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Wayfinding Whilst Driving, Age and Cognitive Functioning

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Abstract

Older drivers are more likely to have difficulty wayfinding in unfamiliar areas than younger people. The present study investigated the role of cognitive functioning and age on wayfinding difficulties and driving performance whilst driving in unfamiliar areas. Forty-seven participants aged between 21 and 82 years completed a wayfinding task in a driving simulator and a battery of neuropsychological tests. Older age was related to reduced driving speed and increased time stopped during the drive. Cognitive variables associated with wayfinding difficulties and driving performance decrements included processing speed, visuospatial ability, and aspects of memory, including verbal and visual immediate and delayed recall. This research suggests that older drivers, particularly those with poorer cognitive functioning, had more difficulty with wayfinding in unfamiliar areas than younger drivers. The findings are discussed with reference to potential safety and mobility benefits of alternative wayfinding strategies.

Key Findings

- Some older drivers found wayfinding in unfamiliar areas challenging.
- They adopted compensatory strategies such as slowing down and pulling over.
- Cognitive functioning was associated with driving performance when wayfinding.

Introduction

Wayfinding whilst driving in unfamiliar areas is a complex, multi-task activity. Wayfinding describes the activity of purposive movement to a destination by following a route through a network of paths, and using mental processes which identify, manipulate and integrate information from both the environment and the individual (Arthur & Passini, 1992; Golledge, 1999; Passini, 1984). An important additional consideration of the wayfinding task is the notion of familiarity of the environment. Arguably, the mental processes and information required for wayfinding in familiar and unfamiliar environments are different. Wayfinding in unfamiliar areas has a higher level of cognitive demand, as there is more need to plan the route, search for information and solve problems (Arthur & Passini, 1992). In unfamiliar surroundings, drivers commonly rely on aides for navigating such as maps, written instructions, or Global

Positioning Systems (GPS). In contrast, in familiar areas, drivers are less reliant on environmental information as salient points have been internalised through memory processes and the formation of cognitive maps.

When driving a vehicle, the secondary task of wayfinding has the potential to divert attention away from the primary driving task. There is substantial evidence which suggests distraction caused by secondary tasks can impact driving performance negatively (Dingus et al., 2016; Engström et al., 2005; Owens et al., 2011; Regan et al., 2008; Young et al., 2013). There is also a growing body of evidence that driving performance is negatively affected when wayfinding whilst driving (Mallon & Wood, 2004; Wood et al., 2009). Moreover, recent research by Cochran and Dickerson (2019) has shown that the nature of wayfinding aides used, specifically paper-based, written instructions versus GPS, has differential effects on driving. Older drivers are more susceptible to driving performance decrements while wayfinding

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compared to younger drivers in some driving contexts (Dingus et al., 1997; Mallon & Wood, 2004). Importantly, the driving performance decrements found whilst wayfinding have been shown to be related to higher crash rates (Wood et al., 2009).

When wayfinding, the driver needs to perform route following tasks while driving in an unfamiliar area. A model developed to explain wayfinding by pedestrians provides a useful framework for understanding the relationship between ageing, cognition and wayfinding. Passini and colleagues describe several high-level processes required for wayfinding, including decision making, decision execution and information processing (Arthur & Passini, 1992; Passini, 1984). More specifically, wayfinding requires individuals to identify information from different environmental sources (e.g., maps, directions and landmarks) and uses internal cognitive processes (e.g., complex attention, visuospatial abilities, memory, planning and decision making) to make correct decisions about where to go (Arthur & Passini, 1992). Fundamentally, the same cognitive abilities are required in both driving and pedestrian wayfinding for which the model was developed, although mode-specific differences would be required to control different actions involved in decision execution (e.g., turn steering wheel to left for a left turn whilst driving vs. veer left when walking).

Researchers have also emphasised the important role of executive processes that govern individuals' ability to make effective plans about the order in which they visit various locations as well as execute route planning and selection, novelty detection, selection and maintenance of navigational goals, spatial working memory, resolution of uncertainty or conflicts, and resetting mechanisms (Taillade et al., 2013; Toglia et al., 2014; Wolbers & Hegarty, 2010). In the driving context, it is important to recognise that the driver must continue to operate the vehicle and identify potential hazards while at the same time, finding their way to a designated destination (Burns, 1998). Many of the cognitive processes identified in Passini and colleagues' model for pedestrian wayfinding are also considered to be important for safe driving. When driving, additional processes are also required including speed of processing and divided attention (Groeger, 2000; Rizzo & Kellison, 2009; Staplin et al., 2012). Robust age-related difficulties have been demonstrated in multi-task conditions across a range of sensory, motor and cognitive domains (Jaroslawska et al., 2021; Verhaeghen et al., 2003). In their meta-analysis of 33 studies, Verhaeghen and colleagues found that both younger and older adults suffer from the effects of dual-task performance but older adults suffer from a larger dual-task cost than younger adults. In some tasks with high central processing demands, cognitive resources may be exceeded by the addition of a second attentionally demanding task. This may lead to interference between the two tasks, and/or prioritising of one or other task, manifested in a decreased performance in one or both tasks (dual-task costs). The more pronounced dual-task costs observed in older adults are likely attributable to age-related declines in processing capacities (Ruffieux et al., 2015). It follows that the dual task of wayfinding whilst driving is likely to place heavy

cognitive demands on drivers of all ages and may be especially difficult for older drivers with age-related cognitive decline.

There is a strong body of evidence describing a relationship between declines in many of the cognitive domains described above, and normal ageing, including specific problems with cognitive mapping (Christensen et al., 2004; Harada et al., 2013; Head & Isom, 2010; Lezak et al., 2012; Murman, 2015; Park et al., 2003; Rabbitt et al., 2004). Older adults also report having wayfinding problems, particularly in unfamiliar areas (Bryden et al., 2013; Vrkljan & Polgar, 2007). Such age-related cognitive declines have been shown to be related to on-road driving performance decrements and increased crash risk in older drivers (Anstey et al., 2005; Anstey & Wood, 2011; De Raedt & Ponjaert-Kristoffersen, 2000; Goode et al., 1998; Janke, 2001; Odenheimer et al., 1994; Stinchcombe et al., 2017; Stutts et al., 1998).

