Chronological Age and Age-related Cognitive Deficits are Associated with an Increase in Multiple Types of Driving Errors in Late-Life

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Abstract

Objective: Older driver research has mostly focused on identifying that small proportion of older drivers who are unsafe. Little is known about how normal cognitive changes in aging affect driving in the wider population of adults who drive regularly. We evaluated the association of cognitive function and age, with driving errors.

Method: A sample of 266 drivers aged 70 to 88 years were assessed on abilities that decline in normal aging (visual attention, processing speed, inhibition, reaction time, task switching) and the UFOV® which is a validated screening instrument for older drivers. Participants completed an on-road driving test. Generalized linear models were used to estimate the associations of cognitive factors with specific driving errors and number of errors in self-directed and instructor navigated conditions.

Results: All errors types increased with chronological age. Reaction time was not associated with driving errors in multivariate analyses. A cognitive factor measuring Speeded Selective Attention and Switching was uniquely associated with the most errors types. The UFOV predicted blindspot errors and errors on dual carriageways. After adjusting for age, education and gender the cognitive factors explained 7% of variance in the total number of errors in the instructor navigated condition and 4% of variance in the self-navigated condition.

Conclusion: We conclude that among older drivers errors increase with age and are associated with speeded selective attention particularly when that requires attending to the stimuli in the periphery of the visual field, task switching, errors inhibiting responses and visual discrimination. These abilities should be the target of cognitive training.

Keywords: automobile driving, attention, function

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Chronological Age and Age-related Cognitive Deficits are Associated with an Increase in Multiple Types of Driving Errors in Late-Life

Concern about the safety of older drivers has been the focus of licensing authorities, researchers and the general public. Much of the focus of research has been on developing methods to detect that small number of older drivers who are truly unsafe (Ball & Owsley, 1993), many of whom have preclinical or early stage dementia or eye disease (Owsley, Stalvey, Wells, Sloane, & McGwin, 2001). Importantly, there is also a need to ensure that older adults maintain their mobility and social participation for as long as possible, and there has been concern that the broader older driver population may be stigmatized by a few unsafe older drivers. However, there is a lack of information on the extent to which the well documented, normal cognitive changes that occur with aging impact on driving skills of older adults who drive regularly in their everyday lives. This is useful for the design of performance based driving skill assessments, the design of roads, signage and vehicles and education of older drivers.

In normal aging without dementia, age-related atrophy of the frontal lobes (Haug & Eggers, 1991; Raz, Gunning-Dixon, Head, Dupuis, & Acker, 1998) may lead to subtle changes in inhibitory control, leading to observed declines in performance on tests of executive function. We have argued previously, in relation to falls, that aging of the frontal cortex leads to failures of inhibition of motor responses and visual attention, thus increasing the risk of injury in later life (Anstey, Wood, Kerr, Caldwell, & Lord, 2009). Behavioral slowing that is ubiquitous with aging (Salthouse, 1996) has been associated with white matter changes (Gunning-Dixon & Raz, 2000) in the brains of healthy adults (Wen, Sachdev, Chen, & Anstey, 2006).

This slowing combined with decrements in frontal lobe function have the potential to affect performance in various driving situations. These could involve decision-making under timed conditions, the inhibition of prepotent responses to avoid other vehicles or pedestrians and the capacity to selectively attend to relevant information under timed conditions in the presence of distractors.

To date, research linking neuropsychological function to driving has mostly focused on global or categorical outcomes such as crashes, or pass versus fail on an on-road test (Anstey, Wood, Lord, & Walker, 2005; Ball, Owsley, Sloane, Roenker, & Bruni, 1993). The more specific relationships between age, cognitive abilities and the probability of making specific types of errors during the driving task have rarely been investigated in samples of older drivers without dementia. Linking cognitive test performance to driving performance requires measurement of the cognitive abilities involved in the driving task, as well as measures of the specific errors drivers may make when operating a vehicle or in specific driving situations.

Baldock, Berndt and Mathias (2008), using a relatively small sample of older drivers (N = 90), found that observation errors and mirror check errors were related to poorer performance on the Computerized Visual Attention Test (CVAT), while positioning errors (e.g., lane straddling) were only related to selective attention. A second study, using an in-vehicle driver monitoring system to focus specifically on lane-change errors (N = 1080), found that poorer performance on the Brief Test of Attention and the Beery-Buktenicka Test of Visual-Motor Integration were predictive of these driving errors (Munro et al., 2010). A study of 111 older drivers and 80 middle-aged drivers found that performance on the Complex Figure Test, Block Design and Grooved Pegboard Task were associated with total driving errors in the older group (Dawson, Uc, Anderson, Johnson, & Rizzo, 2010).

In the present study we investigated how cognitive function is related to a range of different errors in operating automobiles or in responding correctly in a range of driving situations within community-dwelling older drivers. We have recently described the methodology of an on-road test that provides measures of different types of errors made by older drivers (J. M. Wood et al., 2009). Overall, the highest rates of errors involved failure to maintain lane position, errors in approach, blindspot errors, inappropriate brake/accelerator use, errors in observation, and errors in gap selection. Participants reporting a previous crash made significantly more errors overall involving observation. This occurred in both the self-navigated driving condition and the driver-instructed condition. Participants reporting a crash also made more errors using the brake or accelerator and approaching hazards than did participants who did not report a previous crash.

