Advances in Transportation Studies: an international Journal: 121-135

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

Alison, Blane, BSc [1]; Torbjorn Falkmer, PhD[1, 2, 3]; Megan Lee, Bsc (OT) [1] ,Richard Parsons, PhD[1], Hoe Chung-yeung Lee, PhD[1]

[1]School of Occupational Therapy and Social Work, Curtin University, Perth, Australia

Email: HoeLee@curtin.edu.au
Tel: +618 9266 4652

[2]Rehabilitation Medicine, Department of Medicine and Health Sciences (IMH), Faculty of Health Sciences, Linköping University & Pain and Rehabilitation Centre, UHL, County Council, Linköping, Sweden
[3]School of Occupational Therapy, La Trobe University, Melbourne, Victoria, Australia

Abstract

Background: Driving is a complex and multifaceted occupation requiring highly integrated cognitive and perceptual functions 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 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. Other factors that influenced driving cessation in a post-stroke cohort were identified as: level of education and individual 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. The implications of these findings are concerning as they suggest that some post-stroke drivers lack insight into their declining abilities and continue to drive, despite the potential danger. Further screening tools and assessments to identify those at risk when returning to the road post-stroke are required.

Keywords – Cognition, driving cessation, driving status, driving performance, driving simulator, post-stroke, socio-economic factors

1. Introduction

The ability to maintain driving is often considered a part of an individual's identity (Dickerson, Reistetter, Davis, & Monahan, 2011; Griffen, Rapport, 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 occupation 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. 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 (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 exclusively dependent on an individual's motor and cognitive abilities. Regardless of substandard driving performance or ability, 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 (Adler & Rottunda, 2006) and cause increased feelings of loneliness, isolation and depression (Fonda, Wallace, & Herzog, 2001; David. R. Ragland, Satariano, & MacLeod, 2005; Rudman, Friedland, Chipman, & Sciortino, 2006). Reluctance to give up driving has been found to be particularly common in post-stroke drivers (Lister, 1999; Logan, Dyas, & Gladman, 2004; Patomella, Johansson, & Tham, 2009). Previous literature investigating older drivers has reported that social supports, alternative means of transportation, education level, sense of identity, income, self-regulation ability, and the awareness of personal health problems can all influence the decision to continue with or to cease driving (Adler & Rottunda, 2006; Donorfio, D'Ambrosio, Coughlin, & Mohyde, 2009; Kostyniuk & Shope, 2003).

Screening assessments for post-stroke individuals who are at risk of unsafe driving is essential, in order to maintain the safety of all road users. There are currently no standard procedures for evaluation of drivers post-stroke (Galski, Ehle, McDonald, & Mackevich, 2000) and experiences between drivers vary (Lister, 1999). There is 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). Assessments that incorporate screening of an individual's personal and socioeconomic profile may therefore 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 (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.

2. Methods

A case control design was applied to compare driving performance of the drivers with stroke and healthy control.

2.1 Participants

Participants comprised 48 post-stroke adults and 22 healthy controls. Half of the stroke cohort (n=24) had continued driving (post-stroke drivers) and half had ceased driving (post-stroke non-drivers). 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, aged over 50 years, 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 ≥20/40, which is the minimum VA required in order to legally drive in Australia.

2.2 Performance measures and equipment

2.2.1 Cognitive measures

In order to obtain a baseline measure of the cognitive and perceptual abilities of all participants, psychometric assessments were administered. The assessments included the Montreal Cognitive Assessment (Nasreddine et al., 2005) Benton Judgment of Line Orientation Test (Benton, Hamsher, Varney, & Spreen, 1983), Digit Vigilance Test (Lewis & Rennick, 1979), Trail Making Test Part B (Reitan & Wolfson, 1985), and a Road Sign Recognition Test (Lincoln & Fanthome, 1994).

The Montreal Cognitive Assessment (MoCA) 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% (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 et al., 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 predictive of driving continuation post-stroke (reference). 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 (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 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; Reitan & Wolfson, 1985) is a highly utilized psychometric test that is used to asses an individual's higher order functioning, including divided attention, visual perception, and executive functioning. The test 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 (Marshall et al., 2007; Motta, Lee, & Falkmer, 2014; Radford & Lincoln, 2004).

The Road Sign Recognition Test (RSRT) assesses knowledge of road signs, visual recognition, memory, and problem solving abilities (Lincoln & Fanthome, 1994; Radford & Lincoln, 2004). 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 (Lincoln & Fanthome, 1994; MacGregor, Freeman, & Zhang, 2001; Radford & Lincoln, 2004).