There is also some evidence of an association between age, cognitive functioning and wayfinding difficulties. Dingus et al. (1997) compared wayfinding and driving safety performance of older (65-73 years), middle aged (35-45 years) and younger (16-18 years) drivers using a naturalistic on-road driving study method. Participants were given a set origin and destination points and asked to plan out a route on a paper map. Results showed that older drivers took longer to reach their destination and drove more slowly than the younger drivers. The authors explained this result as a compensatory strategy used by the older drivers to cope with the increased task demands of wayfinding. Older drivers were also found to make more long eye glances at wayfinding materials (more than 2.5 seconds) than the middle-aged group and more unplanned lane deviations than both younger groups. This effect on looking behaviour is of particular interest in the current study, given its likely impact on distraction from the primary driving task and implications for safety. With respect to wayfinding performance, Dingus et al. (1997) found that older drivers took longer to plan the route than both younger groups. While there was no difference between age groups on frequency of incorrect turns, the authors highlighted the difficulty of measuring this aspect of wayfinding when drivers planned their own route and were able to make route alterations whilst driving.

A limitation of Dingus and colleagues' study is the absence of cognitive measures which might provide insight on the role of cognitive functioning in wayfinding difficulties of older drivers. Addressing this issue, Wood and colleagues conducted two studies which investigated the relationship between driving errors whilst wayfinding and cognitive functioning in older adults (Anstey & Wood, 2011; Mallon & Wood, 2004). In both studies, driving errors were recorded during an on-road driving assessment under two conditions in which drivers were directed by a passenger (followed route instructions provided by a driving instructor) and self-directed driving (followed road signs independently).

In their first study, Mallon and Wood (2004) compared performance of older drivers (mean age 68.9 years), middle

aged drivers (mean age 52.3 years) and younger drivers (mean age 27.0 years). All drivers had more driving errors when self-directed compared with when instructor-directed. Specific driving errors included maintaining lane position, approach to hazards, brake/accelerator use, observation, gap selection and mirror checks. Driving errors were greatest for the older drivers, indicating that they were more susceptible to difficulties with self-directed wayfinding than younger drivers. The authors also investigated the association between total driving errors during self-directed wayfinding and cognitive changes as assessed by a brief cognitive screening assessment. Driving errors during the self-directed task were correlated with cognitive measures ($r=0.38$). However, as the screening test was summed across multiple cognitive domains, it was not possible to determine the specific areas of cognition that were related to decrements in driving performance during self-directed wayfinding.

In the second study, Anstey and Wood (2011) examined the relationship between driving errors of older drivers (aged 70–88 years) and cognitive performance on tasks of processing speed, complex attention and executive functioning. The findings showed that performance on processing speed and inhibition tasks was predictive of errors in the self-directed wayfinding condition, whereas measures of attention (selective, divided and switching) were not. The authors concluded that these relationships were indicative of the extra demands associated with wayfinding whilst driving. Although this study demonstrates links between driving and wayfinding and some cognitive domains, other cognitive functions such as visuospatial abilities and memory, theoretically associated with wayfinding, were not investigated. Furthermore, wayfinding errors were not analysed and it was not clear what drivers' level of familiarity was with the area in which the task was conducted.

In a simulator-based study, Peng and colleagues examined cognitive correlates of driving in 16 Japanese drivers aged 61 to 90 years with cognitive impairment (self-reported or objectively determined) (Peng et al., 2021). The simulated drive was in an urban environment during daytime and although participants had one practice drive, it is not clear whether the practice drive was the same as the test drive, which may provide a level of route familiarity. Participants followed audio instructions (left/right turns, lane changes, etc). The authors reported a moderately strong correlation between wayfinding (going the wrong way) and performance on the Clock Drawing Test (Agrell & Dehlin, 1998), a general cognitive screening tool which tests the ability to follow directions and visual spatial orientation. This research adds to the findings of Anstey and Wood (2011) and while the small sample size was a serious limitation, the suggestive role for planning and spatial skills in wayfinding and driving warrants further exploration.

Research by Webber and Charlton (2001) also provides some insights on the role of cognition in wayfinding performance through their research with older pedestrians. Using a similar approach to Wood and colleagues, pedestrians were required to follow directional signs to reach unfamiliar

locations. The results revealed that everyday memory ability was related to pedestrian wayfinding to unfamiliar routes, but general cognitive ability, visuospatial ability and semantic knowledge were not. While not predictive of pedestrian wayfinding, other cognitive variables, particularly visuospatial ability, may be expected to play a role in wayfinding in the driving context and with map use.

One important limitation of the research by Mallon and Wood (2004), Anstey and Wood (2011) and Webber and Charlton (2001) is that the tasks investigated in these studies were restricted to selected elements of wayfinding, namely identification of information from road signs and did not require the use of maps or written route instructions. While some older drivers may be able to find their way using road signs, previous research conducted by the authors found that use of a street directory or some other form of paper navigational aid whilst wayfinding was a common strategy used by older drivers (Bryden et al., 2013). With the additional task demands of reading or interpreting the materials, as well as the additional potential for visual distraction, it is likely that wayfinding with the aid of a paper map may require a wider range and potentially different set of cognitive abilities than those investigated by Wood and colleagues.

