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Cognitive decline and driving abilities – a systematic review

Zaburzenia neuropoznawcze a zdolność do prowadzenia samochodu – przegląd systematyczny

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Abstract

Introduction. *Cognitive disabilities (also due to neurodegenerative diseases) significantly impact daily functions for example driving a car, an activity that requires complex cognitive processes.* **Methods.** *Two databases (PubMed and EBSCO) were searched between December 2024 and March 2025, using words: Alzheimer's, dementia, driving ability, driving and dates from 2004. Total of 324 articles were identified and assessed using PRISMA guidelines. Total of 33 studies were included in a review.* **Results.** *Thirty studies used measures to assess cognitive functions (both neuropsychological tests and questionnaires). Eighteen studies confirmed a higher collision risk among those with cognitive decline, 15 studies emphasized longer reaction times among those with cognitive impairment, 14 studies emphasized the need for on-road tests in this group of patients.* **Conclusions.** *This systematic review shoved further interdisciplinary research using validated, objective assessment tools is needed to better understand the relationship between cognitive function and driving ability, particularly in neurodegenerative disorders. Gerontol Pol 2025; 33; 93-104) doi: 10.53139/GP.20253313*

Keywords: *cognitive decline, driving, neurodegenerative disease*

Streszczenie

Wprowadzenie. *Zaburzenia poznawcze (spowodowane miedzy innymi chorobami neurozwyrodnieniowymi) znacząco wpływają na codzienne funkcjonowanie w tym prowadzenie samochodu, które angażuje złożone procesy poznawcze.* **Metody.** *Przeszukano dwie bazy danych (PubMed i EBSCO) w okresie od grudnia 2024 r. do marca 2025 r., używając słów: Alzheimer, demencja, zdolność prowadzenia pojazdów, prowadzenie pojazdów i dat od 2004 roku. Zidentyfikowano łącznie 324 artykuły i oceniono je zgodnie z wytycznymi PRISMA. Do przeglądu włączono łącznie 33 badania.* **Wyniki.** *W 30 badaniach wykorzystano środki do oceny funkcji poznawczych (zarówno testy neuropsychologiczne, jak i kwestionariusze). W 18 badaniach potwierdzono większe ryzyko kolizji wśród osób z zaburzeniami poznawczymi, 15 badań wykazało dłuższy czas reakcji osób z takimi zaburzeniami a 14 badań podkreśliło potrzebę przeprowadzania testów drogowych (w grupie starszych kierowców).* **Wnioski.** *Przegląd systematyczny pokazał, że potrzebne są dalsze interdyscyplinarne badania z wykorzystaniem precyzyjnych narzędzi oceny, aby lepiej zrozumieć związek między funkcjami poznawczymi a zdolnością do prowadzenia pojazdów, szczególnie u osób z zaburzeniami neurozwyrodnieniowymi. co w konsekwencji prowadziłoby do zwiększenie bezpieczeństwa na drodze. Gerontol Pol 2025; 33; 93-104) doi: 10.53139/GP.20253313*

Słowa klucze: *zaburzenia neuropoznawcze, choroby neurodegeneracyjne, prowadzenie samochodu*

Introduction

Cognitive disability and related difficulties are an important topic of research in neurology and psychology, especially in terms of its impact on daily functioning, particularly driving abilities. Driving requires sharp, complex cognitive processes such as: attention, working memory and risk assessment abilities [1]. These cognitive processes are necessary for safe driving, regardless of the driver's age [1]. In presenting the general characteri-

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stics of cognitive processes involved in assessing the driving environment, the following are identified: perception (isolating important elements in the surroundings), memory (storing information), attention (involved in selecting relevant information and maintaining cognitive engagement), thinking (constructing mental models of situations), imagination (creating mental representations of real-world objects), and problem solving [1]. Among the cognitive activities involved in assessing the driving environment, verbal skills are also increasingly recognized. The efficient functioning of the above-mentioned intellectual processes and operations is important to ensure safe driving regardless of age. Changes in these mental abilities, which can be related to age and neurological conditions, may be crucial. According to studies, changes in cognitive processes that can occur due to aging, brain injury or neurodegenerative diseases can lead to reduce driving ability [2].

The literature highlights that people with cognitive impairment often exhibit difficulties in decision-making, which can affect their safety on the road [3]. Studies show that even mild cognitive impairment alongside non-cognitive risk factors may be associated with a higher risk of road accidents [4]. For this reason, understanding the mechanisms by which cognitive abilities operate in the context of driving is crucial to developing effective support and intervention strategies for those affected. It is also relevant to consider that human development follows multiple pathways and dimensions, especially as these become more pronounced with aging [5]. Despite the specific direction of changes occurring in the cognitive sphere, mental processes in senior age group are characterized by plasticity and can be stimulated and modified as needed to support the process of adaptation to cognitive changes.

Aim

This review aims to analyse the impact of cognitive disabilities on driving ability and to present current research in this area.

Materials and Methods

Two databases (PubMed and EBSCO) were searched between December 2024 and March 2025, using key: (Alzheimer's OR AD OR dementia) AND (driving ability OR driving) with a time limit after 2004. Total of 324 articles were identified and assessed by two researchers N.S. and N.C. using Rayaan software and PRISMA [6] guidelines. Inclusion criteria can be found in table I. Decision making process.

All included studies were assessed regarding risk of bias using "Modified Downs and Black checklist for assessment of methodological quality" ONE, PLOS (2020) [7]. Results of the assessment can be found in graph 1 and table II in the results section. Total of 33 articles were included in the review.