2.2.2. Driving Performance Measures

Figure 1: *The STISIM Driving Simulator*

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

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 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. The assessment room was kept well ventilated in order to prevent simulator-induced motion sickness (S. Classen, Bewernitz, & Shechtman, 2011). Incidence of simulator sickness was collected through self-report. Participants were made aware of the possibility for simulator sickness to occur and prior to the assessment they were instructed to inform the researcher should they experience any symptoms during the trial.

2.3 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. (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 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.

2.4 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.

2.5 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 (IBM Corporation, 2012). 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. The effect of cognitive decline on driving performance was 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.

3.0 Results

3.1 Demographic characteristics

No differences were reported in gender distribution between the post-stroke and control groups (X2 = 2.38 p >0.05). 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 (median = 26.38, t=-0.253 (df 46) >0.05). Significant differences in the demographic profile were found in the following variables: years of driving, hours driven per week, reported highest level of education and income (Table 1). Hours driven per week became non-significant when post-stroke non-driving status was controlled for (t=0.643, df = 44 p=0.523).

When comparing the baseline profile of post-stroke drivers and post-stroke non-drivers, no differences were found in age, years of driving or individual income, but there was a significant difference in gender distribution (X2 =6.86 p=0.009) as all post-stroke female participants had ceased driving. A large proportion of post-stroke drivers reported having completed tertiary education (X2 =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.

Table 1. *Demographic information of post-stroke cohort and control groups*

Variables	Controls (N=22)		Post-Stroke Driver (N=24)		Post-Stroke Non-Driver (N=24)		F	p-value
	Mean	(SD)	Mean	(SD)	Mean	(SD)		
Age	64.8	6.7	67.8	17.7	68.2	7.8	0.555	0.577
License length in years	45.9	7.1	56.9	9.0	54.6	11.0	9.024	<0.005
Hours of driving per week	11.1	7.7	9.8	6.1	0	0		<0.005
Gender	(M=17), 77% (F = 5) 23%		(M=24) 100%		(M=18) 75% (F=6) 25%		X^2=6.85	0.032
Highest Education Level							X^2=19.7	0.003
Primary	0		(2) 8%		(8) 33%			
Year 10	(6) 27%		(3) 13%		(6) 25%			

Year 12	(2) 9%		(5) 21%		(6) 25%			
Tertiary	(14) 64%		(14) 58%		(4) 17%			
Income Level							X^2=13.86	0.008
≤$5,000	0		(4) 17%		(2) 8.3%			
$5,000 - $84,999	(3) 14%		(12) 50%		(8) 33.3%			
≥ $85,000	(19) 86%		(8) 33%		(14) 58.3%			
Hours of Driving (weekly)	11.1	7.7	9.82	6.1	N/A	N/A		0.523
Recovery period (month)	N/A		48.6	52.6	44.9	48.3	t=-0.25 (df 46)	>0.005
Declared stroke to authorities	N/A		Y=14 (58%)	N=10 (42%)	Y=14 (58%)	N=10 (42%)	X^2=0	>0.005
Received advice on driving	N/A		Y=14 (58%)	N=10 (42%)	Y=18 (75%)	N=6 (25%)	X^2=5.49	0.19

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 3). There was a significant between-group difference in performance on the MoCA, which is indicative of significant variance in cognitive deficits. 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.

Table 2. *Between groups results from one-way ANOVA analysis*

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

Assumptions of the current research were that the psychometric measures represented baseline 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* which explained 38.1% of the variance, was identified as an “overall cognitive score”, and was calculated for each participant in the following way:

* Overall cognition score = 0.87 *MoCA + 0.529 *Benton - .717 * TMT-B + .523 * RSRT -.249 * DVT (# errors) – .714 *DVT (# time)

All of the driving criteria measured as part of the simulator assessment were combined to form three variables: number of collisions (vehicle or roadway collisions, and pedestrians hit), driver errors (speed exceedances and traffic light tickets,) and unsafe driving manoeuvers (unsafe manoeuvring, centreline crossings, road edge excursions and inappropriate indicator use). A lower score indicated fewer errors and therefore better driving performance. The three driving variables and between-group differences are reported in Table 3.

