Driving and Cognitive Functioning:

Does Age Matter?

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Abstract

There is an established relationship in the literature between cognitive functioning and driving performance in older drivers and new evidence suggests that this relationship also exists in younger drivers. Given this, it follows that this relationship may exist for all drivers, however the relationship between cognitive function and driving in drivers in middle adulthood has not yet been examined. This study therefore aims to examine this relationship in drivers in middle adulthood, and thereby fill the gap in the literature. A secondary aim was to apply a neurocognitive model of driving to this driver group. The participants were 88 drivers aged between 24 and 65. Each participant was assessed on a battery of cognitive tests and completed a drive on a driving simulator. Measures of driving performance included speeding, lane deviation, and an overall driving performance score. The results showed new evidence to suggest that overall cognitive function can predict speeding and overall driving performance. There is preliminary evidence to suggest that a neurocognitive model of driving can explain speeding in drivers in middle adulthood. Future research should focus on the development of a comprehensive model to explain driving performance across all ages and across disciplines.

Declaration of Originality

I hereby confirm that all material contained in this project are my original authorship and ideas, except where the work of others has been acknowledged or referenced. I also confirm that the work has not been submitted for a higher degree to any other university or institution. The research project was approved by the Macquarie University Human Research Ethics Committee (Approval No. 5201600872).

Signed: 

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Driving and Cognitive Functioning: Does Age Matter?

Cognitive function encompasses a large range of skills involving mental processes which can be categorised into separate cognitive domains. These skills are crucial to the performance of everyday tasks (Wesson, Clemson, Brodaty, & Reppermund, 2016). In older adults and those who suffer from cognitive impairment, decline in these abilities leads to difficulty accomplishing complex activities (Gross, Rebok, Unverzagt, Willis, & Brandt, 2011). Driving is one such complex activity which, to be carried out safely, requires the proper functioning of a wide variety of cognitive skills. There is a high level of risk associated with driving, due to the potential of a serious consequence such as property damage, severe injury or fatality (National Roads and Motorists' Association, 2012). It is for this reason that a substantial body of literature has been dedicated to investigating the factors that influence driving proficiency. However, while there is extensive research on the influence of cognitive factors on driving performance in those known to experience cognitive decline, such as older drivers (aged above 65) and those with neurological disorders, there is limited research examining this relationship in younger drivers (aged under 25) and no studies to date investigating this in drivers in middle adulthood (aged between 25 and 65).

In this study, we will attempt to extend on what is already known of the relationship between cognitive functioning and driving and investigate this into the middle adulthood driver group in whom the link has not yet been studied. This will be examined by both, attempting to replicate results of previous research into both younger and older drivers, and also by examining the applicability of a neurocognitive model, the Information Processing Model of Driving Errors developed by Uc and Rizzo (2008), to drivers in middle adulthood.

Cognitive Development Over the Lifespan

It is firstly necessary to review current knowledge about the developmental trajectories of each cognitive domain as this has implications for how cognitive function may influence driving performance across the lifespan. The cognitive domains which have previously been found to be related to driving performance will therefore be examined and include: attention and processing speed, executive function, visuospatial skills, memory, psychomotor function, and mental status (Reger et al., 2004; Uc & Rizzo, 2008).

Attention and processing speed. Attention can be described broadly as the capacity of an individual to focus on information that is relevant to the current task whilst ignoring any distractors (Mathias & Wheaton, 2007). Processing speed refers to the rate at which mental operations are performed, and is often grouped with attention due to the difficulty in untangling the two skills in cognitive testing (Mathias & Wheaton, 2007). McAvinue and colleagues (2012) investigated age-related effects in sustained attention, attentional selectivity, and attentional capacity in 113 participants aged between 12 and 75. They found that while attentional selectivity and attentional capacity peaked in the teens or early 20s and then showed a linear decline, children and teens showed poor performance in sustained attention which rose and then plateaued in young adulthood to middle adulthood, before declining again in old age. When comparing the rate of this decline, the greatest effect size was found for attentional capacity (d = 1.67, r = .6) followed by sustained attention (d = 0.9, r = .4) then attentional selectivity (d = 0.52, r = .33). The rate of decline in attentional capacity and selectivity were found to differ significantly, demonstrating that age had differential effects on separate subskills of attention. The finding that attentional capacity was most affected by age is similar to that of Amodio and colleagues (2002) whom created norms for some well-known tests of attention, the Trail-Making

Tests (TMT) and the Symbol Digit Test. In this study, it was shown that each test showed a steady decline from the age of 20 through to 80, however the decline relative to age was greater in the TMT Part B when compared to the TMT Part A as the former two tests involve shifting ability which requires greater attentional capacity. In summary, it seems that attention reaches peak function in the 20s, and then begins to decline, with varying rates of decline evident for the different sub-types of attention.

Verbal and visual processing speed in 18 to 90-year-olds was assessed by Lawrence, Myerson, and Hale (2010). In this study 131 participants performed four verbal and four visual speed based tasks. The authors found that while both visual and verbal task performance became poorer with each decade of age, visual processing ability declined exponentially and to a much greater extent from age 18 to 90 than verbal processing ability which showed a linear decline. By age 90, the decline in visual task performance was ten times that of the decline in verbal task performance. Park et al. (2002) also tested speed of processing which showed a similar pattern of decline beginning in the 20s. This research indicates that processing speed mediated all age-related variation in the results for processing-intensive tasks. The overall findings suggest that the decline in processing speed begins by the mid to late 20s.

Executive function. Executive function can be described as goal-directed behaviour which includes skills such as planning, organising, problem-solving, self-monitoring, and decision making (Miller & Cohen, 2001; Zelazo, Carter, Reznick, & Frye, 1997). These are higher order skills which require the integration of information from different cognitive domains so one can execute more complex tasks. De Luca and colleagues' (2003) study examines several of these components of executive functioning across ages 8 to 64 in 194 participants. They found that goal-directed behaviour and strategic planning behaviour was at peak performance in those aged between 20 and 29 before declining. Similarly, the youngest and oldest participants are reported to have had poor working memory and poorer sequence selection, but in contrast to this, set-shifting abilities were found to have matured by age 8 to 10 and no decline was observed in the older age groups. Zelazo, Craik, and Booth (2004) assessed three groups, children (*M* = 8.8 years), young adults (*M* = 22.3 years), and elderly adults (*M* = 71.7 years) on both visual and auditory sorting tasks and reported a U-shaped function for visual sorting ability, with both children and elderly adults making more errors than the young adults. However, when examining the results for the auditory sorting task, while children were found to make more errors than the young or elderly adults, no difference in performance was found between the two adult groups. The overall development trajectory of executive functioning varies across studies and measures, however young adults generally perform either the same or better than children or older adults.

Visuospatial skills. Visuospatial function refers to the ability to process visual information and engage with your surroundings by accurately perceiving the environment (Miyake, Friedman, Rettinger, Shah, & Hegarty, 2001). Salthouse (2009) investigated when decline in functioning began for several cognitive domains including visuospatial skills. After assessing up to 295 participants aged between 18 and 60, longitudinally over a maximum of seven years, Salthouse found that visuospatial skills began declining in the 20s to early 30s. The author also found a similar result for memory and processing speed tests included in the study. In another study which assessed older adults aged 64 to 94, visuospatial function was assessed by comparing performance in adults aged up to 74 and those aged 75 and above (Libon et al., 1994). The results showed significantly poorer performance in the older age group in visuospatial function when compared to the younger of the older adults. Park et al. (2002) have found visuospatial memory to decline from the 20s through to the 80s, and Lawrence et al. (2010)

reported that visuospatial processing speed declines steadily between the ages of 20 and 90. Both studies compared the relative decline in visuospatial skill based tasks with verbal memory and verbal processing speed respectively. They found that the decline in performance in visuospatial tasks was always greater than in verbal tasks across the lifespan. Jenkins, Myerson, Joerding, and Hale (2000) similarly compared the difference in performance in visuospatial and verbally based processing speed, working memory, and learning tasks between young adults and older adults. It was observed that visuospatial skill based tasks showed a greater relative decline compared to verbally based tasks regardless of what the task was, and concluded that this decline was domain-specific to visuospatial cognition, which is more age-sensitive than verbal cognition. Overall, it is evident that visuospatial skills begin to decline sometime in the 20s, continuing on through to old age.

Memory. Memory refers to the way in which information is encoded and retrieved and has several subtypes including, working, short-term, and long-term memory. It is often categorised into visual or verbal memory tasks, and semantic memory and episodic memory. Park et al. (2002) investigated performance in visual and verbal memory for long-term, short-term, and working memory across 345 adults aged between 20 and 92. The results showed a steady decline in performance in all measures across the lifespan beginning in the 20s, except for in tasks testing verbal knowledge such as vocabulary tests. Similarly, Jenkins et al., (2000) compared the working memory of young adults compared to older adults and found that older adults had poorer visual and verbal working memory than young adults. However, no difference was observed between visual working memory and verbal working memory performance in older adults, while a large difference was observed between the two tasks in young adults, who had better visual working memory than verbal working memory. This finding therefore suggests that visual working memory undergoes a larger decline across age compared to verbal working memory. In contrast with these results, episodic memory and semantic memory does not show such a clear decline in performance early in life. Rönnlund, Nyberg, Bäckman, and Nilsson (2005) assessed both semantic and episodic memory in 829 adults aged 35 to 80, five years apart, and found that performance increased in semantic memory up to age 55 and in episodic memory up to age 60 before beginning a gradual decline in old age. They also observed that general knowledge did not show signs of declining until age 70. The developmental trajectory of memory function varies widely depending on which type of memory is being observed, and also on whether the memory tasks are verbal or visually based tasks. There is evidence that working, short, and long-term memory begins to decline from the 20s if the task is a visual task, while performance in all forms of verbal memory tasks seem to plateau until middle age. Similarly, semantic and episodic memory also does not show a decline until after older adulthood.

Psychomotor function. Psychomotor function can be defined as the mental coordination between vision and motor function, and includes a reaction time component (Eby, Trombley, Molnar, & Shope, 1998). Spirduso (1980) reviewed psychomotor functioning in early adulthood to late adulthood and found that younger adults were generally faster in reaction time and motor tasks. In support of this finding, Rees, Allen, and Lader (1999) investigated the effects of caffeine on psychomotor function across two groups; younger adults aged 20 to 25, and older adults aged 50 to 65. The authors report that younger drivers' psychomotor performance was better overall in both the pre-test and post-test compared with the older adult group. In conclusion, there is evidence to suggest that younger adults outperform older adults on psychomotor tasks suggesting that decline in this cognitive domain occurs sometime throughout adulthood, however when this occurs is currently unknown.

Mental status. Mental status is a measure of overall cognitive function that assesses skills across several cognitive domains (Kurlowicz & Wallace, 1999). Tests of mental status are typically used to assess the functioning of those suffering cognitive impairment (Reger et al., 2004). The assessments are limited in that they do not allow for a comprehensive examination of any single cognitive domain; however, they are useful in determining an overall capacity for daily functioning as most tasks require the integration of multiple cognitive domains. The Mini-Mental Status Exam (MMSE) is a common test of mental status and is used in clinical populations who experience cognitive deficits such as those who suffer Alzheimer's disease or Parkinson's disease (Kukull et al., 1994; Zadikoff et al., 2008). Two studies which aimed to establish age-related norms for the MMSE found a gradual decline in performance as age increased, with a median score of 29 out of 30 for those aged between 20 and 60, declining to a median score of 25 or 26 for those above the age of 80 (Bleecker, Bolla-Wilson, Kawas, Agnew, 1988; Crum, Anthony, Bassett, & Folstein, 1993). A more recent study by Gluhm and colleagues (2013) compared the MMSE with another assessment of mental status in 254 participants aged 20 to 89, and found a modest decline in both tests with age. Generally, it seems that mental status declines moderately as age increases.

Cognitive development summary. The developmental trajectories of each of the cognitive domains generally follows a trend of peak functioning being achieved in the teens or twenties, however the age at which decline becomes significant is less easy to generalise across domains. This is because some skills such as working memory shows immediate decline in functioning from the 20s (Park et al., 2002) while sustained attention was found to plateau across young and middle adulthood before declining in older adults (McAvinue et al., 2012). The rate of decline also varied across cognitive domains as well as within domains, as observed in the comparison between visual and verbal processing speed where visual processing speed declined at a much greater rate than verbal processing speed (Lawrence et al., 2010). There are some exceptions to these general observations, such as in set-shifting abilities, a component of executive function, which were found to have matured by age 10 with no decline in performance observed with older age (De Luca et al., 2003). Similarly, performance in visual and auditory sorting tasks, another executive function based task, increased between children to young adults, however no decline was observed in the auditory sorting task in older age compared to a significant decline in older adults in the visual sorting task (Zelazo et al., 2004). Finally, verbal knowledge was the only skill that was shown to steadily increase throughout the lifetime (Park et al., 2002).

