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

Alison Louise Blane

This thesis is presented for the Degree of
Doctor of Philosophy
of
Curtin University

March 2017
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
Acknowledgements

Firstly, I wish to acknowledge the participants who gave up their time to help and whose survival stories continually inspired me throughout the research. Particular thanks must go to the post-stroke support groups of Western Australia, and to Curtin FM for their assistance with recruitment.

I would like to acknowledge my supervisory team: Associate Professor Hoe Lee and Professor Torbjörn Falkmer – thank you both for your continual support, guidance, and patience. I know Hoe is listed as the primary supervisor however, I have often felt that throughout the process I have really had two primary supervisors, as you have both provided me with guidance and support whenever I needed it. Also, thank you Torbjörn for giving me the opportunity to study in Sweden, for your multiple proof readings and for our many, often humorous discussions regarding correct grammar. Professor Jonathan Foster – thank you for your guidance and consultation for the psychological elements of the project, particularly in the formative stages. Also your assistance with improving my scientific public-speaking was very useful and will no doubt help me for years to come. Dr Tania Dukic Willstrand – words cannot express how grateful I am to you Tania for the help you have given me. The study trip to Sweden to work with you was one of the best parts of my PhD journey and the feedback and guidance you have provided, that have enabled me to drill down to the core elements of the work and think laterally about the concepts was completely invaluable. Furthermore, I have appreciated your extreme generosity with your time and your ability to provide perspective and that even at its completion, my educational journey has not ended. As you say, the PhD is just the start - a stepping stone. I truly believe that your coming on board with my project has changed it for the better so thank you. Associate Professor Angela Fielding – it seems strange to me when my PhD friends tell me that they have no communication with their chairperson, as you have been so friendly and provided me with so much extra support that I did not even realise I needed to cope with the transition from Public Health and to then flourish within the school of Occupational Therapy and Social Work. You made yourself available for discussions when I’ve had
issues with the project, provided sage advice, as well as being my cheer squad at all of my HDR-related presentations and for this, I will always be grateful.

I am also forever indebted to my academic support crew: Melissa Black, Julia Tang, Derserri Chee, Kiah Evans, Marg Pickup, Anneli Shorter, Aimee Richardson and Dr Wee Lih Lee, as well as Associate Professor Marina Ciccarelli and the team from AIM, i.e., Tim Parkin, Gal Rose and Nathan Chapman, without whom recruitment, testing and data analysis would have been completely overwhelming and forever ongoing. Furthermore, to my PhD cohort: Melissa Black, Julia Tang, Melissa Scott, Megan Hatfield, Derserri Chee, Belinda Cuomo and Robyn Earl – thank you girls so much for your support (I’ll be forever grateful for you helping my move house when I broke my foot) and for the last minute proof reading. I’ve been overawed by your support and feel very lucky to have studied with you. I’m very much looking forward to our graduation day, where we can all stand on stage together, looking like Harry Potter, and know we have done it.

I am grateful to Curtin University for providing me with various HDR scholarships that have funded the duration of my studies. I am also grateful to Professor Jaya Earnest for her assistance with my transfer from the School of Public Health and her support in the aftermath.

There are multiple family and friends all around the world who have provided support throughout this project, however it would take too long to name them all, so please know I am grateful to you all and I will mention only a few who have made particular contributions and are not mentioned elsewhere: my family - Mum, Dad, Kieran, Zoe, Stitch, and friends - Anusha Choolun, Aimee Richardson, Catarina Antão, Jen Bowden, Kate Dorozenko, Kelsea Pyke, Marg Pickup, Michelle Broughton, Michelle Fraser, Sunila Peterson and Yvonne Dalton. Personal thanks for counselling support must go to Penny Fox and Leonie Baxter of the Curtin Counselling and Health Services, without whom, I would not have finished.

Finally, a special acknowledgement must go to my partner Patrick Walton, who, as well as providing me with endless physical and emotional support, also assisted greatly with much of the data analysis, exponentially speeding up the process.
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.

To the two strong women who made me feel I could do anything. Although neither of them is still with me, I have carried the memories of my Grandmother Amelia who taught me the value of education and of my Aunt (but really more like an older sister) Vivienne who made me feel I could accomplish anything I set my mind to.

Finally, to my partner in love and in life, Patrick, you have been my rock for so long and always my number one fan, loving me, supporting me and driving me on whenever I doubted myself and wanted to give up. For this I will always be grateful and so I dedicate this to you.
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.
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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
$\chi^2$ – Chi Square
2CRT – Two-Choice Reaction Time Task
4CRT – Four-Choice Reaction Time Task
List of Publications

List of Published Manuscripts


List of Accepted Manuscripts


List of Manuscripts out for Review


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Signature: ____________________________

Date: 14th March 2017
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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Prof Torbjörn Falkmer
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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 driver 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.*

<table>
<thead>
<tr>
<th>Chapter (Paper)</th>
<th>Submission Year</th>
<th>Format</th>
<th>Objectives Assessed</th>
<th>Design</th>
<th>Methodologies</th>
<th>Findings and Implications</th>
</tr>
</thead>
</table>
| 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 are 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 and 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

<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
<th>Citation</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Driving Habit Questionnaire (DHQ)</td>
<td>Driving habits, driving history, demographic data and medical history was collected using the paper-based Driving Habits Questionnaire</td>
<td>Owsley, Stalvey, Wells, and Sloane (1999).</td>
<td>Questionnaire</td>
</tr>
<tr>
<td>Balloon Analogue Risk Taking Task (BART)</td>
<td>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, &amp; Zuccolotto, 2012)</td>
<td>Lejuez et al. (2002)</td>
<td>Cognitive</td>
</tr>
<tr>
<td>Benton Judgement of Line Orientation Task (BJLOT)</td>
<td>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.</td>
<td>Benton, Hamsher, Varney, and Spreen (1983)</td>
<td>Cognitive</td>
</tr>
<tr>
<td>Block Design</td>
<td>A sub-task of the Wechsler Adult Intelligence Scale used to assess non-verbal visuospatial reasoning.</td>
<td>Wechsler (2008)</td>
<td>Cognitive</td>
</tr>
<tr>
<td>Delis-Kaplan Trail-Making Test (DKEFS-TMT)</td>
<td>A paper and pencil based task that assessed various types of baseline cognitive processes as well as higher order executive functioning and cognitive flexibility.</td>
<td>Delis, Kaplan, and Kramer (2001)</td>
<td>Cognitive</td>
</tr>
<tr>
<td>Digit Vigilance Task (DVT)</td>
<td>A paper and pencil based task used to evaluate sustained attention and speed of cognitive processing</td>
<td>Lewis and Rennick (1979)</td>
<td>Cognitive</td>
</tr>
<tr>
<td>Montreal Cognitive Assessment (MoCA)</td>
<td>A 30-item cognitive screening tool that has been validated for measuring mild cognitive impairment in older adults</td>
<td>Nasreddine et al. (2005)</td>
<td>Cognitive</td>
</tr>
<tr>
<td>Psychomotor Performance</td>
<td>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).</td>
<td>Bunce, Handley, and Gaines (2008)</td>
<td>Cognitive</td>
</tr>
</tbody>
</table>
Chapter One: Introduction

