously been diagnosed with a stroke (either ischemic or haemorrhagic) and had obtained medical clearance to drive. Poststroke participants self-reported their condition; however, where possible, participants were asked to bring in any medical documents relating to their stroke, for demographic verification purposes. Participants were excluded if they had been diagnosed with any neurodegenerative disease, such as Parkinson's disease or dementia, or if they required a wheelchair for mobility. Some poststroke participants had hemiparesis and used assistive equipment whilst driving (e.g., a steering knob, modified pedals, or foot brace); however, as all participants were community dwelling and were driving their own vehicles, they were considered a level two or below on the modified Rankin Scale [19, 20]. Participants were recruited using purposive sampling techniques, including speaking at and recruiting from local community groups and poststroke support groups, as well as advertising in community newspapers and on local radio stations. The recruitment and assessment of participants took place between April 2015 and February 2016.

The total sample consisted of 80 participants including 37 poststroke drivers (male = 30) and 43 controls (male = 35). The mean age of the poststroke group was 65 years (SD = 9) and the ages ranged from 37–81 years. The mean age of the control group was slightly older at 66 years (SD = 7), and ages ranged from 49–81 years; however, the age difference between groups was not significant, $t = -0.61$, $df = 81$, and $p < 0.05$. Driving exposure data were collected from each participant as an estimate of their annual millage in kilometres (km). The poststroke group reported a mean of 15,529 km (SD = 12,440), whereas the controls reported 15,341 km per year (SD = 8066) and the difference was nonsignificant $t = 0.78$, $df = 70$, and $p < 0.05$. The license length of the poststroke group was slightly shorter than that of the control group with means of 47 years, (SD = 8) and 49 years (SD = 8), respectively, with the difference again nonsignificant, $t = -0.86$, $df = 78$, and $p < 0.05$. As there were no significant differences found for these variables, based on previously researched driving criteria, the participants were considered well matched at group level [21].

2.3. Measures

2.3.1. Driving Simulator. The driving simulator based at the Curtin University School of Occupational Therapy and Social Work is a fixed-base car driving simulator that has midlevel physical fidelity and consists of a driving console with three ASUS (24″ 16 : 9 ratio) display screens, onto which the forward facing and peripheral driving scenes are displayed (Figure 1). For consistency, the simulator was configured to use automatic transmission for all participants. A steering knob was installed onto the steering wheel if required by the participant, and the acceleration pedal could be configured as either the left side pedal or right side pedal. This was implemented in order to best simulate any vehicle modifications found in the participant's own vehicle.

Driving scenarios were programmed using the STISIM© driving software [22]. A practice scenario that lasted approximately 10 minutes and included a 60 km per hour dual-lane road was utilised for each participant, in order to familiarise them with the controls and visual stimuli. The experimental scenarios consisted of a lead-car scenario and an emergency stop scenario, which both contained 60 km per hour roads

Figure 1: The Curtin University STISIM driving simulator.

along a two-lane suburban road and a four-lane suburban road, respectively. The lead-car scenario required participants to follow a lead-car for the duration of the scenario, and their main task was to maintain a safe, consistent distance between themselves and the car in front. The emergency stop scenario required participants to apply the brake as soon as a stop sign appeared and their time to react was recorded. Due to the limited time availability of enrolled participants (5 participants including 4 controls and 1 poststroke driver) or the onset of simulator sickness (22 participants including 11 controls and 11 poststroke drivers), 27 participants did not complete the emergency stop scenario. A further 5 participants (3 controls and 2 poststroke drivers) failed to stop within the allotted time for the emergency stop task; therefore, no reaction time data were recorded for these participants and the total number of responses recorded for the emergency stop scenario was 48.

2.3.2. Cognitive Measures. A series of cognitive measures were utilised to assess different aspects of cognition: psychomotor processing, attention, executive function, propensity for risk taking, spatial cognition, and visuospatial function.

(1) Psychomotor Processing. Following criteria and procedures previously implemented in similar cognitive research [23, 24], the participants completed a simple reaction time task (SRT), a two-choice reaction time task (2CRT), and a four-choice reaction time task (4CRT). On all tasks, the participants were instructed to answer both as quickly and as accurately as possible. Hit, miss, and false alarms (where appropriate) were recorded. In order to account for response bias, all response data reported were adjusted for hit rate. Baseline reaction time was measured using the SRT. Participants were presented with the letter X in the middle of the display and told to press the space bar as soon as the X appeared. For the 2CRT and 4CRT, participants were instructed to press the specified key corresponding to where the circle spatially appeared on the screen. All targets were presented randomly. A higher rate of accuracy and lower reaction times were indicators of increased performance.