To summarise, the development of cognitive function is heterogeneous between the cognitive domains as well as within them. However, in general children's and adolescents' cognitive function is on the incline with a peak in functioning observed in around the 20s. Performance in middle adulthood most typically saw either little change or declines in performance though rates of decline varied. In most cases for older adults, test performance was continuing to decrease as cognitive functioning began a steeper decline.

The implication of varied function in cognitive skills lies in its relationship with an individual's ability to accomplish everyday tasks. In extreme cases, such as in those with neurological disorders which are characterised by a severe decline in cognitive function, the deficits in these skills impact upon an individual's capacity to accomplish everyday tasks. Alzheimer's disease, a type of dementia, for example is characterised by a steady decline across the cognitive domains, the most commonly known of which is memory, and one criterion for the diagnosis of dementia is a functional decline in everyday tasks (Gross et al., 2011). Within the assessment of everyday functioning are tasks that can range from being as simple as making toast with butter and jam or choosing clothes for a rainy day, to complex such as managing finances or medication (Wesson, et al., 2016). Driving is a good example of an activity that people frequently participate in, which is cognitively complex and is therefore susceptible to changes in performance with changes in cognitive function.

Driving Statistics

Driving is an activity which millions of people engage in everyday, worldwide. It is also one of the most dangerous activities people regularly undertake, and for those aged between 1 and 44 years of age in Australia, land transport accidents are in the top three leading causes of death (Australian Institute of Health and Welfare (AIHW), 2017). Over 35,000 individuals were hospitalised with injuries resulting from road vehicle traffic crashes in 2013 (AIHW, 2017), and 1,300 road deaths were reported across Australia in 2016 (Bureau of Infrastructure, Transport, and Regional Development (BITRE), 2016). In addition to this, there is a large economic cost associated with road crashes in Australia, estimated at $27 billion per annum (Department of Infrastructure and Regional Development, 2017).

Due to the severe consequences of being involved in an accident, there is a wide expanse of research with a focus on investigating factors that influence crash risk. Two driver groups which have received considerable attention are the age groups that lie at either end of the spectrum i.e., the young, aged below 25; and the old, aged over 65. Younger and older drivers both have a high “crash risk” as these two groups are disproportionally represented in crash statistics (Ryan, Legge, & Rosman, 1998). Ryan et al. found that younger drivers had the highest crash risk overall when comparing rates of licensure across age groups, but that crash involvement for older drivers was similar to younger drivers after adjusting for distance travelled. McGwin and Brown (1999) reported that younger and older drivers are the most likely to be considered at-fault in collisions with injuries as well as fatalities. This pattern is still visible in the crash statistics today with fatalities in younger groups at 7.7 people per 100,000, and older groups at between 5.9 to 9.7 people per 100,000. This is compared to fatalities in those aged between 26 and 64 lying between 5.0 and 5.7 people per 100,000 in 2015 (BITRE, 2015).

The current literature on factors influencing driving performance in younger drivers has been largely focused on experience, personality factors, and social cognitive factors (Ulleberg & Rundmo, 2003). Young drivers have been found to have elevated crash risk in the first year after licensure, and in the first 500 miles after licensure (McCartt, Shabanova, & Leaf, 2003). Some studies have shown that novice drivers have slower and less efficient hazard perception, (Deery, 2000; Borowsky, Shinar, & Oron-Gilad, 2010) however Sagberg and Bjørnskau (2006) measured hazard detection reaction times between novice drivers who were one to nine months post licensure and although they observed declines, all differences failed to reach significance. One possible explanation for this is simply that the difference in eight months of driving is too small to observe, and that significant declines may be seen in hazard detection times between drivers who are one month and one year or two years post licensure, for example.

Personality variables found to relate to driving performance in young drivers include sensation-seeking, aggression, and anxiety as well as altruism (Machin & Sankey, 2008; Ulleberg 2001; Ulleberg & Rundmo, 2003). The social cognitive factors which have been found to relate to crash risk include perception of risk, attitudes towards traffic safety, and propensity to take part in risk driving behaviours (Ulleberg & Rundmo, 2003; Zhang, Fraser, Lindsay, Clarke, & Mao,1998). A model proposed by Ulleberg and Rundmo includes all factors which have been established as influencing risky driving behaviour in young drivers. These factors were comprised primarily of personality variables including anxiety, aggression, and sensation-seeking, and social-cognitive factors such as risk perception, and attitudes towards traffic safety. The model suggests that while social-cognitive factors directly influence risky driving behaviour, personality traits influence driver behaviour indirectly through their influence on social-cognitive factors such as risk perception.

In contrast to the types of variables investigated in younger drivers, the literature surrounding older driver driving performance and crash risk is heavily focused on cognitive factors, vision, and physical function (Anstey, Wood, Lord, & Walker, 2005). In Anstey and colleagues' review of factors enabling safe driving in older drivers, cognition is investigated as one of the most important factors contributing to driving competence. Cognitive functioning is important in determining driving proficiency for older drivers due to the thoroughly documented decline in cognitive abilities that come with age.

Given that road accidents are amongst the leading causes of death in those aged under 44, there has been relatively little research that has investigated the main factors influencing driving safety in drivers in middle adulthood. Drivers in middle adulthood have not received as much focused attention in the driving literature as the younger and older driver groups because of their comparatively lower crash risk. Although there are many studies which include drivers in middle adulthood in their samples, the studies are often non-specific with regards to age and it is therefore difficult to draw conclusions for the middle age driver group alone. For example, Mets and colleagues (2011) investigating the effect of prescription drugs for treatment of insomnia on highway driving, only report an inclusion criteria of 21 to 55 years in reference to the participants' ages. Similarly, a study investigating personality factors such as aggression, and sensation-seeking in adult drivers used a sample of college students from an introductory psychology course with ages ranging from 21 to 51 (Schwebel, Severson, Ball, & Rizzo, 2006). As seen in these two studies, the participants' age range included both young adult drivers and drivers in middle adulthood, meaning no conclusions about the drivers in middle adulthood specifically can be made.

One factor which may be exacerbating this issue of non-specificity with regards to the age of participants, and lack of representation for drivers in middle adulthood in driving studies, is the method of recruitment used for this research. In Neubauer, Matthews, Langheim, and Saxby's (2012) study investigating fatigue and automation in driving, the participants were recruited from an introductory psychology research pool, and the age range for this sample was 18 to 30 years. Although the research topic was non-specific with regards to the age of the driver, due to the recruitment method relying on undergraduate psychology students, the sample falls more in the young adult driver category than in the middle adulthood driver category. For studies investigating non-clinical samples, and where age is not a variable of interest, this may be a common occurrence. Of the studies in the driving literature which do not directly investigate the influence of age, there are some which do include drivers in middle adulthood, these being studies which have a focus on driver experience. One example of this type of study is Klauer and colleague's (2014) study of distraction in novice and experienced drivers. In this particular study however, the experienced driver group had the opposite problem as in the above studies, with ages ranging from 18 to 72 years and therefore including drivers in middle adulthood and older drivers together. There are occasions where they are treated as their own group, but are not the focus of the study. An example of this, which is relevant to the current study, Dawson, Uc, Anderson, Johnson, and Rizzo (2010) investigated the relationship between cognitive function and driving performance in older drivers, who were the focus of the research, as well as middle-aged drivers. In this study, middle-aged drivers were included as a control group for the older drivers as a point of comparison for cognitive test scores and numbers of driving errors. However, while the relationship between these two variables was examined for the older driver group, this relationship was not analysed for the middle-aged driver group. In many studies, drivers in middle adulthood are excluded all together. Strayer and Drews' (2004) study on driver distraction included a younger driver and an older driver sample however there was no representation for the ages between 26 and 64. The reason for this is most likely as mentioned above: there is more interest surrounding younger and older driver groups due to their higher crash risk, and drivers in middle adulthood are therefore neglected as their own age category in the literature.

Driving and Cognitive Function

Cognitive function is normally distributed across the population, meaning there are individual differences in cognitive abilities, with those on the extreme low ends prohibited from driving. However, this raises the question of what the influence of individual differences in cognition are on the driving performance of "normal" adults.

The link between cognitive functioning and driving performance has been most widely investigated in the older driver age group whose performance across the cognitive domains related to driving performance is known to decline. There have also been numerous studies examining the relationship in clinical samples who typically experience cognitive deficits, such as those with Alzheimer's disease and Parkinson's disease (Anderson et al., 2012; Dawson, Anderson, Uc, Dastrup, & Rizzo, 2009; Reger et al., 2004). These two population groups provide the bulk of the evidence in support of a relationship between cognitive functioning and driving ability.

Driving is an activity which is time sensitive and involves many potential distractors amongst cues and stimuli which are necessary to enable safe driving decisions. For example, a driver may be required to attend to road signs or traffic lights which need to be adhered to, or may need to recognise potential hazards such as pedestrians amongst a visually complex scene. Any responses, especially to sudden hazards, require a timely response and failure to either detect the hazards or respond swiftly can quickly result in serious consequences for road users. It is for this reason that attention and processing speed have been a focus of a great number of studies (Reger et al., 2004). Anderson, Rizzo, Shi, Uc, and Dawson (2005), and Reger and colleagues, found significant relationships between performance on attention tasks and driving performance. In the former study, scores on the TMTA were significantly related to the propensity to crash in a crash-avoidance scenario, as well to an overall driving performance score. Reger and colleagues found moderate effect sizes in Alzheimer's disease samples and smaller effect sizes in healthy older adults between performance on attention based tasks and driving performance. In summary, there is an established relationship between measures of attention and processing speed, and driving performance.

Executive function is an important cognitive skill in the driving process that integrates information from all other cognitive domains and may inform decisions such as route choice, gap selection, and adherence to road rules. Molnar, Patel, Marshall, Mon-Song-Hing, and Wilson (2006) have previously reported that the TMTB is the most commonly used assessment of executive function in driving studies. The TMTB was found to be significantly related to simulated driving ability in a study by Anderson et al. (2005), while Marshall et al. (2007) and Grace et al. (2005) found the TMTB was related to on-road driving performance in a sample of drivers following stroke, and in those suffering Parkinson's disease respectively. Reger and colleagues also reported a significant relationship between executive functioning and driving performance in both on-road and non-road driving measures (such as simulated drives or driver knowledge tests) with poorer driving performance associated with a decline in executive functioning. These findings suggest a significant relationship between executive function and driving performance across different measures of driving competence, and across cognitively healthy and those with cognitive impairment driving populations.

As driving is a highly visual task, it is logical to suggest that any deficit in visuospatial skills will impact upon performance. Before a driver can manipulate their vehicle within their environment it is first necessary to accurately perceive the visual scene. Maintenance of lane position and speed is dependent upon the constant renegotiation between visual input and execution of driving decisions. In clinical samples, that is, those who suffer from Alzheimer's and Parkinson's disease, and healthy older adults, visuospatial functioning was predictive of the number of safety errors made whilst driving (Aksan, Anderson, Dawson, Uc, & Rizzo, 2015; Dawson et al., 2009). The Dawson et al. study in particular found that measures of both visuospatial and motor responses were the best predictors of driver errors in drivers with Alzheimer's disease and older adults without dementia. The Alzheimer's disease sample performed significantly worse across most cognitive tests compared with the older driver sample, and only a measure of lane deviation differed significantly between the two groups. In a subsequent study Dawson et al. (2010) investigated the relationship between cognitive functioning and driving errors in older adults, with a middle-aged control group. The results of this study showed that older drivers committed significantly more driving errors compared to the middle-aged group, and performed significantly worse across the vast majority of cognitive tests compared to the middle-aged group. The relationship between cognitive test scores and driving errors was analysed for the older driver group, revealing the strongest associations between driving errors and tests of visuospatial and visuomotor skills. In both studies, the authors concluded that visuospatial and motor skills are required to enable safe driving, and that driving performance is impacted most by deficits in these skills. Further evidence for this is demonstrated in a brain injured sample, where visuospatial skills were predictive of whether drivers passed or failed a driving test (Schanke & Sundet, 2000). Anderson et al. (2005) found a significant relationship between measures of visuospatial skills and their overall composite measure of simulated driving performance, which is in line with Reger and colleagues' (2004) findings that the largest effect sizes (.56) were found for non-road driving measures in both Alzheimer's disease samples and in healthy older adults. The literature shows evidence for a strong relationship between visuospatial skills and driving performance across driver populations.

In the context of driving, memory is used to recall routes and destinations, knowledge from past experiences driving, the understanding of road rules and signs, and how to operate a vehicle. Anderson et al. (2005) found that visual and verbal memory was related to a composite score of driving performance from a simulated drive in those with mild dementia as well as in age matched controls. Reger and colleagues' (2004) meta-analysis collated data on the relationship between several cognitive measures and several types of driving measures in older adults with and without Alzheimer's disease. Moderate effect sizes are reported for both on-road (.44) and non-road (.44) measures of driving in a group including both healthy adults and those with Alzheimer's disease. These findings demonstrate a consistent relationship between memory and several different measures of driving competence.