In the present study, we evaluated how rates of errors in common driving situations increase as a function of age and as a function of decreasing performance on laboratory-based cognitive tests. Importantly, our study included coding of error types under a self-navigated (SN) condition where drivers are required to find their own way to a destination based upon road signs and markings and under an instructor-navigated (IN) condition, where the driving instructor provides instructions about directions (for example, where to turn). Inclusion of self-directed navigation provides the opportunity to evaluate drivers' ability to plan and execute maneuvers appropriately and is representative of the challenges faced by drivers in real-world driving situations (J. M. Wood, 2002).

Due to the lack of published studies on driving errors in older adults who drive regularly and live independently in the community, there is little empirical evidence on which to develop hypotheses about the specific relationships among age, cognitive abilities and frequency of specific types of driving errors.

Previous research has argued that poor executive function differentiates between at risk drivers and safe drivers (Daigneault, Joly, & Frigon, 2002). In the present study we focus on specific cognitive abilities, some of which have been described as aspects of executive function (Bryan & Luszcz, 2000). However the construct of executive function has been subject to varying conceptualizations and measured using a wide range of tests leading to confusion about its nature (Salthouse, 2005). Some authors propose a model of executive function comprising three correlated yet distinct constructs; inhibiting prepotent responses, shifting mental sets and updating working memory (Miyake et al., 2000). Yet others have found only weak evidence in support of these three distinct constructs when they are placed in the broader context of wide range of cognitive abilities (Salthouse, Atkinson, & Berish, 2003). Salthouse (2005) argued that measures of executive function relate strongly to reasoning and processing speed (Salthouse, 2005). Hence for the present study we focused on abilities relevant to executive function rather than endorsing a particular model of executive function. The specific abilities that formed the focus of this study included reaction time, processing speed, inhibition of prepotent responses, visual attention and set-shifting. In addition we included the Useful Field of View Test (UFOV©) which is arguably the best validated predictor of unsafe older drivers (Clay et al., 2005).

We made tentative hypotheses of expected associations between cognitive abilities and driving errors. We expected that errors in more complex driving behaviors requiring decision-making about positioning of the vehicle, selecting gaps in traffic and appropriate planning and preparation in a particular driving situation or manoeuvre) would be associated with poorer performance on measures of selective attention, set-shifting and attention. We expected errors of blind spot checking would be associated with poorer visual selective attention, and errors in braking and accelerating, would be associated with slower reaction time. For situational errors, we had no clear hypotheses. We expected better cognitive performance to be a stronger predictor of driving errors in the self-navigated condition than the instructor-navigated condition, and to be stronger correlates of behavioural than situational errors.

Method

Participants

Community-dwelling persons aged 70 years and over (n = 449) were recruited via the Australian electoral roll (voting is compulsory in Australia) into a larger study on the Prevention of Older Person's Injuries based at the Queensland University of Technology. Current drivers were identified from the study questionnaire with the question 'How often do you usually drive a car?' Possible responses were (less than once per week, twice per week, three times per week, 4 to 6 times per week, everyday). Participants who reported driving once per week or more were invited to participate in the sub-study involving an On Road Driving Test (ORT). Of the 347 drivers identified by the questionnaire, 272 agreed to participate in the ORT. Two participants were excluded because they scored below the cut-off for probable dementia (i.e., < 24) on the Mini Mental Status Examination (MMSE) (Folstein, Folstein, & McHugh, 1975). Three participants were excluded because of incomplete data for the on-road driving assessment and one participant was excluded due to a large amount of missing data on the cognitive assessment. Thus a total of 266 participants were included in the present study. They had an age range of 70 to 88 years (mean age 75.82, SD = 3.95), 50.2% were male and the sample had an average of 11.47 (SD = 3.91) years of education. The study was approved by the Queensland University of Technology Human Research Ethics Committee. Informed written consent was obtained from each participant prior to testing.

Procedure

Participants self-completed a questionnaire prior to testing, providing information on demographics (i.e., age, gender, total years of education), and physical and mental health (details reported elsewhere; Anstey et al., 2009). Testing was conducted in two sessions. The MMSE was administered in the initial session to screen for dementia, followed by a battery of cognitive tests, taking approximately 2 hours. The second session involved an on-road driving assessment that took approximately 50 minutes.

Cognitive Measures

The properties of the cognitive measures used in the POPI study are reported in detail elsewhere (Anstey et al., 2009) and only a summary is provided here.