(2) Attention and Executive Function. There were two types of attention measured as part of this study: selective attention and divided attention. Both were measured using the Useful Field of View© (UFOV) task. The Useful Field of View task was developed as a means of measuring visual, selective, and divided attentions [25] and has been regularly implemented in poststroke driving research [26, 27]. Shorter processing speeds for accurate answers were indicative of greater performance.

A second selective attention task, utilised in previous driving research [24], was administered to assess raw individual reaction times to visual search stimuli. Using E-Prime 2.0 [28], participants were presented with a 6×6 rectangular arrangement of multiple letter O's and told to look for the embedded target letter (Q) amongst them. The instructions were, after each display, to press the corresponding key (X for yes, M for no) on the keyboard to determine the presence of a Q as quickly and accurately as possible. Throughout the 64 experimental trials, the number of yes and no answers was equally distributed; however, the sequence was randomised for each participant. Shorter reaction times for accurate answers were indicative of greater performance.

Executive function was assessed using the Delis-Kaplan Trail Making Task© (DKEFS; [29]). The task included 5 individual component tasks that assessed different levels of cognition. Task 1 was a visual cancellation task and tasks 2, 3, and 5 comprised several connect the circle tasks, which were used to provide a baseline performance score of key components of cognition used within executive function, specifically, visual scanning, number sequencing, letter sequencing, and motor speed, respectively [30]. Task 4 was a number-letter switching task, which was used to asses executive function, specifically through assessing visuospatial thought flexibility [30]. Each task was paper-based and participants were timed to completion. The total time taken for each task was recorded and in order to control for the baseline functions represented in trail tasks 1–3, and 5, contrast scores were calculated [29]. The raw time-to-completion scores were scaled in order to account for age effects [29]. Higher scaled scores were indicative of greater performance. The tests have previously been used to assess cognitive performance in poststroke adults and found to be sensitive to cognitive decline, particularly in frontal lobe function [31, 32].

(3) Propensity for Risk. The Balloon Analogue Risk Task (BART; [33]) was used to measure propensity for risk-taking and aversive behaviour. The objective of the task was to pump up the balloon displayed on screen and collect the most points without allowing the balloon to burst. The number of pumps required for the balloon to burst was randomised and ranged between 1 and 128 pumps, which is the standard for the BART [33]. Participants with lower scores and fewer burst balloons were considered to be risk aversive, whereas participants with higher scores and more burst balloons had a greater propensity for risk. The BART was administered using E-Prime v 2.0 Software and the number of balloons saved, as well as the adjusted average number of pumps for each balloon recorded.

(4) Spatial Cognition and Visuospatial Function. Poststroke adults often experience deficits in visuospatial function [34, 35]; therefore, to test this, the Block Design task (a subtask of the Wechsler Adult Intelligence Scale) was used to measure nonverbal visuospatial reasoning [36]. The test

involved constructing a specified design made out of a series of cuboid blocks as quickly and as accurately as possible. The design increased in difficulty with each alteration and the time limit allowed was extended to correspond with the increased difficulty. Participants were scored depending on the number of designs completed within each allocated time. A time bonus was added depending on the time taken to complete each design. The task was discontinued once the participant had failed to complete two consecutive designs within time. Higher scores were indicative of greater performance.

Spatial cognition, perception, and orientation ability were measured using the Benton Judgement of Line Orientation task [37]. The test consisted of a series of reference lines arranged in a semicircle, from which participants had to identify specified target lines. The rotation and angle alteration of the target lines increased the difficulty of the task as the test progressed. The amount of correctly identified lines was recorded. Higher scores were indicative of greater performance.

2.4. Data Collection and Procedure. Participants were provided with a participant information sheet and screened for minimum visual acuity using the revised charts 1–3 from the 2000 ETDRS visual acuity chart [38]. All participants displayed visual acuity greater than or equal to 20/40, which is the minimum level to legally drive in Western Australia. This screening was implemented to control for any confounding influence of poor visual acuity in the cognitive and driving simulation scenarios. Participants completed the cognitive tasks before completing the tasks in the simulator, and the order of completion for the cognitive tasks was randomised for each participant using the Latin square method [39]. Overall, the process lasted approximately 1½ hours.

2.5. Data Analysis and Processing. Performance in the simulator was assessed by calculating the moment-to-moment instability of each driving-dependent variable (headway, speed, lateral lane position, and steering input), with the measures of central tendency used to report braking reaction time. Finally, the cumulative number of speed exceedances and the cumulative number of crashes in the follow-car scenario were calculated. Reaction time in the simulator was assessed using two variables: braking reaction time and braking stopping time. Braking reaction time was defined as the time it took for the participant to react to the stop sign, and the braking stopping time was the total amount of time taken for the car to come to a complete stop following the stop sign. Following previously implemented driving simulator research [24], analysis consisted of performing a standard error regression with each driving variable (headway, speed, lateral lane position, and steering input), listed as the dependent variable and the time recorded in 0.5 second increments as the independent variable. This technique was used to provide a collated moment-to-moment measure of instability consisting of residuals for the target driving variable [40]. The process of calculating the residual data to be used as a dependent variable in the final analysis was conducted using a Microsoft Excel-based macro, programmed using Visual Basic for Applications [41].

