Cognitive Tests and Determining Fitness to Drive in Dementia: A Systematic Review

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Evidence has shown that although all individuals with dementia will eventually need to stop driving, most can continue to drive safely early in the disease. Fitness to drive needs to be monitored, and the use of cognitive testing to determine driver safety has been suggested. This review is the first to examine cognitive test results pertaining only to individuals with dementia. The aim was to examine the relationship between cognitive tests and driving to determine whether a cognitive assessment can be implemented as a tool to examine driver safety. A systematic review of 28 studies investigating the relationship between cognitive functioning and driving in individuals with dementia was conducted. The results of this review demonstrated a lack of consistency in the findings, with some studies showing a relationship between cognitive testing and driving performance for individuals with dementia, whereas others did not. Results relating to individual cognitive tests and measures confined to a single cognitive domain were variable and not consistently associated with driving performance. Studies consistently found that composite batteries predicted driving performance. The findings from this review support the use of composite batteries comprising multiple individual tests from different cognitive domains in predicting driving performance for individuals with dementia. Scores on individual tests or tests of a single cognitive domain did not predict driver safety. The composite batteries that researchers have examined are not clinically usable because they lack the ability to discriminate sufficiently between safe and unsafe drivers. Researchers need to develop a reliable, valid composite battery that can correctly determine driver safety in individuals with dementia. **J Am Geriatr Soc 64:1904–1917, 2016.**

Key words: dementia; driving; cognitive assessment

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Driving requires the simultaneous processing of visual, auditory, and tactile information in a dynamic and complex environment and as such, places high demands on many different cognitive domains, including memory, attention, executive function, visuospatial skills, and psychomotor coordination.[1] Decline in any of these functions, such as what occurs in dementia, has been demonstrated to increase the risk of crashes.[2] Dementia is a progressive and irreversible neurological disease characterized by impairments of memory and other aspects of cognition including attention, processing speed, and executive function.[3] Progressive decline in these cognitive functions as a result of dementia means that all individuals with the disease will eventually be unsafe to drive.

The effect that dementia has on driving has been widely researched. There is consistent evidence that individuals with dementia have two to eight times the risk of being involved in a motor vehicle crash than age-matched controls,[4] but because dementia is a progressive disease, it is argued that simply having a diagnosis of dementia should not limit one's ability to drive.[5] Most researchers and governing bodies tend to favor the approach that individuals with mild dementia should retain their license to drive because most can continue to drive safely for extended periods of time,[6] but because a lack of insight into one's condition is a common consequence of dementia, determining when to cease driving cannot be left up to the discretion of the individual.

Determining the point at which an individual progresses from being safe to unsafe on the roads is not clear cut. The number of years that an individual with dementia can continue to drive safely varies from 2 to 4 years.[7,8] Although licensing authorities make the final determination regarding license status, this decision is typically made based on recommendations from physicians. Individuals with dementia are generally required to undergo a medical assessment by their general practitioner to determine whether they are fit to drive in Australia. Although there are guidelines from the various medical advisory boards on how to make these determinations, most physicians report that they do not feel equipped to make reliable assessments of driver capacity.[9] As a result, clinicians seek

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additional tools to aid in the decision-making process for individuals with dementia.

As a result of the close relationship between cognitive functioning and effective driving performance, cognitive testing has been proposed as an inexpensive, efficient means of determining driver safety in this population. A large body of research has sought to determine which cognitive tests are associated with driver safety in dementia, with variable results. A 2006 review[10] concluded that there is not enough evidence that any single measure or measures from a single cognitive domain can consistently predict driving performance and that none were sufficient for clinical use because only one study had used cutoff scores, and without cutoff scores, clinical determinations regarding driver safety cannot be made.[10]

Two review articles[10,11] examined the role of cognitive assessments in determining driver safety for dementia and highlighted a number of important considerations. Both noted that not all of the studies have isolated results for dementia participants. In some cases, the results for matched control groups and participants with dementia have been combined in the same analyses, which is problematic because the controls may affect the results. One of these reviews[11] compared results of all studies with those that had isolated dementia and found that the effect sizes were smaller once controls were excluded from the analyses. In light of these findings, it highlighted the need for researchers to isolate findings specific to dementia to enable clinical questions to be answered. The systematic review[10] examined the results of studies that did and did not have results that could be isolated to individuals with dementia. As such, the results from that review cannot be related solely to those with dementia. No review has examined the relationship between driving performance and results on individual cognitive tests or the overall cognitive domains for studies with results that pertain only to participants with dementia.