Computerized versions of the *Trail Making Tests* (Reitan, 1971) were used to measure processing speed (Trails A) and task-switching ability (Trails B), an aspect of executive function. For Trails A (TMTA) participants were directed to press 8 numbered circles in numerical order (e.g., 1-2-3-…8; Part A). For Trails B (TMTB) participants had to press eight numbered and eight lettered circles in alternating order (e.g., 1-A-2-B-…8-H; Part B). A line was drawn from the starting point to each correct number or letter. If the participant made an error, no line was drawn and the participant was unable to progress until they touched the correct letter or number. Auditory feedback during the task, with one tone for a correct response, and another for incorrect. Performance was measured by the total time taken to complete the test. A second measure of processing speed was a computerized *Digit-Symbol Matching* (DS-Match) task (Anstey, Butterworth, Borzycki, & Andrews, 2006; Salthouse, 1994). In each trial, participants were asked to decide by pressing on the screen whether a number-symbol pair was a 'match' or 'no-match' according to a coding key, showing nine symbols and nine corresponding numbers. Response time was recorded for each of 72 pairs. The mean reaction time for correct responses was calculated.

A series of computer-administered reaction tests used a button box with two buttons (hands) and a pair of response pedals (feet) to measure different aspects of reaction time and executive function. The left and right buttons on the button box were used for left and right hand responses, respectively. The left and right pedals were used for left and right foot responses, respectively. For this study, we focus on those tests that have been previously shown to be most important for identifying unsafe drivers (J. M. Wood, Anstey, Kerr, Lacherez, & Lord, 2008). In a S*imple Reaction Time* (SRT) task the target stimulus (a red car) was presented on the screen at random intervals (trials = 30). Participants were instructed to respond to stimulus presentations as quickly and accurately as possible by pressing a button using their dominant hand. *Choice Reaction Time Color* (CRTC) was a variation of CRT that required response inhibition. Participants completed the choice reaction time task where the stimulus was a red car that appeared in one of four quadrants. Left and right top quadrants corresponded to the left and right response buttons and left and right lower quadrants corresponded to the left and right foot pedals. Participants had to respond with their left or right hand or foot depending on the location of the red car. In addition they were instructed not to respond to a distractor stimulus (a blue car) that was presented on random trials in a quadrant. In each quadrant, the target appeared 12 times and the distractor appeared 4 times. Thus blue cars were shown in 16 of 64 trials (25%). Mean reaction time for correct responses (CRTC-RT) and number of correct responses (CRTC-cor) were used as measures in the analyses. Reaction times that were more than three standard deviations from the participants' mean score on a test were treated as outliers and trimmed.

A Visual Search (VSrch) test was used to measure visual selective attention. In this test, a screen was presented displaying rows of numbers. At the left of each row the target number was indicated. Participants had to respond to any occurrences of the target number in the row by touching the numbers on the touch screen. There were 109 trials.

Useful field of view

Visual selective attention and processing speed was assessed using the commercially available version of the useful field of view (UFOV©) test which is PC-based and linked to a touch screen (17 in.) for participant responses (Edwards et al., 2006). The test is performed binocularly and involves three increasingly difficult subtests involving stimulus identification, divided attention, and selective attention. The first subtest (UFOV 1) measures the time it takes to correctly identify a target (silhouette of a car or lorry) presented in a central fixation box. The second subtest (UFOV 2) measures divided attention and involves identification of the central target, together with localization of a simultaneously presented peripheral target (silhouette of a car), presented randomly in 24 different locations at 10°, 20°, or 30° eccentricity along eight radial spokes. The third subtest (UFOV 3) consists of these two tasks, with the addition of visual distractors (triangles of the same size and luminance as the targets) which are presented across the extent of the visual display.

On-road driving assessment

Participants underwent an on-road driving assessment in an automatic dual-brake vehicle during which a trained occupational therapist scored driving performance using specific criteria (J. M. Wood et al., 2009; J. M. Wood, Worringham, Kerr, Mallon, & Silburn, 2005). A validation study has shown that this method has a high correlation with a professional driving instructor assessment (r = 0.76) (J. Wood & Mallon, 2001). An accredited professional driving instructor, who was responsible for monitoring safety, sat in the front passenger seat with access to the dual brake. Participants were allowed a short warm-up drive to familiarize themselves with the vehicle, then they completed a 50 minute testing session. Assessments were conducted in-traffic conditions either mid-morning or mid-afternoon to avoid rush hour traffic. The assessment was terminated early if the driver was considered too unsafe to proceed. Instructions were given to drive along a 19.4 km route consisting of city and suburban streets in the city of Brisbane which has a population of approximately 1 million people. The route included simple and complex intersections and a range of traffic densities. For three quarters of the assessment (75%), the driving instructor gave detailed instructions of the route. The remaining 25% was self-navigated; that is, participants had to find their own way to a given destination. Participants were asked to follow signage to Stone’s Corner, a suburb of Brisbane. They had not driven to this destination in the earlier part of the assessment.