<table>
<thead>
<tr>
<th>Road Sign Recognition Test</th>
<th>A paper-based test requiring the participant to display knowledge of road signs, visual recognition, memory, and problem solving abilities.</th>
<th>Lincoln and Fanthome (1994)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Useful Field of View (UFOV)</td>
<td>The Useful Field of View© (UFOV) is a computer based task that was developed as means of measuring visual, selective and divided attention</td>
<td>Ball, Owsley, Sloane, Roenker, and Bruni (1993)</td>
</tr>
<tr>
<td>STISIM Driving Simulator</td>
<td>A fixed-base car driving simulator programmed using the STISIM© driving software</td>
<td>Allen, Stein, Aponso, Rosenthal, and Hogue (1990)</td>
</tr>
<tr>
<td>On-Road Driving Behaviour Checklist</td>
<td>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.</td>
<td>Chee, Lee, Lee, and Falkmer (2013)</td>
</tr>
</tbody>
</table>
| 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).
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 possibility 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).
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.
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...
Chapter One: Introduction

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.
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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 Commission 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)

<table>
<thead>
<tr>
<th>Group</th>
<th>Gender</th>
<th>Age (years)</th>
<th>Annual Millage (km)</th>
<th>Length of Licence (years)</th>
<th>Time since stroke (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>F</td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
</tr>
<tr>
<td>Post-stroke</td>
<td>40</td>
<td>32</td>
<td>8</td>
<td>65.85</td>
<td>8.94</td>
</tr>
<tr>
<td>Control</td>
<td>45</td>
<td>36</td>
<td>8</td>
<td>66.09</td>
<td>9.73</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Group</th>
<th>AUS</th>
<th>NZ</th>
<th>UK</th>
<th>EU</th>
<th>Africa</th>
<th>Asia</th>
<th>USA/CAN</th>
<th>None</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post-stroke</td>
<td>22</td>
<td>1</td>
<td>9</td>
<td>4</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>40</td>
</tr>
<tr>
<td>Control</td>
<td>21</td>
<td>2</td>
<td>13</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>44</td>
</tr>
<tr>
<td>Total</td>
<td>43</td>
<td>3</td>
<td>22</td>
<td>8</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>84</td>
</tr>
</tbody>
</table>

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*

<table>
<thead>
<tr>
<th>Group</th>
<th>Live alone</th>
<th>Married</th>
<th>De-facto partnership</th>
<th>Separated/Widowed/Divorced</th>
<th>Did not answer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yes</td>
<td>No</td>
<td>Never Married</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post-stroke</td>
<td>11</td>
<td>28</td>
<td>0</td>
<td>27</td>
<td>0</td>
</tr>
<tr>
<td>Control</td>
<td>11</td>
<td>33</td>
<td>1</td>
<td>30</td>
<td>5</td>
</tr>
<tr>
<td>Total</td>
<td>22</td>
<td>61</td>
<td>1</td>
<td>57</td>
<td>5</td>
</tr>
</tbody>
</table>

### Table 6.

*Highest education level achieved for post-stroke drivers and controls*

<table>
<thead>
<tr>
<th>Group</th>
<th>Primary School</th>
<th>Secondary School</th>
<th>TAFE / College Certificate</th>
<th>University Degree</th>
<th>Did not answer</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post-stroke</td>
<td>1</td>
<td>15</td>
<td>13</td>
<td>10</td>
<td>1</td>
<td>40</td>
</tr>
<tr>
<td>Control</td>
<td>0</td>
<td>11</td>
<td>13</td>
<td>20</td>
<td>0</td>
<td>44</td>
</tr>
<tr>
<td>Total</td>
<td>1</td>
<td>26</td>
<td>26</td>
<td>30</td>
<td>1</td>
<td>84</td>
</tr>
</tbody>
</table>
Table 7.

Demographic data for type of stroke and stroke location

<table>
<thead>
<tr>
<th>Stroke Type</th>
<th>Stroke Location</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Left Hemisphere</td>
</tr>
<tr>
<td>Haemorrhagic</td>
<td>4</td>
</tr>
<tr>
<td>Ischemic</td>
<td>10</td>
</tr>
<tr>
<td>Unknown</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td>16</td>
</tr>
</tbody>
</table>

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 assess 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 averse, 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>
<thead>
<tr>
<th>Assessment</th>
<th>Consistency Score</th>
<th>Validity Score</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>BART</td>
<td>Test-retest reliability of between 0.81 and 0.92</td>
<td>Incremental validity score 0.45</td>
<td>Lejuez et al. (2002)</td>
</tr>
<tr>
<td>BJLOT</td>
<td>Test-retest reliability of 0.90</td>
<td>Low to moderate construct validity</td>
<td>Hakamies-Blomqvist, and Almkvist (2003)</td>
</tr>
<tr>
<td>DKEFS TMT</td>
<td>Low to moderate consistency for individual items</td>
<td>Adequate validity for multiple populations, however further study required.</td>
<td>Homack et al. (2005)</td>
</tr>
<tr>
<td>DVT</td>
<td>Test retest reliability of 0.80 – 0.93</td>
<td>Good convergent validity</td>
<td>Kelland and Lewis (1996)</td>
</tr>
<tr>
<td>DHQ</td>
<td>Test retest reliability of sub-scales Dependence - 0.57 Difficulty – 0.87 Adequate validity, however further study required.</td>
<td>Song, Chun, and Chung (2015)</td>
<td></td>
</tr>
<tr>
<td>MoCA</td>
<td>Test-retest reliability of 0.70-0.92 90% - 100% sensitivity 87 – 90% specificity reported</td>
<td>Nasreddine et al. (2005)</td>
<td></td>
</tr>
<tr>
<td>Psychomotor Assessments</td>
<td>No details available but utilised in previous driving research</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RSRT</td>
<td>No details available but previously utilised in driving research</td>
<td></td>
<td></td>
</tr>
<tr>
<td>UFOV</td>
<td>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)</td>
<td>Edwards et al. (2005) (George &amp; Crotty, 2010)</td>
<td></td>
</tr>
</tbody>
</table>
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.

![The Curtin University STISIM Driving Simulator and the SMI head-mounted eye-tracker](image)

**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™ head-mounted monocular eye-tracking glasses (Figure 7 - reft) and the SensoMotoric Instruments™ (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.

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**

*MPS*ometric (*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*

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


*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.

\textit{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.

\textbf{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


http://dx.doi.org/http://dx.doi.org/10.1016/j.aap.2014.01.014

Chapter Two: Research Methodology

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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)


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

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

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 assess 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](image)

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 $t(44) = 0.64, p>0.05, 95\% \text{ CI} [-2.8, 5.42]$. 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 $t(46) = -0.25, p>0.05, 95\% \text{ CI} [-32.99, 25.63]$. 
Table 10.

Demographic information of post-stroke cohort and control groups

<table>
<thead>
<tr>
<th>Variables</th>
<th>Controls (N = 22)</th>
<th>Post-Stroke Driver (N = 24)</th>
<th>Post-Stroke Non-Driver (N = 24)</th>
<th>Statistic Value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
</tr>
<tr>
<td>Age</td>
<td>64.8</td>
<td>6.7</td>
<td>67.8</td>
<td>17.7</td>
<td>68.2</td>
</tr>
<tr>
<td>Licence length in years</td>
<td>45.9</td>
<td>7.1</td>
<td>56.9</td>
<td>9.0</td>
<td>54.6</td>
</tr>
<tr>
<td>Hours of Driving (weekly)</td>
<td>11.1</td>
<td>7.7</td>
<td>9.82</td>
<td>6.1</td>
<td>N/A</td>
</tr>
<tr>
<td>Recovery period (month)</td>
<td>N/A</td>
<td></td>
<td>48.6</td>
<td>52.6</td>
<td>44.9</td>
</tr>
<tr>
<td>Declared stroke to authorities</td>
<td>N/A</td>
<td></td>
<td>Yes = 14 (58%)</td>
<td>No = 10 (42%)</td>
<td>Yes = 14 (58%)</td>
</tr>
<tr>
<td>Received advice on driving</td>
<td>N/A</td>
<td></td>
<td>Yes = 14 (58%)</td>
<td>No = 10 (42%)</td>
<td>Yes = 18 (75%)</td>
</tr>
<tr>
<td>Use of public transport</td>
<td>N/A</td>
<td></td>
<td>Yes = 14 (58%)</td>
<td>No = 10% (42%)</td>
<td>Yes = 12 (50%)</td>
</tr>
<tr>
<td>Availability of help / other drivers</td>
<td>N/A</td>
<td></td>
<td>Friends = 22 (92%)</td>
<td>Family = 2 (8%)</td>
<td>Friends = 12 (50%)</td>
</tr>
</tbody>
</table>

*p-value <0.05

**p-value <0.001
Table 11.

*Education level information of post-stroke cohort and control groups*

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

*p-value <0.05

Table 12.