In addition to the evidence showing a negative effect on driving performance when wayfinding in unfamiliar areas, there is evidence that some older drivers are more likely to report concern about their wayfinding abilities than younger drivers (Burns, 1999). Furthermore, in a recent study, we showed that older drivers who reported difficulty with wayfinding were more likely to self-regulate by avoiding unfamiliar areas or by using a passenger to assist (Bryden et al., 2013). This finding has potential implications for mobility and safety. Excessive avoidance of driving in unfamiliar areas may limit the extent and frequency of driving and in broader terms, lead to restricted mobility and independence and involvement in community-based activities. On the other hand, while passenger assistance may have mobility benefits and contribute to reducing cognitive load in wayfinding, it may also be distracting and/or fail to provide adequate assistance to the driver; potentially compromising safety.

The primary aim of this study was to investigate the relationships between wayfinding, driving performance, driver age and cognitive ability. Based on the review of theoretically important functions for driving and wayfinding and previous research findings presented above, it was hypothesised that both poorer wayfinding and driving performance would be associated with older age, and have a stronger relationship with poorer cognitive functioning in a number of domains including processing speed, complex attention, visuospatial abilities, memory, and executive functions (planning, decision making and inhibition). A secondary aim was to describe patterns of looking behaviour during wayfinding and examine their effect on driving safety.

Method

Participants and Recruitment

Participants were 47 community-dwelling current drivers who held a full driver's licence and were aged 21 years or older. Potential participants were recruited through advertisements in newspapers, presentations to seniors' groups, notices to University staff and students, and by personal invitations to participants from previous studies who gave consent to be contacted for future research. Drivers with a provisional licence were excluded on the basis of the increased crash risk associated with young novice drivers (Mayhew et al., 2003). Exclusion criteria included self-reported dementia or Parkinson's disease and impaired cognition, determined by an objective screening test (see Procedure). Participants with a history of motion sickness were also excluded due to the increased risk of simulator discomfort (Stoner et al., 2011).

A total of 69 participants volunteered for this study. Twenty-two were excluded for various reasons, including inability to complete the driving task due to simulator discomfort ($n=16$), technical difficulties with the simulator ($n=2$), a diagnosis of Parkinson's disease ($n=1$) or other reasons (e.g., difficulty focusing on the simulator screen in the middle distance with progressive bifocal glasses; $n=3$). The remaining 47 participants were aged between 21 and 82 years.

Procedure

This study was approved by and conducted in accordance with the guidelines of the Monash University Human Research Ethics Committee (MUHREC). Informed written consent was obtained from each participant prior to testing. Participants completed a short demographics survey, then completed a simulated driving task followed by a cognitive assessment, with appropriate rest periods as required between sessions. This order of testing was chosen because we anticipated some participants would experience simulator discomfort and this avoided unnecessarily extending the testing time of those participants who were unable to complete the simulator task. In the case of three participants, due to time constraints, the cognitive battery was administered on a separate occasion at the participants' home.

Simulated wayfinding and driving task

The experimenter provided a demonstration of the features and operation of the driving simulator. Participants then completed a practice drive until they felt comfortable with the operation of the simulator. Prior to completing the main driving task, each participant was given a map (including the start position, but without a route marked) and written directions describing the route. They were asked to trace the route on the map with their finger. The route was corrected by the experimenter if necessary to ensure that the driver's wayfinding was not affected by poor planning. There was only one correct route for the driving task.

During the driving task, the participants kept the map and instructions with them and were encouraged to find their way as they usually would when driving their own car. In the event of a crash or incorrect turn, the simulator was programmed to restart immediately before the previous correct turn (or start of the drive if an error was made on the first turn) and the driver was instructed to continue to follow the designated route. This procedure for dealing with incorrect turns allowed drivers to reorient themselves to a familiar section of the drive while still having to re-negotiate the part of the drive that was challenging for them. This approach was taken rather than allowing drivers to find their own way back to the point where a turn was missed which would introduce inconsistency between participants in the routes chosen and drive length. In the case of an incorrect turn or crash, only data for the driver's first attempt up to the crash or turning error were analysed, and any sections of repeat drive were discarded. Analysis was resumed once the driver passed the point of the error or crash event. Subsequent driving attempts were excluded to ensure that data were only analysed from the first exposure to the driving scenario. Driving simulator discomfort was monitored and data collection was terminated where necessary. A videotape recorder was used to record a view of the driver's face and torso for post-hoc analysis of driving performance measures as detailed below. The driver was videoed from the front screen of the driving simulator and the rater had a clear view of when their eyes moved down from the front screens.

Neuropsychological assessment

Drivers' cognitive abilities were screened using the Mini Mental State Exam (MMSE) (Folstein et al., 1975). A cut-off score of 27 was used to minimise the likelihood that participants with undiagnosed dementia were included in the sample (Kukull et al., 1994). In addition to the initial screening, a comprehensive cognitive battery was administered to assess the cognitive domains of processing speed, complex attention (selective, divided and switching), visuospatial abilities, memory, planning, decision making and inhibition. Cognitive domains were selected based on theoretical models and objective studies of the role of cognitive functioning in wayfinding (Anstey & Wood, 2011; Arthur & Passini, 1992; Webber & Charlton, 2001).

Materials

Driving simulator and driving scenarios

The simulated drive was conducted on an ECA FAROS EF-X Portable Driving Simulator. The simulator comprised a small cab with genuine vehicle parts including an adjustable seat, pedals, steering wheel, gear box, seat belt and automatic transmission. The visual images for the driving scenarios were presented on three flat monitors that generate synthetic 3-D images in real time and provided a field of view of 120°. Adjustable rear-view mirrors were depicted on the bottom left and right screen (for the left and right mirrors) and an overhead rear vision mirror was also projected

on the central screen. Audio feedback of the engine noise could be heard through the simulator speakers.

The participants drove on a simulated urban road network with low density traffic, in daylight and in clear weather conditions. There was a 50km/h speed limit throughout the drive, indicated by appropriate signage and the driver also received verbal instructions to obey the speed limit. Street signs were placed at each intersection and street names were based on high frequency of street name use in Victoria (Tulloch, 2010) and high frequency of word use in the English language (Wehmeier, 2010). Intersections encountered through the drive included three types of control: signals (which were always displayed in green phase on approach), stop signs and uncontrolled (no signage). No other vehicles were present in the intersections at the time the drivers made their turn manoeuvres.