2.6. Statistical Analysis. Normality of all variables was assessed using a histogram, box-plots, and Q-Q plots, as well as measures of skewness and kurtosis. A Box-Cox transformation was conducted on the UFOV data, DKEFS data, visual search data, reaction time task data, and headway calculation to improve normality. Between-group differences in simulator performance and cognitive performance were assessed using independent sample t-tests. Following transformation, analysis of non-normally distributed data between groups was performed using a Mann–Whitney U test.

For the cognitive variables and driving simulator performance variables, with 37 and 43 participants in the respective groups, there was 80% power to detect an effect size of 0.64 between the poststroke drivers and controls [42]. For the braking reaction time task, due to significant drop out, there were 22 participants in the smallest group and the standardised difference value dropped. Therefore, there was 80% power to detect an effect size of 0.82. A p value of <0.05 was taken to indicate a statistically significant association in all tests.

2.7. Ethical Considerations. This research and the associated study protocols were approved by the Curtin University Human Research Ethics Committee—approval number HR206-2014 and conformed to the principles of the Declaration of Helsinki. Participants were presented with an information sheet and given the opportunity to ask questions, and each provided signed informed consent prior to participation. Participants were also informed that they could leave the study at any time without incurring any negative consequences. Participants were offered a gift voucher worth $15 (Australian) as compensation for their time and participation.

3. Results

3.1. Differences in Simulator. Overall, the poststroke drivers displayed greater variability in speed, lateral lane position, and steering input, suggesting that the poststroke drivers varied their speed more often, varied their position on the road, and moved the steering wheel more than the control group; however, these results were nonsignificant at group level (Table 1). Interestingly, although the poststroke drivers were on average, quicker to respond to the braking task, they took longer to fully stop the car (Figure 2); although again, this result was nonsignificant at group level (Table 1). The main significant difference between the groups was that the poststroke group displayed less variability in headway (Table 1) suggesting that the poststroke drivers' headway was more consistent than the control group.

There was also no between-groups difference reported for cumulative number of crashes, as there were zero crashes reported. The speed exceedances were grouped into 6 proportionally distributed categories using the binning function in SPSS. The number of speed exceedances recorded was relatively evenly distributed across both groups although the largest differences appeared to be that 40% of poststroke drivers were recorded as having committed ≤4 speed exceedances compared to 21% of the control group, and 10% of the poststroke drivers recorded ≥12 speed exceedances

Table 1: The between-group differences in simulator performance.

Variables	Poststroke driver n	Mean	SD	Controls n	Mean	SD	t value	df	p value
Headway	37	3.26	1.87	43	1.71	1.36	−2.20	48.58	0.03*
Lateral lane position	37	0.73	0.39	43	0.64	0.35	1.18	78	0.24
Speed	37	8.83	1.75	43	8.41	1.14	1.29	78	0.20
Steering input	37	1.48	1.06	43	1.13	0.66	1.80	78	0.13
Braking reaction time	22	1.07	0.31	26	1.08	0.27	−0.19	46	0.85
Braking stopping time	22	6.32	11.03	26	3.98	1.35	1.07	46	0.29

*p value < 0.05.

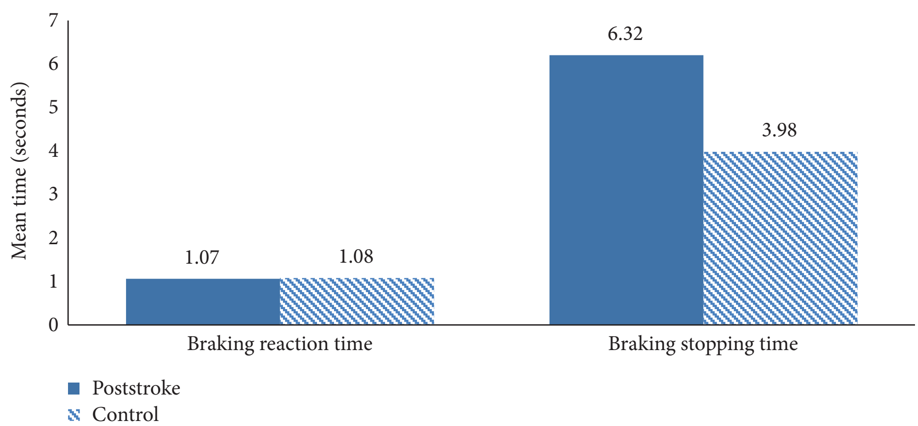

Figure 2: The mean braking reaction time and stopping time in seconds for the poststroke and control groups.

compared to 19% of the control groups (Figure 3). However, overall, there was no significant difference in speed exceedances between groups $X^2 = 4.76$, df = 5, and $p > 0.05$.