*Income level information of post-stroke cohort and control groups*

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

*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*

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

*p-value <0.05

**p-value <0.001
Table 14.

Post-hoc LSD between groups analysis of psychometric task performance

<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>Cohort</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>MoCA (score)</td>
<td>Post-Stroke Driver</td>
<td>Control</td>
</tr>
<tr>
<td></td>
<td>Post-Stroke Non-Driver</td>
<td>Control</td>
</tr>
<tr>
<td></td>
<td>Post-Stroke Non-Driver</td>
<td>Control</td>
</tr>
<tr>
<td>Benton (# correct)</td>
<td>Post-Stroke Driver</td>
<td>Control</td>
</tr>
<tr>
<td></td>
<td>Post-Stroke Non-Driver</td>
<td>Control</td>
</tr>
<tr>
<td></td>
<td>Post-Stroke Non-Driver</td>
<td>Control</td>
</tr>
<tr>
<td>TMT-B</td>
<td>Post-Stroke Driver</td>
<td>Control</td>
</tr>
<tr>
<td></td>
<td>Post-Stroke Non-Driver</td>
<td>Control</td>
</tr>
<tr>
<td></td>
<td>Post-Stroke Non-Driver</td>
<td>Control</td>
</tr>
<tr>
<td>RSRT</td>
<td>Post-Stroke Driver</td>
<td>Control</td>
</tr>
<tr>
<td></td>
<td>Post-Stroke Non-Driver</td>
<td>Control</td>
</tr>
<tr>
<td></td>
<td>Post-Stroke Non-Driver</td>
<td>Control</td>
</tr>
<tr>
<td>DVT (errors)</td>
<td>Post-Stroke Driver</td>
<td>Control</td>
</tr>
<tr>
<td></td>
<td>Post-Stroke Non-Driver</td>
<td>Control</td>
</tr>
<tr>
<td></td>
<td>Post-Stroke Non-Driver</td>
<td>Control</td>
</tr>
<tr>
<td>DVT Time</td>
<td>Post-Stroke Driver</td>
<td>Control</td>
</tr>
<tr>
<td></td>
<td>Post-Stroke Non-Driver</td>
<td>Control</td>
</tr>
<tr>
<td></td>
<td>Post-Stroke Non-Driver</td>
<td>Control</td>
</tr>
</tbody>
</table>

*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:

\[
* \text{Overall cognition score} = 0.87 \times \text{MoCA} + 0.53 \times \text{Benton} - 0.72 \times \text{TMT-B} + 0.52 \\
* \text{RSRT} - 0.25 \times \text{DVT (## errors)} - 0.71 \times \text{DVT (# time)}
\]
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 manoeuvres (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:

\[
\text{Overall driving performance} = 0.75 \times \text{Number of Collisions} + 0.91 \times \text{Driver Errors} + 0.81 \times \text{Unsafe Driving Manoeuvres}
\]

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).**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Odds Ratio</th>
<th>p-value</th>
<th>95% C.I. for Odds Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Lower</td>
</tr>
<tr>
<td>Education</td>
<td></td>
<td>0.01*</td>
<td></td>
</tr>
<tr>
<td>Primary</td>
<td>0.010</td>
<td>0.001**</td>
<td>0.001</td>
</tr>
<tr>
<td>Year 10</td>
<td>0.064</td>
<td>0.02*</td>
<td>0.006</td>
</tr>
<tr>
<td>High School</td>
<td>0.132</td>
<td>0.04*</td>
<td>0.018</td>
</tr>
<tr>
<td>University/Diploma</td>
<td>1 (reference)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Income (annual in $)</td>
<td></td>
<td>0.03*</td>
<td></td>
</tr>
<tr>
<td>50,000</td>
<td>36.929</td>
<td>0.02*</td>
<td>1.734</td>
</tr>
<tr>
<td>50,000 – 84,999</td>
<td>9.372</td>
<td>0.02*</td>
<td>1.393</td>
</tr>
<tr>
<td>85,000 or above</td>
<td>1 (reference)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>1.785</td>
<td>0.354</td>
<td></td>
</tr>
</tbody>
</table>

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 $t(46) = 2.27, p>0.05, d=0.33, 95\% \text{ CI} [0.08, 1.42]$ and overall, statistically fewer social supports than post-stroke non-drivers $t(46) = 2.67, p=0.01, d=0.41, 95\% \text{ CI} [0.03, 1.91]$. 
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 of 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

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Australian Bureau of Statistics.


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


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

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


http://dx.doi.org/10.3922/j.psns.2011.2.012


http://dx.doi.org/10.1016/j.aap.2011.02.007


http://dx.doi.org/10.1177/0733464804263129


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)


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 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 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*

<table>
<thead>
<tr>
<th>Variables</th>
<th>Post-Stroke Driver</th>
<th>Controls</th>
<th>t-value</th>
<th>df</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>Mean</td>
<td>SD</td>
<td>n</td>
<td>Mean</td>
</tr>
<tr>
<td>Headway</td>
<td>37</td>
<td>3.26</td>
<td>1.87</td>
<td>43</td>
<td>1.71</td>
</tr>
<tr>
<td>Lateral Lane Position</td>
<td>37</td>
<td>0.73</td>
<td>0.39</td>
<td>43</td>
<td>0.64</td>
</tr>
<tr>
<td>Speed</td>
<td>37</td>
<td>8.83</td>
<td>1.75</td>
<td>43</td>
<td>8.41</td>
</tr>
<tr>
<td>Steering Input</td>
<td>37</td>
<td>1.48</td>
<td>1.06</td>
<td>43</td>
<td>1.13</td>
</tr>
<tr>
<td>Braking Reaction Time</td>
<td>22</td>
<td>1.07</td>
<td>0.31</td>
<td>26</td>
<td>1.08</td>
</tr>
<tr>
<td>Braking Stopping Time</td>
<td>22</td>
<td>6.32</td>
<td>11.03</td>
<td>26</td>
<td>3.98</td>
</tr>
</tbody>
</table>

*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

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

<table>
<thead>
<tr>
<th></th>
<th>n 35, Median 13.8, Mean 19.31, IQR 0.10</th>
<th>n 42, Median 13.8, Mean 14.53, IQR 0.10</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>UFOV 1</td>
<td></td>
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*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