The driving route involved four turns (three left and one right) and ended with a merge onto a freeway. The drive lasted approximately 8-10 minutes. The driving route was provided to the driver in the form of written instructions listing the direction and street name for each turn. The instructions were accompanied by a map of the road network including street names and start position but without any markings indicating the specific route to be driven.

The driving task included two challenging situations, a pedestrian event and a car-following event. For the pedestrian event, brake reaction time was measured to ascertain speed of response to a pedestrian who stepped out unexpectedly in front of the car. For the car-following event, time headway was measured between the driver and a lead car travelling at 40km/h.

Two equivalent driving routes were constructed, and participants were randomly assigned to the two drives (Drive A and Drive B). The use of two drives was necessitated by a second parallel study in which the same participants also completed the driving task under a passenger-assisted condition (not analysed in the current paper; drives were counterbalanced for order). The two test drives were matched for length, turns and challenging situations. Steps were taken to eliminate variation in driving performance that might be attributed to differences in the use of two alternative routes. To control for this effect, participant raw scores for continuous driving variables were converted to z-scores to create a common scale with the same mean and standard deviation for each route (Kolen, 2007). Participant z-scores were re-categorised according to wayfinding conditions prior to analysis.

Wayfinding and driving performance measures

Two key variables relating to wayfinding performance were measured: pre-drive route identification (time taken, derived from videotaped footage) and number of incorrect turns (manually recorded during the experiment). Five driving performance measures were recorded from the driving simulator output including average speed (km/h), time stopped (seconds), time headway (seconds), lane position variability (centimetres) and brake response time (milliseconds). [Table 2](#) in Results provides definitions for each of the wayfinding and driving performance variables. All measures

were for the first attempt at the drive only, that is, scores did not include repeated sections driven due to incorrect turns.

Measures of looking behaviour

The primary measure used to record looking behaviour was the total number of times a driver looked at the wayfinding materials. In addition, four other measures were scored, including the total number of times drivers referred to materials whilst stopped; the number of brief glances whilst driving (less than two seconds); number of long glances whilst the vehicle was moving (more than two seconds); and number of clusters of three or more glances whilst the vehicle was moving (glances within five seconds of another glance).

Long glances and clusters of glances were logged from the video footage and compared with the simulator output to identify driving performance during these times. For long glances, driving behaviour measures were taken for the period before, during and after each glance (around six seconds). This period of time was used to allow measurement of the potential distraction before and after each long glance, and also to ensure that the sample of driving behaviour was of sufficient length to be meaningful. For glance clusters, a six second period was selected, avoiding the inclusion of any long glances during the cluster. When drivers made repeated long glances or clusters over the drive, a single driving performance score was derived for each variable by averaging the driving performance scores associated with all long glances or clusters for that driver.

Driving performance variables during glances were compared to measures from a six second control driving period which was selected from a segment of driving on a straight, single lane road which did not include long glances, glance clusters or pulling over.

Neuropsychological measures

The cognitive battery included selected subtests from seven neuropsychological tests as outlined in [Table 1](#).

A processing speed variable was calculated by using the mean z-scores of Stroop Dots Trial and Trail Making Test Part A (Reitan, 1958; Spreen & Strauss, 1998). Both tests measure processing speed and visual scanning.

Raw scores rather than scaled scores were used on each measure to capture overall ability level rather than ability relative to age, thus improving predictive accuracy for driving performance (Barrash et al., 2010).

Statistical Analyses

Outliers detected based on responses and scores for the neuropsychological measures were transformed using semi-Winsorization at the 5th and 95th percentiles (Salkind, 2010). Moderately skewed variables (HVLT-R Delay, Trail Making Test Part B, UFOV-2 and UFOV-3) were subjected to a square-root transformation.

To examine the relationships between age and wayfinding and driving variables Pearson product moment correlations were computed for continuous variables. Similarly,

Table 1. Neuropsychological tests and cognitive domains assessed

Test	Cognitive domain assessed
Wechsler Adult Intelligence Scale-IV (WAIS-IV; Wechsler, 2008) - Digit Span subtest - Block Design subtest	- Information processing capacity and working memory - Visuospatial ability
Hopkins Verbal Learning Test-Revised (HVLRT-R; Brandt & Benedict, 2001) - Total Recall Score - Delayed Recall Score	- Immediate verbal memory - Delayed verbal memory
Wechsler Memory Scale-IV (WMS-IV; Wechsler, 2009) - Visual Reproduction I - Visual Reproduction II	- Immediate visual memory - Delayed visual memory
Victoria Stroop Test (Spreen & Strauss, 1998) Ratio Score (calculated by dividing the Colours trial by the Dots trial)	Processing speed and response inhibition
Trail Making Test (Reitan, 1958) Part B	Attentional switching
Behavioral Assessment of the Dysexecutive Syndrome (BADS; Wilson et al., 1996) Zoo Map Subtest (Total score)	Planning ability and problem solving
UFOV (Ball & Owsley, 1992) - Part 2 - Part 3	- Divided attention - Selective attention

correlation analyses were conducted to explore relationships between cognitive variables and wayfinding and driving variables where appropriate.

For the categorical variable incorrect turns, a series of independent-samples t-tests were conducted to determine whether age and cognitive variables differed between participant groups: those who made incorrect turns compared with those who did not. Analysis of gender effects on cognitive measures was not possible due to the relatively small number of female participants. Regression modelling was not used for these analyses due to inadequate power associated with the number of predictors and sample size (Green, 1991).

For long glances and clusters of glances, a series of independent samples t-tests were conducted to determine whether age and cognitive variables differed between those who made glances towards materials (as defined) and those who did not. For those participants who did make long glances and/or clusters of glances, a series of repeated measures t-tests were conducted to assess whether driving behaviour (lane position variability and average speed) differed when making long glances or clusters of glances at materials compared to the control driving period.