3.2. Differences in Cognition. There were significant between-groups differences in several of the cognitive variables: BART, visual search, D-KEFS—Number Letter Switching, and UFOV (Tables 2 and 3). The poststroke drivers saved more balloons in the BART and also had a lower average amount of pumps per balloon, both of which indicate a greater tendency for risk averseness than those in the control group. In the UFOV divided attention task, UFOV selective attention task, and visual search tasks, the poststroke drivers had significantly longer reaction times, all of which indicated poor performance. There were no statistically significant differences between groups for any of the following measures: BJLOT, block design, UFOV 1, or any of the psychomotor tasks.

4. Discussion

4.1. Summary of Findings. As mentioned in the introduction, full driving assessments, i.e., including an on-road component, are both time consuming and costly [11, 12] and constitute a real risk to both the candidate and the assessor [13]. Furthermore, they inherently comprise an uncontrollable component as other road users' actions and interactions cannot be controlled [14, 43]. Hence, if there was a safe way to assess poststroke drivers prior to returning to drive, it would not only save time and money but it would actually increase road safety. The only problem with this is knowing what to assess and how to make those assessments relevant to the fact that potential poststroke drivers will predominantly be older. In the present study, a combination of driving simulator scenarios and psychometric tests was implemented in order to assist with that decision; the idea being that an actual poststroke driving profile would provide support for determining where they would differ from the nonaffected older driver.

Whilst most simulator driving variables did not differ between the two groups, as was expected, given that all participants were licensed drivers, of greater concern was the finding that the older adults in the control group varied their headway more than the poststroke adults. This was an unexpected finding, albeit consistent with the simultaneous finding that on-average, poststroke drivers were more risk aversive than controls. Headway is a known predictor of safe driving and has been established as a valuable assessment in simulator research [44]; therefore, this finding is also quite challenging given that the present study aimed to identify poststroke-specific indicators that could assist driving assessments by allied health professionals. The fact that the control group performed better in several of the cognitive tasks yet displayed more variable headway appears counterintuitive; however, when taken with the result that the poststroke drivers were more risk aversive, this may suggest that the less

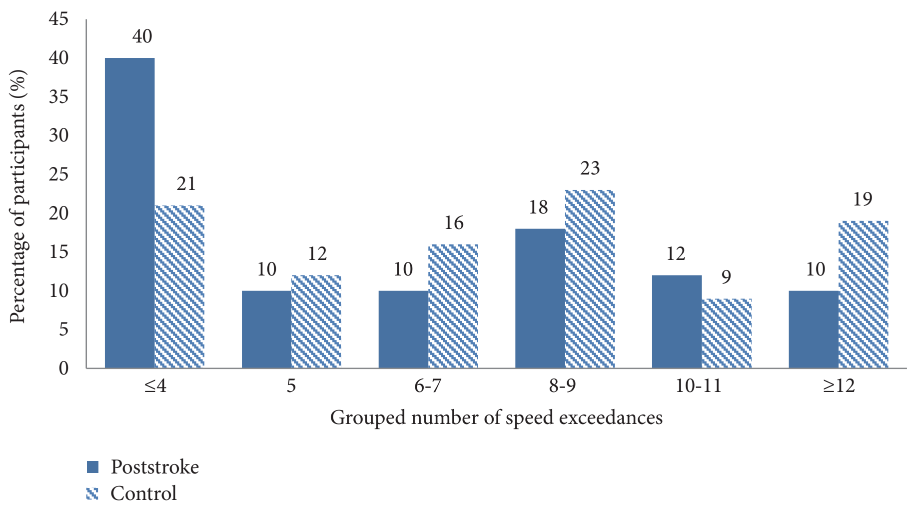

Figure 3: The grouped number of speed exceedances in the poststroke and control groups.

Table 2: The between-group analysis of significant cognitive variables.