The current study represents the first systematic review to investigate the relationship between cognitive assessment and driving performance in individuals with dementia. It used an aggregate and a disaggregate approach, with results on individual cognitive tests that each study used being examined (disaggregate), as well as results when measures were grouped into their overarching cognitive domains (aggregate). A further aim of the review was to determine whether there is sufficient evidence to support the practical implementation of cognitive measures in determining fitness to drive in individuals with dementia.

METHODS

Literature Search

A comprehensive search of the Medline, PsycInfo, Scopus, Cinahl, Sage, Embase, and the Cochrane Library databases was completed. The following search terms were used individually and in combination: dementia, Alzheimer*, driving, automobile, car, motor, vehicle, crash, accident, collision, competence, fitness, neuropsych*, assessment, neuropsychological test, cognitive functioning, and cognitive assessment. A manual search of the reference lists of selected articles was performed to locate further articles.

Inclusion and Exclusion Criteria

All studies that the search yielded were examined to determine whether they met the following eligibility criteria: included participants with dementia and used an accepted diagnostic criteria for determining dementia, included a measure of driving ability (motor vehicle crashes, caregiver reports, driving cessation, simulator or computerized assessment, on-road assessment), and used standardized cognitive measures to determine fitness to drive.

Articles that were presented in the form of case studies, letters, editorials, guidelines, books, dissertations, reviews, and unpublished studies were excluded. Only articles written in English were considered. If a study failed to isolate results for participants with dementia, it was excluded.

Selection of Studies

A comprehensive breakdown of the selection of studies according to criteria is presented in Figure 1. The primary author (JMB) completed an initial screen of title and abstract of each paper, which yielded 260 articles. Two reviewers (JMB, EC) then collaborated to determine whether the articles met the inclusion and exclusion criteria and selected 28 articles for inclusion.[8,12–38] Two independent studies were reported in two of the articles,[26,30] which brought the number of studies included to 30. A further four articles[8,13,20,25] included results relating to more than one measure of driving performance, bringing the total number of studies to 35.

Quality Assessment

This study used the Newcastle-Ottawa Quality Assessment Scale for Cohort and Case Control Studies (NOS).[39] The measure provides a rating out of 4 for selection, 2 for comparability, and 3 for exposure in case–control studies and outcome in cohort studies, which equates to a total possible score of 9. "Selection" describes how participants are allocated to different groups, which in the present context was on the basis of a diagnosis of dementia. "Comparability" measures whether possible confounding variables were controlled. The two possible confounding variables were age and education, because they have been shown to have a relationship with dementia and driving performance. "Exposure" or "outcome" is scored on the basis of how the target outcome was measured, for example, if the investigators were blind to group (case, control) membership.

All studies were also compared using the National Health and Medical Research Council (NHMRC) guidelines for assessing levels of evidence.[40] These guidelines stipulate that the highest level of evidence for comparative studies (nonrandomized or observational designs) is a systematic review (I), followed by prospective cohort studies (II), all or none (all or none of the participants experienced the expected outcome) (III-1), retrospective cohort studies (III-2), case–control studies (III-3), and cross-sectional studies (IV).