Driving performance was assessed by an occupational therapist, experienced in driving assessment, seated in the rear of the vehicle. At each of 146 locations along the route, seven aspects of driving behavior were scored: general observation (OBS) (appropriate scanning of the road environment, attention to signs and road markings, other road users and use of mirrors as appropriate); observation of blind-spots (BSP) (including shoulder-check for vehicles in the car's blind-spot); indication (IND) (appropriate use of the directional indicator); braking/acceleration (BA) (appropriate speed of driving manoeuvres, including driving over the speed limit or heavy sudden braking without due cause); lane positioning (LP) (including veering left or right instead of staying within the lane lines and appropriate choice of lane when turning); gap selection (GS;between the driver's vehicle and the one in front, or the gap selected by the driver when entering traffic); and approach (APP; appropriate planning and preparation in a particular driving situation or manoeuvre). Each location was also allocated into one of six driving situation categories: traffic light controlled intersections (TRL); one-way traffic (OWAY; straight or curved driving in a road with one-way traffic); two-way traffic (TWAY; straight or curved driving in a road with two-way traffic); give way (GWAY; entering traffic from an intersection where there is a stop or give-way sign, or where there are no traffic lights, negotiating a pedestrian crossing, or roundabout); maneuvering (MAN; including turnaround manoeuvres, driving in a traffic calming area, negotiating a car park, or reversing); and merging (MER; changing lanes, entering traffic from a turn-left-with-care intersection, or pulling into or out of a parking space) (see Wood et al., 2009, for further details). For statistical analyses, the number of each type of error was used as the dependent variable. This included seven behavioral errors and six situational errors.

As the driving test comprised a driver instructed and self-navigated component, it was possible to evaluate the degree to which cognitive performance was associated with driving errors in these two conditions. The number of errors in each condition was summed to create two variables measuring errors in the Driver instructed condition (Driveinserr) self-navigated condition (Selferr). Critical errors requiring instructor intervention to prevent a crash were also counted (Criterr).

Statistical Analyses

Unadjusted associations between total and individual error types on the on-road test and the cognitive variables were calculated with Pearson correlation coefficients. The cognitive test battery was reduced using factor analysis, using Principal Axis Factoring (PFA) analysis and oblimin rotation with Kaiser Normalization. This approach was taken because some of the cognitive tests measured the same or similar abilities (eg. Trails A, Trails B and DSS and visual search all involve processing speed and attention) and to determine how the UFOV subtest loaded with the cognitive tests. The number of factors was chosen on the basis of substantive interpretation of pattern matrix. Factor scores were saved from the analysis using the Bartlett method and used in later analyses.

The associations between cognitive factors and each error type were estimated using generalized linear models with a Poisson distribution and logit link function. This was because the error variables were counts and the Poisson distribution best models counts data including over dispersion (Tabachnick & Fidell, 2007). The models were adjusted for age, gender and education and all cognitive factors were included in each model simultaneously, allowing for the identification of unique variance between the factor and error type to be identified.

Further post hoc analyses were conducted to evaluate whether the strength of associations between cognitive factors and errors varied between the self-navigated and instructor-navigated components of the on-road test. The counts of errors in each condition had normal distribution so multiple regression was used. Demographic variables were entered at Step 1 and then at Step 2, all cognitive factors were entered as predictors. This provided an estimation of variance explained by the cognitive factors in each condition and the relative contribution of the different cognitive factors to performance under the self-navigation and instructor-navigated conditions. Analyses were conducted in PASW Statistics 18 and for regression analyses alpha was set at $p < .01$.

Results

Differences between drivers who agreed to participate in the On Road Assessment and those who did not

To evaluate potential self selection of better drivers into the ORT part of the study, those who agreed to participate in the ORT were compared with those drivers who declined participation in the ORT. Those who agreed to participate were younger [75.82 vs 77.46) $t(345) = 3.033$, $p < .01$] and more likely to be male [70.9% vs 37.8%; χ^2 (1) = 29.54, $p < .01$]. They scored better on the UFOV [139.887 vs 189.354; $t(345) = 3.95$, $p < .01$]. They did not differ in their MMSE score, visual acuity, or their score on the SF36 Physical functioning of Mental Health subscales. These findings indicate that older participants, females and poorer drivers are less likely to volunteer for the ORT resulting in a higher functioning sub-sample who completed this study.

Descriptive data on the error types and cognitive tests is shown in Table 1. Blindspot errors were the most common behavioral errors followed by lane position, indicator errors and approach errors. Situational errors were less frequent that behavioral errors and the most common was traffic light error. The greater number of errors in the driver-navigated component of the test reflects the longer time period spent in this condition compared with self-navigation.

Factor analysis of cognitive measures

Factor analysis was used to reduce the number of cognitive variables and analyse the factor structure among them. A five factor solution provided the best distinction between the abilities that the battery was designed to measure so this was retained and factor scores used as independent variables in later analyses. The total variance accounted for was 58.6%. Results of the factor analysis to reduce the number of cognitive variables are shown in Table 1. The first factor explained 33.02% of the variance and was named a Speeded Attention and Switching Factor (SAttSw). It was indicated by DSMatch, Trails A, Trails B, and VSrch. The second factor was defined by UFOV2 and UFOV3 so was named UFOV. It explained 6.54% of the variance. A third factor onto which CRT-C RT and SRT loaded was named Reaction Tim (RT) and explained 3.92% of variance. A fourth factor onto which only the UFOV1 loaded was named Discrimination (Discrim) and explained 2.86% of the variance. A fifth factor, onto which the errors score from the CRT-C task loaded was named Inhibition (Inhib) and explained 1.80% of the variance. These five factors were used as independent variables in later analyses. Factor intercorrelations are also shown in Table 2. RT and UFOV had a moderate association with SATTSw. Inhib had a moderate correlation with UFOV.