Table 3. *Scores of Post-Stroke Drivers and Healthy Controls on the Simulated Driving*

Driving Score Criteria	Control (n=22) Mean(SD)	Post-Stroke (n=48) Mean(SD)	*t*-test	*df*	*p*-value
Number of Collisions	1.14 (0.83)	2.29 (1.15)	-4.76	55	<0.001
Driver Errors	11.18 (5.88)	15.46 (6.94)	-2.67	48	0.01
Unsafe Driving Manoeuvres	4.05 (1.53)	5.56 (2.44)	-3.16	61	0.002

The first component of PCA explained 67.57% of the variance of the overall driving performance score, therefore it was adopted and calculated as:

> Overall driving performance = .7465* Number of Collisions + .905 * Driver Errors + .808 Unsafe Driving Manoeuvres

Used in this way, the PCA aggregated 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).

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 ($F=8.08$, $df=2$, $p<0.01$) and overall cognitive performance ($F=31.78$, $df=2$, $p<0.0001$). Post-hoc analysis revealed significant differences in overall driving performance between the healthy controls and post-stroke non-drivers ($p<0.001$) and between the post-stroke drivers and post-stroke non-drivers ($p<0.05$). The control group demonstrated superior performance in the driving task when compared with the post-stroke drivers. In general, the post-stroke non-drivers scored worst among the three groups. The results also revealed significant differences between all groups for overall cognitive performance (see Table 4).

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 (L. Evans, 2004). It was found that there was no significant relationship between the two variables (R^2 = 0.063, F = 0.727, p = 0.579) in the post-stroke group.

Table 4. *Comparison of overall cognition and overall driving performance for all groups.*

Variable	Group	Mean (SD)	p-value	
			Post-Stroke Drivers	Post-Stroke Non-Drivers
Overall Driving Performance	Control	-0.53 (0.7)	0.079	<0.0001
	Post-Stroke Driver	0.54 (0.99)		0.027
	Post-Stroke Non-Driver	0.542 (0.98)		
Overall Cognition	Control	0.85 (0.66)	<0.001	<0.001
	Post-Stroke Driver	0.07 (0.83)		<0.001
	Post-Stroke Non-Driver	0.85 (0.67)		

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. 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 were no missing cases 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 the those in lower income groups. Tests for multicollinearity and tolerance statistics were conducted with no violation of assumptions.

Table 5. *Logistic regression model predicting driving cessation in post-stroke adults (95% CI based on 48 samples).*

	Odds Ratio	p-value	95% C.I. for Odds ratio	
			Lower	Upper
Education		.011		
Primary	0.010	0.001	0.001	0.174
Year 10	0.064	0.019	0.006	0.634
High School	0.132	0.048	0.018	0.980
University/Diploma	1 (reference)			
Income (annual in $)		0.027		
50000	36.929	0.021	1.734	786.643
50,000 – 84,999	9.372	0.021	1.393	63.068
85,000 or above	1 (reference)			
Constant	1.785	0.354		

Nagelkerke R^2 = 0.476; Cox & Snell R^2 = 0.357; pseudo R^2 = 0.672

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 3 shows a scatter plot of the overall driving performance scores for both drivers and non-drivers in the post-stroke group. The figure outlines that the differences in performance between groups. 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.