Results

Table II. Quality of the studies included in the review

Quality of the studies	Number of studies in category
poor	6
fair	15
good	12
excellent	0

The Role of Neuropsychological Measures in Evaluating Driving Risk

Among the most commonly used cognitive tests, Trail Making Test A (TMT-A) and Trail Making Test B (TMT-B) stand out as primary indicators of driving performance. TMT-A was used in 7 studies [8-13] while TMT-B appeared in 8 studies [8-12, 14-16]. These tests measure processing speed and cognitive flexibility, which are critical for safe driving. The TMT-B, which requires greater cognitive flexibility, has often been used in studies focusing on complex driving tasks. Although most studies used TMT-A and TMT-B as part of broader neuropsychological assessments, several demonstrated that poorer performance on these tests was associated with specific deficits in driving performance, including

Table I. Review criteria

Category	Inclusion criteria	Discussion criteria
Participants	With Alzheimer's disease or cognitive disability due to neurodegenerative disease, age over 65.	Healthy participants < 65 years of age.
Article type	Original paper	Literature review
Research type	Intervention or driving assessment	Drugs based research
Year of the publication	After 2004	Before 2004
Language	Polish or English	Other than Polish or English

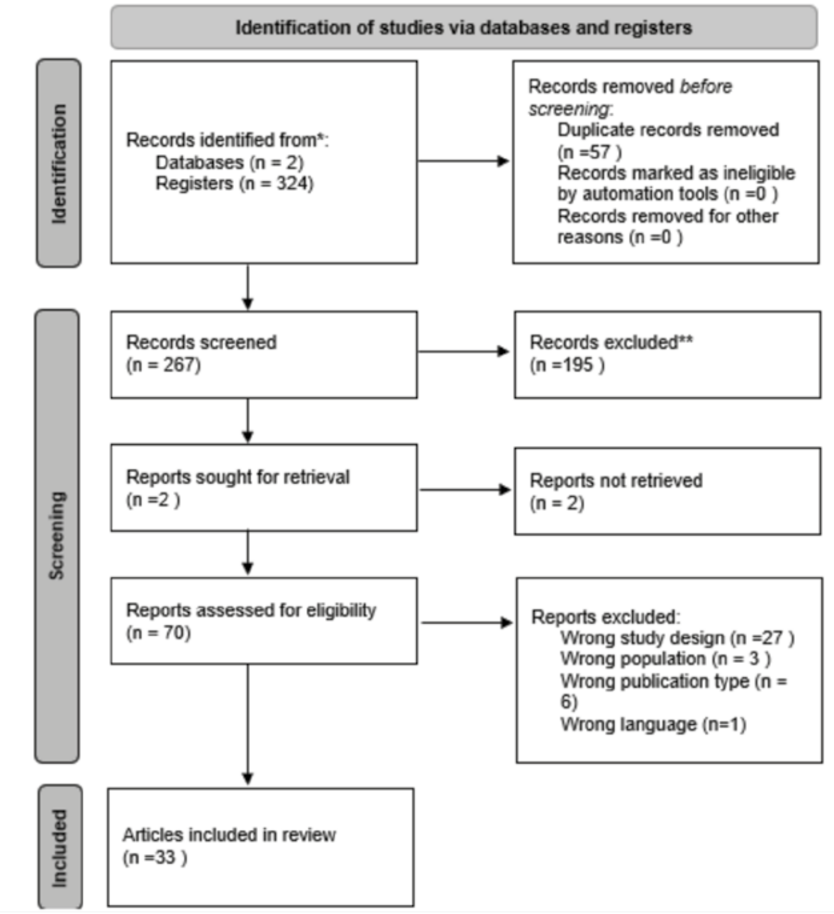

Figure 1. Prisma flowchart

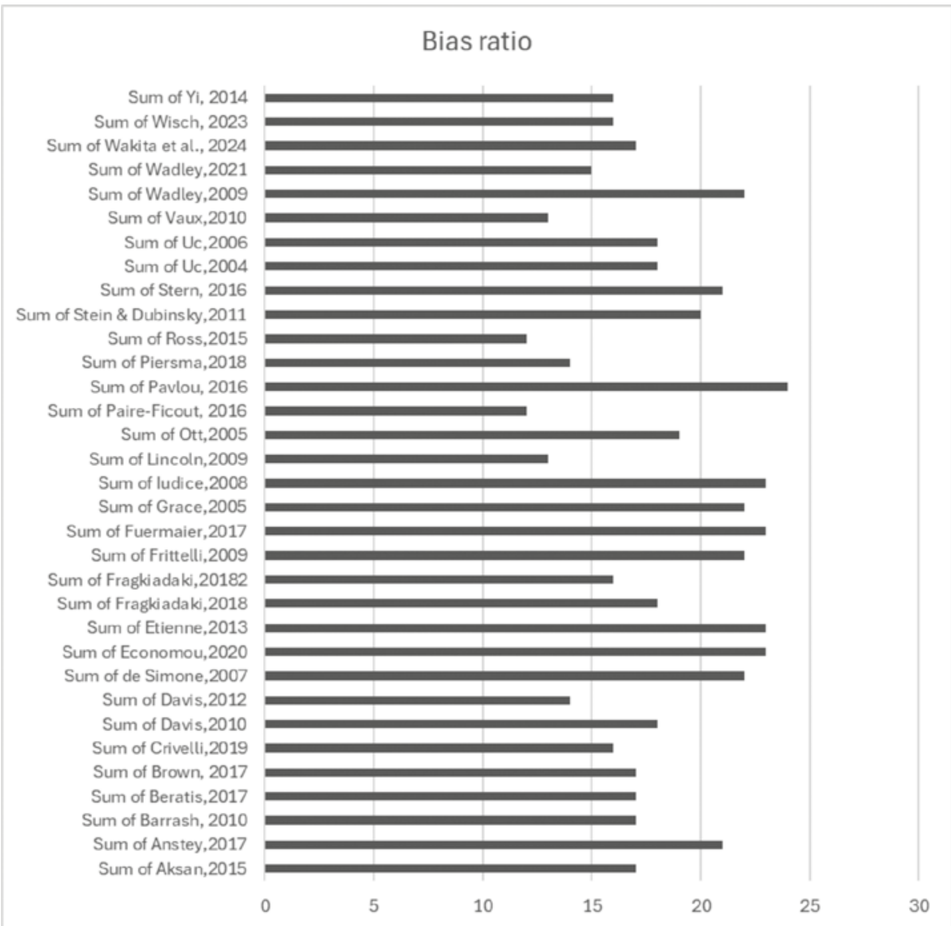

Figure 2. Results of bias assessment

slower reaction times, impaired hazard perception, and difficulties in lane maintenance [8,10,11,16]. These findings support the relevance of processing speed and cognitive flexibility as critical domains for driving competence, even if direct correlations with specific driving errors were not always the primary focus. Crivelli et al. [14] and Davis et al. [17] further demonstrated a strong correlation between poor performance on these tests and increased driving errors in both simulator-based and on--road evaluations. The study by Uc et al. [13,15] provided further evidence that individuals with AD committed more errors in driving tasks requiring rapid attentional shifts.