Correlations among Demographic, Cognitive and Driving Error Scores

Table 3 shows the unadjusted associations among demographic variables, and cognitive factors, and error types in the full sample. Age was positively associated with all behavioral errors, and with critical errors requiring instructor intervention during the test. This indicated that driving performance was less safe at older ages. Figure 1 shows the average frequency of critical errors according to age group. Gender, education and general health were not associated with behavioral errors, but lower levels of education were associated with more critical errors requiring instructor intervention. SAttAW and UFOV had the highest number of bivariate associations with errors on the driving test.

Cognitive Factors Associated with Driving Behavior Errors and Situation Errors

Table 4 shows the results of the generalized linear models with a Poisson distribution. SAttSw, Discrim and Inhib each uniquely predicted Observation errors. Blind sport errors were only predicted by UFOV. Indicator errors were not associated with any of the cognitive factors. Brake/accelerate and Gap selection errors were associated with SAttSw scores only. Lane position and Approach errors were both predicted by SattsW and Discrim scores.

There were fewer significant associations between the cognitive factors and the six situational error types and no associations with errors recorded in Stop/Give way, Maneuvering or Merging situations. Turn left errors were associated with SAttSw, Single lane errors were predicted by Inhib amd Dual Carriage way errors were predicted by UFOV.

Post hoc analyses for self-directed and driver directed driving conditions.

Table 5 shows the multiple regression analyses of cognitive factors as correlates of total number of errors in both the self-navigation and driver instructed conditions. RT and Inhib were associated with the total number of errors in the Self Navigation condition whereas SAttSw and Inhib were associated with errors in the Instructor directed condition. After adjusting for demographic variables including age, the cognitive variables explained more variance in the driver instructed condition (7% versus 4%).

Discussion

In a large sample of community-dwelling older drivers who drove regularly, we found that all types of behavioral driving errors and errors in specific driving situations, increased with chronological age. Critical errors requiring instructor intervention also increased with age. Age was weakly (but still significantly) associated with errors on one-way streets, at give way or stop signs, maneuvers and merging. These findings therefore demonstrate the ubiquitous association between chronological age and the propensity to make errors during an on-road driving test, even in a sample of drivers without dementia who are living within the community.

Once age was adjusted for in statistical models, our findings supported our hypothesis that behavioral errors would have more associations with cognitive factors than situational errors. Reviewing all the findings from the study, the SAttSw factor had more associations with driving errors than the other factors. This may in part have been due to measurement of this factor including a wider range of indicators variables capturing multiple abilities in comparison to Inhib, Discrim and RT which captured single abilities.

Surprisingly, the UFOV was only uniquely associated with blindspot errors. Performance on the UFOV2 and UFOV3 subtests relies on peripheral vision which is important for detecting stimuli in the periphery and may hence be important for awareness of blindspots in the field of vision. Blindspot errors were by far the most common errors recorded, possibly explaining the overall consistent findings in the literature that UFOV predicts crashes and driving performance (Clay et al., 2005). Moreover, the analyses estimated the effects of cognitive factors simultaneously so that the effects unique to the UFOV were likely to be those visual aspects of the test that are not captured by the other cognitive measures. Scores on the UFOV factor also predicted errors on dual carriage ways, again suggesting that in the context of this test battery UFOV may be measuring aspects of visual selective attention in the wider visual field that is not captured by more traditional cognitive tests.

Although our overall results were consistent with related literature showing visual selective attention and processing speed to predict crashes, we had mixed support for our hypotheses relating to specific errors types and specific cognitive abilities. We did find that complex tasks were predicted by the factor measuring Speeded Selective Attention and Switching but this cognitive factor also predicted brake/accelerator errors. It is possible that brake/accelerator errors are the result of lapses in higher level decision-making regarding complex traffic situations rather than failures of motor responses. Our results were consistent with a previous study (Baldock et al., 2008) in finding an association between visual selective attention and observation errors, but our results also showed that inhibition and discrimination are also important in correctly observing traffic situations. Similar to Baldock et al., we also found that Lane position was associated with selective attention, but again we found that discrimination predicted these errors as well. Our finding that SAttSw predicted Gap Selection is consistent with previous research showing that lane changing was associated with attention (Munro et al., 2010).

An important finding from this study was that reaction time alone did not predict driving errors, yet the measures of selective attention, task switching, and discrimination were all speeded. Hence it appears that reaction time alone is too nonspecific to use as an index of driving ability.

A difference in the pattern of results was evidence for self-navigated compared with instructor-navigated conditions. It appeared that the self-navigated condition drew on a wider range of cognitive abilities, which would be expected as the driver needs to focus attention both on the driving task and navigation. The self-navigation condition is more similar to naturalistic driving situations. The fact that more variance was explained by the cognitive factors in the instructor-navigated condition was unexpected. This may be been an artifact of the longer duration of this test condition, which would have led to a more reliable and sensitive measure of total driving errors, increasing the likelihood of significant associations with the cognitive factors. However it is also possible that the need to listen to instructions during the ORT increased the working memory load of participants leading to more errors.