<table>
<thead>
<tr>
<th>Variables</th>
<th>Post-Stroke Driver</th>
<th>Controls</th>
<th>t-value</th>
<th>df</th>
<th>p-value</th>
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<td>n</td>
<td>Mean</td>
<td>SD</td>
<td>n</td>
<td>Mean</td>
</tr>
<tr>
<td>DKEFS TMT 1</td>
<td>37</td>
<td>7.38</td>
<td>3.62</td>
<td>43</td>
<td>10.90</td>
</tr>
<tr>
<td>DKEFS TMT 2</td>
<td>37</td>
<td>9.08</td>
<td>3.75</td>
<td>43</td>
<td>11.47</td>
</tr>
<tr>
<td>DKEFS TMT 3</td>
<td>37</td>
<td>8.51</td>
<td>4.07</td>
<td>43</td>
<td>11.72</td>
</tr>
<tr>
<td>DKEFS TMT 4</td>
<td>37</td>
<td>8.27</td>
<td>4.43</td>
<td>43</td>
<td>11.65</td>
</tr>
<tr>
<td>DKEFS TMT 5</td>
<td>37</td>
<td>9.68</td>
<td>2.92</td>
<td>43</td>
<td>12.02</td>
</tr>
<tr>
<td>DKEFS TMT 2+ TMT3</td>
<td>37</td>
<td>9.12</td>
<td>4.02</td>
<td>43</td>
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<table>
<thead>
<tr>
<th>Variables</th>
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<th>Median</th>
<th>Mean</th>
<th>IQR</th>
<th>n</th>
<th>Median</th>
<th>Mean</th>
<th>IQR</th>
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<tbody>
<tr>
<td>DKEFS EF 4</td>
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<td>2.92</td>
<td>4.50</td>
<td>43</td>
<td>1.00</td>
<td>1.67</td>
<td>0.00</td>
<td>0.02*</td>
</tr>
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</table>

*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 averse 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 averse, 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.

Acknowledgements

Alison Blane was supported by a Curtin University CSIRS scholarship. The authors also wish to acknowledge the following: the Stroke Support groups of WA for their time and assistance with recruitment, Patrick Walton for his assistance with the cognitive and simulator data processing, Dr Richard Parsons for his statistical assistance and Melissa Black, Julia Tang, Robyn Earl, Kiah Evans, Aimee Richardson, Marg Pickup, Anneli Shorter and Dr Wee Lih Lee for their assistance with data collection. Finally, the authors would like to acknowledge the Laboratory for Cognitive and Decision Sciences at Michigan State University for providing the initial code for development in the Balloon Analogue Risk Taking Task, and Prof David Bunce for his guidance with E-Prime and reaction time coding and assessments.
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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.
Chapter Five: Investigating cognitive ability and self-reported driving performance of post-stroke adults in a driving simulator contains material that is unable to be reproduced here due to copyright restrictions.
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.
Chapter Six: Cognitive ability as a predictor of task demand and self-rated driving performance in post-stroke drivers - implications for self-regulation contains material that is unable to be reproduced here due to copyright restrictions.
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.
Chapter Seven: On-road visual scanning in post-stroke drivers in relation to their cognitive function contains material that is unable to be reproduced here due to copyright restrictions.
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
Chapter Eight: Discussion, Recommendations and Conclusion

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


Chapter Eight: Discussion, Recommendations and Conclusion


Chapter Eight: Discussion, Recommendations and Conclusion

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Appendix 1: Statement of Author Contribution
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.


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:
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.


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: ________________________
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.


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:
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.


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: ____________________________
Dear Sir or Madam,

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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
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 neurodegenerative 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
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
4135.14ROAD122110.335.5130.330.3319.8120001001000200200
4200A4010006*1=4
4264.86ROAD122110.335.5130.330.3319.8120001001000200200
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
4402BLDG502.9220.67H*1;2
4405BLDG472.44-19.67H*1;3;2
4405BLDG487.68-19.67H*1;2
4500ES
Scenario: Hazard Perception

METRIC
0,ROAD,6.66,4,2,2,0.3,3.05,3.05,0.12,0.12,0,-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,-304.8,7,6.5,0,-4.88,6
0,SL,-6070,8,0,0,-4.88,6,1,1,0
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,6.66,4,2,2,0.3,3.05,3.05,0.12,0.12,19.8119998488464,0,0,0,3.05,0,3.05,0,
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
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,
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783.48,BARL,304.8,0,3,0,0,0,0,-11.71,1,1
787.48,BARL,304.8,0,3,0,0,0,0,-11.03,1,1
792.48,BARL,304.8,0,3,0,0,0,0,-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,304.8,0,3,0,0,0,0,-10.25,1,1
798.58,BARL,304.8,0,3,0,0,0,0,-9.49,1,1
801.62,BARL,304.8,0,3,0,0,0,0,-9.03,1,1
804.67,BARL,304.8,0,3,0,0,0,0,-8.27,1,1
807.72,BARL,304.8,0,3,0,0,0,0,-8.27,1,1
810.77,BARL,304.8,0,3,0,0,0,0,-8.27,1,1
813.82,BARL,304.8,0,3,0,0,0,0,-8.27,1,1
816.86,BARL,304.8,0,3,0,0,0,0,-8.27,1,1
820.48,BARL,304.8,0,3,0,0,0,0,-9.03,1,1
824.53,BARL,304.8,0,3,0,0,0,0,-9.49,1,1
828.58,BARL,304.8,0,3,0,0,0,0,-10.25,1,1
832.62,BARL,304.8,0,3,0,0,0,0,-10.71,1,1
836.62,BARL,304.8,0,3,0,0,0,0,-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
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1600,A,55,1000,6,4
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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
6825,BLDG,502.92,-17.67,H3
6840,BLDG,497.62,17.67,H3
6850,BLDG,497.62,17.67,H1
6875,BLDG,502.92,17.67,H14
6880,BLDG,502.92,-17.67,B5
6895,BLDG,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
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7000, Vehicles, 574.548,-
13.9248(0),.03048(0),1,*S8;F: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),,,
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7125, BLDG, 472.44,-17.67,H3
7155, BLDG, 487.68,17.67,H14
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7285, BLDG, 487.68,-17.67,H1
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7405, BLDG, 487.68,-17.67,H1
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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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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