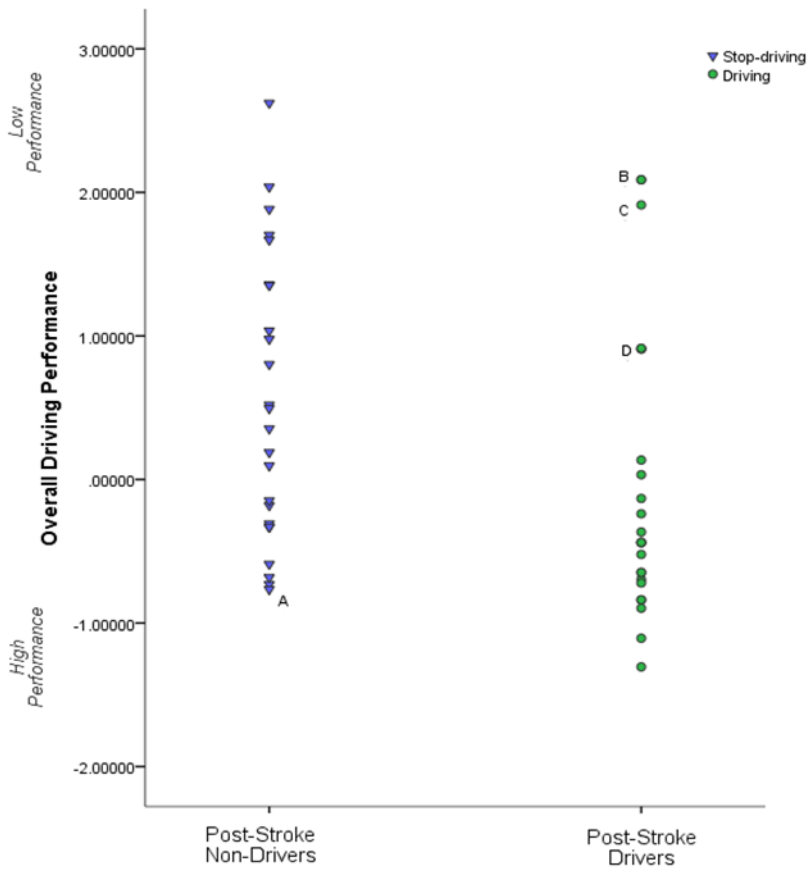

Figure 2. *A scatter-plot outlining the individual scores of post-stroke drivers in each group.*

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.

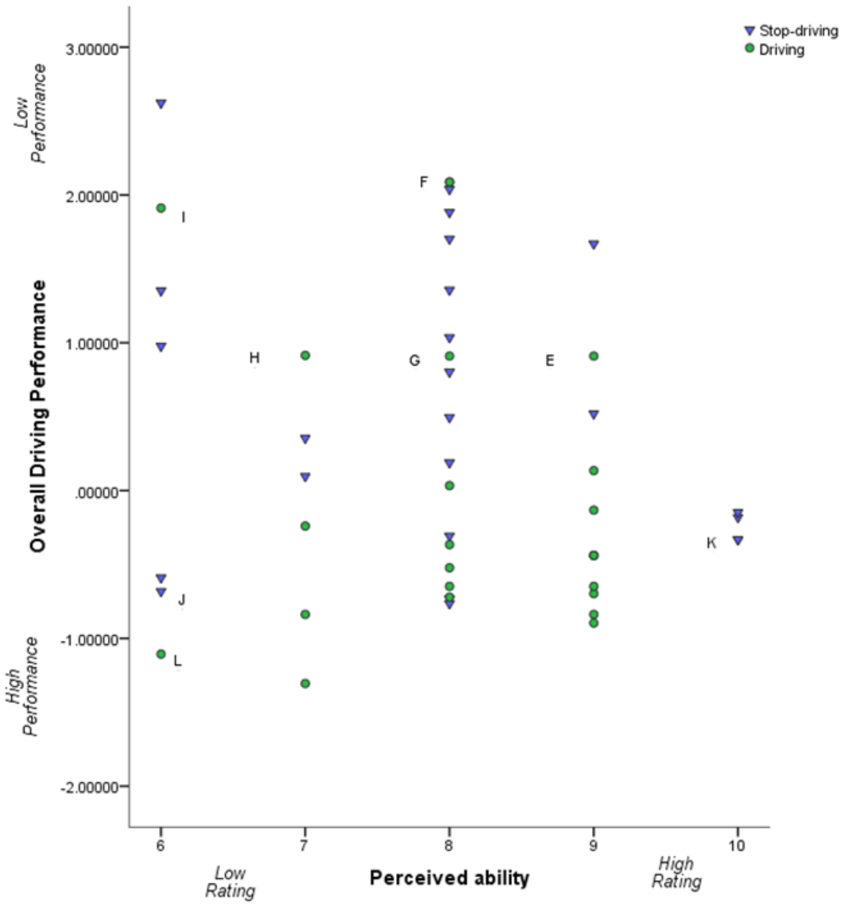

Figure 3. *A scatterplot of the post-stroke cohort individual scores of driving performance compared to perceived driving ability and separated by driving status.*

Overall, this finding may suggest either a lack of insight in stroke post-stroke drivers or a potential disregard for personal risk and has implications for reliance upon self-regulation practices.

Table 6. *Cross-tabulation analysis of social supports available for the post-stroke cohort depending on driving status.*

# Available drivers to help	**0**	**1**	**2**	**3**	**4**	**Total**
Post-Stroke Non-Driver	0	10	6	6	2	24
Post-Stroke Driver	8	8	4	2	2	24

Although the availability of social supports was not included in the final model, further cross tabulation analysis showed that all participants in this study who ceased driving after their stroke had social support, which consisted of family and friends, while 8/24 participants who had returned to driving post-stroke had no additional drivers to assist them. There were greater numbers of drivers available for the post-stroke non-driver group as outlined in Table 6. In addition, only 8% of the post-stroke drivers had the support of family whilst the other 92% reported that they relied on friends for support.