The Mini-Mental State Examination (MMSE) was used in 22 studies [8-11,13-16,17-22,24,27-31,33-35]. While MMSE is a broad measure of cognitive function, Stern et al. [16] indicated that it lacks specificity in predicting collision risk. However, Holland et al [10] found that participants with lower MMSE scores were significantly more likely to fail on-road driving tests.

Other neuropsychological measures included the Digit Symbol Modalities Test (DSMT), which was present in 4 studies [11,16,20,21] assessing processing speed, and the Boston Naming Test (BNT), used in 3 studies [11,17,22] which evaluates language functions. The Benton Visual Retention Test (BVRT) has been reported in 5 studies [11,13,15,17,18]. These tests primarily serve to measure specific cognitive domains relevant for complex tasks like driving. Although they do not directly assess driving performance, some studies [11,17] demonstrated that deficits in processing speed and language comprehension—as measured by these tests—may be associated with increased driving errors, particularly in situations requiring rapid decision-making.

Two additional assessments, Useful Field of View (UFOV) (used in 3 studies: [8,14,16] and DriveSafe/DriveAware, used in 2 studies: [8,16] were particularly effective in predicting real-world driving risks. Stern et al. concluded that UFOV provided a more reliable indication of unsafe driving behaviors than MMSE, suggesting that attention-related processes, such as the ability to select relevant information and divide attention between multiple stimuli, are particularly important for driving safety [16].

Methods of Driving Evaluation

The on-road driving test remains the gold standard for assessing driving competence, with 14 studies using this method [8-12,14-20,34,35]. These studies provided strong empirical support for direct observational assessments conducted by professional evaluators. Davis et al. found a strong correlation between on-road test performance and naturalistic driving behavior, emphasizing its ecological validity [17]. Similarly, Wadley et al. underscored the necessity of expert evaluations in determining driving performance [23].

The driving simulator was utilized in 12 studies [13,21-25,27,28,30,31,36,37]. Simulators offer a controlled environment to assess driving behavior under standardized conditions.

Collision Risk and Retrospective Studies

A significant number of studies confirmed the increased collision risk among drivers with cognitive impairment. The 18 studies supported this conclusion [8-12, 13-15, 17-20, 23, 25- 29]. In particular, Uc et al. observed that drivers with AD were more prone to dangerous situations, especially at intersections and during rear-end collision avoidance [13,15]. Pavlou et al. found that people with cognitive impairments often adopted compensatory strategies, such as avoiding complex driving conditions [26], which may obscure their true level of impairment.

In another, 7 studies used retrospective analyses [9,14,16,18,21,26,29] to examine historical accident data and driver-reported traffic incidents. These studies indicated that caregivers and family reports could be valuable but should be used in conjunction with objective assessments.

Fifteen studies [9,13,14,21,22,24,25,27,28,30-34] studied participants with Alzheimer's disease (AD) or mild cognitive impairment (MCI) in real-time driving simulations. These studies consistently showed that cognitive impairment led to longer reaction times, poorer hazard detection, impaired lane keeping, and increased collision risk. For example, drivers with AD showed delayed braking responses and difficulty maintaining lane position in rear-end collision scenarios [13] while participants with MCI showed impaired left-turn manoeuvres under cognitive load [20] and overestimated their driving abilities in rural environments [27].

Table III. Details of included studies

No.	Author	Number of Participants	Dementia Rating	Age	Gender	Driving Experience	NP/Sensory Scores	Driving A ssessment	Findings
1	Aksan et al. (2015)	148 (77 healthy, 32 AD, 39 PD)	AD, PD diagnosis	70–89 (M = 75)	104M/44F	Licensed drivers	Visuospatial, memory, speed processing, executive function	18-mile on-road test assessing safety errors, navigation, and hazard detection	Drivers with AD and PD had worse driving performance than healthy controls ($p < 0.001$), with navigation tasks increasing errors ($p < 0.001$). Memory and set-shifting predicted navigation errors ($p < 0.001$), processing speed predicted safety errors ($p < 0.001$), and visuospatial skills predicted baseline errors ($p = 0.005$).
2	Anstey et al. (2017)	302 (57 MCI, 245 CN)	Winblad Criteria (MCI)	65–96 (M = 75.7, SD = 6.18)	40% female	Not specified	Neurocognitive test battery (Multi-D, DriveSafe)	On-road driving test (ORT) + off-road screening tests	Drivers with MCI demonstrated lower safety ratings than cognitively normal participants (5.61 ± 1.77 vs. 6.05 ± 1.51, $p = 0.021$) and exhibited poorer performance on DriveSafe ($p < 0.001$), Multi-D ($p = 0.021$), and Dot Motion ($p = 0.006$).
3	Barrash et al. (2010)	83 (24 healthy, 26 AD, 33 PD)	Mild AD, Parkinson's Disease	65+	Not specified	Not specified	Trail-Making, Benton Visual Retention, Block Design	On-road driving test (45 min route)	Raw neuropsychological scores significantly predicted driving errors (R‹ = 0.199, $p = 0.005$), while demographically adjusted scores did not (R‹ = 0.113, $p = 0.107$). Strongest predictors were Trail-Making A ($p = 0.045$), Complex Figure Test ($p < 0.001$), and Block Design ($p = 0.05$). Demographic adjustments reduced predictive accuracy for driving performance.
4	Beratis et al. (2017)	24 (MCI)	MCI, depressive symptoms	67.42 (SD = 7.13)	Not specified	Licensed drivers	PHQ-9, neuropsychological tests	Driving simulator	Drivers with MCI and higher depressive symptoms exhibited greater speed variability ($p = 0.017$), reduced headway distance ($p = 0.006$), more crashes ($p = 0.009$), and increased lateral position variation ($p = 0.002$) compared to cognitively healthy individuals. Depressive symptoms significantly predicted driving impairments even after controlling for sleep disturbances and cognitive deficits (R‹ = 0.635, $p < 0.05$)
5	Brown et al. (2005)	75 (17 mild AD, 33 very mild AD, 25 controls)	CDR 0.5 (very mild AD), CDR 1 (mild AD)	40–90	Not specified	Driving at least 1 trip per week	MMSE	On-road driving test	Neurologists' assessments were significantly associated with on-road driving scores and had the highest accuracy in predicting unsafe driving (74% correct classification). Informants were moderately accurate (64.4%), while self-assessments were the least reliable (53.2%). The driving instructor was the most stringent rater, classifying more participants as unsafe. MMSE scores were borderline predictive ($p = 0.07$), and on-road test performance significantly differed across AD severity levels ($p < 0.001$).
6	Crivelli et al. (2019)	56 (28 AD, 28 controls)	Mild dementia	Not specified	Not specified	Not specified	Digit Symbol Modalities Test, Boston Naming Test	On-road driving test (ORDT) + simulator	Drivers with mild dementia made significantly more errors on the On-Road Driving Test (ORDT) ($p < 0.0001$) and had slower responses in the driving simulator ($p < 0.0001$) compared to cognitively normal controls. Age, the Digit Symbol Modalities Test (DSMT), and the Boston Naming Test (BNT) were the strongest predictors of driving performance, forming a logistic regression model for detecting unsafe driving ($p < 0.05$).