Variables	Poststroke driver n	Poststroke driver Mean	Poststroke driver SD	Controls n	Controls Mean	Controls SD	t value	df	p value
BART average number of pumps per balloon	37	25.16	3.32	43	27.49	17.78	2.46	78	0.02*
BART average saved balloons	37	20.15	10.18	43	22.90	4.71	−2.31	68.51	0.02*
BJLOT	36	24.64	5.07	43	25.44	9.93	−0.78	65.33	0.44
Block design	37	37.60	10.50	43	40.40	10.22	−1.21	78	0.23
SRT (milliseconds)	34	375.59	161.35	43	244.19	78.05	1.12	78	0.27
2CRT (milliseconds)	34	97.99	172.91	43	50.58	88.64	1.46	46.56	0.15
4CRT (milliseconds)	34	427.62	258.67	43	333.33	255.92	1.60	75	0.11
Visual attention (simple visual search task)	34	693.99	422.08	43	494.11	150.97	2.89	39.70	0.01*
UFOV divided attention	35	82.89	112.33	42	36.29	38.84	2.52	40.78	0.02*
UFOV selective attention	35	144.31	110.33	41	90.13	50.70	2.82	46.09	0.01*
	n	Median	Mean	IQR	n	Median	Mean	IQR	p value
UFOV processing speed	35	13.8	19.31	0.10	42	13.8	14.53	0.10	0.82

*Significant data; p value < 0.05.

headway variation in the poststroke group is due to the licensed drivers' awareness of their limitations and amending their driving as a result of executive function deficits. Although further exploration of this relationship is beyond the scope of the present study, more research is planned to investigate this, specifically, whether poststroke awareness of cognitive deficits is associated with amended driving behaviour.

In many of the cognitive tests, the poststroke drivers were found to have poorer scores than their control group counterparts. These findings corroborate previous research, suggesting that a mixture of off-road neuropsychological tasks, as well as using a driving simulator, may be beneficial in establishing who is safe to drive, prior to undertaking an on-road assessment [45]. Specifically, this study suggests that a battery of tasks assessing attention, baseline cognition, executive functions, and propensity for risk (i.e., the UFOV, the D-KEFS TMT, and the BART) may be a useful screening tool for poststroke drivers, prior to undertaking a full on-road driving assessment. Furthermore, these tasks may also provide a baseline for assistive poststroke driver training. The final finding of the current study is that the following tests did not contribute to the pre-on-road screening; psychomotor processing ability (SRT, 2CRT, and 4CRT); spatial cognition, perception, and orientation ability (BJLOT); and visuospatial function (Block Design). This suggests that although poststroke drivers may be lacking in these cognitive skills, ultimately, these deficits may not affect their ability to drive and therefore using the respective assessments as a pre-screening for driving ability is unnecessary.

4.2. Limitations. As with all simulator research, there is much debate on the use of driving simulators for driving assessments [14]. This study aimed to emulate driving on-road in a safe, replicable environment for the purpose of establishing baseline driving performance in licensed drivers; therefore, a

Table 3: The between-group analysis of D-KEFS TMT variables.

Variables	Poststroke driver n	Mean	SD	Controls n	Mean	SD	t value	df	p value
Visual scanning (D-KEFS TMT 1)	37	7.38	3.62	43	10.90	2.17	−5.19	57.06	0.001**
Numerical sequencing and visual attention (D-KEFS TMT 2)	37	9.08	3.75	43	11.47	3.01	−3.16	78	0.003*
Letter sequencing, visual attention, and visuomotor abilities (D-KEFS TMT 3)	37	8.51	4.07	43	11.72	2.57	−4.14	58.97	0.001**
Cognitive flexibility and executive function (D-KEFS TMT 4)	37	8.27	4.43	43	11.65	2.35	−4.16	52.86	0.001**
Motor and processing speed (D-KEFS TMT 5)	37	9.68	2.92	43	12.02	1.71	−4.30	56.26	0.001**
Combined number sequencing and letter sequencing (D-KEFS TMT 2 + TMT 3)	37	9.12	4.02	43	12.35	2.89	−4.04	64.29	0.001**
	n	Median	Mean	IQR	n	Median	Mean	IQR	p value
D-KEFS cognitive flexibility and executive function contrast score (D-KEFS TMT 4–2 & 3)	37	1.00	2.92	4.50	43	1.00	1.67	0.00	0.02*

*p value < 0.05. **p value < 0.001.

simulator was used, which has previously been validated for on-road driving performance [46]. Similarly, although on-road driving performance was not the focus of the study, the participants sampled were those who were licensed drivers. This was in order to ensure that all participants were of a sufficient standard to drive, facilitating generalisation to on-road driving capability. Despite the driving simulator being validated, it should also be noted that participants spent a relatively short amount of time in the driving simulator, which can limit the representativeness of the results [43]. This was partly due to the measurements being assessed and partly to minimise the effects of simulator sickness [43]. As part of this research, the majority of participants attempted all scenarios; however, there was a relatively small attrition rate for the emergency stop task as many of the participants developed simulator sickness and the assessment was halted. There was also a small number of participants who did not have data recorded for some cognitive assessments, due to a mixture of logging errors, participant choice, or restraints on the participant's time. Due to this attrition rate and the initial relatively small sample size, there were fewer participants with recorded data, which increases the potential for a type II error; therefore, the results should be interpreted with caution and further research with a larger sample is required for verification.