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 (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, & Lee, 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 decline was not a strong predictor of post-stroke driving performance.

Although the overall driving performance of post-stroke drivers 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.

In line with previous research investigating older drivers 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). 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 drivers lacked insight into their deteriorating performance as evidenced by their bias in self-rating and poorer performance. However, whether the cognitive stroke-related cognitive deficit caused this lack of insight could not be determined. Alternatively, 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, & Almeida, 2011).

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; David R 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 (Sherrilene 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 cross tabulations 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. Participants were recruited from a small section of the 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 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 (Ardila, Ostrosky-Solis, Rosselli, & Gómez, 2000; Arenaza-Urquijo et al., 2013; Beydoun et al., 2014; D. A. Evans et al., 1993). 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 (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, Cameron, et al., 2003; Lee, Lee, & Cameron, 2003; Stedmon et al., 2009) .

A mild degree of simulator sickness (SS) was reported by 4% of participants. This is within the normal incidence range of SS and no resulting measurements were missing as a results of SS. Previous studies on older adult drivers using a similar simulator have found that approximately 9% of individuals experience some SS when placed behind the wheel of the driving simulator (Lee, Cameron, et al., 2003). The low incidence of SS in this study was likely to be due to the configuration of the simulated driving scenario where sharp right angled turns and winding roads were avoided; as well as ensuring that the research laboratory was adequately ventilated (S. Classen et al., 2011).

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. Further research should consist of a development of a reliable screening tool that can use sound psychometric measures and driving simulator information to identify post-stroke adults at risk of unsafe driving practices.

6. Reference

1. Adler, G., & Rottunda, S. (2006). Older adults' perspectives on driving cessation. *Journal of Aging Studies, 20*(3), 227-235. http://dx.doi.org/http://dx.doi.org/10.1016/j.jaging.2005.09.003
2. Akinwuntan, A. E., Feys, H., De Weerdt, W., Baten, G., Arno, P., & Kiekens, C. (2006). Prediction of driving after stroke: a prospective study. *Neurorehabilitation and neural repair, 20*(3), 417-423.
3. Allen, R. W., Stein, C. A., Aponso, B. L., Rosenthal, T. J., & Hogue, J. R. (1990). A low cost, part task driving simulator based on microcomputer technology. *69th Annual Meeting of the Transportation Research Board., held in Washington, DC.*: Transportation Research Board.
4. Anstey, K. J., Wood, J., Lord, S., & Walker, J. G. (2005). Cognitive, sensory and physical factors enabling driving safety in older adults. *Clinical Psychology Review,*
5. Ardila, A., Ostrosky-Solis, F., Rosselli, M., & Gómez, C. (2000). Age-related cognitive decline during normal aging: The complex effect of education. *Archives of Clinical Neuropsychology, 15*(6), 495-513. http://dx.doi.org/http://dx.doi.org/10.1016/S0887-6177(99)00040-2
6. Arenaza-Urquijo, E. M., Landeau, B., La Joie, R., Mevel, K., Mézenge, F., Perrotin, A., . . . Chételat, G. (2013). Relationships between years of education and gray matter volume, metabolism and functional connectivity in healthy elders. *NeuroImage, 83*, 450-457. Retrieved from http://www.scopus.com/inward/record.url?eid=2-s2.0-84880949143&partnerID=40&md5=3956887b1e1cc6b682ec5ef91b7133eb
7. Benton, A. L., Hamsher, K., Varney, N. R., & Spreen, O. (1983). *Judgment of line orientation*: Oxford University Press New York.
8. Beydoun, M. A., Beydoun, H. A., Gamaldo, A. A., Teel, A., Zonderman, A. B., & Wang, Y. (2014). Epidemiologic studies of modifiable factors associated with cognition and dementia: Systematic review and meta-analysis. *BMC Public Health, 14*(1)Retrieved from http://www.scopus.com/inward/record.url?eid=2-s2.0-84904348791&partnerID=40&md5=ab0ae83513049f49163b68e5d30d60f4
9. Burns, P. C. (1999). Navigation and the mobility of older drivers. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences, 54*(1), S49-S55.
10. Classen, S., Bewernitz, M., & Shechtman, O. (2011). Driving simulator sickness: An evidence-based review of the literature. *American journal of occupational therapy, 65*(2), 179-188.
11. Classen, S., Wang, Y., Crizzle, A. M., Winter, S. M., & Lanford, D. N. (2012). Gender differences among older drivers in a comprehensive driving evaluation. *Accident Analysis and Prevention*, http://dx.doi.org/10.1016/j.aap.2012.10.010
12. Cordell, R., Lee, H. C., Granger, A., Vieira, B., & Lee, A. H. (2008). Driving assessment in Parkinson's disease—A novel predictor of performance? *Movement Disorders, 23*(9), 1217-1222. http://dx.doi.org/10.1002/mds.21762
13. Devos, H., Akinwuntan, A. E., Nieuwboer, A., Tant, M., Truijen, S., De Wit, L., . . . De Weerdt, W. (2009). Comparison of the effect of two driving retraining programs on on-road performance after stroke. *Neurorehabilitation and Neural Repair, 23*(7), 699-705.