Results

Participant Demographics and Neuropsychological Test Performance

[Table 2](#) shows participant demographics for the sample. The sample included participants from across a wide span of driver ages, with older drivers intentionally oversampled, given the specific focus of the study. There was an over-

representation of males, and participants tended to be well educated and live in urban locations. A large proportion of the drivers were married and the majority of drivers in both groups rated themselves in good health. Most participants reported driving regularly and around a third of drivers reported some difficulties with their wayfinding ability.

General Wayfinding and Driving Performance

Almost 15% of drivers made a planning error which was corrected before the drive. During the simulated drives, approximately one third of participants made at least one incorrect turn. Only 6.4% of participants crashed during the drive, and all collisions occurred during the pedestrian event. As the number of participants who made a planning error or crashed was so small, no further analyses were undertaken on these variables. [Table 3](#) shows that driving performance from the two alternative forms of the drive were roughly equivalent for most variables.

Relationship Between Age and Wayfinding/Driving Variables

Results of the Pearson product correlations revealed that age was significantly associated with average speed ($r = -0.36$, $p = 0.012$) and time stopped ($r = 0.38$, $p = 0.008$). These results indicated that older participants tended to drive more slowly during the task and spent more time stopped compared with younger participants. Age was not significantly associated with pre-drive route identification time ($r = 0.25$, $p = 0.116$), total glances directed to wayfinding materials ($r = -0.20$, $p = 0.198$), time headway ($r = 0.15$,

Table 2. Demographic, health and driving information (n=47)

Demographics		n (%)
<i>Age</i>		
	Under 25	2 (4.3)
	25-34	7 (14.9)
	35-44	8 (17.0)
	45-54	5 (10.6)
	55-64	3 (6.4)
	65-74	17 (36.2)
	75-84	5 (10.6)
<i>Gender</i>		
	Female	10 (21.3)
	Male	37 (78.7)
<i>Marital status</i>		
	Married/de facto	32 (68.1)
	Single/divorced/widowed	15 (31.9)
<i>Education</i>		
	At least some secondary	15 (31.9)
	Tertiary	32 (68.1)
<i>Residential location</i>		
	Urban	38 (80.9)
	Regional	5 (10.6)
	Rural	4 (8.5)
<i>Driving frequency</i>		
	Daily or almost daily	29 (61.7)
	1-4 days per week	14 (29.8)
	Less than weekly	4 (8.5)
<i>Distance driven per week</i>		
	50km or less	16 (34.0)
	51-200km	21 (44.7)
	More than 200km	10 (21.3)
<i>Self-rated wayfinding</i>		
	Poor/fair	14 (29.8)
	Good	23 (48.9)
	Very good	10 (21.3)
<i>Self-rated health</i>		
	Fair	5 (10.6)
	Good	30 (63.8)
	Very good	12 (25.5)

$p = 0.304$), lane position variability ($r = 0.17$, $p = 0.265$) or brake response time ($r = -0.11$, $p = 0.455$). A t-test revealed that the average age of participants who made incorrect turns was not significantly different from those who did not ($t(45) = -0.95$, $p = 0.348$).

Relationship Between Neuropsychological Test Scores and Wayfinding/Driving Variables

To examine the relationships between neuropsychological test scores and wayfinding and driving performance, Pearson product moment correlations were computed for continuous wayfinding/driving variables (Table 4). For the categorical variable of incorrect turns, participants were grouped by performance outcome (0 vs. 1+ incorrect turns)

Table 3. Descriptive information for wayfinding and driving performance measures

Measure	Description	Drive A M (SD)	Drive B M (SD)
Route identification time (seconds) ^a	The time taken to find the predetermined route on the map before the drive using written direction and a map of the area.	92.50 (41.12)	91.00 (48.19)
Incorrect turns (binomial)	Whether one or more incorrect turns were taken throughout the drive (0, 1+).	0.52 (0.65)	0.36 (0.66)
Average speed (km/h)	Mean speed was computed for the entire driving route, excluding time stopped.	34.88 (6.15)	33.53 (7.19)
Time stopped (seconds)	The total time stopped during the drive. The drives had low density traffic and green lights thus there was no requirement to stop for extended times during the drive.	18.69 (22.83)	14.96 (26.62)
Time headway (seconds)	Mean time headway calculated over 200 metres during a car following event. One participant was excluded as the driver pulled over during the car following event.	4.21 (3.87)	6.69 (5.67)
Lane position variability (cm)	The standard deviation of the vehicle lane position on a 100 metre straight, one lane drive. Four participants were excluded from analysis due to erroneous turn or pulling over during the segment.	19.26 (11.31)	15.37 (11.41)
Brake response time (milliseconds)	Drivers' braking response time (starting or increasing braking) following the unexpected pedestrian event.	1.33 (0.87)	2.44 (1.55)
Total looks directed to wayfinding materials (number) ^a	The total number of eye movements away from the driving scene to the map or wayfinding instructions during the drive (including when stopped or driving).	15.67 (15.18)	13.65 (9.51)

NB. Separate results are shown for alternative drives A and B, before applying z-score standardisation.

M = mean; SD = standard deviation

^a Video recording malfunction prevented calculation of scores for some drivers.

and group differences in neuropsychological test scores were examined using independent groups *t*-tests (Table 5).

The results confirmed relationships between a number of neuropsychological measures and wayfinding performance measures including route identification time, time stopped, looking behaviour and incorrect turns. Longer route identification time was associated with poorer performance on Digit Span, processing speed and Block Design (*r*'s between 0.32 and 0.37). Increased time stopped was associated with poorer performance on UFOV-2 and Zoo Map (*r*'s between 0.30 and 0.35). The total number of glances directed towards wayfinding materials was associated with HVLT-R Total Recall Score (*r*=0.37). Participants who made at least one incorrect turn performed significantly poorer on processing speed, Visual Reproduction 1 and Block Design compared to those who made no turning errors and effect sizes were large ($\eta^2=0.11$ to 0.18).