7	Davis et al. (2012)	103 (44 healthy, 59 cognitive impairment)	MMSE, CDR 0.5–1	60-90	Not specified	Licensed drivers	MMSE, Roadwise Review, cognitive tests	Standardized road test + naturalistic driving (4-hour video observation)	Cognitively impaired older adults made significantly more driving errors than cognitively healthy controls on both a standardized road test ($p < 0.001$) and in naturalistic driving conditions ($p < 0.001$). Although error rates were higher in naturalistic settings, global safety ratings did not differ between the two assessments (kappa = 0.33). Road test errors correlated with crash history ($p = 0.01$), while naturalistic errors did not. MMSE scores correlated with both driving assessments ($p = 0.001$ for road test, $p = 0.02$ for naturalistic driving).
8	Davis et al. (2020)	33 (AD, preclinical AD, healthy)	Preclinical and Early AD	60+	Not specified	Licensed drivers	Trail Making Test A	In-vehicle monitoring (GPS, G-force video) for naturalistic driving behavior	Drivers with early AD exhibited increased unsafe driving behaviors, including late responses, excessive speed, traffic violations, and poor judgment. G-force triggered video events captured frequent near-collisions, rolling stops, and failure to scan intersections. GPS data showed higher rates of hard braking and sudden acceleration in early AD compared to cognitively normal (CN) and preclinical AD (CN/A+) groups. Preclinical AD drivers compensated by driving more cautiously, with fewer speeding events ($p < 0.01$).
9	De Simone et al. (2007)	30 (15 FTD, 15 Controls)	Frontotemporal Dementia (FTD)	Not specified	Not specified	Active drivers	Neuropsychiatric symptoms, executive dysfunction	Driving simulation test	Patients with FTD exhibited significantly higher average driving speed (31.9 ± 9 mph vs. 25.6 ± 3 mph, $p < 0.05$) and greater speed variability (14.2 ± 8.2 vs. 8 ± 1, $p < 0.001$). They received more speeding tickets (11.8 ± 11 vs. 1.8 ± 2, $p = 0.003$), were more likely to ignore stop signs (33% vs. 0%, $p = 0.003$), and had a higher incidence of collisions (60% vs. 0%, $p = 0.003$). Additionally, their memory performance was significantly lower (1.8 ± 1 vs. 4.8 ± 2, $p < 0.001$).
10	Economou et al. (2020)	74 (37 MCI, 16 AD, 21 Controls)	MCI, Mild AD	52+ (MCI: 68.4 ± 9.1, AD: 75.4 ± 4.9, Controls: 63.5 ± 8.4)	26 women, rest men	Licensed drivers, over 10 years of experience	MMSE, Frontal Assessment Battery (FAB)	Driving simulator: speed, reaction time, headway variability, lateral position variability, accident probability	Drivers with AD had significantly lower speed ($p < 0.001$), greater headway distance ($p < 0.001$), and slower reaction times ($p < 0.001$) compared to controls. MCI drivers also showed slower speeds and longer headway distances in distraction conditions ($p < 0.05$). However, accident probability did not differ between groups.
11	Etienne et al. (2013)	39 (10 AD, 29 Controls)	Early AD	AD: 65-81 (Mean 74.86, SD 5.36), Controls: Mean 70.83 (SD 2.95)	Not specified	All AD patients drove at least once a week, minimum 3000 km/year	Mini-Mental State Exam (MMSE), Plus-Minus Test (PMT), Shift Cost	Driving simulator: mental flexibility tasks, reaction time, errors, speed variability	AD patients had longer response times ($p < 0.001$), more errors ($p < 0.001$), and higher shift costs ($p < 0.01$) in the Plus-Minus Test. In the driving simulator, they exhibited slower reactions ($p < 0.001$), increased errors in flexibility-demanding tasks ($p < 0.001$), and reduced speed ($p < 0.01$).
12	Fragkiadaki et al. (2016)	70 (35 MCI, 35 controls)	MCI	MCI: 65.09 (SD = 7.81), Controls: 62.46 (SD = 9.35)	16F/19M (MCI), 20F/15M (Controls)	Not applicable	Self-awareness of cognitive function, verbal & visual memory	Cognitive test self-evaluation (accuracy vs. actual performance)	MCI patients overestimated speed ($p < 0.001$), underestimated headway ($p = 0.008$), and overestimated reaction time ($p = 0.006$) in rural but not urban environments. Findings suggest environmental cues enhance self-awareness, supporting cue-based interventions.
13	Fragkiadaki et al. (2018)	53 (27 MCI, 26 controls)	Amnestic MCI	63.01 ± 7.8 (Controls), 66.59 ± 8.2 (MCI)	Not specified	Licensed drivers	Cognitive, self-awareness measures	Driving simulator assessing reaction time, speed, headway	Patients with MCI exhibited impaired self-awareness of driving ability, particularly in rural environments where they overestimated speed ($p < 0.001$), underestimated headway distance ($p = 0.008$), and overestimated reaction times ($p = 0.006$). In contrast, no significant differences were observed in urban environments.