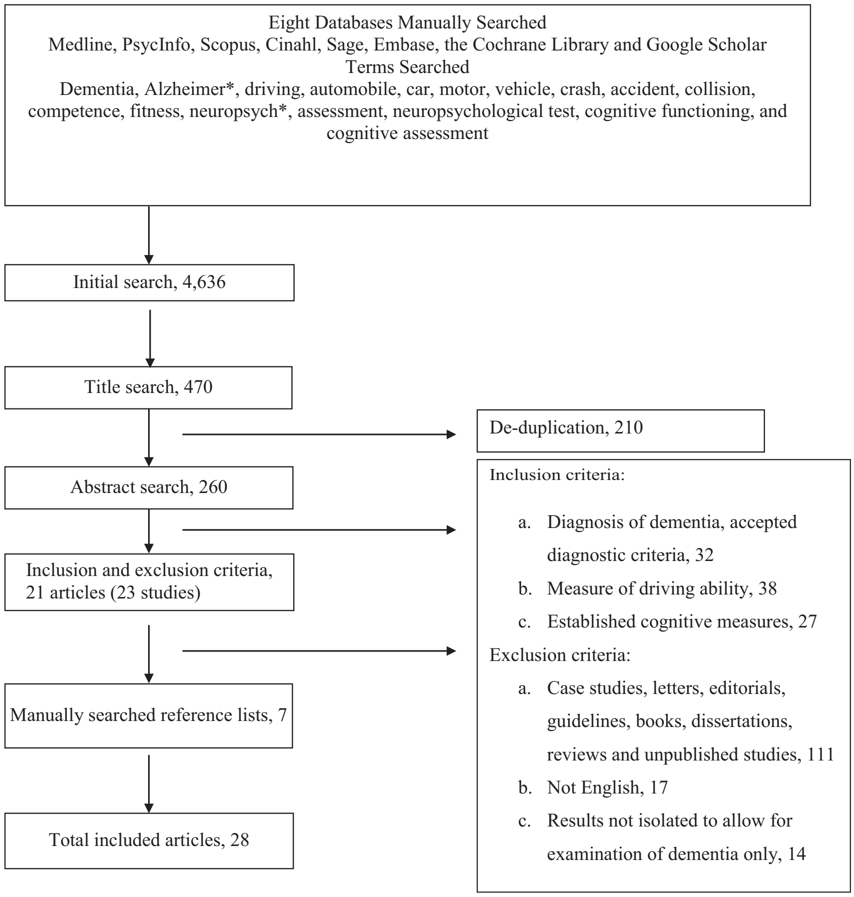

Figure 1. Systematic review process for study selection.

RESULTS

Description of Studies

The characteristics of the included studies are presented in Table 1. Studies were examined according to the outcome measure used to determine driving ability. Studies most commonly used on-road assessment (n = 14), followed by caregiver report (n = 13), driving simulator (n = 3), driving cessation (n = 2), motor vehicle crash data (n = 2), and computerized driving performance test (n = 1). The most common design was cross-sectional (n = 27), with a further seven retrospective studies and one prospective longitudinal study. Eighteen studies were cohort and the remaining 17 were case–control. The size of the samples of the participants with dementia ranged from 9 to 883, with a median sample size of 56. The results of the cognitive tests and their association with driving performance were examined according to a number of characteristics, study sample size, country of origin, and the driving outcome measure, and no systematic differences were found.

Studies Quality and Design

Article quality as measured according to the NOS and the NHMRC guidelines are presented in the final column of Table 1. Quality was assessed for the 28 individual articles and the two independent studies included in a single article.[26,30] Four of the articles[8,13,20,25] compared the results of the cognitive tests with more than one driving measure, but this was in a single study and has been treated as such for the purposes of quality assessment.

Of the 30 independent studies, 25 were cross-sectional, four were retrospective, and one was prospective; 15 were cohort studies, and 15 were case–control. According to NHMRC guidelines,[40] the cross-sectional studies were rated as providing the lowest level of evidence.

All of the included studies were rated according to the NOS. The ratings given to the studies ranged from 2 to 8. Breaking the study scores into three categories (weak (0–3), average (4–6) and strong (7–9)), 12 fell into the weak category, 13 were of average quality, and five were of strong research quality. The results of the cognitive tests and their association with driving performance were compared for each of the three quality categories (weak, average, strong). There was no evidence of a consistent pattern of results according to quality level. For example, four studies that used the Trail-Making Test (TMT) Part B were of strong methodological rating, with two of those studies finding an association[27,28] and two not.[32,33] Similarly, there was no consensus regarding the relationship between scores on measures of attention and driving performance within the stronger studies, with an association between results being found in seven studies and no association in seven studies. Finally, all studies found a positive