Similarly, several cognitive measures were found to be associated with driving performance measures. Slower average speed was associated with poorer performance on several neuropsychological tests (*r*'s between -0.30 and 0.51). Larger time headways were associated with poorer performance on processing speed, Digit Span, Block Design, UFOV-2 and UFOV-3 (*r*'s between 0.31 and -0.43). Increased lane position variability was associated with poorer performance on processing speed, HVLT-R Total Recall Score and Block Design (*r*'s between -0.31 and 0.37). Increased brake response time was associated with poorer performance on processing speed, HVLT-R Total Recall Score and HVLT-R Delay (*r*'s between 0.32 and -0.36).

Glances Directed to Wayfinding Materials

With one exception, all participants looked at wayfinding materials in some manner during the drive (97.60%), with almost half (45.24%) of the participants stopping to check materials, on average, 2.16 times (*SD*=1.38) during the drive. An independent-samples *t*-test revealed a significant effect of age on stopping frequency, $t(40)=-2.57$, $p=0.014$, $\eta^2=0.14$. Participants who stopped to refer to materials ($M=62.11$, $SD=15.10$) were significantly older than those who did not ($M=48.30$, $SD=18.99$).

Most participants (90.50%) made brief glances towards wayfinding materials and made an average of 14.34 brief glances (*SD*=11.81) whilst driving. Long glances (over two seconds in length) were observed for 40.50% of participants and on average, those participants made 3.59 long glances (*SD*=3.45) during the driving task. A series of independent-samples *t*-tests revealed that there were no significant differences between participants who made long glances and those who did not, with respect to age and cognitive variables. Half of the participants made glances in clusters of three or more (including short and/or long glances). On average, these participants made 2.33 glance clusters (*SD*=1.80) per drive. An independent-samples *t*-test revealed a significant effect of age on number of glance clusters, $t(40)=2.33$, $p=0.025$, $\eta^2=0.12$. Participants who made clusters of glances were significantly younger ($M=48.24$, $SD=17.23$) than those who did not ($M=60.86$, $SD=17.91$).

There were no significant effects of cognitive variables on the number of glance clusters. Of the participants who made either long glances or glance clusters, 65.20% made

Table 4. Correlations between neuropsychological variables and wayfinding/driving variables

	DS	PS	HL	HD	VR1	VR2	BD	TMT-B	STR	U2	U3	ZM
Route identification time	-0.32*	0.32*	-0.10	-0.15	-0.20	-0.21	-0.37*	0.26	-0.05	0.20	0.23	-0.06
Glances to Materials (total)	-0.08	0.20	-0.37*	-0.27	-0.04	-0.12	-0.18	0.13	0.28	0.23	0.06	0.05
Average speed	0.51***	-0.30*	0.34*	0.24	0.25	0.39**	0.48***	-0.40**	-0.42**	-0.43**	-0.46**	0.27
Time stopped	-0.26	0.17	-0.01	0.06	-0.05	-0.07	0.06	0.07	0.03	0.30	* 0.23	-0.35*
Lane position variability	-0.07	0.37*	-0.37*	-0.20	-0.21	-0.21	-0.31*	0.24	0.13	0.18	0.28	0.02
Time headway	-0.43**	0.31*	-0.15	-0.17	-0.15	-0.23	-0.38*	0.19	0.15	0.33*	0.31 *	-0.18
BRT	-0.16	0.32*	-0.36*	-0.35*	-0.06	0	-0.08	0.13	0.17	0.24	0.08	-0.07

* $p < .05$; ** $p < .01$; *** $p < .001$

DS = Digit Span; PS = Processing speed; HL = HVLT-R Total Recall Score; HD = HVLT-R Delay; VR1 = Visual Reproduction 1; VR2 = Visual Reproduction 2; BD = Block Design; TMT-B = Trail Making Test Part B; STR = Stroop Colour Ratio Score; U2 = UFOV-2; U3 = UFOV-3; ZM = Zoo Map; BRT = brake response time

Table 5. Difference in neuropsychological test performance of participants who made at least one incorrect turn compared to those who did not

	Incorrect turns M (SD)	No Incorrect turns M (SD)	t	η^2
Digit Span	29.38 (5.62)	31.70 (6.33)	1.23	0.03
Processing Speed	0.49 (0.96)	-0.28 (0.69)	-3.19 **	0.18
HVLT-R Total Recall Score	25.00 (5.51)	26.80 (4.85)	1.16	0.03
HVLT-R Delay	-1.45 (0.85)	-1.31 (0.92)	0.50	0.01
VR1	35.75 (5.72)	39.07 (3.97)	2.44*	0.12
VR2	28.59 (9.79)	31.17 (9.33)	0.90	0.02
Block Design	37.06 (12.40)	45.47 (11.55)	2.29 *	0.11
TMT-B	9.40 (2.02)	8.16 (2.16)	-1.88	0.07
Stroop Ratio	2.24 (0.67)	2.43 (0.77)	0.87	0.02
UFOV-2	8.33 (5.17)	6.93 (4.02)	-1.03	0.02
UFOV-3	12.37 (3.98)	11.14 (3.84)	-1.04	0.02
Zoo Map	11.18 (2.90)	11.97 (3.33)	0.42	0.00

* $p < 0.05$, ** $p < 0.01$

M = mean; SD = standard deviation

both, 26.10% made glance clusters only and 8.70% made long glances only.