5. Conclusion

Although poststroke adults have decreased cognitive ability, they can perform at a similar level in a driving simulator to licensed controls. As this research was conducted on licensed drivers, it presents a baseline indication for the use of off-road and simulator assessments as predictive tools. Specifically, the study suggests that driving simulators and those tasks assessing performance in propensity for risk, executive function, selective attention, and divided attention may be useful for future researchers and clinicians as assessment, rehabilitation, and training tools for nonlicensed poststroke adults who wish to return to driving.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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References

[1] K. J. Anstey, J. Wood, S. Lord, and J. G. Walker, "Cognitive, sensory and physical factors enabling driving safety in older adults," *Clinical Psychology Review*, vol. 25, no. 1, pp. 45–65, 2005.

[2] J. A. Groeger, *Understanding Driving: Applying Cognitive Psychology to a Complex Everyday Task*, Psychology Press, Hove, East Sussex, UK, 2000.

[3] S. C. Marshall, F. Molnar, M. Man-Son-Hing et al., "Predictors of driving ability following stroke: a systematic review," *Topics in Stroke Rehabilitation*, vol. 14, no. 1, pp. 98–114, 2007.

[4] M.-J. Perrier, N. Korner-Bitensky, A. Petzold, and N. Mayo, "The risk of motor vehicle crashes and traffic citations post stroke: a structured review," *Topics in Stroke Rehabilitation*, vol. 17, no. 3, pp. 191–196, 2010.

[5] J. K. Haselkorn, B. A. Mueller, and F. A. Rivara, "Characteristics of drivers and driving record after traumatic and nontraumatic

brain injury," *Archives of Physical Medicine and Rehabilitation*, vol. 79, no. 7, pp. 738–742, 1998.

[6] K. Strong, C. Mathers, and R. Bonita, "Preventing stroke: saving lives around the world," *The Lancet Neurology*, vol. 6, no. 2, pp. 182–187, 2007.

[7] G. D. Fisk, C. Owsley, and L. V. Pulley, "Driving after stroke: driving exposure, advice, and evaluations," *Archives of Physical Medicine and Rehabilitation*, vol. 78, no. 12, pp. 1338–1345, 1997.

[8] R. C. Bryer, L. J. Rapport, and R. A. Hanks, "Chapter 7 - determining fitness to drive: neuropsychological and psychological considerations A2 - Pellerito, Joseph Michael," in *Driver Rehabilitation and Community Mobility*, pp. 165–184, Mosby, Saint Louis, 2006.

[9] Austroads and National Transport Commision Australia, *Assessing Fitness to Drive for Commercial and Private Vehicle Drivers: Medical Standards for Licensing and Clinical Management Guidelines*, Austroads, Sydney, NSW, Australia, 2016.

[10] M. Murie-Fernandez, S. Iturralde, M. Cenoz, M. Casado, and R. Teasell, "Driving ability after a stroke: evaluation and recovery," *Neurología (English Edition)*, vol. 29, no. 3, pp. 161–167, 2014.

[11] H. C. Lee, D. Cameron, and A. H. Lee, "Assessing the driving performance of older adult drivers: on-road versus simulated driving," *Accident Analysis & Prevention*, vol. 35, no. 5, pp. 797–803, 2003.

[12] H. C. Lee and A. H. Lee, "Identifying older drivers at risk of traffic violations by using a driving simulator: a 3-year longitudinal study," *The American Journal of Occupational Therapy*, vol. 59, no. 1, pp. 97–100, 2005.

[13] T. Galski, H. T. Ehle, M. A. MCdonald, and J. Mackevich, "Evaluating fitness-to-drive after cerebral injury: basic issues and recommendations for medical and legal communities," *The Journal of Head Trauma Rehabilitation*, vol. 15, no. 3, pp. 895–908, 2000.

[14] A. Stedmon, M. Young, and B. Hasseldine, "Keeping it real or faking it: the trials and tribulations of real road studies and simulators in transport research," in *Contemporary Ergonomics 2009: Proceedings of the International Conference on Contemporary Ergonomics 2009*, CRC Press, London, UK, 2009.

[15] M. A. Hird, K. A. Vesely, L. E. Christie et al., "Is it safe to drive after acute mild stroke? A preliminary report," *Journal of the Neurological Sciences*, vol. 354, no. 1, pp. 46–50, 2015.

[16] C. McKay, L. J. Rapport, R. C. Bryer, and J. Casey, "Self-evaluation of driving simulator performance after stroke," *Topics in Stroke Rehabilitation*, vol. 18, no. 5, pp. 549–561, 2011.