Table 1. Study Characteristics

Author, Year (Country)	Driving Outcome Measure	Design Type	Participants with Dementia, n	Conclusion	Newcastle-Ottawa Scale Score			National Health and Medical Research Council Score
					Selection	Comparability	Exposure	
Friedland 1988 (United Kingdom)[12]	Caregiver report (MVC)	Retrospective case–control	30	No relationship between any tests and MVC	3	0	1	III-3
Lucas-Blaustein 1988 (United States)—A[13]	Caregiver report (driving cessation)	Retrospective cohort	53	MMSE and category naming test were significantly different between those driving and no longer driving	2	0	1	III-2
Lucas-Blaustein 1988 (United States)—B[13]	Caregiver report (MVC)	Retrospective cohort	53	No relationship between any tests and MVC	2	0	1	III-2
Gilley 1991 (United States)—A[8]	Caregiver report (driving cessation)	Retrospective cohort	333	MMSE worse for those who had ceased driving; no difference in premorbid IQ	2	0	1	III-2
Gilley 1991 (United States)—B[8]	Caregiver report (MVC)	Retrospective cohort	93	MMSE and premorbid IQ estimate not related to MVC	2	0	1	III-2
Gilley 1991 (United States)—C[8]	Caregiver report (problematic driving)	Retrospective cohort	93	MMSE and premorbid IQ estimate not related to problematic driving behaviors	2	0	1	III-2
Donnelly 1992 (United States)[14]	On-road	Cross-sectional case–control	12	No relationship between any cognitive test and driving performance	4	0	2	IV
Logsdon 1992 (United States)[15]	Caregiver report (problematic driving)	Cross-sectional cohort	100	MMSE, BDRS, Dementia Rating Scale scores significantly different between those still driving and those no longer driving; IQ not different between groups	2	0	1	IV
O'Neill 1992 (United Kingdom)[16]	Caregiver report (problematic driving)	Cross-sectional Cohort	57	Only ADL scores significantly different between those with diminished and normal driving skills	2	0	3	IV
Rebok 1994 (United States)[17]	Computerized driving performance test	Cross-sectional case–control	10	MMSE and Category Fluency Test correlated with driving performance	1	0	1	IV
Harvey 1995 (United Kingdom)[18]	Simulator	Cross-sectional cohort	13	MMSE, performance IQ, perceptual tasks worse in poor drivers	2	0	1	IV
Tuokko 1995 (Canada)[19]	MVC	Retrospective case–control	165	Functional Rating Scale did not predict MVC	3	1	1	III-3
Trobe 1996 (United States)—A[20]	MVC	Cross-sectional case–control	143	Relationship between Wechsler Memory Scale and Verbal IQ and MVC was in opposite direction than expected; better performance on both cognitive tests associated with being in a MVC; no relationship found between any other tests and MVC	3	1	1	IV
Trobe 1996 (United States)—B[20]	Driving cessation	Cross-sectional case–control	143	Those driving performed significantly better on MMSE, Finger Oscillation Test, Wechsler Memory Scale	3	1	1	IV

(Continued)

Table 1 (Contd.)

Author, Year (Country)	Driving Outcome Measure	Design Type	Participants with Dementia, n	Conclusion	Newcastle-Ottawa Scale Score			National Health and Medical Research Council Score
					Selection	Comparability	Exposure	
Shua-Haim 1996 (United States)[21]	Simulator	Cross-sectional cohort	41	MMSE, but not ADLs, related to driving performance	2	0	1	IV
Fox 1997 (Austraila)[22]	On-road	Cross-sectional cohort	19	MMSE and Wechsler Adult Intelligence Scale III Block Design only tests to correlate with total driving score	2	0	1	IV
Bieliaukas 1998 (United States)[23]	On-road	Cross-sectional case–control	9	Only Shipley Institute of Living Scale, Southern California Figure-Ground Test correlated with driving errors	2	1	1	IV
Ott 2000 (United States)[24]	Caregiver report (problematic driving)	Cross-sectional cohort	79	Clinical Dementia Rating, ADLs, Clocks, but not MMSE, correlated with driving ability	2	0	1	IV
Zuin 2002 (Argentina)—A[25]	Caregiver report (problematic driving)	Cross-sectional case–control	56	BDRS for ADLs and Clinical Dementia Rating associated with abnormal driving behavior	2	2	1	IV
Zuin 2002 (Argentina)—B[25]	Caregiver report (MVC)	Cross-sectional case–control	56	BDRS for ADLs associated with MVC	2	2	1	IV
Ott 2003 (United States)—A[26]	Caregiver report (problematic driving)	Cross-sectional cohort	27	Porteus Maze only predictor of driver rating	2	0	0	IV
Ott 2003 (United States)—B[26]	Caregiver report (problematic driving)	Cross-sectional case–control	34	Strong relationships between computerized mazes and driver ratings	4	0	1	IV
Grace 2005 (United States)[27]	On-road	Cross-sectional case–control	20	TMT, Rey-Osterreith Complex Figure had strongest correlations with driving performance	3	2	2	IV
Whelihan 2005 (United States)[28]	On-road	Cross-sectional case–control	23	Maze navigation, Useful Field of View tests had significant relationship with driving performance; maze navigation had 80% classification	4	2	2	IV
Hermann 2006 (Canada)[29]	Driving cessation	Prospective longitudinal cohort	883	MMSE and Global Staging significantly correlated with driving cessation	2	0	0	II
Lincoln 2006 (United Kingdom)—A[30]	On-road	Cross-sectional case–control	37	Developed a predictive equation that included Stroke Driver Screening Assessment, MMSE, Behavioral Assessment and Space Perception Battery, Stroop, Visual Object and Space Perception Battery, Adult Memory and Information Processing Battery and Salford Objective Recognition Test; classification of 92%	4	1	2	IV

(Continued)

Table 1 (Contd.)