14. Dickerson, A. E., Reistetter, T., Davis, E. S., & Monahan, M. (2011). Evaluating driving as a valued instrumental activity of daily living. *American Journal of Occupational Therapy, 65*(1), 64-75.
15. Donorfio, L. K., D'Ambrosio, L. A., Coughlin, J. F., & Mohyde, M. (2009). To drive or not to drive, that< i> isn't</i> the question—the meaning of self-regulation among older drivers. *Journal of safety research, 40*(3), 221-226.
16. Evans, D. A., Beckett, L. A., Albert, M. S., Hebert, L. E., Scherr, P. A., Funkenstein, H. H., & Taylor, J. O. (1993). Level of education and change in cognitive function in a community population of older persons. *Annals of Epidemiology, 3*(1), 71-77. http://dx.doi.org/http://dx.doi.org/10.1016/1047-2797(93)90012-S
17. Evans, L. (2004). *Traffic safety / Leonard Evans*. Bloomfield, Michigan: Science Serving Society.
18. Fisk, G. D., Owsley, C., & Pulley, L. V. (1997). Driving after stroke: Driving exposure, advice, and evaluations. *Archives of Physical Medicine and Rehabilitation, 78*(12), 1338-1345. http://dx.doi.org/http://dx.doi.org/10.1016/S0003-9993(97)90307-5
19. Fonda, S. J., Wallace, R. B., & Herzog, R. A. (2001). Changes in driving patterns and worsening depressive symptoms among older adults. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences, 56*(6), S343-S351.
20. Freund, B., Colgrove, L. A., Burke, B. L., & McLeod, R. (2005). Self-rated driving performance among elderly drivers referred for driving evaluation. *Accident Analysis & Prevention, 37*(4), 613-618.
21. Galski, T., Ehle, H. T., McDonald, M. A., & Mackevich, J. (2000). Evaluating fitness-to-drive after cerebral injury: Basic issues and recommendations for medical and legal communities. *The Journal of Head Trauma Rehabilitation, 15*(3), 895-908.
22. Griffen, J. A., Rapport, L. J., Bryer, R. C., & Scott, C. A. (2009). Driving status and community integration after stroke. *Topics in stroke rehabilitation, 16*(3), 212-221.
23. Heikkilä, V. M., Korpelainen, J., Turkka, J., Kallanranta, T., & Summala, H. (1999). Clinical evaluation of the driving ability in stroke patients. *Acta Neurologica Scandinavica, 99*(6), 349-355. http://dx.doi.org/10.1111/j.1600-0404.1999.tb07363.x
24. Horswill, M. S., Anstey, K. J., Hatherly, C., Wood, J. M., & Pachana, N. A. (2011). Older drivers' insight into their hazard perception ability. *Accident Analysis & Prevention, 43*(6), 2121-2127. http://dx.doi.org/http://dx.doi.org/10.1016/j.aap.2011.05.035
25. IBM Corporation. (2012). IBM SPSS Statistics for Windows, Version 21.0. Armonk, NY: IBM Corp.
26. Kelland, D. Z., & Lewis, R. F. (1996). The digit vigilance test: reliability, validity, and sensitivity to diazepam. *Archives of Clinical Neuropsychology, 11*(4), 339-344. http://dx.doi.org/10.1093/arclin/11.4.339
27. Kostyniuk, L. P., & Shope, J. T. (2003). Driving and alternatives: Older drivers in Michigan. *Journal of Safety Research, 34*(4), 407-414. http://dx.doi.org/http://dx.doi.org/10.1016/j.jsr.2003.09.001
28. Kulikov, E. (2010). The Social and Policy Predictors of Driving Mobility Among Older Adults. *Journal of Aging & Social Policy, 23*(1), 1-18. http://dx.doi.org/10.1080/08959420.2011.531991