Driving is an activity that has a strong physical component, such as when drivers turn the steering wheel, apply the brakes, or change gears. The seamless coordination between visuospatial skills, processing speed, and motor function is required for safe driving. Psychomotor skills refer to the speed and accuracy with which motor tasks are carried out, and in the driving context may include the ability to simultaneously coordinate steering and braking or accelerating, brake quickly in response to hazards, or steer accurately whilst turning corners or merging through traffic. The grooved pegboard test is a measure of psychomotor skills which has found to be related to several measures of driving safety. Anderson et al. (2012) found a significant moderate relationship (-.40) between scores on the Grooved Peg Board and driving errors in cognitively healthy older adults, and those with Alzheimer's, Parkinson's disease or stroke. Poorer performance on the Grooved Peg Board was associated with an increased number of driving errors. Alosco, Spitznagel, Cleveland, and Gunstad (2013) found that number of collisions in a simulated drive was related to the Grooved Peg Board in patients with heart failure, a condition associated with some cognitive decline. Finally, Aslaksen, Ørbo, Elvestad, Schäfer, and Anke (2013) reported that scores on the grooved pegboard test along with two other measures of attention and reaction time were able to categorise a sample of people who have experienced stroke or traumatic injury as either safe or unsafe with an accuracy of 82.1%. Overall, there is consistent evidence to suggest that psychomotor function is significantly related to driving performance across several measures of driving competence, and within several different driver groups.

As mental status is a measure of overall cognitive functioning, it follows that scores on the MMSE, the most common test of mental status, should be associated with driving performance given the abundance of literature that supports relationships between all of the cognitive domains mentioned above. Adler, Rottunda, and Dysken (2005) reviews 11 studies on the use of the MMSE with dementia patients and recommended that those who scored 24 or below be referred on for further driving evaluation. Shua-Haim and Gross (1996) were able to predict failure on a simulated drive with scores of 22 or below in the MMSE, and Fitten and colleagues (1995) report negative correlations between MMSE scores and on-road driving performance. Taken together, these findings support the notion that mental status is significantly related to driving performance.

Overall Cognitive Function and Driving

The evidence for each of these different cognitive domains suggests that the relationship between cognitive function and driving performance is multidimensional, and cannot be investigated in terms of single cognitive domains alone. However even though tests of mental status are designed to test overall cognitive functioning, because they have been shown to have lower levels of sensitivity, they are not sufficient for use in measuring the relationship between cognitive function and driving performance overall. As a result, some researchers have suggested that an overall measure of cognitive functioning is necessary, arguing that it is the best and most consistent predictor of driving performance when compared to measures on individual cognitive domains (Bennett, Chekaluk, & Batchelor, 2016). Dawson et al. (2009) reported that a composite measure of cognitive functioning created using scores from eight neuropsychological tests was the best predictor of driving errors in those with Alzheimer’s disease, when compared with any individual cognitive test and in a successive study, the composite measure of cognitive function was again found to be the best predictor of driving errors in older drivers (Dawson et al., 2010). Anderson et al. (2005) also reported a significant relationship between a composite measure of cognitive function and a composite score from a simulated drive in drivers with no neurologic disease and those with mild dementia. Participants who crashed in a crash-avoidance scenario in the drive were found to have performed significantly worse on the composite cognitive measure. These findings are supported by the findings from Bennett and colleagues' (2016) systematic review across all recent studies examining cognitive variables and driving ability in samples of drivers with dementia. It was found that while the majority of the associations supported a relationship between each individual cognitive domain and driving performance, there were still some associations which did not reach significance. Dawson et al. (2009, 2010) suggested that an overall score of cognitive function would best predict driving performance given the heavy demands the task places across the cognitive domains. Bennett et al. were in agreement, advising that measures on any individual cognitive domain are insufficient in predicting driving performance, as multiple cognitive domains are important factors in enabling driving safety. Therefore, it was recommended that all components of cognitive function relevant to driving be assessed by either an overall cognitive measure or composite cognitive test battery designed for this purpose.

The argument that the relationship between driving performance and cognitive function should include multiple cognitive domains is not limited to those with cognitive impairment. Anstey et al. (2005) similarly reviewed literature examining factors which are associated with driving performance in a sample of older drivers with no cognitive deficit. They reported evidence showing consistent associations between the cognitive skills of reaction time and processing speed, visual attention, short term memory, and executive function with driving performance examined through either on-road tests or crash statistics, both self-reported and independently sourced. Their conclusions are in line with the literature reviewed above in the range of cognitive skills that have been shown to be related to driving. Anstey et al. saw the potential benefit of proposing a framework which included the diverse range of factors which influence driving. Their preliminary model of factors which enable driving competence in older drivers identifies cognition, vision, and physical function as the main variables which influence an individual’s capacity to drive. Here, cognition is included as a single factor rather than including each cognitive skill individually. The authors posit that the interaction between the various cognitive factors is ongoing throughout the driving task. By this reasoning, it follows that overall cognition rather than functioning on any one cognitive skill would be a better predictor for driving performance, as it is the combined and interactive effect of each cognitive skill which produces the driving behaviour. In an attempt to examine the relationship between cognitive function and driving performance for younger drivers, two recent studies, Ledger, Bennett, and Chekaluk (2016), and Zicat, Bennett, and Chekaluk (2016) have found that a composite cognitive test battery can also predict driving performance in younger drivers.

A Neurocognitive Model of Driving Performance

In an effort to explain the relationship between cognitive function and driving performance, a neurocognitive model, the Information Processing Model of driving was introduced by Uc and Rizzo (2008) and proposes a mechanism by which each cognitive skill might disrupt safe driving practice and cause unsafe driving. The authors purport that at different stages of the driving task (e.g., perceive, attend and interpret the stimulus, or execute action) different types of cognitive deficit or dysfunction can result in driving errors. For example, when drivers are required to accurately attend to and perceive visual stimuli, abnormal visual perception may disrupt the processing of information leading to errors in driving such as potentially missing a hazard on the road. The cognitive skills highlighted by the model are visual perception, attention, memory, executive function, and motor function. The Information Processing Model is presented in Figure 1.

The cognitive skills highlighted in the model are in line with previous research investigating the cognitive domains related to driving ability in not only neurologically impaired drivers, but cognitively healthy drivers as well. This model also further bolsters the argument that an overall cognitive test battery which examines all of the cognitive domains related to driving would be more accurate in predicting unsafe driving behaviours as opposed to a single measure of cognition, as the single measure would not capture possible carry over effects from deficits in another cognitive domain which are likely to cause an accident. As one form of cognitive dysfunction can carry forward errors through each level of the model, any type of cognitive dysfunction can result in dangerous consequences on the road. Although this model was developed with neurologically impaired drivers in mind, it is possible that this model can account for driving errors in cognitively healthy drivers as well. Zicat et al. (2016) tested this model in a sample of younger drivers through the use of a battery of cognitive tests covering the cognitive skills in the model and were able to significantly predict speeding and lane deviation in a simulated drive.

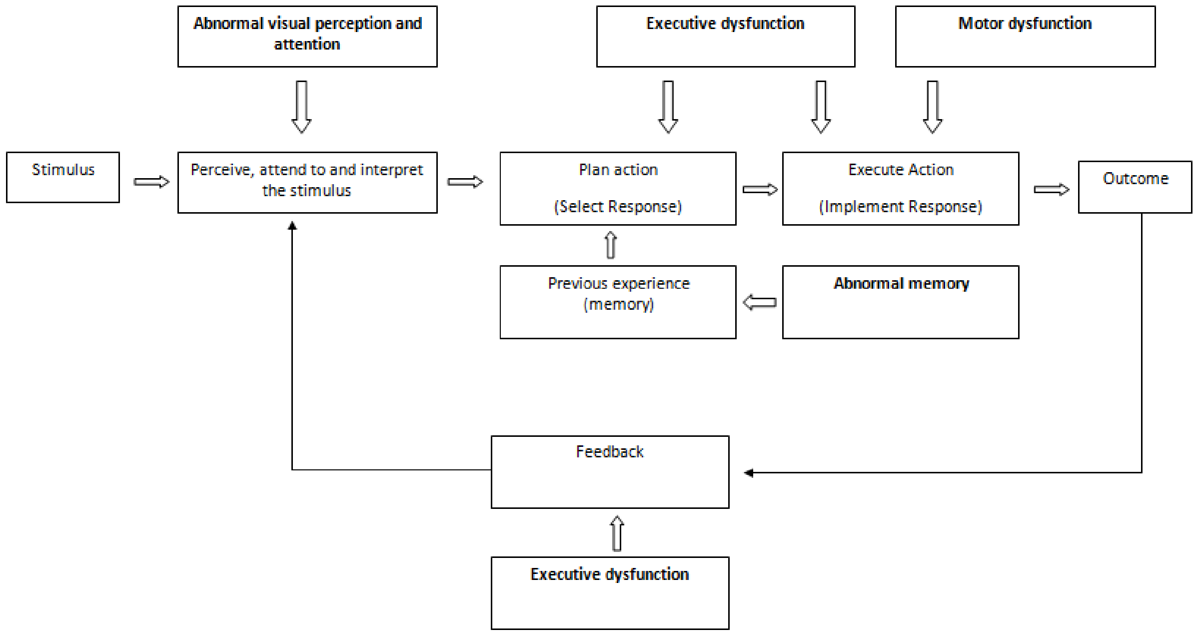

Figure 1. The Information Processing Model. Adapted from Uc, E.Y., & Rizzo, M. (2008). Driving and neurodegenerative diseases. *Current Neurology and Neuroscience Reports, 8*, 377-383.

Driver Age and Cognitive Function

In the current literature, there is strong evidence to suggest that the cognitive domains of attention and processing speed, executive function, visuospatial skills, memory, psychomotor function, and mental status are related to driving performance. The samples used to examine this relationship however are overwhelmingly composed of older drivers and those with neurological impairments. There is little research examining this relationship in younger drivers, and none to the authors' knowledge, investigating drivers in middle adulthood. Ledger et al. (2016) suggested that cognitive functioning may have some influence on driving performance in younger drivers who have comparable crash risk to older drivers and whose cognitive functioning may not be fully developed. They investigated the relationship between overall functioning and several measures of simulated driving in young drivers aged between 17 and 23 and older drivers aged between 63 and 84. Overall cognitive functioning was found to be significantly related to overall driving performance in both younger and older drivers. A comparison of the correlation coefficients between the individual cognitive test scores and driving measures between younger and older drivers found no difference in the relationship between cognition and driving performance between the two groups, suggesting that the influence of cognitive function on driving performance between these two cohorts is the same. Zicat et al. (2016) similarly investigated the relationship between overall cognitive functioning and simulated driving performance with the addition of personality and driver attitude variables. They report that overall cognitive functioning significantly predicted performance on two driving measures, speeding and lane deviation, after controlling for the influence of personality and driver attitudes. It is also important to note that as per Bennett and colleagues' (2016) suggestion, a cognitive test battery used as measure of overall cognitive functioning was successfully used to predict driving performance in these studies.

Our review of the literature on developmental trends of cognitive function showed that it is highly varied across cognitive skills within and between domains, across the age groups. While some cognitive skills may not be fully developed in younger drivers, they are at peak performance in other skills. Those in middle adulthood however are experiencing a slow cognitive decline, in at least half of the cognitive skills examined, often from their 20s. It is reasonable to suggest that cognitive function may influence driving performance in middle aged drivers as well, given that younger drivers may be functioning the same or even better than middle aged drivers. As we see this relationship for both younger and older drivers when they are at opposite ends of the cognitive functioning spectrum, it is therefore reasonable to assume that the relationship between cognitive function and driving performance may exist across all age groups.

Aim and Rationale

Ledger et al. (2016) investigated the relationship between cognitive function and driving performance in younger and older drivers without the inclusion of drivers in middle adulthood. Therefore, the overall aim of this study is to fill this gap in previous literature and determine whether there is any influence of overall cognitive functioning on driving performance in drivers in middle adulthood. Ledger and colleagues (2016) found that cognition was a significant predictor of driving performance in younger drivers, and confirmed the relationship between cognitive function and driving performance for older drivers. Given the extensive evidence for the influence of cognitive variables in older drivers, and this new evidence suggesting a similar relationship in younger drivers, it follows that this relationship may exist in for all drivers. A secondary aim of this study is to apply Uc and Rizzo's (2008) Information Processing Model of driving to drivers in middle adulthood, to work towards a comprehensive model of factors which enable driving across all driver populations. Zicat et al. (2016) previously demonstrated that a cognitive test battery derived from the model was able to significantly predict driver errors in young drivers, however no research has been done to date on the middle adulthood group.