14	Frittelli et al. (2008)	59 (20 AD, 20 MCI, 19 controls)	CDR 1 (AD), CDR 0.5 (MCI)	AD: 72 (SD = 5.5), MCI: 71.6 (SD = 5.3), Control: 68.9 (SD = 6.3)	AD: 18M/2F, MCI: 16M/4F, Control: 12M/8F	AD: 40 years, MCI: 41.7 years, Control: 36.1 years	MMSE, Visual Reaction Time	Simulated driving test	Drivers with mild AD (CDR 1) demonstrated significantly poorer performance than both MCI (CDR 0.5) and cognitively normal (CN) controls, with longer completion times ($p < 0.001$), shorter time to collision ($p < 0.001$), more off-road events ($p < 0.01$), and slower visual reaction times ($p < 0.001$). MCI drivers exhibited intermediate deficits, with a significantly shorter time to collision compared to controls ($p < 0.001$).
15	Fuermaier et al. (2016)	18 MCI	MCI	Not specified	Not specified	Licensed drivers	Neuropsychological assessment	On-road driving test and simulator	Among 18 MCI patients, 66.7% passed the on-road test. The fitness-to-drive model (AUC = 94.4%, $p = 0.003$) with neuropsychological assessment and driving simulation showed high accuracy (100% sensitivity, 83.3% specificity), while clinical interviews were not predictive (AUC = 0.528, $p = 0.851$).
16	Grace et al. (2005)	39 (10 AD, 29 controls)	Early AD	Not specified	Not specified	Licensed drivers	Mental flexibility tests, executive function assessments	Driving simulator - mental flexibility impairment under different conditions	Drivers with AD were more impaired than those with PD and healthy controls, making significantly more operational, strategic, and tactical errors on a standardized road test ($p < 0.001$). In PD, unsafe driving was associated with postural instability ($p = 0.04$), axial rigidity, and impaired visuospatial/executive function ($p < 0.01$). In AD, unsafe drivers exhibited deficits in visual attention, executive function, and working memory ($p < 0.001$).
17	Iudice et al. (2008)	Mild AD (n = 20), MCI (n = 20), Controls (n = 20)	Mild AD (CDR = 1), MCI (CDR = 0.5), Controls	Age-matched groups	Not specified	Not specified	MMSE, Visual Reaction Time (VRT)	Simulator-based driving test	AD group performed significantly worse than MCI and controls on length of run and mean time to collision ($p < 0.001$) and number of off-road events ($p < 0.01$). MCI had shorter time-to-collision than controls ($p < 0.001$). AD had longer VRT ($p < 0.001$), but MMSE did not predict driving performance
18	Lincoln et al. (2009)	148 (118 dementia, 30 controls)	Dementia diagnosis	Not specified	Not specified	Licensed drivers	MMSE, SDSA Road Sign Recognition, SDSA Square Matrices Directions, BADS Key Search	Nottingham Neurological Driving Assessment (25 driving behaviors scored), blind instructor assessment, on-road observation: mirror checks , lane keeping, road sign obedience	Among 118 dementia patients, 27 (22.9%) were deemed unsafe, while all 30 controls passed the on-road assessment. Dementia patients performed significantly worse in rear observations ($p = 0.016$), lane keeping ($p = 0.039$), and road sign obedience ($p = 0.018$). Driving performance correlated with SDSA Road Sign Recognition ($p < 0.001$), SDSA Square Matrices Directions ($p < 0.05$), MMSE ($p = 0.001$), and BADS Key Search ($p < 0.05$)
19	Ott et al. (2005)	50 (mild AD)	CDR 0.5–1.0	Mean 75.7 (SD = 6.6)	31M/19F	Mean 53.8 years driving	MMSE, CDR, visuospatial, praxis, executive function, attention	On-road test with clinician ratings and standardized scoring	Clinician assessments of driving competence in mild dementia showed moderate accuracy (62–78%) when compared to standardized road test results. Dementia specialists achieved higher predictive accuracy (72–78%) than general practitioners (62–64%). The most reliable predictors were dementia duration ($p < 0.05$), CDR and MMSE scores ($p < 0.05$), and visuospatial/executive function tests ($p < 0.01$)
20	Paire-Ficout et al. (2016)	54 (18 AD, 18 healthy older, 18 younger)	Early AD diagnosis	AD: 72.7 (SD = 4.8), Healthy: 74.5 (SD = 5.4)	AD: 16M/2F, Healthy: 13M/5F	Licensed drivers	MMSE, Zazzo's Cancellation Test, Stroop, Stop Signal	In-traffic driving test, left turn maneuvers under different navigation instructions	Older drivers, both healthy and with early AD, performed worse at left-turn intersections when navigation instructions were provided, increasing cognitive load and impairing planning and decision-making skills ($p < 0.05$). Younger drivers were unaffected by navigation complexity. Findings suggest that navigation systems should be adapted to minimize cognitive demands for older drivers to improve safety