Author, Year (Country)	Driving Outcome Measure	Design Type	Participants with Dementia, n	Conclusion	Newcastle-Ottawa Scale Score			National Health and Medical Research Council Score
					Selection	Comparability	Exposure	
Lincoln 2006 (United Kingdom)—B[30]	On-road	Cross-sectional cohort	17	Validated predictive equation that included tests from Lincoln 2006—A and created cutoff score of 5; classification of 88%	2	1	1	IV
Berndt 2008 (Australia)[31]	On-road	Cross-sectional cohort	115	MMSE and Clinical Dementia Rating predicted driving performance; cutoff score of Clinical Dementia Rating >1 should no longer be driving	2	0	1	IV
Ott 2008 (United States)[32]	On-road	Cross-sectional case–control	88	Total maze time and Hopkins Verbal Learning Test significantly related to driving performance; computerized mazes had classification of 69%	3	2	2	IV
Dawson 2009 (United States)[33]	On-road	Cross-sectional case–control	40	Benton Visual Retention Test, TMT-A, Rey-Osterreith Complex Figure Test—Copy, Functional Reach, Useful Field of View significant predictors of driving errors. Composite Cognitive Battery best predictor of driving performance (suggesting one single test not sensitive enough to be accurate predictor of driving performance)	4	2	1	IV
Frittelli 2009 (Italy)[34]	Simulator	Cross-sectional case–control	20	MMSE did not correlate with driving performance, but visual reaction time did	3	2	1	IV
Lincoln 2010 (United Kingdom)[35]	On-road	Cross-sectional cohort	65	Predictive equation from Lincoln 2006 with cutoff score of 0 correctly classified 76.2% of drivers; reducing some of subtests and adding TMT and more subsets of Visual Object and Space Perception Battery increased classification up to 90.2%	2	0	1	IV
Selander 2010 (Sweden)[36]	On-road	Cross-sectional case–control	119	Nordic Stroke Driver Screening Assessment does not predict driving performance in AD	4	1	1	IV
Carr 2011 (United States)[37]	On-road	Cross-sectional cohort	99	AD-8, Clock Drawing Test, TMT-A, Snellgrove Maze Test all predictors of driving failure; AD-8, Clock Drawing Test, Snellgrove Maze Test developed into predictive equation that classified 53%	2	2	1	IV

(Continued)

Table 1 (Contd.)

Author, Year (Country)	Driving Outcome Measure	Design Type	Participants with Dementia, n	Conclusion	Newcastle-Ottawa Scale Score			National Health and Medical Research Council Score
					Selection	Comparability	Exposure	
Hoggarth 2013 (New Zealand)[38]	On-road	Cross-sectional cohort	279	Eight-factor model including simple sensory-motor and tests of higher cognitive processes correctly classified 75.6% of drivers	2	1	1	IV

AD = Alzheimer's disease; AD-8 = Eight-item Informant Interview to Differentiate Aging and Dementia; ADL = activity of daily living; BDRS = Blessed Dementia Rating Scale; IQ = intelligence quotient; MMSE = Mini-Mental State Examination; MVC = motor vehicle crash; TMT = Trail-Making Test.

association between scores on composite batteries and driving performance, including both of those rated strong in methodological quality.

Associations Between Cognitive Test Scores and Driving Performance

Associations between cognitive test scores and driving performance are presented in a consistent manner with prior studies in Table 2.[10] To be consistent with the work of previous authors,[10,11] the tests have been grouped according to the primary cognitive domain that they measure. These were general mental or cognitive status, attention and concentration (including working memory and processing speed), visuospatial skills, memory, executive function, and language. An "other" group was created for tests that did not fit into the six domain classifications. Many studies used multiple individual cognitive measures, and accordingly, in any one study, multiple comparisons between driving performance and cognitive functioning were reported. Therefore, from this point on, the term "finding" refers to these individual comparisons. Overall, there were 178 individual findings and 87 cognitive measures.

Mental or cognitive status was the domain most frequently measured, with 41 individual findings and nine measures used in the different studies. There were 39 findings relating to executive function and 20 measures. Attention and concentration had 28 individual findings and 19 measures. For the visuospatial domain, there were 21 findings and 10 measures used. For memory, there were 19 findings and 13 measures. Language had nine findings and five measures. In the "other" group, there were 22 findings and 12 measures.