<table>
<thead>
<tr>
<th>Condition</th>
<th>Code</th>
<th>Dual lane round about (U-turn)</th>
<th>Code</th>
<th>Turning into small street cont.</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Approach with appropriate speed</td>
<td>Planning</td>
<td>Approach with appropriate speed</td>
<td>Planning</td>
<td>Stopped at appropriate position next to traffic island (not blocking oncoming traffic)</td>
<td>Position</td>
</tr>
<tr>
<td>Approach left lane</td>
<td>Planning</td>
<td>Head turns, check mirror</td>
<td>Attention</td>
<td>Check oncoming traffic (head turns)</td>
<td>Attention</td>
</tr>
<tr>
<td>Head turn, check mirror</td>
<td>Attention</td>
<td>Indicate right before entering</td>
<td>Interaction</td>
<td>Proceed with smooth manoeuvre when way is clear</td>
<td>Manoeuvre</td>
</tr>
<tr>
<td>Indicate/signal left before advancing</td>
<td>Interaction</td>
<td>Appropriate signalling</td>
<td>Interaction</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exit in left lane after round-about</td>
<td>Planning</td>
<td>Proceed when way is clear</td>
<td>Planning</td>
<td>Noticed and approached stop sign with appropriate speed</td>
<td>Planning</td>
</tr>
<tr>
<td>Speed bump/pedestrian crossing</td>
<td>Maneuver</td>
<td>Maneuvering around round about is smooth</td>
<td>Maneuver</td>
<td>Come to a complete stop before proceeding</td>
<td>Planning</td>
</tr>
<tr>
<td>Approach with appropriate speed</td>
<td>Planning</td>
<td>Exit in correct lane</td>
<td>Position</td>
<td>Stopped before &amp; close to the stop line</td>
<td>Position</td>
</tr>
<tr>
<td>Did not hit speed bump at high speed, speed adjustment</td>
<td>Speed adjustment</td>
<td>Check mirror after manoeuvre</td>
<td>Attention</td>
<td>Check oncoming traffic (head turns)</td>
<td>Attention</td>
</tr>
<tr>
<td>Gave way to pedestrians (if applicable)</td>
<td>Attention</td>
<td>T-junction (turn left)</td>
<td>Interation</td>
<td>Appropriate signal (turning right)</td>
<td>Interaction</td>
</tr>
<tr>
<td>Compiled with km/hr rule</td>
<td>Speed adjustment</td>
<td>Check mirror before entering</td>
<td>Attention</td>
<td>Proceed with smooth manoeuvre when way is clear</td>
<td>Manoeuvre</td>
</tr>
<tr>
<td>Round about (straight)</td>
<td>Approach junction with appropriate speed</td>
<td>Approach junction with appropriate speed</td>
<td>Planning</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Approach with appropriate speed</td>
<td>Planning</td>
<td>Head turns, check traffic</td>
<td>Attention</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Head turn, check mirror</td>
<td>Attention</td>
<td>Appropriate signal</td>
<td>Interaction</td>
<td>Approach with appropriate speed</td>
<td>Planning</td>
</tr>
<tr>
<td>Maneuvering around round about is smooth</td>
<td>Maneuver</td>
<td>Proceed with smooth manoeuvre when way is clear</td>
<td>Maneuver</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Round about (straight)</td>
<td>Approach junction with appropriate speed</td>
<td>Approach junction with appropriate speed</td>
<td>Planning</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Approach with appropriate speed</td>
<td>Planning</td>
<td>Traffic lights</td>
<td>Planning</td>
<td>Exit in correct lane before merge</td>
<td>Position</td>
</tr>
<tr>
<td>Head turn, check mirror</td>
<td>Attention</td>
<td>Approach with appropriate speed</td>
<td>Planning</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maneuvering around round about is smooth</td>
<td>Maneuver</td>
<td>Stop at appropriate distance to car in front</td>
<td>Maneuver</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Give way (right turn) Tricky junction with constant flow of traffic</td>
<td>Noticed lights; stopped (red) or go (green) as indicated</td>
<td>Approach left lane</td>
<td>Planning</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Noted and approached with appropriate speed at give way sign</td>
<td>Planning</td>
<td>Proceed with smooth manoeuvre when way is clear</td>
<td>Manoeuvre</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Signal right</td>
<td>Interaction</td>
<td>(moved into right hand lane before traffic light in preparation for next turning)</td>
<td>Planning</td>
<td>Indicate/signal left before advancing</td>
<td>Interaction</td>
</tr>
<tr>
<td>Check oncoming traffic (head turns)</td>
<td>Attention</td>
<td>Turning into small street</td>
<td>Parking (Bay 7)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Proceed with smooth manoeuvre when way is clear</td>
<td>Maneuver</td>
<td>Check mirrors</td>
<td>Attention</td>
<td>Check for traffic behind using rear mirror</td>
<td>Attention</td>
</tr>
<tr>
<td>Check mirrors</td>
<td>Attention</td>
<td>Appropriate signal (turning right)</td>
<td>Interaction</td>
<td></td>
<td>Planning</td>
</tr>
<tr>
<td>Moved into right hand lane</td>
<td>Planning</td>
<td>Correct signalling</td>
<td>Interaction</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Appropriate signal (turning right)</td>
<td>Interaction</td>
<td>Apply handbrake</td>
<td>Maneuver</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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: MU2017/120.4

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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 confidently 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 $50 Cola / Metro Voucher.

Contact Alison Blame
Tel | 4118 9266 7681
Email | alison.blame@curtin.edu.au

Curtin University
Driving the Brain: Investigating Driving Post-Stroke

Can YOU help us with exciting new driving research?

Participant Information
(Pre-Stroke Drivers)

Participant Information
(Post-Stroke Drivers)

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 | 4118 9266 7681
Email | alison.blame@curtin.edu.au
Website | www.curtin.edu.au

Curtin University
Study Topics Reference & support: #3 2014/2015

Fare-Tracking Devices
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 assessment 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 this stroke. This is to help with analysis and all information will be kept strictly confidential.

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 (from 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 in 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 Blame using alison.blame@curtin.edu.au or on 9266 7681.

Are there any risks involved?

All measures involved in this 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 refer 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 Blame using the details listed below.
Appendix 7: Ethical Approval Numbers

<table>
<thead>
<tr>
<th>Memorandum</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>To</strong></td>
</tr>
<tr>
<td><strong>From</strong></td>
</tr>
<tr>
<td><strong>Subject</strong></td>
</tr>
<tr>
<td><strong>Date</strong></td>
</tr>
</tbody>
</table>
| **Copy** | Alison Blane Occupational Therapy  
Professor Torgeir Falkner Occupational Therapy  
Prof Jonathan Foster Occupational Therapy |

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:
  1. Annual progress reports on the project must be submitted to the Ethics Office.
  2. 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)](https://www.wausda.org.au).

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](https://research.curtin.edu.au/guides/ethics/non_low_risk_hrec_forms.cfm) 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](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)](https://www.wausda.org.au)

Yours sincerely,

Professor Peter O’Leary  
Chair Human Research Ethics Committee
Appendix 7: Ethical Approval Numbers

Memorandum

To: Dr Hoe Lee
From: Teena Bowman
Subject: Protocol Approval OTSW-20-2011
Date: 15 November 2011
Copy: Ms Megan Yumin Lee

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.

Teena Bowman
Research Centre Administrator
School of Occupational Therapy and Social Work
Telephone: 9266 4651
Email: l.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 U2987, Perth, 6845 or by telephoning 9266 2784 or hrec@curtin.edu.au

Curtin University
Office of Research and Development
Human Research Ethics Committee
Telephone: 9266 2784
Facsimile: 9296 3793
Email: hrec@curtin.edu.au
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 neurodegenerative 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 neurodegenerative disease such as: Parkinson’s disease, Alzheimer’s disease, Dementia etc.
Appendix 8: Participant Information Sheet

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
Appendix 8: Participant Information Sheet

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.
Appendix 8: Participant Information Sheet

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.
### Appendix 9: Risk Assessment

#### Health & Safety Risk Assessment

<table>
<thead>
<tr>
<th>Activity / Task / Location: PhD Project: Investigating Cerebrovascular Accident and Driving Performance – Phase 1 -3 Location: Curtin University Bentley Campus</th>
<th>Date: 30.07.2014</th>
</tr>
</thead>
<tbody>
<tr>
<td>Developed by: Alison Blane</td>
<td>Approved By: Dr Hoe C. Lea</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hazard Identification</th>
<th>Risk Assessment</th>
<th>Control</th>
<th>Residual Risk Assessment</th>
<th>Which Responsibilities Implement the Changes</th>
<th>Date Finalised</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase 1-3</td>
<td>Harm to Human Subjects</td>
<td>Moderate</td>
<td>Unlikely</td>
<td>Medium</td>
<td>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.</td>
</tr>
</tbody>
</table>