Looking Behaviour and Driving Safety

A series of repeated measures *t*-tests were conducted to assess whether driving performance (lane position variability and average speed) differed when looking at wayfinding materials compared to a control drive period for the same driver in which no long glances or glance clusters were observed. The results revealed that lane position was significantly more variable during the long glance segments ($M=24.39$, $SD=20.10$) compared with control segments of driving ($M=10.07$, $SD=13.86$), $t(15)=-2.36$, $p=0.032$, $\eta^2=0.27$. Average speed during segments of driving with long glances ($M=27.08$, $SD=9.03$) was not significantly different from that of control segments ($M=30.01$, $SD=12.04$), $t(15)=0.88$, $p=0.395$. Analyses of segments of the drive with clustered glances and control driving segments revealed no significant differences with respect to lane position variability, $t(15)= -0.86$, $p=0.402$; and average speed, $t(15)= -0.59$, $p=0.572$.

Discussion

The current study investigated the relationships between age, cognitive functioning and wayfinding using a paper map and instructions. An important finding was that measures of processing speed, visuospatial ability and memory were related to measures of both wayfinding ability and driving performance, suggesting that these specific cognitive abilities play a central role in wayfinding whilst driving. Older participants, on average, drove significantly more slowly and spent more time stopped compared with younger participants. This study also investigated the patterns of looking behaviour during wayfinding and their impact on driving safety. Long glances at wayfinding materials while driving were relatively common amongst drivers and were associated with driving performance decrements irrespective of age and cognitive functioning.

Notwithstanding that the route for the simulated driving task was relatively short with just four turns, the performance of some drivers in this study suggests they found the wayfinding task difficult. One third of participants missed at least one turn during the drive. Furthermore, the average speed was slower (approximately 35 km/hr) than might be expected, given that a 50 km/hr speed limit applied throughout the drive, traffic density was low, and there were no red lights. Almost all participants chose to refer to materials (map or instructions) and a substantial proportion did so in a potentially unsafe way, taking their eyes off the road for extended time periods (over two seconds) while the vehicle was moving. Previous research has shown that the visual distraction caused by long glances is associated with increased crash risk (Klauer et al., 2006; Östlund et al., 2004; T. et al., 2015). The findings from the current study suggest that visual distraction from the driving task associated with wayfinding may affect some aspects of driving performance (e.g., lane position), thus compromising

safety. The current study found that repeated glances off road (clusters including short glances only) was not associated with driving performance. Glance frequency has been associated with task complexity (Östlund et al., 2004), and glance duration is influenced by task characteristics and interface design more so than the temporal sequence of repeat glances (Lee et al., 2017). However, there has been little research to determine whether clusters of repeated glances while engaging in secondary tasks affects driving safety. In the current study, younger drivers were more likely to make repeated glances towards navigation materials. More research is needed to understand whether and why older drivers might intentionally refrain from this type of glance pattern.

Consistent with previous wayfinding research, we also found that increased age was associated with slower driving speed (Dingus et al., 1997). Dingus et al. (1997) interpreted this finding as a compensatory strategy by older drivers to cope with the added cognitive load associated with wayfinding while driving. Findings reported by Horberry and colleagues lend support to this notion, showing that drivers opt to drive at slower speeds as a way of compensating for cognitively demanding driving situations (Horberry et al., 2006). A number of studies have shown that older drivers have a general tendency to drive more slowly than younger drivers, regardless of the driving context (Chu, 1994; Fildes et al., 1991; Hakamies-Blomqvist et al., 1999). In a recent naturalistic driving study, Davis and colleagues showed this compensatory driving pattern is also influenced by cognitive impairment (Davis et al., 2020). Slower average speeds were observed for older drivers with cognitive deficits compared with cognitively normal older adults (Davis et al., 2020). In the current study, it is difficult to tease out the relative contribution of wayfinding and other possible factors explaining slower driving speeds.

Older drivers were also more likely to pull over to review wayfinding materials whilst driving. This finding suggests that older drivers may have had more difficulty with remembering the directions, performing the driving and wayfinding tasks simultaneously, or simply needed to reorient more often during the drive. Arguably, the practice of checking the map and instructional materials when the vehicle is stationary is safer than when moving. By stopping safely, older drivers were able to reorientate and get to their destination. Rather than being viewed as unsafe, potentially this practice should be encouraged when drivers have trouble getting to their destination and may help to maintain their mobility and independence. Taken together with slowed driving, this finding suggests that older drivers in this study were more likely to self-regulate their driving in a safe and cautious manner under cognitively demanding situations.

Age was not related to any of the other wayfinding or driving variables including most of the looking behaviours measured in this study. This finding contrasts with findings from previous studies showing an association between older age and poorer driving performance whilst wayfinding (Dingus et al., 1997; Mallon & Wood, 2004). These studies reported decrements in driving measures including lane

deviations and other components of driving performance (such as lane positioning and gap selection). Methodological differences may account for the discrepancy in findings across studies. For example, previous studies have used an on-road driving task rather than a simulated drive, and the drives included a different array of challenging events which may impact the level of difficulty of the task. An alternative explanation is that participants in the current study were encouraged to “find their way as they usually would”. It is possible that this instruction resulted in greater use of compensatory behaviours in the current study including slower driving speeds and pulling over where necessary. These compensatory strategies may have reduced the cognitive demands of the wayfinding task and led to fewer decrements in driving performance.

A key finding of the study was that cognition was related to several wayfinding and driving safety variables and suggested that drivers with poorer cognitive abilities experience more difficulties with specific aspects of wayfinding. Difficulties in the cognitive domains of working memory, complex attention (selective attention, divided attention and switching), delayed visual memory, response inhibition and planning were related to slower driving speeds, longer time stopped and/or longer time-headway. Driving slowly, pulling over and longer stopping distances are suggestive of drivers’ efforts to compensate for (perceived or actual) difficulty with the wayfinding task.