The primary research question of this study is to investigate whether overall cognitive functioning can predict driving performance in drivers in middle adulthood, in a similar pattern as it does for younger and older drivers. To answer this research question, the methodology from Ledger and colleagues' (2016) study will be utilised and participants will be assessed on a cognitive test battery of six tests which are known to assess the cognitive domains previously found to be related to driving, and have been shown to be related to driving performance directly.

Participants' driving performance will be assessed through one drive on a driving simulator, from which three measures of driving proficiency will be taken. Data on speeding, lane deviation, and overall driving performance will be used as the outcome measures with the cognitive test battery acting as a single composite predictor.

The secondary research question will address whether the Information Processing Model (Uc & Rizzo, 2008) can successfully be applied to drivers in middle adulthood as a mechanism of explaining driving performance for this cohort. For this part of the study, an additional three cognitive test measures will be added to the cognitive test battery to reflect the cognitive skills highlighted in the model. This test battery will then be used to predict the same three driving outcome measures, speeding, lane deviation, and overall driving from the simulated drive.

Hypotheses

The specific hypotheses of this study are as follows:

1. Overall cognitive function as measured by the cognitive test battery will significantly predict driving performance as measured by: speeding, lane deviation, and overall driving performance in drivers in middle adulthood.

2. The cognitive test battery derived from the Information Processing Model will significantly predict speeding, lane deviation, and overall driving performance in drivers in middle adulthood.

Method

Design and Overview

The current study employed a correlational design examining the relationship between cognitive function and driving performance. The predictor variable, cognitive function, was operationalised through the use nine cognitive tests measuring cognitive function across several cognitive domains. The outcome variable, driving performance, was operationalised by utilising a driving simulator. Two types of driving errors were measured: speeding, and lane deviation. A third score for overall driving performance was obtained by playing back the drives and manually scoring their performance on 48 driving manoeuvres, assessing each participant's response to these events in the drive. A sample size calculation was not feasible due to the exploratory nature of the study however a 10-to-1 ratio of participants to predictors was utilised as a starting point for the stability of the regression. Ethics approval was obtained from the Macquarie University Human Research Ethics Committee (Reference Number: 5201600872).

Participants

There were 88 participants in this study with ages ranging from 24 to 65 (M = 38.9). There were 58 females (65.9%) and 30 males (34.1%). All participants were required to be between 24 and 65 years of age, to speak fluent English, have normal or corrected to normal vision, hold a current driver's licence Provisional P1 or above, and have driven within the last 3 months. Information regarding the distribution of participant ages is included in Table 1. Of the participants, 55 were students at Macquarie University enrolled in a first year or second year psychology subject. They were recruited through the university participant pool website (SONA) and received one hour of course credit for participating. The remaining 33 participants were recruited from the community through the distribution of flyers or were a convenience sample comprised of friends and acquaintances of the experimenter. These participants were reimbursed $20 for taking part in the study. The participants had 20.1 years driving experience and drove 10.2 hours a week on average. There were 54 participants (61.36%) who reported having completed a Bachelor degree or above, 24 participants (27.27%) who reported having compled a certificate or diploma level qualification, and 10 participants (11.36%) who reported having completed up to Year 12.

Table 1

Distribution of Participant Ages

Age (years)	N	%
24-30	32	36.36
31-35	10	11.36
36-40	10	11.36
41-45	10	11.36
46-50	5	5.68
51-55	6	6.81
56-60	7	7.95
61-65	8	9.09

A total of six participants were removed from the study. One participant was unable to complete the drive due to developing simulation sickness, and one other participant did not complete the drive as per instructions. Three participants had missing data, and one participant was removed due to being an extreme outlier on their lane deviation score. This resulted in 82 participants being included in the final analysis.

Apparatus

Driving simulator. Driving performance measures were acquired through the use of the STISIM driving simulator Version 3. The STISIM Version 2 has previously demonstrated a strong level of ecological validity and has been used as an objective measure of driving ability (de Winter et al., 2009). The STISIM is run via a Dell T3500 computer with a Xeon W3530 CPU processor with 2.8GHz processing speed and 4GB of RAM. Sound was produced via internal speakers and the graphics were produced using Version 3 of the STISIM Driver Interactive Driving Simulator Software.

The simulated drive is displayed using three 27 inch LCD computer monitors positioned at eye level. The two monitors on either side of the driver show the front halves of the front windows of the vehicle, with the middle screen displaying the front windscreen directly in front of the driver. The side mirrors and rear-view mirrors, as well as the speedometer and tachometer are displayed on the screens, positioned in accordance with what a driver is usually able to see. The simulator includes a steering wheel, horn, accelerator and brake pedals, and driver's seat. All elements are positioned in accordance with a traditional automatic car. The driver's seat includes a seatbelt and is adjustable to allow the most comfortable positioning for each individual participant. A photo of the simulator is in Appendix A.

Materials

Information and consent form. Participants were required to read and sign an information and consent form prior to participation. The form described the research topic, the tasks included in the experiment, and the possible risks associated with performing these tasks. If they consented, participants signed two copies of the form; one each for the participant and the experimenter. A copy of the information and consent form can be found in Appendix B.

Demographic questionnaire – Driving events. A short demographic questionnaire was completed by all participants and included questions about the participants' age and gender, as well as their driving habits (e.g., number of hours spent driving a week) and driving experience (e.g., number of years spent driving, license status). In addition to this, the questionnaire included questions asking whether participants had experienced any problems whilst driving in the last 3 months including any accidents, traffic infringements, and mistakes made while driving. A copy of this questionnaire can be found in Appendix C.

Cognitive test battery. The following list of tests were selected based on previous research showing them to be related to driving performance in older drivers and younger drivers. This battery covers each of the cognitive domains which are thought to be important in enabling driving competence (Bennett, 2017).

Trail Making Test Parts A and B. The Trail Making Test (TMT) consists of two parts, Part A and Part B. This test evaluates participants' proficiency in visual attention and task switching, visual search speed, scanning, speed of processing, mental flexibility and executive functioning (Corrigan & Hinkeldey, 1987; Tombaugh, 2004). Both parts involve participants connecting a series of 25 circles in the correct order with a line, as quickly as they can. The circles in Part A includes only numbers (1 to 25), whilst Part B includes numbers (1-13) and letters (A-L). In Part A the circles must be connected in a numerical ascending order, whilst in Part B, the participant is instructed to alternate between numbers and letters throughout, whilst maintaining the numerical and alphabetical order of both. The time taken (in seconds) for participants to complete each part of the TMT is recorded, with higher scores marking poorer performance. The test re-test reliability for the TMT A and B range from $r_{tt} = .75$ to $r_{tt} = .85$ (Giovagnoli et al., 1996).

Rey Complex Figure Test. The Rey Complex Figure Test (CFT) is an assessment used to evaluate visuospatial abilities, short term memory, working memory, attention, and executive function (Lezak, 1995). For the current study, 3 parts of the test: the copy, immediate recall, and organisation conditions were administered. The test involves the use of a complicated line drawing, with 18 different components. In the copy condition the figure is placed before the participant who is then instructed to reproduce it on a blank sheet of paper. The participant's drawing is scored by assessing how accurately each of the 18 components were drawn to reproduce the overall figure. The organisation condition is administered concurrently with the copy condition, and involves the experimenter recording the order in which participants drew the lines in the copy condition. The recall condition is completed approximately three minutes after the copy condition and participants are asked to reproduce the figure from memory. The copy and recall conditions are scored out of 36 while the organisation condition is scored out of 24. Higher scores signify better performance in all three conditions. The inter-rater reliability for each condition lies between .93 and .99 and the test re-test reliability for the immediate recall condition has been reported as $r_{tt} = .76$ (Meyers & Meyers, 1995).

Mini-Mental Status Exam. The Mini-Mental Status Exam (MMSE) is a short questionnaire which assesses global cognitive functioning, commonly used to determine whether an individual might be experiencing cognitive impairment (Folstein, Folstein, & McHugh, 1975). The MMSE examines orientation, recall, attention and calculation, and language ability. Although the MMSE, like other tests of mental status, has been designed to cover a broad range of cognitive skills across all cognitive domains, it should be noted that the test does not provide a comprehensive examination of any one cognitive domain, and does not include any assessment of executive function. Given this, the MMSE alone is not sufficient to examine overall cognitive functioning, necessitating the use of a cognitive test battery as recommended by Dawson et al. (2009) and Bennett et al. (2017). This questionnaire includes simple questions (e.g. what city are we in?) and tasks (e.g. spell the word “world” backwards). The questionnaire is scored out of 30, and higher scores indicate better overall cognitive performance. The test re-test reliability for this test ranges between $r_{tt} = .80$ and $r_{tt} = .95$ (Tombaugh & McIntyre, 1992). Cohen’s kappa for inter-rater reliability is reported as being high at $k = .97$ (O’Connor et al., 1989).

Visual Object and Space Perception Battery. The Visual Object and Space Perception Battery (VOSP) is a test designed specifically to assess space and object perception without employing other cognitive abilities. The battery has 8 parts however only three subscales were used in the current study; these were: incomplete letters, number location and cube analysis. These three subscales were chosen based on previous research establishing their relationship with driving performance (Lincoln, Radford, Lee & Reay, 2006; McKenna, Jefferies, Dobson, & Frude, 2004; Quental, Brucki, & Bueno, 2013). In the incomplete letter subscale participants must identify 20 letters which are 70% degraded in perceptual clarity. The number location subscale has 10 items. Each consists of two squares, the top square containing randomly distributed numbers and the bottom square containing one black dot. Participants must identify which number in the top square corresponds with the position of the dot in the bottom square. In the cube analysis subtest participants view 10 images with three-dimensional arrangements of cubes, or solid bricks. The participant is instructed to identify how many cubes appear in the image, including any that are hidden by other cubes. The scores on each subscale were summed to create a total VOSP score. The number of items answered correctly across the three subscales make up a total score out of 40 with higher scores indicating better performance. Cronbach's alpha for the three subscales were: incomplete letters, $\alpha = .54$, number location $\alpha = .84$, and cube analysis, $\alpha = .77$ (Bonello, Rapport, & Millis, 1997).

Grooved Peg Board Test. The Grooved Peg Board Test (GPB) is a manual dexterity task which assesses fine motor skills, complex visual-motor coordination, and finger speed (Schmidt, Oliviera, Rocha & Abreu-Villaca, 2000). The test involves the use of a board containing 25 holes arranged in five rows of five. Each hole has the same shape, a conjoined circle and square, however the shape of the holes are orientated randomly across the board. Participants must place

25 metal pegs, which have the same combined circle and square shape, into each hole one at a time as quickly as they can, manoeuvring the pegs to fit them to the orientation of the holes. The pegs must be placed starting on the opposite side of the board to their hand, completing one row at a time moving from top to bottom. Participants must complete two trials, first using only their dominant hand, then using only their non-dominant hand. The final score for each hand is the sum of the time in seconds to complete the task and the number of unintentional drops made with higher scores indicating poorer performance. Test re-test reliability was good for both the dominant (r_{tt} = .80) and non-dominant (r_{tt} = .81) conditions, as reported in the administration manual.

The Drives.

Practice drive. The practice drive took approximately 2 minutes to complete and included a set of traffic lights and two bends in the road to ensure participants became accustomed to the controls (including turning, braking, and accelerating) and the visuals of the simulated drives before the test drive. The drive was programmed manually using the STISIM Interactive Driving Simulator Software by the experimenter.

Experimental drive. The experimental drives comprised five types of roadway scenes: city, school area, residential, country town, and highway. Three test drives were created by randomising the scenes and the drives were then randomised across participants, with each participant completing one of the drives. The drive included scenarios and events which typically occur during a real world drive, such as stop signs, and turning at an intersection, otherwise called expected events. Events which do not regularly occur whilst driving, for example, a pedestrian suddenly walking out, or a car pulling out in front of them were also included in the drive, otherwise known as unexpected events. There were 48 events in total with 36 in the expected event category, and 12 in the unexpected category. The drive took between 9 and 12 minutes to complete.

Overall driving measure. Each drive was recording through the STISIM software and then played back and scored manually by the experimenter for the purposes of creating an overall driving performance score. The driving scenarios which are created with driving simulators can be highly varied, and thus there is no standard practice for scoring simulated drives. Therefore, the method of scoring and the categorisation of driver responses were created through collaboration by the experimenters, using guidelines from the local licensing agency on on-road driving assessments, and with advice from a trained testing officer for older drivers. Responses to a total of 48 events in the drive were coded as being either safe, unsafe, or intermediate. The selected events fell into both the expected event and unexpected events categories. Examples include gap selection and response to stop signs in the expected event category, or response to a pedestrian walking out or an oncoming car in the unexpected event category. Safe or appropriate responses were given a score of one, intermediate responses were given a score of two, and unsafe or inappropriate responses were given a score of three. The scores were then summed across the drive to give a raw score with unsafe responses weighted more than safer responses. These raw scores were converted to a percentage of the maximum possible score for each individual participant, as not all events occurred for each participant. For example, a participant who missed a turn would not be scored on gap selection, or a participant who did not change lanes would not be scored on indicating. A higher percentage indicated worse overall performance. This measure was dual scored for inter-rater reliability of $r = .89$. A copy of the scoring sheet can be found in the Appendix D.