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Version 2.0

Uncontrolled document when printed

Health and Safety

Page 1 of 4

360
## Appendix 9: Risk Assessment

### Health & Safety Risk Assessment

<table>
<thead>
<tr>
<th>Phase 1: Cognitive Assessments including computerised assessments, eye tracker and questionnaires</th>
<th>None</th>
<th>N/A</th>
<th>N/A</th>
<th>N/A</th>
<th>N/A</th>
<th>01/09/2014</th>
</tr>
</thead>
<tbody>
<tr>
<td>The researchers will make participants aware of the symptoms prior to the assessment and advise them to inform the researcher if 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</td>
<td>None</td>
<td>Low</td>
<td>PhD student</td>
<td>Researcher</td>
<td></td>
<td></td>
</tr>
<tr>
<td>01/09/2014</td>
<td>01/09/2014</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase 1: Off-road driving simulator assessment</td>
<td>Simulator sickness</td>
<td>Insignificant</td>
<td>Possible</td>
<td>Low</td>
<td>Insignificant</td>
<td>None</td>
</tr>
<tr>
<td>01/09/2014</td>
<td>01/09/2014</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Driver Difficulty</td>
<td>Moderate</td>
<td>Possible</td>
<td>Medium</td>
<td>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</td>
<td>Rare</td>
<td>Low</td>
</tr>
<tr>
<td>01/09/2014</td>
<td>01/09/2014</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Traffic Collision</td>
<td>Moderate</td>
<td>Possible</td>
<td>Medium</td>
<td>the maximum speed limit is 70km per hour and does not consist of any tasks 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. Moderate</td>
<td>Rare</td>
<td>Low</td>
</tr>
<tr>
<td>01/09/2014</td>
<td>01/09/2014</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

The maximum speed limit is 70km per hour and does not consist of any tasks 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.
Appendix 9: Risk Assessment

Health & Safety Risk Assessment

Health & Safety Risk Matrix

Determining the Risk Level: Risk Level = Consequence Level x Likelihood Level

Maximum Permissible 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.

<table>
<thead>
<tr>
<th>IMPACTS</th>
<th>LIKELIHOOD</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Family Fatality</td>
<td>Critical</td>
<td>The event may occur only in exceptional circumstances</td>
</tr>
<tr>
<td>Permanent Total Disability</td>
<td>Major</td>
<td>Not expected, but the event may occur at any time</td>
</tr>
<tr>
<td>Significant Permanent or Illness</td>
<td>Moderate</td>
<td>The event will probably occur in most circumstances</td>
</tr>
<tr>
<td>Serious Illness</td>
<td>Minor</td>
<td>The event is expected to occur or has occurred and is continuing to occur</td>
</tr>
<tr>
<td>Last three days</td>
<td>Insufficient</td>
<td></td>
</tr>
<tr>
<td>Injury or Illness requiring medical treatment</td>
<td>Insufficient</td>
<td></td>
</tr>
<tr>
<td>Last two days</td>
<td>Insufficient</td>
<td></td>
</tr>
<tr>
<td>Injury or Illness requiring first aid treatment</td>
<td>Insufficient</td>
<td></td>
</tr>
<tr>
<td>Last one day</td>
<td>Insufficient</td>
<td></td>
</tr>
</tbody>
</table>

Risk Management Action:

- **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 implemented by the manager or supervisor to reduce the risk to as low as reasonably practicable. The effectiveness of risk control strategies shall be evaluated and reported to management and relevant parties.
- **Moderate:** A mitigation plan shall be developed. Control strategies are implemented and periodically reviewed to determine changes which may affect the risk.
- **Low:** Storage of documented evidence processes and procedures. Monitor periodically to determine changes which may affect the risk.
Appendix 10: Approval from Advances in Transportation Studies re. Copyright Permissions

Allison 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.

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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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Signed

[Signature]

Name: Alessandro Calvi

Position: Editor in Chief of Advances in Transportation Studies

Date: 13th March, 2017

Please return signed form to Alison Blane at Alison.Blane@curtin.edu.au
The cognitive and socio-demographic influences on driving performance and driving cessation in post-stroke drivers

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1School of Occupational Therapy and Social Work, Curtin University, Perth, Australia
email: HoeLee@curtin.edu.au
2Rehabilitation Medicine, Department of Medicine and Health Sciences (IMH), Faculty of Health Sciences, Linköping University & Pain and Rehabilitation Centre, UHL, County Council, Linköping, Sweden
3School of Occupational Therapy, La Trobe University, Melbourne, Victoria, Australia

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, socioeconomic 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 assess 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.
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 $\chi^2 = 2.38, p > 0.05$ 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 $\chi^2 = 10.25, p = 0.02$ 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 $t(46) = -.253, p > .05, 95\% CI [-32.99, 25.63]$.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Controls (N = 22)</th>
<th>Post-Stroke Driver (N = 24)</th>
<th>Post-Stroke Non-Driver (N = 24)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>Mean 64.8</td>
<td>Mean 67.8</td>
<td>Mean 68.2</td>
<td>0.555</td>
</tr>
<tr>
<td>License length in years</td>
<td>SD 6.7</td>
<td>SD 17.7</td>
<td>SD 7.8</td>
<td>0.577</td>
</tr>
<tr>
<td>Hours of driving per week</td>
<td>Mean 54.9</td>
<td>Mean 56.9</td>
<td>Mean 54.6</td>
<td>&lt;0.005</td>
</tr>
<tr>
<td>Hours of Driving (weekly)</td>
<td>SD 7.1</td>
<td>SD 9.0</td>
<td>SD 11.0</td>
<td>&lt;0.005</td>
</tr>
<tr>
<td>Recovery period (month)</td>
<td>N/A</td>
<td>Mean 44.9</td>
<td>Mean 48.3</td>
<td>&gt;0.005</td>
</tr>
<tr>
<td>Declared stroke to authorities</td>
<td>N/A</td>
<td>Yes = 14 (58%)</td>
<td>Yes = 14 (58%)</td>
<td>&gt;0.005</td>
</tr>
<tr>
<td>Received advice on driving</td>
<td>N/A</td>
<td>Yes = 14 (58%)</td>
<td>No = 10 (42%)</td>
<td>&gt;0.005</td>
</tr>
</tbody>
</table>

- 80 -
Tab. 2 - Education level information of post-stroke cohort and control groups

<table>
<thead>
<tr>
<th>Education Level</th>
<th>Controls (N = 22)</th>
<th>Post-Stroke Driver (N = 24)</th>
<th>Post-Stroke Non-Driver (N = 24)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tertiary</td>
<td>(14) 64%</td>
<td>(14) 58%</td>
<td>(4) 17%</td>
<td>$X^2 = 19.7$</td>
</tr>
<tr>
<td>Year 12</td>
<td>(2) 9%</td>
<td>(5) 21%</td>
<td>(6) 25%</td>
<td></td>
</tr>
<tr>
<td>Year 10</td>
<td>(6) 27%</td>
<td>(3) 13%</td>
<td>(6) 25%</td>
<td></td>
</tr>
<tr>
<td>Primary</td>
<td>0</td>
<td>(2) 8%</td>
<td>(8) 33%</td>
<td></td>
</tr>
</tbody>
</table>