Memory has been shown to be associated with pedestrian wayfinding (Webber & Charlton, 2001) and is also theoretically likely to play a key role in wayfinding (Arthur & Passini, 1992). In the current study, we showed a link between a number of memory measures and both wayfinding performance and driving safety variables. Poorer verbal learning was associated with increased brake response time and lane position variability, as well as increased references to materials. Poorer visual immediate memory was associated with increased missed turns. Similar findings were reported by Aksan and colleagues in an on-road driving task showing that memory (visual and verbal) function of older drivers, both with and without neurodegenerative disorders, predicted performance in navigation-related secondary tasks (Aksan et al., 2015). These results suggest that the ability to learn new information is central to wayfinding ability, and more importantly, safe driving performance whilst wayfinding. Delayed verbal memory ability was associated with brake response time. It is possible that drivers with poorer recall of directions had to attend to external sources of information (including road signs) more often, which may have, in turn, reduced their ability to detect potential hazards.

Participants with poorer processing speed drove more cautiously (as evidenced by slower speeds and longer headways) yet were also more likely to have poorer wayfinding performance and driving safety. Poorer speed of processing was associated with making incorrect turns and increased (pre-trip) time to identify the route on a map. Those with slower processing speeds were more likely to have longer brake response time and more variability in lane position. This is consistent with and extends findings of previous re-

search which suggests that processing speed is associated with driving errors whilst wayfinding (following road signs) as well as driving performance and crashes under normal driving conditions (Anstey & Wood, 2011; Davis et al., 2020; Goode et al., 1998; Janke, 2001; Odenheimer et al., 1994; Stutt et al., 1998).

Similarly, participants who performed more poorly on a test of complex visuospatial ability were also more likely to have poorer wayfinding and driving performance despite driving more cautiously. Poorer visuospatial ability was associated with making incorrect turns and increased (pre-trip) time to identify the route on a map. This is consistent with findings by Peng and colleagues (2021) who found an association between errors on a clock drawing visual-spatial task and wayfinding errors (incorrect turns) which required drivers to follow turn-by-turn audio instructions during simulated driving. Those with poorer visuospatial ability were also more likely to show more variability in lane position. Like processing speed, complex visuospatial tests have been previously shown to be associated with driving performance and crashes under both normal driving conditions (De Raedt & Ponjaert-Kristoffersen, 2000; Goode et al., 1998) and when driving and wayfinding (Aksan et al., 2015). In contrast, a study examining pedestrian activity reported no evidence for a relationship between visuospatial tests and pedestrian wayfinding amongst older people (Webber & Charlton, 2001). The discrepancy in results may be due to visuospatial ability being particularly important when wayfinding and driving are performed simultaneously. One important caveat to this finding is that this test of complex visuospatial abilities also measures aspects of executive functioning (reasoning, problem solving) and processing speed (Lichtenberger & Kaufman, 2009). Executive functioning and processing speed have been objectively and theoretically related to wayfinding whilst driving (Anstey & Wood, 2011; Arthur & Passini, 1992). Further studies with larger sample sizes are recommended to tease out the relationships between these cognitive domains and wayfinding.

A strength of this study was the use of a driving simulator which made it possible to study wayfinding and driving under the same conditions and on a standardised, unfamiliar route. Indeed, driving simulators have been shown to have good relative validity for assessing many driving performance variables (Mullen et al., 2011) and have also been shown to be an effective method for examining navigation (Cochran & Dickerson, 2019). However, an inherent drawback of simulators is their reduced ecological representativeness compared to on road driving. In particular, driving in a simulator may encourage increased off-road glances due to lack of serious consequences compared with on-road driving. A second drawback of simulator use in this study was the high attrition rate of older participants due to simulator discomfort. The likelihood of simulator discomfort was potentially increased during the study due to the older age of drivers and the inclusion of turns in the route (Classen et al., 2011; Stoner et al., 2011). It is possible that this resulted in a sample bias in terms of the cognitive and driving performance of those who withdrew compared with

study participants. It is also important to highlight that the small sample size of this study reduced power and limited the investigation of multivariate relationships. Type I and II errors also cannot be ruled out. The results of the current study should be used to inform further research into wayfinding and driving, particularly the importance of including visuospatial ability and memory measures.

Conclusions

The current study is the first to investigate the relationships between age, cognitive functioning and wayfinding using a paper map. Findings from the current study suggest that some drivers found wayfinding in unfamiliar areas challenging, as evidenced by the adoption of compensatory strategies such as slowing down. This effect was particularly associated with drivers' increasing age. This has implications for the mobility of older drivers if drivers who experience difficulties choose to avoid driving to unfamiliar areas, as indicated by our previous research (Bryden et al., 2013). Avoidance of unfamiliar areas may inhibit engagement in new social relationships and access to new services which can be necessary when circumstances change (e.g. downsizing, death of a spouse, or management of medical illnesses). Most importantly, the current research identified that older drivers who performed at lower levels of cognitive functioning in processing speed, visuospatial ability and/or memory (albeit not clinically impaired) showed driving performance decrements when using a map to find their way in unfamiliar areas. Alternative wayfinding strategies, such as use of passengers or navigation systems, may offer a safer option for all drivers; arguably reducing the need for drivers to remember directions and check materials, while allowing more time to attend to the driving task. Further research is warranted to test these hypotheses.

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Author Contributions

Kelly Bryden contributed to project conception, development and execution of methodology, analyses, interpretation of results, manuscript preparation and critical revision for intellectual content. Judith Charlton contributed to project conception, development of methodology, interpretation of results, manuscript preparation and review and critical revision for intellectual content. Jennifer Oxley contributed to project conception, development of methodology, interpretation of results, manuscript review and critical revision for intellectual content. Georgia Lowndes contributed to project conception, development of methodology, interpretation of results, manuscript review and critical revision for intellectual content. All authors have read and agreed to the published version of the manuscript.

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Human Research Ethics Review

All study participants gave their informed consent for inclusion before they participated in the study. The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by and conducted in accordance with the guidelines of the Monash University Human Research Ethics Committee (CF09/0644 - 2009000263).

Conflicts of interest

The authors declare that there are no conflicts of interest.

Data Availability Statement

Under the terms of the study's ethics approval, the data cannot be shared with third parties. All derivative data are included in the manuscript.

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