Procedure

First, the experimenter confirmed that participants met the age and driving licensure requirements for participation. All participants were then given a consent form to read and sign. Following the obtainment of consent, the experimenter began the administration of the cognitive tests.

All participants completed the copy condition of the CFT first. As participants drew the figure the experimenter concurrently recorded each line drawn by the participant in chronological order for the organisational portion of the test. Upon completing the task, the CFT stimulus figure, organisation scoring sheets, and the participant’s reproduction of the figure were removed from the participant’s view. The participants were then asked to complete a short demographic questionnaire. Following this, participants were asked to draw the CFTstimulus figure from memory on a blank sheet of paper for the CFT immediate recall condition.

Next, the TMT (A & B), the MMSE, the VOSP, and the GPB (dominant and non-dominant) were administered to the participants, with the order counterbalanced across all individuals. In accordance with the administration manuals, the TMT part A was always administered before part B, and the GPB dominant hand condition was tested before the non-dominant hand condition. All tests were administered as is outlined in their respective manuals.

Following the completion of all cognitive tests participants were asked to take a seat in the driving simulator. The experimenter then instructed participants on how to use each of the components of the simulator necessary for the drive. Participants were informed that they would be alone in the room for the duration of their drives and were instructed to drive as they normally would. The experimenter then made sure to answer any questions the participants had. Following this, the participants undertook their two minute practice drive. After completion of the practice drive, the experimenter checked for possible simulator sickness, provided another opportunity to ask questions and gave instructions for the test drive. They were told that this drive would take approximately 10 minutes and were reminded to drive as they normally would. Following this, the experimenter left the room and the participants completed the test drive.

Upon finishing the test drive, participants were debriefed, and told they would receive their course credit, or were given $20 reimbursement depending on their method of recruitment.

Statistical Analysis Plan

There were three driving performance outcome measures in this study. Two driving performance measures were selected from the data collected from the simulated drives. These are the percentage of time spent over the speed limit for the duration of the drive as a measure of speeding behaviour and the percentage of time spent out of lane for the duration of the drive as a measure of lane deviation. The two measures have been used by both Ledger et al. (2016) and Zicat et al. (2016) in studies investigating the relationship between cognitive function and driving performance. A third driving performance measure, overall driving score, was previously utilised by Ledger et al. (2016) and Bennett (2017).

The first research question investigated the relationship between overall cognitive functioning (as measured by the six cognitive tests utilised in Ledger et al., 2016) and each of the driving outcome variables; speeding, lane deviation, and overall driving for drivers in middle adulthood. This will be examined by performing linear regressions which include all six cognitive test variables used in Ledger et al.'s (2016) study, the TMT part A, TMT part B, CFT Copy condition, CFT Recall condition, CFT Organisation condition, and MMSE as predictors for all three driving performance outcome measures. The full model including all six cognitive test scores will be used each time to determine whether overall cognitive function is predictive of different driving performance measures for drivers in middle adulthood.

The second research question applying the neurocognitive model, Uc and Rizzo's (2008) Information Processing Model, to drivers in middle adulthood will include an additional three cognitive test predictors on top of the six predictors used for research question one, and the same three driving performance outcome measures. The three additional cognitive tests, the VOSP, GPB Dominant condition, and GPB Non-dominant condition were included by Zicat and colleagues' (2016) study investigating overall cognitive function for younger drivers on speeding and lane deviation. The full model for the linear regressions will include nine cognitive test scores to investigate whether overall cognitive function as defined by the Information Processing Model is predictive of speeding, lane deviation, and overall driving performance.

The regression coefficients pertaining to the individual contribution of each predictor in the model will be reported for each regression. The *B* or unstandardized beta coefficient represents the change in the dependent variable which is associated with a single unit change in the predictor, or the slope of the regression line. *SE B* or the standard error of *B*, represents the accuracy of the regression line. It is the standard deviation of the slope, or the average distance of the observed values from the regression line. Finally, B represents the standardised beta coefficient which is the number of standard deviations of change in the dependent variable for a single standard deviation change in the predictor variables. This coefficient is useful in determining the relative strength or importance of each variable in predicting the dependent variable.

Results

Descriptive Statistics

All variables included in the study are numeric. The cognitive function measures include the Trail Making Tests Part A (TMTA) and Part B (TMTB), the Rey Complex Figure Test Copy (CFTCopy), Recall (CFTRecall), and Organisation (CFTOrg) conditions, the Mini Mental Status Exam (MMSE), the Visual Object and Space Perception Battery (VOSP), and the Grooved Peg Board Dominant (GPBD) and Non-Dominant (GPBND) conditions. The driving performance measures included percentage of time spent speeding (Speeding), percentage of time spent out of lane (Lane Deviation), and the Overall Driving score. The descriptive statistics of interest are displayed in Table 2.

Table 2

Descriptive Statistics for Variables of Interest

Variable	M (SD)	Range (Min-Max)
Cognitive Performance Variables		
TMTA	22.45 (7.00)	36.16 (11.59-47.75)
TMTB	56.76 (19.71)	97.02 (26.43-123.45)
CFTCopy	32.04 (2.86)	12.5 (23.5-36)
CFTRecall	18.97 (5.56)	22.5 (7-29.50)
CFTOrg	14.70 (4.82)	16 (8-24)
MMSE	29.16 (.936)	3 (27-30)
VOSP	38.59 (1.40)	7 (33-40)
GPBD	63.10 (7.64)	36.87 (45.35-82.22)
GPBND	68.97 (10.53)	63.22 (47.75-110.97)
Driving Performance Variables		
Speeding	3.79 (2.68)	13.66 (0-13.66)
Lane Deviation	10.83 (2.67)	13.71 (3.07-16.78)
Overall Driving	.48 (.05)	.31 (.33-.64)

Note: TMTA = Trail Making Test – Part A, TMTB = Trail Making Test – Part B, CFTCopy = Rey Complex Figure Test – Copy, CFTOrg = Rey Complex Figure Test – Organisation, CFTRecall = Rey Complex Figure Test – Immediate Recall, MMSE = Mini Mental Status Exam, GPBD = Grooved Peg Board Dominant Hand; GPBND = Grooved Peg Board Non-Dominant Hand.

Bivariate Correlation Coefficients

Bivariate correlation coefficients for the cognitive performance measures and the driving performance measures are displayed in Table 3. No collinearity was found using the r <.07

Table 3

Bivariate Correlations: Cognitive Performance and Driving Performance Measures

Variable	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
1. TMTA	-	.524**	-.087	-.183	.090	-.170	-.236*	.274*	.237*	-.073	.186	.054
2. TMTB		-	-.104	-.195	-.113	-.194	.030	.242*	.181	-.235*	.051	-.034
3. CFTCopy			-	.452**	.092	.088	.151	-.223*	-.087	-.082	.125	-.182
4. CFTRecall				-	.292**	.128	.149	-.193	-.183	-.030	.027	-.247*
5. CFTOrg					-	.044	.119	-.056	.090	.228*	.018	-.063
6. MMSE						-	.060	-.198	-.121	-.315**	-.119	-.331**
7. VOSP							-	-.106	-.041	-.028	.044	-.155
8. GPBD								-	.658**	.001	.054	.093
9. GPBND									-	-.153	.106	-.001
10. Speeding										-	.052	.515**
11. Lane Deviation											-	.144
12. Overall Driving												-

Note: TMTA = Trail Making Test – Part A, TMTB = Trail Making Test – Part B, CFTCopy = Rey Complex Figure Test – Copy, CFTOrg = Rey Complex Figure Test – Organisation, CFTRecall = Rey Complex Figure Test – Immediate Recall, MMSE = Mini Mental Status Exam, GPBD = Grooved Peg Board Dominant Hand; GPBND = Grooved Peg Board Non-Dominant Hand.

* Correlation is significant at the 0.05 level. ** Correlation is significant at the 0.01 level.

criterion for the predictor variables. The assumptions for each variable were checked and found to satisfy the criteria necessary to perform the analyses.

Predicting Driving Performance from Cognitive Performance

Applying cognitive function to driving in middle adulthood. To investigate the relationship between cognitive functioning and driving performance for drivers in middle adulthood as Ledger et al. (2016) did for younger and older drivers, three multiple regressions were performed including the same cognitive tests as predictors and the same driving performance outcome variables. The predictors were TMTA, TMTB, CFTCopy, CFTRecall, CFTOrg, and MMSE. Full linear multiple regression models were performed including these six predictors for each of the outcome variables: speeding, lane deviation, and overall driving.

The full model predicting speeding was found to be significant, $F(6,75) = 4.180$, $p = .001$. This model accounted for 25.1% of the total variance in speeding. The regression coefficients for this model are displayed in Table 4. The full model predicting lane deviation was found to be non-significant, $F(6,75) = .913$, $p = .490$. The regression coefficients for this model are displayed in Table 5. The full model predicting overall driving performance was found to be significant, $F(6,75) = 2.701$, $p = .020$. This model accounted for 17.8% of the total variance in overall driving performance. The regression coefficients for this model are displayed in Table 6. For predictors with a significant *B*, this value represents the predicted change in the dependent variable for every one unit change in the predictor variable. For example, in Table 4 there is a reported -1.059 change in speeding for every one unit change in MMSE scores. Participants who score 30 compared to those who score 28 in the MMSE would be expected to spend 2.118% (2x-1.059) less time over the speed limit over the course of the simulated drive.

Table 4

Regression: Speeding

Variable	*B*	*SE B*	Β
TMTA	-.011	.046	-.028
TMTB	-.039*	.016	-.288
CFTCopy	-.062	.105	-.066
CFTRecall	-.042	.058	-.087
CFTOrg	.137*	.060	.245
MMSE	-1.059**	.294	-.370

Note: TMTA = Trail Making Test – Part A, TMTB = Trail Making Test – Part B, CFTCopy = Rey Complex Figure Test – Copy, CFTOrg = Rey Complex Figure Test – Organisation, CFTRecall = Rey Complex Figure Test – Immediate Recall, MMSE = Mini Mental Status Exam, GPBD = Grooved Peg Board Dominant Hand; GPBND = Grooved Peg Board Non-Dominant Hand.

* *p*<.05. ** *p*<.01.

Table 5

Regression: Lane Deviation

Variable	*B*	*SE B*	Β
TMTA	.084	.051	.220
TMTB	-.010	.018	-.071
CFTCopy	.135	.117	.145
CFTRecall	.004	.064	.008
CFTOrg	-.011	.066	-.021
MMSE	-.307	.326	-.108

Note: TMTA = Trail Making Test – Part A, TMTB = Trail Making Test – Prt B, CFTCopy = Rey Complex Figure Test – Copy, CFTOrg = Rey Complex Figure Test – Organisation, CFTRecall = Rey Complex Figure Test – Immediate Recall, MMSE = Mini Mental Status Exam, GPBD = Grooved Peg Board Dominant Hand; GPBND = Grooved Peg Board Non-Dominant Hand.

* *p*<.05. ** *p*<.01.

Table 6

Regression: Overall Driving

Variable	*B*	*SE B*	Β
TMTA	.000	.001	.046
TMTB	.000	.000	-.168
CFTCopy	-.001	.002	-.079
CFTRecall	-.002	.001	-.192
CFTOrg	-9.137E-5	.001	-.009
MMSE	-.018**	.006	-.324

Note: TMTA = Trail Making Test – Part A, TMTB = Trail Making Test – Part B, CFTCopy = Rey Complex Figure Test – Copy, CFTOrg = Rey Complex Figure Test – Organisation, CFTRecall = Rey Complex Figure Test – Immediate Recall, MMSE = Mini Mental Status Exam, GPBD = Grooved Peg Board Dominant Hand; GPBND = Grooved Peg Board Non-Dominant Hand.

* *p*<.05. ** *p*<.01.

Applying a neurocognitive model of driving to middle adulthood. To investigate and apply Uc and Rizzo's (2008) Information Processing Model to drivers in middle adulthood as Zicat et al. (2016) did for younger drivers, three more cognitive function predictors, VOSP, GPBD, and GPBND were added to the regression models. Full linear multiple regression models were performed including the nine predictors TMTA, TMTB, CFTCopy, CFTRecall, CFTOrg, MMSE, VOSP, GPBD, and GPBND, for each of the outcome variables: speeding, lane deviation, and overall driving.

The full model predicting speeding was found to be significant, $F(9,72) = 3.235$, $p = .002$. This model accounted for 28.8% of the total variance in speeding. The regression coefficients for this model are displayed in Table 7. The full model predicting lane deviation was found to be non-significant, $F(9,72) = .729$, $p = .681$. The regression coefficients for this model are displayed in Table 8. The full model predicting overall driving was found to be non-significant, $F(9,72) = 1.940$, $p = .060$. The regression coefficients for this model are displayed in Table 9.