21	Pavlou et al. (2016)	137 (93 brain pathology, 44 controls)	AD, PD, MCI	Not specified	Not specified	Licensed drivers	Questionnaire on driving habits	Self-reported driving behavior	Drivers with brain pathologies (AD, MCI, PD) were more likely to avoid driving due to concerns about their abilities (p = 0.002) and perceive passenger conversations as dangerous (p = 0.002). They exhibited compensatory behaviors, such as slowing down, maintaining larger headways, and driving closer to the road's edge (p < 0.01).
22	Piersma et al. (2018)	34 (non-AD Dementia)	Vascular Dementia, FTD, DLB	Not specified	Not specified	Not specified	Neuropsychological tests, clinical interviews	On-road driving test	Among non-AD dementia patients (VaD, FTD, DLB), 58.8% failed the on-road test. Neuropsychological assessment predicted driving ability (AUC = 0.786, p = 0.006), whereas clinical interviews (AUC = 0.559, p = 0.564) and simulator rides (AUC = 0.417, p = 0.537) were not predictive. The combined model (AUC = 0.635, p = 0.316) lacked reliability, underscoring the need for dementia-specific fitness-to-drive assessments.
23	Ross et al. (2015)	43 (Cognitive impairment)	MMSE <26	Mean 74 (range 55–90)	33M/10F	Licensed drivers	Roadwise Review, hazard perception, visual tests, working memory	Standardized 18-km on-road test with fail/pass criteria	A combination of hazard perception, leg strength, visual acuity, working memory, and medication count significantly predicted on-road driving performance in cognitively impaired older adults (AUC = 0.80, p = 0.03). The model achieved 71% sensitivity and 75% specificity in classifying pass/fail outcomes. The Roadwise Review alone was not predictive (p = 0.37), but hazard perception tests (HPTs) significantly predicted disqualifications (p = 0.03).
24	Stein & Dubinsky (2011)	80 (17 AD, 63 controls)	Clinical Dementia Rating (CDR 0.5 & 1)	Elderly	Not specified	Not specified	Not specified	Driving simulator (19.3 km course)	Drivers with probable AD (CDR 1) exhibited significantly higher rates of accidents, collisions, and pedestrian strikes (p < 0.0001), greater lane deviation (p = 0.0001), and impaired divided attention (p < 0.0001) compared to cognitively normal controls.
25	Stern et al. (2016)	84 (44 controls, 20 MCI, 20 Dementia)	MCI, Dementia	Not specified	Not specified	Not specified	UFOV Divided Attention, NAB Driving Scenes	Office-based assessment of at-risk driving	A combination of office-based tests accurately predicted at-risk drivers in older adults with and without cognitive impairment (C-statistic = 0.90). The best predictors were UFOV Divided Attention (p < 0.001), NAB Driving Scenes (p < 0.001), and age (p = 0.008). No single cutoff score achieved both ≥80% sensitivity and specificity
26	Uc et al. (2004)	32 (Mild AD)	Mild AD	75.9 (SD = 6.2)	27M/5F	Licensed drivers	Cognitive and visual tests	Route-following and safety errors in on-road driving	Drivers with mild AD made significantly more incorrect turns (p < 0.0001), got lost more frequently (p = 0.0159), and committed more at-fault safety errors (p < 0.0001) than cognitively normal controls during a route-following task. These errors were associated with deficits in verbal memory (AVLT-RECALL, p < 0.0001), visual attention (UFOVTOT, p = 0.0027), and visuospatial perception (CFT-COPY, p = 0.0026).
27	Uc et al. (2006)	61 (Mild AD)	Mild AD	73.5 (SD = 8.5)	Not specified	72 miles/week	Cognitive and visual tests	Rear-end collision avoidance in a driving simulator	Drivers with mild AD had a significantly higher rate of unsafe outcomes (89% vs. 65%, p = 0.0007) in a rear-end collision (REC) avoidance scenario. They were more likely to slow down abruptly (70% vs. 37%, p < 0.0001) or stop prematurely (66% vs. 45%, p = 0.0115), increasing the risk of being struck from behind (p = 0.0262). Unsafe outcomes were predicted by deficits in visual perception (p < 0.01), attention (p < 0.01), memory (p < 0.01), visuospatial abilities (p < 0.01), and vehicle control (p = 0.0006).

28	Vaux et al. (2010)	32 (6 AD, 8 PD, 18 controls)	AD, PD	Not specified	Not specified	Not specified	Cognitive and visual tests	Collision detection simulation task	Drivers with AD and PD showed significantly reduced collision detection sensitivity (d□ = 0.81 vs. 1.59, $p < 0.01$), worsening with increased object count ($p < 0.01$) and longer TTC ($p < 0.01$). Impairment was greatest in high-load, short-TTC conditions. Poor cognition (COGSTAT, $p < 0.01$) and selective attention (UFOV-3, $p < 0.05$) correlated with detection deficits, highlighting neurodegenerative impact on visual-attentional processes critical for driving safety.
29	Wadley et al. (2009)	105 (46 MCI, 59 Controls)	MCI	Older adults (not specified)	Not specified	Active drivers	Neuropsychological assessment	Driving rehabilitation specialist rating	AD patients had significantly greater speed variability and lane deviation ($p < 0.01$).
30	Wadley et al. (2021)	103 (MCI/Mild Dementia)	MCI/Mild Dementia	Not specified	Not specified	Not specified	Processing speed, neuroimaging biomarkers	On-road driving evaluation	Cognitive processing speed was significantly associated with instrumental activities of daily living (IADLs) ($p < 0.001$), mobility ($p < 0.001$), and on-road driving performance ($p = 0.002$) in individuals with MCI and early AD.
31	Wakita et al. (2024)	30 (19 AD, 11 aMCI)	MMSE, VSRAD (MRI)	Aged 65+	Not specified	Licensed drivers	MMSE, VSRAD MRI markers	Driving simulator assessing operational errors, reaction time	Patients with AD exhibited more attention allocation errors than those with aMCI ($p = 0.0008$), correlating with MMSE scores ($r = -0.4354$, $p = 0.0162$). Decision time in the selective reaction test correlated with medial temporal atrophy ($r = 0.4807–0.4862$, $p < 0.05$).
32	Wisch et al. (2023)	60	Preclinical AD vs. Controls	62-87 (Median 75)	Not specified	Older adults, active drivers	Neuroimaging, lumbar puncture biomarkers, reaction time, hazard perception	Naturalistic driving data, road diets impact on driving speed, reduced speed in preclinical AD	Drivers with preclinical AD drove slower at baseline ($p = 0.007$) than those without AD. After road diet implementation, speed differences disappeared, indicating infrastructure impacts driving behavior regardless of cognition. Attentional control mediated 36% of speed reduction in AD ($p < 0.001$) but did not affect road diet-induced changes.
33	Yi et al. (2015)	28 (Mild AD)	Mild AD	Not specified	Not specified	Not specified	MMSE, Trail Making Test B	Driving simulator with GPS settings	Patients with AD made significantly more operational errors in attention allocation than those with aMCI in the complex task test ($p = 0.0008$). The number of these errors correlated negatively with MMSE scores ($r = -0.4354$, $p = 0.0162$), indicating greater cognitive impairment. Decision time in the selective reaction test correlated positively with medial temporal atrophy ($r = 0.4807–0.4862$, $p < 0.05$). Findings suggest that errors in attention allocation may indicate progression from aMCI to AD, and medial temporal atrophy may predict impaired driving judgment. Driving simulators could be useful for assessing driving ability in aMCI and AD.