[17] S. Kotterba, W. Widdig, S. Brylak, and M. Orth, "Driving after cerebral ischemia—a driving simulator investigation," *Wiener Medizinische Wochenschrift*, vol. 155, no. 15, pp. 348–353, 2005.

[18] A. Lundqvist, B. Gerdle, and J. Ronnberg, "Neuropsychological aspects of driving after a stroke—in the simulator and on the road," *Applied Cognitive Psychology*, vol. 14, no. 2, pp. 135–150, 2000.

[19] J. Rankin, "Cerebral vascular accidents in patients over the age of 60: II. Prognosis," *Scottish Medical Journal*, vol. 2, no. 5, pp. 200–215, 1957.

[20] J. C. van Swieten, P. J. Koudstaal, M. C. Visser, H. J. Schouten, and J. van Gijn, "Interobserver agreement for the assessment of handicap in stroke patients," *Stroke*, vol. 19, no. 5, pp. 604–607, 1988.

[21] L. Evans, *Traffic Safety*, Science Serving Society, Bloomfield Hills, MA, USA, 2004.

[22] R. W. Allen, C. A. Stein, and B. L. Aponso, "A low cost, part task driving simulator based on microcomputer technology," in *69th Annual Meeting of the Transportation Research Board*, Transportation Research Board: Washington, DC, USA, 1990.

[23] D. Bunce, R. Handley, and S. O. Gaines Jr, "Depression, anxiety, and within-person variability in adults aged 18 to 85 years," *Psychology and Aging*, vol. 23, no. 4, pp. 848–858, 2008.

[24] D. Bunce, M. S. Young, A. Blane, and P. Khugputh, "Age and inconsistency in driving performance," *Accident Analysis & Prevention*, vol. 49, pp. 293–299, 2012.

[25] K. Ball and C. Owsley, "The Useful Field of View test: a new technique for evaluating age-related declines in visual function," *Journal of the American Optometric Association*, vol. 64, no. 1, pp. 71–79, 1993.

[26] G. D. Fisk, C. Owsley, and M. Mennemeier, "Vision, attention, and self-reported driving behaviors in community-dwelling stroke survivors," *Archives of Physical Medicine and Rehabilitation*, vol. 83, no. 4, pp. 469–477, 2002.

[27] S. George and M. Crotty, "Establishing criterion validity of the Useful Field of View assessment and stroke drivers' screening assessment: comparison to the result of on-road assessment," *American Journal of Occupational Therapy*, vol. 64, no. 1, pp. 114–122, 2010.

[28] W. Schneider, A. Eschman, and A. Zuccolotto, *E-Prime 2.0*, Psychology Software Tools, Inc., Pittsburgh, 2012.

[29] D. C. Delis, E. Kaplan, and J. H. Kramer, *Delis-Kaplan Executive Function System (D-KEFS) Examiner's Manual*, The Psychological Corporation, San Antonio, TX, USA, 2001.

[30] J. Swanson, "The Delis-Kaplan Executive Function System: a review," *Canadian Journal of School Psychology*, vol. 20, no. 1/2, pp. 117–128, 2005.

[31] S. Homack, D. Lee, and C. A. Riccio, "Test review: Delis-Kaplan Executive Function System," *Journal of Clinical and Experimental Neuropsychology*, vol. 27, no. 5, pp. 599–609, 2005.

[32] T. J. Wolf and M. C. Rognstad, "Changes in cognition following mild stroke," *Neuropsychological Rehabilitation*, vol. 23, no. 2, pp. 256–266, 2013.

[33] C. Lejuez, J. P. Read, C. W. Kahler et al., "Evaluation of a behavioral measure of risk taking: the Balloon Analogue Risk Task (BART)," *Journal of Experimental Psychology: Applied*, vol. 8, no. 2, pp. 75–84, 2002.

[34] J. Kaplan and D. B. Hier, "Visuospatial deficits after right hemisphere stroke," *American Journal of Occupational Therapy*, vol. 36, no. 5, pp. 314–321, 1982.

[35] S. Stone, B. Wilson, A. Wroot et al., "The assessment of visuo-spatial neglect after acute stroke," *Journal of Neurology, Neurosurgery & Psychiatry*, vol. 54, no. 4, pp. 345–350, 1991.

[36] D. Wechsler, *Wechsler Adult Intelligence Scale–Fourth Edition (WAIS–IV)*, NCS Pearson, San Antonio, TX, 2008.

[37] A. L. Benton, K. D. Hamsher, N. R. Varney, and O. Spreen, *Judgment of Line Orientation*, Oxford University Press, New York, USA, 1983.

[38] Precision Vision, *Series Revised ETDRS Charts*.

[39] D. A. Grant, "The Latin square principle in the design and analysis of psychological experiments," *Psychological Bulletin*, vol. 45, no. 5, pp. 427–442, 1948.