Table 7

Regression Information Processing Model: Speeding

Variable	*B*	*SE B*	Β
TMTA	-.003	.049	-.007
TMTB	-.040*	.017	-.294
CFTCopy	-.062	.106	-.066
CFTRecall	-.055	.058	-.113
CFTOrg	.132*	.060	.238
MMSE	-1.047**	.295	-.366
VOSP	.009	.206	.005
GPBD	.053	.048	.150
GPBND	-.006	.034	-.260

Note: TMTA = Trail Making Test – Part A, TMTB = Trail Making Test – Part B, CFTCopy = Rey Complex Figure Test – Copy, CFTOrg = Rey Complex Figure Test – Organisation, CFTRecall = Rey Complex Figure Test – Immediate Recall, MMSE = Mini Mental Status Exam, GPBD = Grooved Peg Board Dominant Hand; GPBND = Grooved Peg Board Non-Dominant Hand.

* p<.05. ** p<.01.

Table 8

Regression Information Processing Model: Lane Deviation

Variable	*B*	*SE B*	Β
TMTA	.092	.056	.242
TMTB	-.013	.019	-.095
CFTCopy	.129	.120	.138
CFTRecall	.008	.065	.017
CFTOrg	-.018	.068	-.032
MMSE	-.311	.334	-.109
VOSP	.174	.233	.091
GPBD	-.014	.054	-.040
GPBND	.028	.039	.109

Note: TMTA = Trail Making Test – Part A, TMTB = Trail Making Test – Part B, CFTCopy = Rey Complex Figure Test – Copy, CFTOrg = Rey Complex Figure Test – Organisation, CFTRecall = Rey Complex Figure Test – Immediate Recall, MMSE = Mini Mental Status Exam, GPBD = Grooved Peg Board Dominant Hand; GPBND = Grooved Peg Board Non-Dominant Hand.

* $p<.05$. ** $p<.01$.

Table 9

Regression Information Processing Model: Overall Driving

Variable	*B*	*SE B*	Β
TMTA	.000	.001	.024
TMTB	.000	.000	-.149
CFTCopy	-.001	.002	-.068
CFTRecall	-.002	.001	-.203
CFTOrg	1.333E-5	.001	.001
MMSE	-.018**	.006	-.318
VOSP	-.003	.004	-.082
GPBD	.001	.001	.087
GPBND	-.001	.001	-.137

Note: TMTA = Trail Making Test – Part A, TMTB = Trail Making Test – Part B, CFTCopy = Rey Complex Figure Test – Copy, CFTOrg = Rey Complex Figure Test – Organisation, CFTRecall = Rey Complex Figure Test – Immediate Recall, MMSE = Mini Mental Status Exam, GPBD = Grooved Peg Board Dominant Hand; GPBND = Grooved Peg Board Non-Dominant Hand.

* $p<.05$. ** $p<.01$.

Discussion

The overall aim of this study was to investigate the relationship between cognitive performance and driving performance in drivers in middle adulthood, and thereby fill a gap in the literature. The primary research question examined whether the relationship between cognitive functioning and driving performance in drivers in middle adulthood would show a similar pattern of results as previously seen in younger and older drivers. It was hypothesised that overall cognitive function would significantly predict driving performance as measured by: speeding, lane deviation, and overall driving in drivers in middle adulthood. This hypothesis was partially supported. A further aim of this study was to apply a neurocognitive model of driving, Uc and Rizzo's (2008) Information Processing Model, to drivers in middle adulthood. The hypothesis that overall cognitive function as derived from the Information Processing Model, would significantly predict driving performance in drivers in middle adulthood as measured by: speeding, lane deviation, and overall driving was also partially supported.

Applying Findings for Younger/Older Drivers to Drivers in Middle Adulthood

The first research question sought to address the gap in the literature regarding the relationship between cognitive functioning and driving performance in drivers in middle adulthood. The hypothesis that overall cognitive function would significantly predict driving performance in three measures of driving for drivers in middle adulthood was partially supported, and thus provides preliminary evidence for a relationship between cognition and driving performance in this driver group, supporting the notion that this relationship exists in all drivers.

The results show that overall cognitive function significantly predicts speeding in drivers in middle adulthood. This finding supports the overall hypothesis that there is a relationship between cognitive function and driving performance in this group. This result matches those of Ledger and colleagues' (2016) study who found that cognitive function significantly predicted speeding in older drivers. This finding is particularly compelling as speeding has previously been reported as a factor implicated in 34% of fatalities due to car accidents (Australian Transport Council, 2011). When considering this statistic in combination with data showing that land transport accidents are amongst the top three leading causes of death in those aged under 44, these findings provide evidence that the influence of cognition on speeding behaviours may be having an impact on real world driving.

Overall cognitive function did not significantly predict lane deviation in drivers in middle adulthood. This result was contrary to expectations based on previous literature for other driver populations, as well as the results from the younger driver group from Ledger and colleagues’ (2016) study. This finding does however conform to the previous finding in Ledger and colleagues’ older driver sample for whom no significant relationship between cognitive function and lane deviation was found. There are several possible explanations for this finding. First, it is possible that there simply is no relationship between cognitive functioning and lane deviation in drivers in middle adulthood and older drivers. However, this would be in contrast to the specific findings from Dawson and colleagues’ (2009) study regarding lane deviation and cognitive function in drivers diagnosed with Alzheimer’s disease, and a sample of older drivers without dementia. In this study, scores on tests of visuospatial skills, speed of visual processing, attention, and motor skills significantly predicted lane deviation across the entire sample. In this study however, participants’ driving errors were measured from an on-road driving test with an instrumented car which included videotapes recording the drive. A trained driving instructor was employed to review the number of driving errors committed for each participant. The discrepancy between these findings and the findings of the current study could be explained by the difference in methodology and measurement of lane deviation.

The driving simulator used in this study calculates the percentage of time in the drive spent out of lane, similar to the speeding measure which is calculated as the percentage of time spent over the speed limit in the drive. The use of the speeding measure is intuitive as speeding behaviour can easily be categorised into dichotomous responses i.e., yes, they are speeding, no, they are not speeding, which is then converted into the proportion of time each participant spends in one category. This is also in line with law enforcement with regards to speeding on the roads as there is a discrete point past which drivers can conclusive be said to be over the speed limit. In the attempt to keep the measures standard from previous studies, and within this study, the lane deviation measure which corresponded directly to the speeding measure was utilised. The measure was again a dichotomous categorisation of lane keeping: yes, were they in lane, no, they were out of lane. When examining the average time spent speeding (3.79%) and the average time spent out of lane (10.83%) in this study it is clearly evident that it was much more common for participants to deviate from their lane when compared to speeding. Given this, it is possible that the measure employed in this study is overly sensitive in capturing small deviations in lane position, making it easier for participants to be categorised as being out of lane. As a result, by changing the mechanism by which lane keeping is recorded, such as to average distance out of the lane, or the standard deviation of the lateral position, might yield different results. Unfortunately, neither of these indices were available for this study.

Furthermore, the discrepancy in these findings could be in part explained by familiarity with a simulated environment. There is evidence to suggest that experience playing video games significantly improves performance across a variety of simulated environments. These include surgical training simulators (Jalink, Goris, Heineman, Pierie, & Henk, 2014; Schlickum, Hedman, Enochsson, Kjellin, & Felländer-Tsai, 2009) as well as navigation tasks in virtual environments (Richardson, Powers, & Bousquet, 2011). A large-scale demographic survey of players of massively multi-user online role-playing games gathered responses from 30,000 users over three years. Although the age range of participants was large (11-68 years), the mean age of responders was 26.57, with the youngest quarter aged 19 and below, and the oldest quarter aged 32 and above (Yee, 2006). Given this, one possible explanation for the lack of a significant association between cognitive function and lane deviation in the middle adulthood driver group, as well as in the older driver group in Ledger and colleagues' (2016) study could be that these groups have less video game experience. Lack of familiarity with virtual environments in these age cohorts could lend to difficultly in adapting to the virtual driving scene, leading to increased errors in manoeuvring the simulated car. The use of a driving simulator as the measure of driving performance therefore has potentially inflated participants' estimated lane keeping ability by including variation in performance which may be influenced by inexperience with simulated environments rather than cognitive ability. The reason speeding is not impacted by this inexperience is likely due to participants receiving direct feedback about their speed through the observation of the speedometer on the screen, however the simulator does not provide feedback regarding their lane keeping performance.

Overall cognitive function significantly predicted overall driving performance in drivers in middle adulthood. This finding is in support of the hypothesis and shows strong support for the idea that overall cognitive function is also related to driving performance in drivers in middle adulthood, as well as younger and older drivers as shown in Ledger and colleagues' (2016) study. This result is also in accordance with the findings of Dawson et al. (2009, 2010) who reported that an overall measure of cognitive function showed the strongest associations with the overall number of driving errors made in both drivers with Alzheimer's disease, and in older drivers without cognitive impairment. This finding is also supports that of Anderson et al. (2005) who reported that an overall measure of cognitive function was significantly related to a composite measure of driving performance in a simulated drive for drivers with mild dementia, and those without cognitive deficit. This result is noteworthy in that it is the first empirical evidence that suggests that the relationship between overall cognitive functioning and overall driving performance exists across all drivers regardless of age.

Applying a Neurocognitive Model of Driving to Drivers in Middle Adulthood

The second research question addressed whether Uc and Rizzo's (2008) Information Processing Model could successfully be applied to drivers in middle adulthood. The hypothesis that overall cognitive function as defined by the Information Processing model, would significantly predict driving performance on three measures in drivers in middle adulthood was partially supported. This study provides some preliminary evidence for the valid application of the Information Processing Model to the middle adulthood driver group.

Speeding was significantly predicted by overall cognitive functioning as derived from the Information Processing Model. This was in line with the hypothesis, and supports the findings from Zicat et al. (2016) showing that this model can be applied to driver populations outside those with neurodegenerative disorders, and providing new evidence that this model can not only be applied to younger drivers, but now also to drivers in middle adulthood. This finding also further bolsters the findings of this study illustrated previously, that there is a strong association between cognitive function and driving performance in the middle adulthood driver population. This finding is important when considering the future directions of this research. There is little holistic understanding of the factors which influence driving performance in drivers in middle adulthood and across driver groups. The successful application of the Information Processing Model to this driver group is an important step towards a more comprehensive understanding of the factors which impact driving across all age groups.

Overall cognitive functioning was not significantly related to lane deviation in drivers in middle adulthood. This result did not support the hypothesis and was incongruent with the findings of Zicat et al. (2016) who reported a significant relationship between the factors in the Information Processing Model, operationalised through the use of the same cognitive test battery as in the current study, and lane deviation in young drivers. This finding is comparable however with the finding from this study outlined above, that overall cognitive function did not significantly predict lane deviation in drivers in middle adulthood. As the sample and the method of measurement for lane deviation is identical across these two analyses, it therefore is not surprising that this result is not significant given the highlighted potential problems with the measurement of lane deviation and the characteristics of the sample with regards to their familiarity with virtual environments.

The relationship between overall cognitive function as defined by the Information Processing Model, and overall driving performance was found to be non-significant. To the author's knowledge there has been no previous application of the Information Processing Model to overall driving performance. This result however, is contrary to the findings for younger drivers from Zicat et al. (2016) who reported a significant relationship between overall cognitive function as derived from the Information Processing Model and the two measures of driving performance: speeding and lane deviation. When considering the individual cognitive domains which were assessed and included in the analyses, the results are also incongruent with the vast breadth of literature showing strong relationships between driving performance and each of the cognitive domains across several driver populations.

One probable explanation for this unexpected result is that there was insufficient power for the analyses to reach significance. Due to time constraints, a total of 88 participants were assessed instead of the recommended 90 for a participant-to-predictor ratio of 10-to-1. Of these participants, it was necessary to remove six for various reasons including simulation sickness, outliers, and missing data. The results of this analysis had a p-value of 0.06. To test this theory of a lack of power, the scores for two of the tests, the Grooved Peg Board dominant condition and the non-dominant condition were combined into a single score and the analysis was re-run. This ensured that the data in the multiple regression remained the same (as it was a total score, so those with poorer performance on each of the grooved pegboard tasks, also had poorer performance on this composite score overall) and all that changed was the number of predictors in the model. The results of this analysis showed a significant relationship between the cognitive test battery and overall driving performance, showing that the removal of a single predictor, and therefore meeting the recommended participant-to-predictor ratio, was sufficient in providing enough statistical power for a significant result. This provides evidence that when time permits, it would be prudent to recruit enough participants to meet the participant-predictor ratio required to perform this analysis appropriately. This would overcome the limitations of insufficient power, and enable us to examine whether the non-significant finding was in fact an artefact of this study, and determine whether there is a relationship between cognitive function and overall driving performance for middle adulthood. As it stands however a conclusive result cannot be determined here regarding the efficacy of the Information Processing Model to explain overall driving performance in drivers in middle adulthood.