When interpreting the results there are some study limitations that should be considered. The focus of the present study was on cognitive abilities, so we did not include other factors that predict driving errors such as visual function (Anstey et al., 2005; J. M. Wood et al., 2008). The range of cognitive tests included was limited and it is possible that future research including more comprehensive test batteries will identify a greater number and stronger associations between cognitive abilities and driving errors. Despite the initial recruitment from the electoral role, there was a self selection bias in the sub-sample who agreed to undertake the ORT such that they had better driving skills as demonstrated by their better UFOV scores. Hence it is likely that our findings under-estimate the strength of association between cognitive abilities and driving ability in the broader population of older drivers. Although males were more likely to do the ORT, there were no gender differences in the numbers of errors between males and females, indicating that the associations observed between cognitive function and driving errors are not gender specific. Finally, as with any study of older adults, it is possible that the sample included participants with preclinical dementia despite the fact we screened for this with the MMSE. Our approach of using the MMSE as a screening instrument was consistent with other studies (J. M. Wood et al., 2008) that do not include a full neurological assessment. The use of the MMSE cutoff to exclude participants is a relatively crude approach but remains common practice in the absence of a diagnostic test for Alzheimer's Disease or other dementias. Although education level does influence the sensitivity and specificity of the MMSE, education has been shown to account for only a small proportion of the variance in scores (Jones & Gallo, 2001).

We conclude that driving performance does decline with normal aging and that a large range of errors become more prevalent with increasing age in late life. Aspects of normal cognitive aging, namely reductions in processing speed, visual attention, task-switching, reaction time and inhibition are associated with increased errors during driving in community dwelling older adults and are not restricted to those with cognitive impairment. The UFOV® test is particularly sensitive to detecting blindspot errors which are the most common errors committed in this age-group. The implications of these findings are that the normative declines in cognitive performance experienced by a wide range of older adults living in the community place them at greater risk of making errors when they drive, particularly in cognitively demanding situations. This needs to be considered when designing roads and vehicles for older drivers. This research provides further evidence for targeting measures such as speed of processing and visual selective attention in cognitive training programs if there is potential for these improved skill sets to transfer to improvements in driving skills (Ball, Edwards, & Ross, 2007; Edwards et al., 2009; Roenker, Cissell, Ball, Wadley, & Edwards, 2003).

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Table 1.

Descriptive statistics for demographic variables, driving errors and cognitive tests (N = 263 to 266)

	M (SD)	*Minimum- Maximum*
Age	75.74 (3.90)	70 – 88
Gender	1.29 (.45)	1 – 2
Education	12.40 (4.07)	0.00 – 29.00
Observation of total errors	2.40 (2.78)	0.00 – 19.00
Blindspot total errors	11.22 (3.65)	2.00 – 19.00
Indicator total errors	6.69 (2.63)	1.00 – 18.00
Brake accelerator total errors	5.22 (5.14)	0.00 – 29.00
Lane position total errors	7.00 (5.13)	0.00 – 38.00
Gap selection total errors	2.46 (2.47)	0.00 – 25.00
Traffic light errors.	5.99 (4.95)	0.00 – 30.00
Turn left with care total errors	3.55 (2.51)	0.00 – 12.00
Straight driving one-way total errors	1.42 (1.32)	0.00 – 7.00
Straight driving dual- total errors	1.39 (1.57)	0.00 – 9.00
Stop give-way total errors	0.47 (0.64)	0.00 – 2.00
Turnaround manoeuvre total errors	0.77 (0.42)	0.00 – 1.00
Merging total errors	2.14 (0.83)	0.00 – 3.00
Instructor-navigated total errors	19.57 (7.04)	7.00 – 57.00
Self-navigated total errors	8.32 (3.72)	0.00 – 18.00
UFOV subtest 1	24.01(14.61)	16.00 – 116.00
UFOV subtest 2	138.92 (115.79)	16.00 – 500.00
UFOV subtest 3	302.20 (118.78)	80.00 – 500.00

SRT	0.33 (0.09)	0.19 – 0.84
Trails A	6.55 (3.07)	2.30 – 28.01
Trails B	41.35 (23.66)	13.12 – 295.28
Digit symbol matching	2.46 (0.47)	1.72 – 4.64
CRT-C RT	0.79 (0.12)	0.55 – 1.24
CRT-errors	46.22 (1.53)	39 – 48
Visual search	145.45 (32.45)	61.08 – 307.47

Note. SRT = Simple reaction time; CRT_C RT = reaction time for the correct trials on the colour choice reaction time test; CRT-errors = the number of errors on the colour choice reaction time test.

Table 2.