For all cognitive domains, there was a positive association between the cognitive measure and driving in 82 of the 178 findings (46%). More than half of the findings were of positive relationships with driving performance for mental or cognitive status (23/41, 56%), executive function (20/39, 51%), and attention and concentration (18/28, 50%). The other domains had fewer than half of the findings showing a positive relationship with driving performance (visuospatial skills (10/21, 48%), memory (7/19, 37%), and measures of language (1/9, 11%)), although the one measure for language revealed a significant positive association with driving in a direction opposite of that expected.[20]

For all of the individual tests in each of the cognitive domains, the results were also variable. The Mini-Mental State Examination (MMSE) was the most commonly used individual test, with 14 of the 25 findings (56%) showing a positive association with driving. The next two most commonly measures had a similar pattern in terms of variable results. The TMT-A was examined six times, with a positive association being reported four times, and the TMT-B was examined eight times, with three findings showing a positive association. For all tests, studies with stronger methodological rigor found a mix of positive associations and no association between test scores and driving performance.

The development of cutoff scores was examined, with only five of the 30 studies using some form of discrimination

Table 2. Associations Between Cognitive Test Scores and Driving Performance

Cognitive Domain	Cognitive Test	Positive Association ($P < .05$)	No Association ($P > .05$)	Included in Analysis, n	Cutoff Reported
Mental or cognitive status	AD-8: Eight-item Informant Interview to Differentiate Aging and Dementia	Carr 2011[37]		99	No
	Blessed Dementia Rating Scale	Logsdon 1992[15]		100	No
			Trobe 1996—A[20]	42	No
			Trobe 1996—B[20]	114	No
	Clinical Dementia Rating	Ott 2000[24]		79	No
		Zuin 2002—A[25]		56	No
			Zuin 2002—B[25]	56	No
			Ott 2003—A[26]	27	No
		Ott 2003—B[26]		27	No
	Dementia Rating Scale		Donnelly 1992[14]	12	No
		Logsdon 1992[15]		100	No
	Functional Rating Scale		Tuokko 1995[19]	165	No
	Global Deterioration Scale	Hermann 2006[29]		883	No
	Mini-Mental State Examination		Friedland 1988[12]	30	No
		Lucas-Blaustein 1988—A[13]		53	No
			Lucas-Blaustein 1988—B[13]	53	No
		Gilley 1991—A[8]		333	No
			Gilley 1991—B[8]	93	No
			Gilley 1991—C[8]	93	No
			Donnelly 1992[14]	12	No
		Logsdon 1992[15]		100	No
			O'Neill 1992[16]	57	No
		Rebok 1994[17]		10	No
		Harvey 1995[18]		13	No
			Trobe 1996—A[20]	42	No
		Trobe 1996—B[20]		118	No
		Shua-Haim 1996[21]		41	No
		Fox 1997[22]		19	No
			Bieliaukas 1998[23]	9	No
			Ott 2000[24]	79	No
			Ott 2003—A[26]	27	No
		Hermann 2006[29]		883	No
		Lincoln 2006—A[30]		37	No
		Lincoln 2006—B[30]		17	Yes
		Berndt 2008[31]		115	Yes
		Ott 2008[32]		88	No
			Frittelli 2009[34]	20	No
		Lincoln 2010[35]		65	Yes
	Shipley IQ Estimate	Bieliaukas 1998[23]		9	No
	WAIS Full IQ		Logsdon 1992[15]	100	No
		Ott 2003—A[26]		27	No
Attention and concentration	Action Fluency		Whelihan 2005[28]	23	No
	Balloons Test		Lincoln 2006—A[30]	37	No
	Choice Reaction Time		Bieliaukas 1998[23]	9	No
	Complex Attention Test	Hoggarth 2013[38]		279	Yes
	Digit Symbol		Fox 1997[22]	19	No
	Divided Attention Test	Hoggarth 2013[38]		279	Yes
	Letter Cancellation Test		Whelihan 2005[28]	23	No
	Neuropsychological Assessment Battery Driving Scenes Test		Grace 2005[27]	20	No
	Test of Everyday Attention		Lincoln 2006—A[30]	37	No
	Selective Attention Test		Donnelly 1992[14]	12	No
	Simple Reaction Time		Bieliaukas 1998[23]	9	No
		Frittelli 2009[34]		20	No
	Useful Field of View	Whelihan 2005[28]		23	No

(Continued)

Table 2 (Contd.)