Cognitive Function and Driving Performance in Middle Adulthood

Previous literature has overwhelmingly focused on the relationship between cognitive function and driving performance only in older drivers and cognitively impaired cohorts. The main rationale for this is the increased crash risk in older drivers, and because of the well-established age-related decline in cognitive functioning in these groups. For younger drivers who share this high crash risk with the older driver population, there is new research suggesting a significant relationship between cognitive function and driving performance. It was initially hypothesised that young drivers share this relationship with older drivers due to similarities in their cognitive profiles with the younger cohort still undergoing cognitive development whilst the older cohort is experiencing cognitive decline. However, a review of the literature on the cognitive development of each of the cognitive domains has shown that the cognitive functioning of young drivers aged between 18 and 25 may be the same or better than those in middle adulthood. Thus, this study aimed to discover whether drivers in middle adulthood whose cognitive function is similar to that of young drivers, would share this relationship between cognitive function and driving performance. In accordance with this aim, the results of this study show preliminary evidence to suggest that cognitive performance in the middle adulthood driver group is significantly related to driving performance. The use of a composite measure assessing overall cognitive function as recommended by Dawson et al. (2009, 2010) and Bennett et al. (2016) was also justified by the results of this study.

While the focus in the literature on higher crash risk groups is valid, that is not to say that drivers in middle adulthood are never involved in road crashes and never suffer fatalities or injury on the road. This focus on other groups has led to most research overlooking the largest driver age cohort, the drivers in middle adulthood who are cognitively healthy. The recent evidence of a significant relationship between cognition and driving performance in young drivers (Ledger et al., 2016; Zicat et al., 2016), and the new evidence from this study showing preliminary support for this relationship in drivers in middle adulthood, is an indication that cognitive function may impact upon the driving performance of all drivers, regardless of age or cognitive health.

The secondary aim of this research was to assess whether the Information Processing Model could successfully be applied to drivers in middle adulthood and explain the relationship between cognitive function and driving performance for this cohort. The results for this part of the study were mixed, however the relationship between the cognitive test battery, which reflects the factors included the model, and the driving performance measure of speeding was strong. In the discussion of the specific results above, several reasons for the unexpected results with regards to the lane deviation and overall driving measures are suggested. Although the overall results regarding the Information Processing Model remain inconclusive, there is evidence to suggest that the cognitive skills included in the model are predictive of some components of driving performance. Given the ambiguity of results, particularly related to overall driving performance further investigation is warranted.

Although the findings in the current study showed some mixed results, there is a high likelihood that these can be partially explained by problems with the lane deviation driving measures, and insufficient power for the analyses. Future investigation into this relationship in drivers in middle adulthood should endeavour to rectify these issues through alternative methods of operationalising driving performance measures, and recruiting a greater number of participants.

Towards a Comprehensive Model for Driving Across All Ages

Current models of driving are most often constrained to a specific driver group as seen with Anstey and colleagues' (2005) model enabling safe driving behaviour in older drivers, with Uc and Rizzo's (2008) Information Processing Model for those with neurodegenerative diseases, and with Ulleberg and Rundmo's (2003) younger driver model for the relationship between risky driving behaviour and personality and social cognitive factors. Each model is also restricted to roughly one population group. The advantages of creating and using models for driving behaviour is that they summarise the current knowledge of driving behaviour in a concise and organised format, allowing for a more holistic understanding of the factors related to the task. They are also useful in informing us about the mechanism by which cognition or other variables, such as personality, translate into driving behaviour. Most of all, these models of driving can be applied practically and tested in order refine the current understanding of factors which influence driving in a systematic way.

This study attempted a preliminary application of the Information Processing Model, which was designed to explain deficits in driving performance for those with cognitive impairment, to a new driver group as a follow up to Zicat and colleagues' (2016) study which successfully applied the model to young drivers. Although there is some promising evidence, including the findings from this study, to suggest that this model can be useful for driver groups outside cognitively impaired drivers, further investigation is required to understand to what extent this model can explain driving behaviour from cognitive function in these cohorts.

When examining younger drivers, Zicat and colleagues (2016) not only tested the information processing model, but they also further tested elements of Ulleberg and Rundmo's (2003) young driver model, including social-cognitive variables such as driver attitudes and personality variables. They tried to determine the interplay between these models to examine whether cognitive functioning could potentially be a significant factor influencing driving performance for younger drivers, over and above previously well established factors. They did this by analysing the additional variance in driver performance explained by the cognitive test battery derived from the Information processing model, over and above personality and social cognitive factors. The findings showed that for both speeding and lane deviation measures, performance on the cognitive tests explained a significant amount of variance in the driving measures over and above the social-cognitive and personality variables. Ultimately, this finding shows that the current disparate models of driving performance are not sufficient on their own. The development of a comprehensive, multidisciplinary model which can partition off variance within driving performance and represent the relationship between each factor currently established to be related to driving performance is the ideal. To achieve this, a systematic effort must be made to combine and refine these models and apply them across all driver groups. This study is one contribution to the attainment of this goal.

Strengths of the Current Study

There are a number of key strengths of the current study including the application of previously used methodology to enable comparison between groups, the use of a driving simulator enabling greater experimental control and flexibility, and the use of cognitive tests previously established to be related to driving performance for the overall cognitive test battery.

One main strength of this study is in the application of methodology used in previous studies to a new driver group, the drivers in middle adulthood. An overarching question concerning the nature of the relationship between cognitive function and driving performance pertains to the similarity or difference in this relationship between driver groups. It is advantageous to be able to directly compare results between studies without concern for any differences between groups to be attributable to differences in methodology. Specifically, the use of Ledger and colleagues' (2016) methodology has allowed for the comparison between cognitive function and driving performance between the middle adulthood driver group and the young and older adult driver groups. Furthermore utilising Zicat and colleagues' (2016) study methodology has allowed for the comparison of the relationship between cognitive function and driving performance between the middle adulthood driver group and the young adult driver group in the application of Uc and Rizzo's (2008) Information processing model. This has enabled us to draw appropriate conclusions about the similarities and differences between each of the driver groups.

Another strength of this study lies in the use of a simulated drive. Driving simulators have many advantages which include: the ability to standardise the drive across all participants, the ability to easily re-watch the drive for scoring purposes, the ease with which driver performance scores can be collected, the cost effectiveness of research, and the flexibility in including a variety of events in the drive, some of which may be too hazardous or unrealistic to test on real roads. The ability to use standardised drives allows for increased experimental control, negating the possibility of error being introduced into the data due to uncontrollable events on the road such as variable weather, or the varied behaviour of other road-users. The other benefit of standardised drives is in the ease of scoring driving performance. There are a finite number of events to be scored and a finite number of response types meaning that a score sheet can be utilised with minimal training and therefore minimal cost, as there is no need for a trained assessor to score the drives as seen for example in Dawson and colleagues' (2009) study where videotaped drives were assessed by a trained driving instructor.

The ability to include a variety of scenarios and events in the drives, including hazardous events, enables more variance in driver skill to be captured. This is especially pertinent as previous research shows that cognitive function is associated with errors at a variety of levels of drive scenario complexity such as errors made in everyday situations (e.g., merging, speed control, lane deviation) (Anstey & Wood, 2011; Dawson et al., 2009) or errors made in unexpected scenarios (e.g., unexpected vehicle entering intersection). (Anderson et al., 2005). As a result, this drive included a variety of scenarios including expected events (e.g., red traffic lights, speed limit signs) and unexpected events (e.g., oncoming car, pedestrian walking out). The higher level of variability in driving scenarios and therefore driver responses increases the variance in the driving performance scores, and better distinguishes between different levels of driving ability. This also increases the generalisability of the results of the study to a wider range of driving scenarios.

A further strength of this study is in the use of cognitive tests selected on the basis of previous evidence examining the relationship between cognitive function and driving performance. The selected tests have been shown, in a recent systematic review, to have the strongest relationship to driving performance across the relevant cognitive domains known to be related to driving performance (Bennet, Chekaluk, & Batchelor, 2016). These tests were then combined into a battery to give a comprehensive overall measure of cognitive function. Given the recommendations for the use of overall measures of cognition (Bennett, Chekaluk, & Batchelor, 2016; Dawson et al., 2009, 2010), this method of selecting the tests aids in the creation of the best possible battery for this purpose. This is an advantage for an exploratory study of this nature where there has not yet been any investigation, as we are taking an evidence based approached to the examination of the relationship between cognitive function and driving performance in this new population.

Limitations of the Current Study

There are a number of limitations in the current study that could be improved upon in future research. These include, the way in which lane deviation was measured, the insufficient participant-predictor ratio with regards to the second hypothesis, and the limited representativeness of the sample.

One possible limitation of the current study as discussed above is the way in which lane deviation was measured. The results from this study regarding lane deviation were incongruous with findings from previous research and this may be due to the specific interaction between the age and simulator experiences of the driver group in the study. The way in which lane deviation is measured will have to be modified or substituted in future research in order to clarify whether cognitive function can or cannot predict lane deviation in drivers in middle adulthood.

A second possible limitation of this study is the insufficient sample size when performing the regressions to test the second hypothesis. With the increased number of predictors in the model, the sample size may have become insufficient to allow any possible effects to reach significance due to a lack of statistical power. The ambiguity of the results from this analysis means that it is difficult to draw any definite conclusions about that specific hypothesis. Whilst ideally, a power analysis would be performed to calculate the required sample size, due to the exploratory nature of the study, no previous effect size information was available. The issue of inadequate sample sizes is discussed by Molnar et al. (2011) in their systematic review of cognitive predictors in determining fitness to drive. The authors posit that there are numerous studies with limited sample sizes and insignificant results which may have committed a type II error where no significant effect is found where one does in fact exist. Future research should aim to avoid the potential ambiguity of insignificant results by utilising adequate sample sizes based on power calculations. Given that there is no previous information regarding the required sample size to investigate these relationships in this driver group, it is also possible that the insignificant lane deviation result for the primary hypothesis could also have been affected by issues of sample size despite meeting the 10-to-1 participant-to-predictor ratio. Due to this, no strong conclusions can yet be drawn with regards to lane deviation and cognition in drivers in middle adulthood. However, future researchers can use the findings of the current study as a starting point for their own power calculations in this field.

One final limitation of this study is the generalisability of the findings given the profile of the drivers recruited for the study. Over half of the participants in this study were university students recruited through first and second year undergraduate psychology classes and 61.36% of all participants had reportedly completed a Bachelor degree or above in contrast with 22% of the general population having done so in those aged 15 and over

(Australian Bureau of Statistics, 2017). A further related issue is that just over a third of participants were aged between 24 and 30 years. In a study by Barrash and colleagues' (2010) it was found that age and education reduced the ability of cognitive test scores to predict driving performance. The authors suggested that demographic information diminishes the predictive accuracy of the model in cases where performance is directly dependent on cognitive performance. These results suggest that the nature of the relationship between cognitive function and driving performance will remain constant regardless of education or age, however it remains that there may still exist an absolute difference in driving performance if either demographic variable is related to cognitive performance. The results of this study do not contradict the hypothesis that cognitive function does influence driving in some drivers in middle adulthood however further investigation into this area is warranted. Future studies should employ a wider, more representative sample to examine whether the results of the current study hold across drivers of different education levels, ages, and socio-economic groups.

Future Direction

There are several key areas which should be focused on to extend upon the current findings. These include, rectifying issues with the measurement of certain aspects of driver performance, the use of samples spanning the whole driver population, the integration of different areas of traffic psychology, and progress towards a comprehensive model of factors which enable driving competence for all driver groups.

First, to improve upon the current study, future investigation should endeavour to elucidate the relationship between cognitive function and lane deviation in drivers in middle adulthood and in older drivers by utilising a different measure of lane deviation, perhaps by modifying the parameters for what constitutes lane deviation in simulated drives, or by assessing participants on-road. In general, the use of multiple types of driving measures across studies is advised as they each have their own strengths and weaknesses. For example, an on-road test is the gold standard measurement of driving performance while a simulated drive offers more experimental flexibility and control when compared. While driving simulator studies are appropriate for exploratory research given they are low cost and efficient and show good relative validity (Mullen, Charlton, Devlin, & Bedard, 2011), on-road driving tests are needed to determine what absolute differences might exist between drivers of varying cognitive function. The use of both will give a more comprehensive understanding of the factors, such as cognition, which influence driving performance.

Considering the preliminary new evidence from this study supporting the existence of a relationship between cognitive function and drivers in middle adulthood, future research should aim to extend upon this by replicating and adding to this study. Further research can be especially beneficial by systematically investigating the relative influence of each factor known to be related to driving across driver populations and across disciplines. For example, a follow up study to this current study could include all drivers of all ages, investigating the relative influence of personality variables and cognitive variables on the driving performance of each age category. These kinds of comprehensive studies will allow for ease of comparison between driver groups as well as between variables from different disciplines. In this way, future studies can lend themselves to the development of a comprehensive multidisciplinary driving model which is all inclusive with regards to all driver populations.