29. Lee, H. C., Cameron, D., & Lee, A. H. (2003). Assessing the driving performance of older adult drivers: on-road versus simulated driving. *Accident Analysis & Prevention, 35*(5), 797-803.
30. Lee, H. C., Drake, V., & Cameron, D. (2002). Identification of appropriate assessment criteria to measure older adults' driving performance in simulated driving. *Australian Occupational Therapy Journal, 49*(3), 138-145. http://dx.doi.org/10.1046/j.1440-1630.2002.00314.x
31. Lee, H. C., & Lee, A. H. (2005). Identifying older drivers at risk of traffic violations by using a driving simulator: A 3-year longitudinal study. *The American Journal of Occupational Therapy, 59*(1), 97-100.
32. Lee, H. C., Lee, A. H., & Cameron, D. (2003). Validation of a driving simulator by measuring the visual attention skill of older adult drivers. *The American Journal of Occupational Therapy, 57*(3), 324. Retrieved from http://graphics.tx.ovid.com/ovftpdfs/FPDDNCLBAHJKIJ00/fs047/ovft/live/gv024/00000448/00000448-200305000-00010.pdf
33. Lee, H. C., Lee, A. H., Cameron, D., & Li-Tsang, C. (2003). Using a driving simulator to identify older drivers at inflated risk of motor vehicle crashes. *Journal of Safety Research, 34*(4), 453-459. http://dx.doi.org/http://dx.doi.org/10.1016/j.jsr.2003.09.007
34. Lewis, R., & Rennick, P. (1979). Manual for the repeatable cognitive-perceptual-motor battery. *Gross Point, MI: Axon,*
35. Lincoln, N., & Fanthome, Y. (1994). Reliability of the stroke drivers screening assessment. *Clinical Rehabilitation, 8*(2), 157-160.
36. Lister, R. (1999). Loss of ability to drive following a stroke: The early experiences of three elderly people on discharge from hospital. *The British Journal of Occupational Therapy, 62*(11), 514-520. Retrieved from http://www.ingentaconnect.com/content/cot/bjot/1999/00000062/00000011/art00006
37. Logan, P. A., Dyas, J., & Gladman, J. R. (2004). Using an interview study of transport use by people who have had a stroke to inform rehabilitation. *Clinical Rehabilitation, 18*(6), 703-708.
38. Lundberg, C., Caneman, G., Samuelsson, S. M., Hakamies-Blomqvist, L., & Almkvist, O. (2003). The assessment of fitness-to-drive after a stroke: The Nordic Stroke Driver Screening Assessment. *Scandinavian journal of psychology, 44*(1), 23-30.
39. MacGregor, J. M., Freeman, D. H., & Zhang, D. (2001). A Traffic Sign Recognition Test Can Discriminate Between Older Drivers Who Have and Have Not Had a Motor Vehicle Crash. *Journal of the American Geriatrics Society, 49*(4), 466-469. http://dx.doi.org/10.1046/j.1532-5415.2001.49095.x
40. Marottoli, R. A., de Leon, C. F. M., Glass, T. A., Williams, C. S., Cooney, L. M., & Berkman, L. F. (2000). Consequences of driving cessation: Decreased out-of-home activity levels. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences, 55*(6), S334-S340. http://dx.doi.org/10.1093/geronb/55.6.S334
41. Marshall, S. C., Molnar, F., Man-Son-Hing, M., Blair, R., Brosseau, L., Finestone, H. M., . . . Wilson, K. G. (2007). Predictors of driving ability following stroke: A systematic review. *Topics in Stroke Rehabilitation, 14*(1), 98-114. Retrieved from http://thomasland.metapress.com/content/38561t27257u7642/fulltext.pdf
42. Mathias, J. L., & Lucas, L. K. (2009). Cognitive predictors of unsafe driving in older drivers: A meta-analysis. *International Psychogeriatrics, 21*(04), 637-653.