Tab. 3 - Income level information of post-stroke cohort and control groups

<table>
<thead>
<tr>
<th>Income Level</th>
<th>Controls (N = 22)</th>
<th>Post-Stroke Driver (N = 24)</th>
<th>Post-Stroke Non-Driver (N = 24)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤$5,000</td>
<td>0</td>
<td>(4) 17%</td>
<td>(2) 8.3%</td>
<td>$X^2 = 13.86$</td>
</tr>
<tr>
<td>$5,000 - $84,999</td>
<td>(3) 14%</td>
<td>(12) 50%</td>
<td>(8) 33%</td>
<td></td>
</tr>
<tr>
<td>≥ $85,000</td>
<td>(19) 86%</td>
<td>(8) 33%</td>
<td>(14) 58.3%</td>
<td></td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Psychometric Task</th>
<th>Control (N = 22)</th>
<th>Post-Stroke Driver (N = 24)</th>
<th>Post-Stroke Non-Driver (N = 24)</th>
<th>F-value (df = 2, 67)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>MoCA (# items Correct)</td>
<td>26.82 1.82</td>
<td>25.21 2.90</td>
<td>23.29 2.97</td>
<td>10.32</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>RSRT (# items correct)</td>
<td>77.59 25.59</td>
<td>125.31 38.66</td>
<td>171.67 95.35</td>
<td>13.23</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>DVT (Errors)</td>
<td>4.14 1.13</td>
<td>3.25 1.39</td>
<td>3.17 1.44</td>
<td>3.70</td>
<td>0.03</td>
</tr>
<tr>
<td>DVT (Time)</td>
<td>437.09 92.53</td>
<td>529.71 142.00</td>
<td>656.08 144.59</td>
<td>16.62</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>
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:

\[
* \text{Overall cognition score} = 0.87 \times \text{MoCA} + 0.529 \times \text{Benton} - 0.717 \times \text{TMT-B} + 0.523 \times \text{RSRT} - 0.249 \times \text{DVT (# errors)} - 0.714 \times \text{DVT (# time)}
\]  

(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 manoeuvres (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:

\[
\text{Overall driving performance} = 0.7465 \times \text{Number of Collisions} + 0.905 \times \text{Driver Errors} + 0.808 \times \text{Unsafe Driving Manoeuvres}
\]  

(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)

<table>
<thead>
<tr>
<th>Education</th>
<th>Odds Ratio</th>
<th>p-value</th>
<th>95% C.I. for Odds Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Lower</td>
</tr>
<tr>
<td>Primary</td>
<td>0.010</td>
<td>0.011</td>
<td>0.001</td>
</tr>
<tr>
<td>Year 10</td>
<td>0.064</td>
<td>0.019</td>
<td>0.006</td>
</tr>
<tr>
<td>High School</td>
<td>0.132</td>
<td>0.048</td>
<td>0.018</td>
</tr>
<tr>
<td>University/Diploma</td>
<td>1 (reference)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Income (annual in $)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50000</td>
<td></td>
<td>0.027</td>
<td></td>
</tr>
<tr>
<td>50,000–84,999</td>
<td>36.929</td>
<td>0.021</td>
<td>1.734</td>
</tr>
<tr>
<td>85,000 or above</td>
<td>9.372</td>
<td>0.021</td>
<td>1.393</td>
</tr>
<tr>
<td>Constant</td>
<td>1.785</td>
<td>0.354</td>
<td></td>
</tr>
</tbody>
</table>

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 \( t(46) = 2.27, p > 0.05, d = .33, 95\% \text{ CI [.084, 1.42]} \) and overall, statistically fewer social supports than post-stroke non-drivers \( t(46) = 2.67, p = 0.01, d = .41, 95\% \text{ CI [.026, 1.91]} \).

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


Appendix 12: Approval from Behavioural Neurology re. Copyright Permissions

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Sent: Thursday, 23 February 2017 9:30 PM
To: Alison Blane
Subject: RE: 1378308: Your manuscript has been accepted

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Best regards,

Salma

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Assessing Cognitive Ability and Simulator-Based Driving Performance in Poststroke Adults

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Received 18 November 2016; Accepted 14 February 2017; Published 7 May 2017

Academic Editor: Fred S. Sarfo

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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 hemorrhagic 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 mileage 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.
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 assess 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 averse, 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 sub-task of the Wechsler Adult Intelligence Scale) was used to measure nonverbal visuospatial reasoning [36]. The test

Figure 1: The Curtin University STISIM driving simulator.
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.
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: BILOT, 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 averse 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 averse, this may suggest that the less
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 tests 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 2: The between-group analysis of significant cognitive variables.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Poststroke driver</th>
<th>Controls</th>
<th>t value</th>
<th>df</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>BART average number of pumps per balloon</td>
<td>37 25.16 3.32 43</td>
<td>27.49 17.78 78</td>
<td>2.46</td>
<td>78 0.02*</td>
<td></td>
</tr>
<tr>
<td>BART average saved balloons</td>
<td>37 20.15 10.18 43</td>
<td>22.90 4.71 68.51 0.02*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BJLOT</td>
<td>36 24.64 5.07 43</td>
<td>25.44 9.93 65.33 0.44</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Block design</td>
<td>37 37.60 10.50 43</td>
<td>40.40 10.22 78 0.23</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SRT (milliseconds)</td>
<td>34 375.59 161.35 43</td>
<td>244.19 78.05 78 0.27</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2CRT (milliseconds)</td>
<td>34 97.99 172.91 43</td>
<td>50.58 88.64 46.56 0.15</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4CRT (milliseconds)</td>
<td>34 427.62 258.67 43</td>
<td>333.33 255.92 75 0.11</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Visual attention (simple visual search task)</td>
<td>34 693.99 422.08 43</td>
<td>494.11 150.97 39.70 0.01*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UFOV divided attention</td>
<td>35 82.89 112.33 42</td>
<td>36.29 38.84 40.78 0.02*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UFOV selective attention</td>
<td>35 144.31 110.33 41</td>
<td>90.13 50.70 46.09 0.01*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UFOV processing speed</td>
<td>35 13.8 19.31 0.10</td>
<td>13.8 14.53 0.10 0.82</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Significant data; p value < 0.05.
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 nonlicensed poststroke adults who wish to return to driving.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

Alison Blane was supported by a Curtin University CSIRS scholarship. The authors also wish to acknowledge the following: the Stroke Support groups of WA for their time and assistance with recruitment, Patrick Walton for his assistance with the cognitive and simulator data processing, Dr. Richard Parsons for his statistical assistance, and Melissa Black, Julia Tang, Robyn Earl, Kiah Evans, Aimee Richardson, Mark Pickup, Anneli Shorter, and Dr. Wee Lih Lee for their assistance with data collection. Finally, the authors would like to acknowledge the Laboratory for Cognitive and Decision Sciences at Michigan State University for providing the initial code for development in the Balloon Analogue Risk-Taking Task and Professor David Bunce for his guidance with E-Prime and reaction time coding and assessments.

References


[38] Precision Vision, *Series Revised ETDRS Charts*.