Conclusion

This is the first study to investigate the relationship between overall cognitive function and driving performance in drivers in middle adulthood. In summary, this study successfully found new evidence to support the relationship between overall cognitive functioning and driving performance, thereby satisfying the overall aim of this study, and filling a key gap in the literature. Previously there had been no investigation into the relationship between cognitive function and driving performance in drivers in middle adulthood, and little research investigating this relationship in younger drivers. The findings from this study, in corroboration with the recent findings from studies investigating younger drivers, suggest that the relationship between cognitive function and driving performance exists for all drivers, regardless of age. A secondary aim of the study was to assess whether the Information Processing Model of driving could successfully be applied to drivers in middle adulthood. The result of this investigation is inconclusive with mixed results.

Future research should aim to continue investigation into drivers in middle adulthood and younger drivers with regards to the relationship between cognitive function and driving performance. Beyond this, future investigations should endeavour to move towards a holistic understanding of driving performance across driver groups, and across traffic disciplines. Furthermore, progress should be made towards an all-encompassing model of driving for all drivers. As investigation in this area continues, we may conclude that all driver groups may be more alike than initially thought.

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Appendix A

STISIM Driving Simulator version 3

Appendix B

Information and Consent Form

MACQUARIE University
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Department of Psychology
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Chief Investigator's / Supervisor's Name: Dr. Eugene Chekaluk

Information and Consent Form

Name of Project: Driving and Cognitive Functioning: Does Age Matter?

You are invited to participate in a study which is examining the relationships between a series of cognitive assessments and simulated driving performance. The purpose of the study is to determine the relationship between cognitive functioning and driving ability in everyday drivers.

The study is being conducted by Selena Ledger (PH: 0452 466 676, selena.ledger@students.mq.edu.au) to meet the requirements of a Master of Research under the supervision of Eugene Chekaluk of the Department of Psychology (PH: 9850 8009, eugene.chekaluk@mq.edu.au).

If you decide to participate, you will be asked to complete a demographic questionnaire asking information about your driving habits. Following this you will complete a series of cognitive assessments. Then you will be asked to complete 2 drives on the simulator. The first of which will be a pilot drive to get you accustomed to the controls, which will be followed by a longer 10 minute drive. This should take approximately 1 hour. All aspects of the experiment are voluntary.

It is important to note that the simulator does involve the possible risk of physical discomfort in the form of motion sickness. If you suffer from migraines or epilepsy, or experience discomfort when playing video games or watching 3D movies, it is advised that you do not participate in this study as you might find the simulator experience uncomfortable and it may make you feel unwell. If you decide to participate, you are advised to keep half an hour free after the experiment to cater for the possibility of any adverse physical side-effects.

For participating you will receive 1 hours (2 points) course credit OR be reimbursed $20.

Any information or personal details gathered in the course of the study are confidential, except as required by law. No individual will be identified in any publication of the results. Only the named researchers will have access to the original data and this will be coded utilising participant numbers only. A summary of the results will be posted to participants upon request.

Participation in this study is entirely voluntary: you are not obliged to participate and if you decide to participate, you are free to withdraw at any time without having to give a reason and without consequence.

I, ________________________________ have read and understand the information above and any questions I have asked have been answered to my satisfaction. I agree to participate in this research, knowing that I can withdraw from further participation in the research at any time without consequence. I have been given a copy of this form to keep.

Participant's Name:____

(Block letters)

Participant's Signature: ____________________________ Date:_____________________

Investigator's Name: SELENA LEDGER

(Block letters)

Investigator's Signature: _______________________ ___ Date:_____________________

The ethical aspects of this study have been approved by the Macquarie University Human Research Ethics Committee. If you have any complaints or reservations about any ethical aspect of your participation in this research, you may contact the Committee through the Director, Research Ethics & Integrity (telephone (02) 9850 7854; email ethics@mq.edu.au). Any complaint you make will be treated in confidence and investigated, and you will be informed of the outcome.

(INVESTIGATOR'S [OR PARTICIPANT'S] COPY)

Appendix C

Demographic Questionnaire

1) Date of Birth: ________/_______/_______
2) Age: _________
3) Gender: _______________
4) What is your ethnicity (ie. Anglo Australian)?________________________________
5) What is the highest level of education you completed (ie. Tertiary: Bachelor Degree)?

   ____

6) Current drivers licence status:____
7) Years spent driving:____
8) How many hours do you spend driving per week:

   ____

9) What are your reason's for driving (ie. work, social, shopping, appointments etc.)?

   ____

   ____

   ____

   ____

10) In what locations do you drive (ie. Residential areas/motorways)?:

   ____

   ____

   ____

   ____

11) Under what conditions do you drive (ie. dry, day time etc.)?

12) Do you drive with passengers? How many times per week?

13) Do you require assistance from your passenger (ie. they provide directions)?

14) Do you receive lifts from family and friends? How many times per week?

15) Have you been involved in any form of motor vehicle accident in the last 3 months? If yes, please provide details (ie. how many times, what the collision was with, if at fault).

____

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____

16) Have you received any form of infringement notice in the last 3 months? (ie. parking, speeding, using mobile phone, provisional passenger restrictions, DUI etc.) If yes, please specify.

____

____

____

____

17) Have you experienced any of the following problems whilst driving in the last 3 months?

- ☐ Failed to respond to road signs (ie. Stop at a stop sign)
- ☐ Hit curbs
- ☐ Swerving in the lane/having trouble maintaining lane position
- ☐ Made an error at an intersection
- ☐ Confused the accelerator and the brake
- ☐ Got lost
- ☐ Forgot where you were driving to

Appendix D

Drive Scoring Sheet

Participant ID: ____________________ **Testing Date:** _______________________

Drive One

Drive Order

1) City
2) Highway
3) Country Town
4) School Area
5) Residential

Response to Speed Signs From 0 to 70km/h	1) Response timely to speed adjustment 2) Response Eventually (Slow adjustment) 3) No change in speed Note the speed they reach: ____
Indicating when merging into the centre lane	1) Time appropriate 2) Not time appropriate 3) Failed to indicate
Pedestrian Walking Out	1) Stop in time 2) Almost hit/Tire Screeching 3) Hit them (Automatic Fail)/ No response
Red Light	1) Stopped, proceeded when safe 2) Stopped late/after crossing the line, proceeded when safe 3) Failed to Stop, Proceeded when unsafe
Indicating at Left Turn	1) When given instruction 2) Indicate but not time appropriate 3) Failed to Indicate
Turn Instruction: Lane Position (before)	1) Correct lane position 2) Crossing two lanes 3) Wrong Lane
Left turn pedestrian	1) Stay stopped until they crossed 2) Move and then stopped 3) Came close/hit them

Turn Instruction: Lane Position (after)	1) Correct lane position 2) Wobbling 3) Wrong Lane
Indicating when merging into the centre lane (if applicable)	1) Time appropriate 2) Not time appropriate 3) Failed to indicate
Taxi Pulled Out	1) Responded appropriately 2) Responded but late (almost hit/tire screeching) 3) Did not respond
Maintaining Distance	1) 3 car lengths from car in front 2) In between distances 3) Tailgating
Indicating when merging	1) Time appropriate 2) Not time appropriate 3) Failed to indicate
Response to Speed Signs Up to 110km/h	1) Response timely to speed adjustment 2) Response Eventually (Slow adjustment) 3) No change in speed Note the speed they reach: ______________________________
Response to Speed Signs Down from 110km/h to 90km/h	1) Response timely to speed adjustment 2) Response Eventually (Slow adjustment) 3) No change in speed Note the speed they reach: ______________________________
Car on the wrong side of the road	1) Brake and Swerve to move out of the way 2) Brake (but no swerve) 3) No response
Response to Speed Signs Increase speed after stopping to 110km/h	1) Response timely to speed adjustment 2) Response Eventually (Slow adjustment) 3) No change in speed Note the speed they reach: ______________________________
Response to Speed Signs	1) Response timely to speed adjustment 2) Response Eventually (Slow adjustment) 3) No change in speed

Down from 110km/h to 70km/h	Note the speed they reach: ________________
Car Pulled Out	1) Responded appropriately 2) Responded but late (almost hit/tire screeching) 3) Did not respond
Maintaining Distance	1) 3 car lengths from car in front 2) In between distances 3) Tailgating
Pedestrian Walking Out	1) Stop in time 2) Almost hit/Tire Screeching 3) Hit them (Automatic Fail)
Pedestrian Walking Out	1) Stop in time 2) Almost hit/Tire Screeching 3) Hit them (Automatic Fail)
Give Way Sign	1) Slowed appropriately, proceeded when safe 2) Slowed late/after crossing the line, proceeded when safe 3) Ignored the sign, proceeded when unsafe
Pedestrian Walking Out	1) Stop in time 2) Almost hit/Tire Screeching 3) Hit them (Automatic Fail)
Ambulance Pulled Out	1) Responded appropriately 2) Responded but late (almost hit/tire screeching) 3) Did not respond
Stop Sign	1) Stopped at line, proceeded when safe 2) Stopped away from the line (too far away, or over the line), proceeded when safe 3) Failed to Stop, Proceeded when unsafe
Response to Speed Signs Return to speed of 70km/h	1) Response timely to speed adjustment 2) Response Eventually (Slow adjustment) 3) No change in speed Note the speed they reach: ________________
Stop Sign	1) Stopped at line, proceeded when safe 2) Stopped away from the line (too far away, or over the line), proceeded when safe 3) Failed to Stop, Proceeded when unsafe

Response to Speed Signs Down from 70km/h to 30km/h	1) Response timely to speed adjustment 2) Response Eventually (Slow adjustment) 3) No change in speed Note the speed they reach: ______________________________
Pedestrian Crossing	1) Slowed appropriately, proceeded when safe 2) Slowed late/after crossing the line, proceeded when safe 3) Ignored the sign, proceeded when unsafe
Bus Pulled Out	1) Responded appropriately 2) Responded but late (almost hit/tire screeching) 3) Did not respond
Indicating at Right Turn	1) When given instruction 2) Indicate but not time appropriate 3) Failed to Indicate
Turn Instruction: Lane Position (before)	1) Correct lane position 2) Wobbling 3) Wrong Lane
Readying the vehicle for turn	1) Move slightly into the intersection 2) Move completely into the intersection/too much onto the other side of the road 3) No movement into the intersection
Right turn gap	1) Wait for cars/people before turning 2) Going but then stopping for a person 3) Collision with car/pedestrian
Turn Instruction: Lane Position (after)	1) Correct lane position 2) Wobbling 3) Wrong Lane
Indicating when merging to single lane	1) Time appropriate 2) Not time appropriate 3) Failed to indicate
Maintaining Lane Position on Unmarked Road Way	1) Roughly in the middle 2) Wobbling 3) Too close to one side
Cyclist Pulled Out	1) Responded appropriately 2) Responded but late (almost hit/tire screeching) 3) Did not respond
Response to Speed Signs	1) Response timely to speed adjustment 2) Response Eventually (Slow adjustment)

Speed to 40km/h	3) No change in speed Note the speed they reach: ____
Maintaining Lane Position on Unmarked Road Way	1) Roughly in the middle 2) Wobbling 3) Too close to one side
Pedestrian Walking Out	1) Stop in time 2) Almost hit/Tire Screeching 3) Hit them (Automatic Fail)
Stop Sign	1) Stopped at line, proceeded when safe 2) Stopped away from the line (too far away, or over the line), proceeded when safe 3) Failed to Stop, Proceeded when unsafe
Accommodating other vehicle in the single lane street	1) Waited for/moved over to allow space 2) Narrow side by side (too close to vehicle/other vehicles on the side) 3) Did not accommodate causing accident
Response to Speed Signs Up towards 70Km/h	1) Response timely to speed adjustment 2) Response Eventually (Slow adjustment) 3) No change in speed Note the speed they reach: ____
Response to Speed Signs down towards 40Km/h	1) Response timely to speed adjustment 2) Response Eventually (Slow adjustment) 3) No change in speed Note the speed they reach: ____
Construction Zone Cones	1) Slow, smoothly negotiate 2) Slow, eventually/wobble 3) Failed to slow/Hit the cones

Speeding (Empirical Output)	1) <5% of time/distance 2) Between 5 – 10% of the time/distance 3) > 10 % of time/distance
Maintaining Lane Position (Over the	1) <5% of time/distance 2) Between 5 – 10% of the time/distance 3) > 10 % of time/distance

whole drive – Empirical Output)	

Total Scores

Disqualifying Events: ____

Total number of 1's: ____

Total number of 2's: ____

Total number of 3's: ____

Overall Rating: ____

Additional Notes

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