Discussion

In most rapidly aging societies, there may soon be a need to monitor the ability of elderly drivers, especially those with neurodegenerative diseases to drive. Some of the results of this review may be helpful in government recommendations for issuing and maintaining driver's licenses. The role of neuropsychological assessment in the proper evaluation of driving ability seems to have a very significant impact on road safety. Individual neuropsychological assessment tools have proven effective in evaluating drivers especially in cognitively impaired populations, as shown in studies by Crivelli et al. [14] and Davis et al. [17]. However, there is still a great need to to search for more precise assessment tools that could better reflect the actual risks associated with driving.

It is also interesting to note that some studies,] have shown that people with neurodegenerative diseases are more likely to make errors in tasks requiring rapid shifts of attention [13]. This finding may have important implications for health policy and the guiding support programmes for people with cognitive impairment. So that people could stay safe on roads whilst sustaining the practical and social role connected with being a driver.

Methods for assessing driving ability also merit detailed analysis. Road tests, in fact, as the gold standard, are proving their value in assessing driver competence – e.g. studies by Davis et al. [17] and Wadley et al. [23] highlighted that the results of these tests correlate strongly with driver behaviour under natural conditions, which proves their ecological validity. On the other hand, driving simulators, while providing the opportunity to control conditions, may not fully reflect the actual challenges drivers face in everyday life. Therefore, even from an ethical point of view we have to somehow overcome this issue – perhaps with on road tests within closed and "animated" areas where the obstacles would be more secure but still providing a real-life challenge.

Another interesting aspect of analysed studies is the different approaches to collision risk assessment and understanding. Many studies [9-15,17-20,25-29,32] have confirmed an increase in risk among drivers with cognitive impairment and the tendency to implement compensatory strategies mainly Uc et al. [13,15] e.g. using less travelled roads. In terms of implementing a standardised, effective and objective driving assessment those findings indicate the need for more complex systems to assess driving ability. It is most beneficial to test drivers in a natural environment and put them through the challenges of busy and jammed roads. Furthermore, those "hands-on" tests should be complemented by information gained from family members, as retrospective data [9,14,16,18,21,26,29] has shown that they may have crucial observations of driving abilities of their loved ones.

The diversity of the cognitive functioning of seniors results primarily from the impact of various factors on people throughout their lives. The greatest impact on the mental fitness of people over 65 years of age is their health status: the presence of one or two chronic diseases contributes to a faster loss of cognitive abilities in this age group, especially in the case of cardio-vascular diseases, which disrupt the proper blood flow to the brain. In the case of the progressive process of dementia or Alzheimer's disease, this decline is even faster.

In conclusion, there is a need for further research into the relationship between cognitive functioning and driving ability, especially in relation to neurodegenerative disorders.

The use of more specific assessment tools and the integration of different research methods from different disciplines can contribute to a better understanding of this complex issue, which is crucial for improving road safety and creation of comprehensive guidelines.

Limitations of the review

The main limitation is the quality of the research – only 13 studies were assessed as having good methodological quality. None of the studies were classified as excellent.

Conflict of interest
None

References

1. Ledger S, Bennett JM, Chekaluk E, Batchelor J. Cognitive function and driving: Important for young and old alike. Transp Res Part F Traffic Psychol Behav. 2018;60: 262-73.
2. Whelihan W, Dicarlo M, Paul R. The relationship of neuropsychological functioning to driving competence in older persons with early cognitive decline. Arch Clin Neuropsychol. 2004;20(2): 217–228.
3. Ratcliff R, Vanunu Y. The effect of aging on decision-making while driving: A diffusion model analysis. Psychol Aging. 2022;37(4): 441-55.