43. Motta, K., Lee, H., & Falkmer, T. (2014). Post-stroke driving: Examining the effect of executive dysfunction. *Journal of Safety Research, 49*, 33.e31. http://dx.doi.org/10.1016/j.jsr.2014.02.005
44. Nasreddine, Z. S., Phillips, N. A., Bédirian, V., Charbonneau, S., Whitehead, V., Collin, I., . . . Chertkow, H. (2005). The Montreal Cognitive Assessment, MoCA: A brief screening tool for mild cognitive impairment. *Journal of the American Geriatrics Society, 53*(4), 695-699.
45. Odenheimer, G. L., Beaudet, M., Jette, A. M., Albert, M. S., Grande, L., & Minaker, K. L. (1994). Performance-based driving evaluation of the elderly driver: safety, reliability, and validity. *Journal of Gerontology, 49*(4), M153-M159. Retrieved from http://geronj.oxfordjournals.org/content/49/4/M153.full.pdf
46. Patomella, A.-H., Johansson, K., & Tham, K. (2009). Lived experience of driving ability following stroke. *Disability & Rehabilitation, 31*(9), 726-733.
47. Patomella, A.-H., Kottorp, A., & Tham, K. (2008). Awareness of driving disability in people with stroke tested in a simulator. *Scandinavian Journal of Occupational Therapy, 15*(3), 184-192.
48. Pendlebury, S. T., Cuthbertson, F. C., Welch, S. J. V., Mehta, Z., & Rothwell, P. M. (2010). Underestimation of cognitive impairment by Mini-Mental State Examination versus the Montreal Cognitive Assessment in patients with transient ischemic attack and stroke: A population-based study. *Stroke, 41*(6), 1290-1293. http://dx.doi.org/10.1161/strokeaha.110.579888
49. Perrier, M.-J., Korner-Bitensky, N., & Mayo, N. E. (2010). Patient factors associated with return to driving poststroke: findings from a multicenter cohort study. *Archives of physical medicine and rehabilitation, 91*(6), 868-873.
50. Ponsford, A.-S., Viitanen, M., Lundberg, C., & Johansson, K. (2008). Assessment of driving after stroke—a pluridisciplinary task. *Accident Analysis & Prevention, 40*(2), 452-460.
51. Qualls, C. E., Bliwise, N. G., & Stringer, A. Y. (2000). Short forms of the Benton Judgment of Line Orientation test: Development and psychometric properties. *Archives of Clinical Neuropsychology, 15*(2), 159-163. http://dx.doi.org/http://dx.doi.org/10.1016/S0887-6177(98)00043-2
52. Radford, K. A., & Lincoln, N. B. (2004). Concurrent validity of the stroke drivers screening assessment. *Archives of physical medicine and rehabilitation, 85*(2), 324-328.
53. Ragland, D. R., Satariano, W. A., & MacLeod, K. E. (2004). Reasons given by older people for limitation or avoidance of driving. *The Gerontologist, 44*(2), 237-244.
54. Ragland, D. R., Satariano, W. A., & MacLeod, K. E. (2005). Driving cessation and increased depressive symptoms. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences., 60*(3), 399-403.
55. Reitan, R. M., & Wolfson, D. (1985). *The Halstead-Reitan neuropsychological test battery: Theory and clinical interpretation*: Neuropsychology Press Tucson, AZ.
56. Rudman, D. L., Friedland, J., Chipman, M., & Sciortino, P. (2006). Holding on and letting go: The perspectives of pre-seniors and seniors on driving self-regulation in later life. *Canadian Journal on Aging, 25*(1), 65-76.
57. Scheffer, M., Monteiro, J. K., & Almeida, R. M. M. d. (2011). Frontal stroke: problem solving, decision making, impulsiveness, and depressive symptoms in men and women. *Psychology & Neuroscience, 4*(2), 267-278.

58. Selander, H., Lee, H., Johansson, K., & Falkmer, T. (2011). Older drivers: On-road and off-road test results. *Accident Analysis and Prevention. , 43* (4), 1348-1354.
59. Stedmon, A., Young, M., & Hasseldine, B. (2009). *Keeping it real or faking it: The trials and tribulations of real road studies and simulators in transport research.* Paper presented at the Contemporary Ergonomics 2009: Proceedings of the International Conference on Contemporary Ergonomics 2009
60. Unsworth, C. A., Wells, Y., Browning, C., Thomas, S. A., & Kendig, H. (2007). To continue, modify or relinquish driving: Findings from a longitudinal study of healthy ageing. *Gerontology*, *53*(6), 423-431. Retrieved from http://www.karger.com/DOI/10.1159/000111489