Pattern Matrix from Factor analysis of Cognitive Tests and Factor Intercorrelation Matrix (N = 263)

	Factor loadings				
	SAttSw	UFOV	RT	Discrim	Inhib
UFOV1	.02	-.14	.00	.52	-.02
UFOV2	-.04	-.82	.15	.18	.04
UFOV3	.12	-.52	-.07	.07	-.20
SRT	-.01	-.00	.80	-.04	-.06
Trails A	.29	-.10	.08	-.08	.07
Trails B	.46	-.17	-.06	-.09	-.23
DSmatch	.69	-.07	.09	.17	-.27
CRT-C RT	.22	-.10	.42	.18	-.08
CRT-C Errors	.02	.01	-.07	-.01	.48
Vsearch	.54	.13	.08	.18	.06
	Factor intercorrelations				
UFOV	-.42				
RT	.51	-.29			
Discrim	.24	-.28	.27		
Inhib	-.25	.47	-.20	-.17	

Note. CRT-C RT = reaction time for the correct trials on the colour choice reaction time test; CRT-errors = the number of errors on the colour choice reaction time test.

SAttSw = Speeded attention and task switching; UFOV = the UFOV subtests 2 and 3; RT = Reaction Time; Discrim = discrimination as measured by the UFOV subtest 1; Inhib = Inhibition measured by errors on the CRT-C task.

Table 3

Bivariate Associations Between Demographic Variables and Specific Driver Errors and Between Cognitive Measures and Specific Driver Errors

(N = 263-266)

			Behavioral errors							Situational errors					
Predictor	NonCI	CI	OBS	BSP	IND	BA	LP	GS	APP	TRL	OWAY	TWAY	GWAY	MAN	MER
Demographics															
Age	.03	.35**	.51**	.33**	.43**	.40**	.40**	.30**	.49**	.42**	.21**	.38**	.24**	.26**	.28**
Gender	-.03	.14*	.11	-.05	-.05	.04	.20**	.06	.11	.08	.16*	.13*	.04	.10	.00
Education	.05	-.17*	-.10	-.08	-.10	.02	-.15*	-.05	-.06	-.02	-.10	-.02	-.11	-.07	-.11
Cognitive Factors															
SAttSw	.08	.14*	.20**	.12*	.09	.25**	.21**	.15*	.22**	.26**	.13	.17**	-.00	.04	.20**
UFOV	.01	-.16*	-.23**	-.18**	-.18**	-.24**	-.19**	-.09	-.23**	-.26**	-.14	-.22**	.09	-.01	-.18**

RT															
	.01	.11	.18*	.15*	.07	.17	.18*	-.01	.21**	.17**	.15	.07	-.01	-.13	.22**
Discrim															
	.12	.08	.11	.03	-.02	.03	.11	-.01	.09	-.01	-.12	.05	.13*	-.07	.10
Inhib															
	.02	-.12	-.25**	.01	-.07	-.13*	-.06	-.04	-.16*	-.10	.17**	-.10	.03	.00	.02

Note. NonCI = non-critical instructor interventions; CI = critical interventions; OBS = observation; BSP = blind spot; IND = indicator; BA = brake/accelerator; LP = lane position; GS = gap selection; APP = approach; TRL = traffic light; OWAY = one-way; TWAY = two-way; GWAY = give way; MAN = maneuvering; MER = merging; SAttSw = Speeded attention and task switching; UFOV = the UFOV subtests 2 and 3; RT = Reaction Time; Discrim = discrimination as measured by the UFOV subtest 1; Inhib = Inhibition measured by errors on the CRT-C task.

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

Table 4

Regression Weights (B) for Cognitive Factors as Predictors of Behavioral Errors and Situational Errors Adjusted for Age, Gender and Education (n = 263 to 266)

	Behavioral errors													
	Observation		Blind spot		Indicator		Brake/accelerate		Lane position		Gap selection		Approach	
Predictor	B (SE)	*p*	B (SE)	*p*	B (SE)	*p*	B (SE)	*p*	B (SE)	*p*	B (SE)	*p*	B (SE)	*p*
SAttSw	**.15(.03)**	**<.01**	.00(.02)	.84	.00(.02)	.94	**.15(.02)**	**<.01**	**.11(.02)**	**<.01**	**.13(.04)**	**<.01**	**.12(.02)**	**<.01**
UFOV	.01(.04)	.77	**-.03(.02)**	.03	-.02(.02)	.37	-.04(.03)	.05	-.01(.03)	.62	.05(.04)	.26	-.01(.02)	.84
RT	.00(.03)	.79	.02(.02)	.07	.00(.02)	.97	.02(.02)	.33	.02(.02)	.39	-.08(.04)	.02	.03(.02)	.16
Discrim	**.04(.02)**	**<.01**	.00(.01)	.61	-.01(.01)	.51	.02(.01)	.15	**.04(.01)**	**<.01**	.00(.02)	.91	**.03(.01)**	**<.01**
Inhib	**-.08(.02)**	**<.01**	.01(.01)	.38	.01(.02)	.51	-.03(.02)	.03	.00(.01)	.95	-.01(.03)	.82	-.03(.02)	.03

	Turn Left		Single lane		Dual carriage		Stop/Give way		Maneuvering		Merging	
SAttSw	**.08(.03)**	**<.01**	.00(.05)	.98	.09(.05)	.05	.05(.09)	.56	.03(.07)	.62	.03(.04)	.44