4. Toepper M, Schulz P, Beblo T, Driessen M. Predicting on-road driving skills, fitness to drive, and prospective accident risk in older drivers and drivers with mild cognitive impairment: The importance of non-cognitive risk factors. J Alzheimers Dis. 2020;79(1): 401-14.
5. Baltes PB. Theoretical propositions of life-span developmental psychology: On the dynamics between growth and decline. Dev Psychol. 1987;23(5):611–626.
6. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ. 2021; n71.
7. PLOS ONE. Modified Downs and Black checklist for assessment of methodological quality. Version 1. PLoS One. 2020.
8. Anstey KJ, Eramudugolla R, Chopra S, Price J, Wood JM. Assessment of driving safety in older adults with mild cognitive impairment. J Alzheimers Dis. 2017;57(4): 1197–1205.
9. Grace J, Amick MM, D'Abreu A, Festa EK, Heindel WC, Ott BR. Neuropsychological deficits associated with driving performance in Parkinson's and Alzheimer's disease. J Int Neuropsychol Soc. 2005;11(6):766-75.
10. Holland PJ, Tappen RM, Newman DO, Freeman-Costin KC, Fisher LJ. Effect of memantine on prolonging safe driving in early AD: a pilot study. Can Geriatr J. 2021;24(4): 292–296.
11. Barrash J, Stillman A, Anderson SW, Uc EY, Dawson JD, Rizzo M. Prediction of driving ability with neuropsychological tests: demographic adjustments diminish accuracy. J Int Neuropsychol Soc. 2010;16(4): 679–686.
12. Aksan N, Anderson SW, Dawson J, Uc E, Rizzo M. Cognitive functioning differentially predicts different dimensions of older drivers' on-road safety. Accid Anal Prev. 2014;75: 236–244.
13. Uc EY, Rizzo M, Anderson SW, Shi Q, Dawson JD. Unsafe rear-end collision avoidance in Alzheimer's disease. J Neurol Sci. 2006;251(1–2): 35–43.
14. Crivelli L, Russo MJ, Farez MF, Bonetto M, Prado C, Calandri IL, et al. Driving and Alzheimer's disease: a neuropsychological screening battery for the elderly. Dement Neuropsychol. 2019;13(3): 312–320.
15. Uc EY, Rizzo M, Anderson SW, Shi Q, Dawson JD. Driver route-following and safety errors in early Alzheimer disease. Neurology. 2004;63(5): 832–837.
16. Stern RA, Abularach LM, Seichepine DR, Alosco ML, Gavett BE, Tripodis Y. Office-based assessment of at-risk driving in older adults with and without cognitive impairment. J Geriatr Psychiatry Neurol. 2016;29(6): 352–360.
17. Davis JD, Papandonatos GD, Miller LA, Hewitt SD, Festa EK, Heindel WC, et al. Road test and naturalistic driving performance in healthy and cognitively impaired older adults: does environment matter? J Am Geriatr Soc. 2012;60(11): 2056–2062.
18. Ott BR, Anthony D, Papandonatos GD, D'Abreu A, Burock J, Curtin A, et al. Clinician assessment of the driving competence of patients with dementia. J Am Geriatr Soc. 2005;53(5): 829–833.
19. Ross RWJ, Scialfa CT, Cordazzo STD. Predicting on-road driving performance and safety in cognitively impaired older adults. J Am Geriatr Soc. 2015;63(11): 2365–2369.
20. Paire-Ficout L, Marin-Lamellet C, Lafont S, Thomas-Antérion C, Laurent B. The role of navigation instruction at intersections for older drivers and those with early Alzheimer's disease. Accid Anal Prev. 2016;96: 249–254.
21. Beratis IN, Andronas N, Kontaxopoulou D, Fragkiadaki S, Pavlou D, Papatriantafyllou J, et al. Driving in mild cognitive impairment: the role of depressive symptoms. Traffic Inj Prev. 2016;18(5): 470–476.
22. Vaux LM, Ni R, Rizzo M, Uc EY, Andersen GJ. Detection of imminent collisions by drivers with Alzheimer's disease and Parkinson's disease: a preliminary study. Accid Anal Prev. 2010;42(3): 852–858.
23. Wadley VG, Bull TP, Zhang Y, Barba C, Bryan RN, Crowe M, et al. Cognitive processing speed is strongly related to driving skills, financial abilities, and other instrumental activities of daily living in persons with mild cognitive impairment and mild dementia. J Gerontol A Biol Sci Med Sci. 2020;76(10): 1829–1838.
24. Economou A, Pavlou D, Beratis I, Andronas N, Papadimitriou E, Papageorgiou SG, et al. Predictors of accidents in people with mild cognitive impairment, mild dementia due to Alzheimer's disease and healthy controls in simulated driving. Int J Geriatr Psychiatry. 2020;35(8): 859–869.
25. De Simone V, Kaplan L, Patronas N, Wassermann E, Grafman J. Driving abilities in frontotemporal dementia patients. Dement Geriatr Cogn Disord. 2006;23(1): 1–7.

26. Pavlou D, Papantoniou P, Papadimitriou E, Vardaki S, Economou A, Yannis G, et al. Self-assessment of older drivers with brain pathologies: reported habits and self-regulation of driving. J Transp Health. 2016;4: 90–98.
27. Frittelli C, Borghetti D, Iudice G, Bonanni E, Maestri M, Tognoni G, et al. Effects of Alzheimer's disease and mild cognitive impairment on driving ability: a controlled clinical study by simulated driving test. Int J Geriatr Psychiatry. 2008;24(3): 232–238.
28. Stein AC, Dubinsky RM. Driving simulator performance in patients with possible and probable Alzheimer's disease. Neurol Clin. 2011;29(2): 325–334.
29. Wadley VG, Okonkwo O, Crowe M, Vance DE, Elgin JM, Ball KK, et al. Mild cognitive impairment and everyday function: an investigation of driving performance. J Geriatr Psychiatry Neurol. 2009;22(2): 87–94.
30. Etienne V, Marin-Lamellet C, Laurent B. Mental flexibility impairment in drivers with early Alzheimer's disease: a simulator-based study. IATSS Res. 2013;37(1): 16–20.
31. Fuermaier ABM, Piersma D, De Waard D, Davidse RJ, De Groot J, Doumen MJA, et al. Assessing fitness to drive—a validation study on patients with mild cognitive impairment. Traffic Inj Prev. 2016;18(2): 145–149.
32. Wakita H, Takahashi Y, Masuzugawa S, Miyasaka H, Sonoda S, Shindo A, et al. Alterations in driving ability and their relationship with morphometric magnetic resonance imaging indicators in patients with amnestic mild cognitive impairment and Alzheimer's disease. Psychogeriatrics. 2024;24(4): 830–837.
33. Yi J, Lee HC, Parsons R, Falkmer T. The effect of the global positioning system on the driving performance of people with mild Alzheimer's disease. Gerontology. 2015;61(1): 79–88.
34. Brown LB, Ott BR, Papandonatos GD, Sui Y, Ready RE, Morris JC. Prediction of on-road driving performance in patients with early Alzheimer's disease. J Am Geriatr Soc. 2005;53(1): 94–98.
35. Davis JD, Babulal GM, Papandonatos GD, Burke EM, Rosnick CB, Ott BR, et al. Evaluation of naturalistic driving behavior using in-vehicle monitoring technology in preclinical and early Alzheimer's disease. Front Psychol. 2020;11:596257.
36. Fragkiadaki S, Beratis IN, Kontaxopoulou D, Pavlou D, Andronas N, Papanicolaou A, Economou A, Yannis G, Papageorgiou SG. Self-awareness of driving ability in the healthy elderly and patients with mild cognitive impairment (MCI). Alzheimer Dis Assoc Disord. 2018;32(2):107–113.
37. Piersma, D, Fuermaier, A B, De Waard, D, Davidse, R J, De Groot, J, Doumen, M J, et al. Assessing fitness to drive in patients with different types of dementia. Alzheimer Dis Assoc Disord. 2017; 32: 70-75.