Appendix 14: Eye-Tracking Coding Matrix
<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>*</td>
<td>Area / Object</td>
</tr>
<tr>
<td>*11</td>
<td>The Road</td>
</tr>
<tr>
<td>110</td>
<td>Ahead Left Lane (same direction)</td>
</tr>
<tr>
<td>111</td>
<td>Ahead Right Lane (opposing direction)</td>
</tr>
<tr>
<td>112</td>
<td>Straight ahead (middle of roadway / roadway horizon)</td>
</tr>
<tr>
<td>113</td>
<td>Road bump</td>
</tr>
<tr>
<td>114</td>
<td>Road behind driver's car</td>
</tr>
<tr>
<td>115</td>
<td>Road to the left of driver's car</td>
</tr>
<tr>
<td>116</td>
<td>Road to the right of driver's car</td>
</tr>
<tr>
<td>117</td>
<td>Upcoming intersection</td>
</tr>
<tr>
<td>*12</td>
<td>Pavement / Footpath / Cycleways</td>
</tr>
<tr>
<td>120</td>
<td>Pavement to the left</td>
</tr>
<tr>
<td>121</td>
<td>Pavement to the right</td>
</tr>
<tr>
<td>122</td>
<td>Pavement in front</td>
</tr>
<tr>
<td>123</td>
<td>Cycleway to the left</td>
</tr>
<tr>
<td>124</td>
<td>Cycleway to the right</td>
</tr>
<tr>
<td>125</td>
<td>Cycleway infront</td>
</tr>
<tr>
<td>126</td>
<td>Pedestrian using pathway on the left</td>
</tr>
<tr>
<td>127</td>
<td>Pedestrian using pathway on the right</td>
</tr>
<tr>
<td>128</td>
<td>Pedestrian using pathway in front</td>
</tr>
<tr>
<td>129</td>
<td>Cyclist using cycleway to the left</td>
</tr>
<tr>
<td>1290</td>
<td>Cyclist using cycleway to the right</td>
</tr>
<tr>
<td>*13</td>
<td>Pedestrian crossing</td>
</tr>
<tr>
<td>130</td>
<td>Entrance / Exit Pedestrian Crossing Left</td>
</tr>
<tr>
<td>131</td>
<td>Entrance / Exit Pedestrian Crossing Right</td>
</tr>
<tr>
<td>132</td>
<td>Middle of crossing / crossing markings painted on-road</td>
</tr>
<tr>
<td>133</td>
<td>Pedestrian using crossing</td>
</tr>
<tr>
<td>*14</td>
<td>T-junction/Intersection</td>
</tr>
<tr>
<td>140</td>
<td>Intersection entrance / exit left</td>
</tr>
<tr>
<td>141</td>
<td>Intersection entrance / exit right</td>
</tr>
<tr>
<td>142</td>
<td>Intersection entrance / exit straight ahead</td>
</tr>
<tr>
<td>143</td>
<td>Oncoming vehicle on right side</td>
</tr>
<tr>
<td>144</td>
<td>Oncoming vehicle on left side</td>
</tr>
<tr>
<td>145</td>
<td>Oncoming vehicle opposite coming straight ahead</td>
</tr>
<tr>
<td>146</td>
<td>Oncoming vehicle turning left into junction</td>
</tr>
<tr>
<td>147</td>
<td>Oncoming vehicle turning right into junction</td>
</tr>
<tr>
<td>148</td>
<td>Vehicle ahead of driver in intersection</td>
</tr>
<tr>
<td>*15</td>
<td>Roundabout</td>
</tr>
<tr>
<td>150</td>
<td>Roundabout left entrance / exit</td>
</tr>
<tr>
<td>151</td>
<td>Roundabout right entrance / exit</td>
</tr>
<tr>
<td>152</td>
<td>Roundabout opposite entrance / exit</td>
</tr>
<tr>
<td>153</td>
<td>Oncoming vehicle from left side</td>
</tr>
<tr>
<td>154</td>
<td>Oncoming vehicle right side</td>
</tr>
<tr>
<td>155</td>
<td>Oncoming vehicle opposite side</td>
</tr>
<tr>
<td>156</td>
<td>Vehicle ahead of driver in intersection</td>
</tr>
<tr>
<td>157</td>
<td>Roundabout Island</td>
</tr>
<tr>
<td>*16</td>
<td>Refuge Islands</td>
</tr>
<tr>
<td>160</td>
<td>Traffic refuge, island</td>
</tr>
<tr>
<td>161</td>
<td>Median strip</td>
</tr>
<tr>
<td>Code</td>
<td>Description</td>
</tr>
<tr>
<td>------</td>
<td>-------------------------------------------</td>
</tr>
<tr>
<td>162</td>
<td>Pedestrian using median strip or refuge island</td>
</tr>
<tr>
<td>*17</td>
<td>Inside the car / mirrors / wipers</td>
</tr>
<tr>
<td>170</td>
<td>Middle rear view mirror</td>
</tr>
<tr>
<td>171</td>
<td>Left rear view mirror</td>
</tr>
<tr>
<td>172</td>
<td>Right rear view mirror</td>
</tr>
<tr>
<td>173</td>
<td>Spedometer</td>
</tr>
<tr>
<td>174</td>
<td>Inside car / vehicle controls</td>
</tr>
<tr>
<td>*18</td>
<td>Other road users</td>
</tr>
<tr>
<td>180</td>
<td>Vehicle in front of user same direction</td>
</tr>
<tr>
<td>181</td>
<td>Vehicle in front of user - opposite direction</td>
</tr>
<tr>
<td>182</td>
<td>Vehicle at the left side of the user</td>
</tr>
<tr>
<td>183</td>
<td>Vehicle at the right side of the user</td>
</tr>
<tr>
<td>184</td>
<td>Vehicle behind user</td>
</tr>
<tr>
<td>185</td>
<td>Vehicle entering road from the left</td>
</tr>
<tr>
<td>186</td>
<td>Vehicle entering road from the right</td>
</tr>
<tr>
<td>187</td>
<td>Pedestrian on -road / jay walking</td>
</tr>
<tr>
<td>*19</td>
<td>Lines and markings</td>
</tr>
<tr>
<td>190</td>
<td>Roadway dividing line</td>
</tr>
<tr>
<td>191</td>
<td>Edge Line</td>
</tr>
<tr>
<td>192</td>
<td>Stop line</td>
</tr>
<tr>
<td>193</td>
<td>Give way line</td>
</tr>
<tr>
<td>194</td>
<td>Pedestrian crossing line (zig zag line / zebra crossing etc.)</td>
</tr>
<tr>
<td>195</td>
<td>Arrow / direction line</td>
</tr>
<tr>
<td>*20</td>
<td>Signs information</td>
</tr>
<tr>
<td>200</td>
<td>Signage</td>
</tr>
<tr>
<td>201</td>
<td>Bus stop</td>
</tr>
<tr>
<td>202</td>
<td>Advertisement boards</td>
</tr>
<tr>
<td>203</td>
<td>Pole</td>
</tr>
<tr>
<td>*21</td>
<td>Traffic Light Intersection</td>
</tr>
<tr>
<td>210</td>
<td>Traffic light</td>
</tr>
<tr>
<td>211</td>
<td>Roadway in middle of traffic light intersection</td>
</tr>
<tr>
<td>212</td>
<td>Opposing traffic to the right of traffic light intersection</td>
</tr>
<tr>
<td>*22</td>
<td>Parking area</td>
</tr>
<tr>
<td>220</td>
<td>Vehicle parked right side</td>
</tr>
<tr>
<td>221</td>
<td>Vehicle parked left side</td>
</tr>
<tr>
<td>222</td>
<td>Car park</td>
</tr>
<tr>
<td>*23</td>
<td>Horizon / Sky</td>
</tr>
<tr>
<td>230</td>
<td>Horizon</td>
</tr>
<tr>
<td>*24</td>
<td>Landscape</td>
</tr>
<tr>
<td>240</td>
<td>Grass area</td>
</tr>
<tr>
<td>241</td>
<td>Trees</td>
</tr>
<tr>
<td>*25</td>
<td>Buildings on the side of the road</td>
</tr>
<tr>
<td>250</td>
<td>Building</td>
</tr>
<tr>
<td>251</td>
<td>Curtin Bus station</td>
</tr>
<tr>
<td>*26</td>
<td>Other</td>
</tr>
<tr>
<td>261</td>
<td>Other - Alison to check</td>
</tr>
</tbody>
</table>

Note: Blue Text is traffic relevance
Red Text is non traffic relevance