UFOV	-.04(.03)	.26	-.01(.05)	.08	**-.14(.05)**	**<.01**	.17(.10)	.10	.04(.07)	.61	-.03(.04)	.50
RT	.01(.03)	.63	.07(.04)	.10	-.02(.04)	.62	-.04(.08)	.65	-.08(.07)	.24	.04(.02)	.25
Discrim	-.01(.02)	.77	.00(.03)	.92	.04(.03)	.11	.08(.05)	.08	-.02(.04)	.58	.02(.03)	.37
Inhib	.01(.02)	.69	**.13(.04)**	**<.01**	.04(.03)	.18	.03(.06)	.67	.01(.05)	.88	.12(.03)	.58

Note. SAttSw = Speeded attention and task switching; UFOV = the UFOV subtests 2 and 3; RT = Reaction Time; Discrim = discrimination as measured by the UFOV subtest 1; Inhib = Inhibition measured by errors on the CRT-C task. Significant effects are shown in bold.

Table 5

Hierarchical Multiple Regression of Driver Errors In the Self-navigated and Instructor-navigated Conditions (n = 263-266)

	Total Errors Self-navigated Condition			Total Errors Driver-naviaged Condition		
	Inc. Rsquare	beta	p-value	Inc. Rsquare	beta	p-value
Step 1.	.04**			.17**		
Age		.20	<.01		.34	<.01
Education		-.03	.43		.03	.38
Gender		.03	.47		.10	<.01
Step 2.	.08**			.24**		
SAttSw		.00	.98		.25	<.01
UFOV		-.11	.02		-.01	.78
RT		.12	<.01		.04	.27
Discrim		.03	.51		.06	.07
Inhib		.11	<.01		-.10	.01

Note. Inc. Rsquare = incremental R square

Note. Inhib = Inhibition factor; AttSS = Attention, Speed and Switching; RT = reaction time; UFOV = Useful Field of View

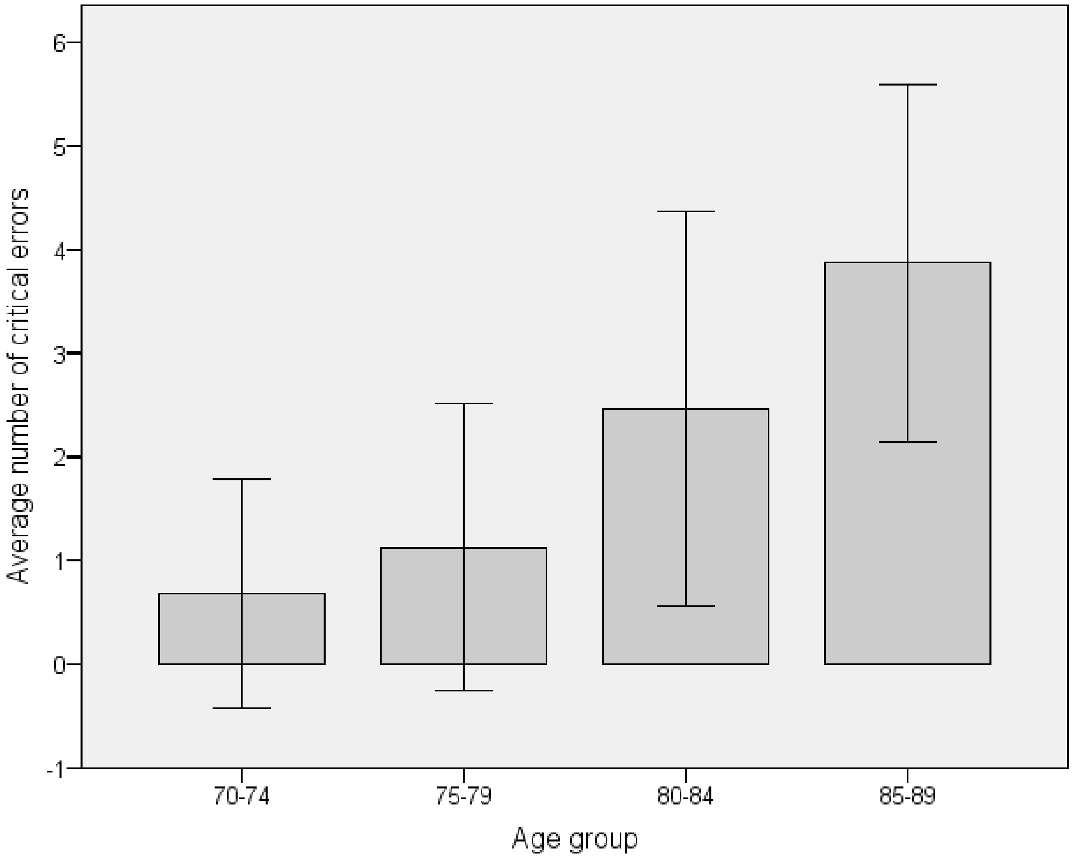

Figure 1. Average frequency of critical errors made during the on-road test for each age group (n = 266). Standard deviations are represented in the figure by the error bars attached to each column.