Cognitive Domain	Cognitive Test	Positive Association ($P < .05$)	No Association ($P > .05$)	Included in Analysis, n	Cutoff Reported
			Dawson 2009[33]	40	No
Attention—working memory	Digit Span—Forward		Carr 2011[37]	99	No
	Digit Span—Backward		Carr 2011[37]	99	No
Attention—processing speed	Adult Memory and Information Processing Battery	Lincoln 2006—A[30]		37	No
		Lincoln 2006—B[30]		17	Yes
	Stroke Driver Screening Assessment: Dot Cancellation	Lincoln 2006—A[30]		37	No
		Lincoln 2006—B[30]		17	Yes
	Stroke Driver Screening Assessment: Dot Cancellation Shortened	Lincoln 2010[35]		65	Yes
	Trail-Making Test A		Fox 1997[22]	19	No
		Grace 2005[27]		20	No
			Whelihan 2005[28]	23	No
		Ott 2008[32]		88	No
		Dawson 2009[33]		40	No
		Carr 2011[37]		99	No
Visuospatial skills	WAIS III Block Design Subtest	Fox 1997[22]		19	No
			Dawson 2009[33]	40	No
	Benton Line Orientation		Rebok 1994[17]	10	No
	Rey-Osterreith Complex Figure Test—Copy	Grace 2005[27]		20	No
			Ott 2008[32]	88	No
		Dawson 2009[33]		40	No
	Clocks	Ott 2000[24]		79	No
			Ott 2003—A[26]	27	No
		Carr 2011[37]		99	No
	Figure Ground Test	Bieliaukas 1998[23]		9	No
	Judgment of Line Orientation		Fox 1997[22]	19	No
			Dawson 2009[33]	40	No
	Visual Form Discrimination Test		Fox 1997[22]	19	No
			Whelihan 2005[28]	23	No
	Visuospatial Task		O'Neill 1992[16]	57	No
	Visual Object and Space Perception Battery	Harvey 1995[18]		13	No
		Lincoln 2006—A[30]		37	No
		Lincoln 2006—B[30]		17	Yes
		Lincoln 2010[35]		65	Yes
	WAIS Picture Completion		Donnelly 1992[14]	12	No
			Fox 1997[22]	19	No
Memory	Auditory Verbal Learning Test		Dawson 2009[33]	40	No
	Brief Visual Memory Test—Revised		Whelihan 2005[28]	23	No
	Benton Visual Retention Test		Fox 1997[22]	19	No
		Dawson 2009[33]		40	No
	Rey-Osterreith Complex Figure Test—Recall		Dawson 2009[33]	40	No
	Hopkins Verbal List Learning Test	Ott 2008[32]		88	No
	Hopkins Verbal List Learning Test—Revised	Grace 2005[27]		20	No

(Continued)

Table 2 (Contd.)

Cognitive Domain	Cognitive Test	Positive Association ($P < .05$)	No Association ($P > .05$)	Included in Analysis, n	Cutoff Reported
	Logical Memory		Rebok 1994[17]	10	No
	Recognition Memory Test for Words and Faces		Harvey 1995[18]	13	No
	Selective Reminding Test		Trobe 1996—A[20]	17	No
			Trobe 1996—B[20]	81	No
	Salford Objective Recognition Test	Lincoln 2006—A[30]		37	No
		Lincoln 2006—B[30]		17	Yes
		Lincoln 2010[35]		65	Yes
	Spatial Recognition Test		Lucas-Blaustein 1988—A[13]	53	No
			Lucas-Blaustein 1988—B[13]	53	No
	WAIS Visual Reproduction		Rebok 1994[17]	10	No
	Wechsler Memory Scale	Trobe 1996—A (better performance associated with more crashes)[20]		46	No
			Trobe 1996—B[20]	109	No
Executive function	Behavioral Assessment and Space Perception Battery	Lincoln 2006—A[30]		37	No
		Lincoln 2006—B[30]		37	Yes
		Lincoln 2010[35]		65	Yes
	Category Fluency	Rebok 1994[17]		10	No
	Category Naming Task	Lucas-Blaustein 1988—A[13]		53	No
			Lucas-Blaustein 1988—B[13]	53	No
	Rey-Osterreith Complex Figure—Organisation	Grace 2005[27]		20	No
			Ott 2008[32]	88	No
	Computerized Mazes	Ott 2003—B[26]		34	No
		Ott 2008[32]		88	No
			Grace 2005[27]	20	No
	Controlled Oral Word Association		Ott 2003—A[26]	27	No
			Whelihan 2005[28]	23	No
			Dawson 2009[33]	40	No
	Delis-Kaplan Executive Function System Trail Making	Lincoln 2010[35]		65	Yes
	Maze Navigation Test	Whelihan 2005[28]		23	No
	Nordic Stroke Driver Screening Assessment		Selander 2010[36]	32	No
	Planning Test	Hoggarth 2013[38]		279	Yes
	Porteus Maze	Ott 2003—A[26]		27	No
	Ruff Figural Test		Whelihan 2005[28]	23	No
	Shipley Institute of Living Scale—Abstraction	Bieliaukas 1998[23]		9	No
	Snellgrove Maze Test	Carr 2011[37]		99	No
	Stroop Test		Donnelly 1992[14]	12	No
		Lincoln 2006—A[30]		37	No
		Lincoln 2006—B[30]		17	Yes
		Lincoln 2010[35]		65	Yes
	Trail-Making Test B		Donnelly 1992[14]	12	No
			Fox 1997[22]	19	No
		Ott 2003—A[26]		27	No
		Grace 2005[27]		20	No
		Whelihan 2005[28]		23	No
			Ott 2008[32]	88	No
			Dawson 2009[33]	40	No
			Carr 2011[37]	99	No