[40] J. R. Bloomfield and S. A. Carroll, "New measures of driving performance," in *Contemporary Ergonomics*, S. A. Robertson, Ed., pp. 335–340, Taylor & Francis, London, UK, 1996.

[41] Microsoft Office, *Visual Basic for Applications*, 2010.

[42] J. Cohen, *Statistical Power Analysis for the Behavioral Sciences*, L. Erlbaum Associates, Hillsdale, N.J, USA, 1988.

[43] O. Carsten and A. H. Jamson, "Driving simulators as research tools in traffic psychology," in *Handbook of Traffic Psychology*, B. E. C. Porter, Ed., pp. 87–96, Elsevier Science, Burlington, 2011.

[44] K. Vogel, "A comparison of headway and time to collision as safety indicators," *Accident Analysis & Prevention*, vol. 35, no. 3, pp. 427–433, 2003.

[45] H. L. Lew, J. H. Poole, E. H. Lee, D. L. Jaffe, H. C. Huang, and E. Brodd, "Predictive validity of driving-simulator assessments following traumatic brain injury: a preliminary study," *Brain Injury*, vol. 19, no. 3, pp. 177–188, 2005.

[46] H. C. Lee, A. H. Lee, and D. Cameron, "Validation of a driving simulator by measuring the visual attention skill of older adult drivers," *The American Journal of Occupational Therapy*, vol. 57, no. 3, pp. 324–328, 2003.

Appendix 14: Eye-Tracking Coding Matrix

Code	Description
*	**Area / Object**
***11**	**The Road**
110	Ahead Left Lane (same direction)
111	Ahead Right Lane (opposing direction)
112	Straight ahead (middle of roadway / roadway horizon)
113	Road bump
114	Road behind driver's car
115	Road to the left of driver's car
116	Road to the right of driver's car
117	Upcoming intersection
***12**	**Pavement / Footpath / Cycleways**
120	Pavement to the left
121	Pavement to the right
122	Pavement in front
123	Cycleway to the left
124	Cycleway to the right
125	Cycleway infront
126	Pedestrian using pathway on the left
127	Pedestrian using pathway on the right
128	Pedestrian using pathwway in front
129	Cyclist using cycleway to the left
1290	Cyclist using cycleway to the right
***13**	**Pedestrian crossing**
130	Entrance / Exit Pedestrian Crossing Left
131	Entrance / Exit Pedestrian Crossing Right
132	Middle of crossing / crossing markings painted on-road
133	Pedestrian using crossing
***14**	**T-junction/Intersection**
140	Intersection entrance / exit left
141	Intersection entrance / exit right
142	Intersection entrance / exit straight ahead
143	Oncoming vehicle on right side
144	Oncoming vehicle on left side
145	Oncoming vehicle opposite coming straight ahead
146	Oncoming vehicle turning left into junction
147	Oncoming vehicle turning right into junction
148	Vehicle ahead of driver in intersection
***15**	**Roundabout**
150	Roundabout left entrance / exit
151	Roundabout right entrance / exit
152	Roundabout opposite entrance / exit
153	Oncoming vehicle from left side
154	Oncoming vehicle right side
155	Oncoming vehicle opposite side
156	Vehicle ahead of driver in intersection
157	Roundabout Island
***16**	**Refuge Islands**
160	Traffic refuge, island
161	Median strip

162	Pedestrian using median strip or refuge island
***17**	**Inside the car / mirrors / wipers**
170	Middle rear view mirror
171	Left rear view mirror
172	Right rear view mirror
173	Spedometer
174	Inside car / vehicle controls
***18**	**Other road users**
180	Vehicle in front of user same direction
181	Vehicle in front of user - opposite direction
182	Vehicle at the left side of the user
183	Vehicle at the right side of the user
184	Vehicle behind user
185	Vehicle entering road from the left
186	Vehicle entering road from the right
187	Pedestrian on -road / jay walking
***19**	**Lines and markings**
190	Roadway dividing line
191	Edge Line
192	Stop line
193	Give way line
194	Pedestrian crossing line (zig zag line / zebra crossing etc.)
195	Arrow / direction line
***20**	**Signs information**
200	Signage
201	Bus stop
202	Advertisment boards
203	Pole
***21**	**Traffic Light Intersection**
210	Traffic light
211	Roadway in middle of traffic light interseciotn
212	Opposing traffic to the right of traffic light intersection
***22**	**Parking area**
220	Vehicle parked right side
221	Vehicle parked left side
222	Car park
***23**	**Horizon / Sky**
230	Horizon
***24**	**Landscape**
240	Grass area
241	Trees
***25**	**Buildings on the side of the road**
250	Building
251	Curtin Bus station
***26**	**Other**
261	Other - Alison to check

Note : Blue Text is traffic relevance

Red Text is non traffic relevance