(Continued)

Table 2 (Contd.)

Cognitive Domain	Cognitive Test	Positive Association ($P < .05$)	No Association ($P > .05$)	Included in Analysis, n	Cutoff Reported
	WAIS Picture Arrangement		Donnelly 1992[14]	12	No
			Rebok 1994[17]	10	No
	Wisconsin Card Sorting Test		Bieliaukas 1998[23]	9	No
	Wisconsin Card Sorting Test—Preservative Errors		Whelihan 2005[28]	23	No
	Wechsler Intelligence Scale Children Maze		Donnelly 1992[14]	12	No
Language	Boston Naming Test		Lucas-Blaustein 1988—A[13]	53	No
			Lucas-Blaustein 1988—B[13]	53	No
	Generative Naming (animals)		Wheilhan 2005[28]	23	No
	Graded Naming Test		Harvey 1995[18]	13	No
	Shipley Institute of Living Scale—Verbal		Bieliaukas 1998[23]	9	No
	WAIS Verbal IQ		Logsdon 1992[15]	100	No
			Harvey 1995[18]	13	No
		Trobe 1996—A (better performance associated with more crashes)[20]		40	No
			Trobe 1996—B[20]	92	No
Other	Activities of Daily Living	O'Neill 1992[16]		57	No
			Shua-Haim 1996[21]	41	No
		Ott 2000[24]		79	No
		Zuin 2002—A[25]		56	No
		Zuin 2002—B[25]		56	No
	Arrows Perception Test	Hoggarth 2013[38]		279	Yes
	Ballistic Movement Test	Hoggarth 2013[38]		279	Yes
	Functional Autonomy Measurement System		Herrmann 2006[29]	883	No
	Kew		O'Neill 1992[16]	57	No
	Motor Free Visual Perceptual Test		Carr 2011[37]	99	No
	Premorbid IQ		Gilley 1991—A[8]	333	No
			Gilley 1991—B[8]	93	No
			Gilley 1991—C[8]	93	No
	Premorbid IQ—National Adult Reading Test		Harvey 1995[18]	13	No
			Ott 2003—A[26]	27	No
	Short Blessed Test		Carr 2011[37]	99	No
	Tracking Tests	Hoggarth 2013[38]		279	Yes
	Visual Search Time		Bieliaukas 1998[23]	9	No
	WAIS Performance IQ		Logsdon 1992[15]	100	No
		Harvey 1995[18]		13	No
			Trobe 1996—A[20]	41	No
			Trobe 1996—B[20]	94	No

IQ = intelligence quotient; WAIS = Wechsler Adult Intelligence Scale.

analysis to determine whether participants fell into safe or unsafe driver categories on the basis of performance on the cognitive measures. Of these, three studies provided predictive equations with cutoff scores.

Composite Batteries of Cognitive Tests

Six studies examined the relationship between scores on a composite battery of cognitive tests and driving performance in individuals with dementia. The list of studies is presented in On-Line Table S1. Four composite batteries were used in the six studies, the Composite Cognitive Battery (COGSTAT) in one,[33] a battery that the authors developed in three,[30,35] and two separate batteries were each examined once.[37,38] Scores on each battery were found to have a significant association with driving performance. In all cases, poorer performance on the battery of tests was associated with poorer driver performance in individuals with dementia. Predictive equations with usable cutoff scores were reported for only two of the studies. Predictive equations and cutoff scores of 5 were reported in one study[30] and 0 in the other.[35]

Each of the four composite batteries measures multiple cognitive domains. The battery used in two of the studies used seven measures,[30] and a third used eight.[35] The measures used in all three of these batteries addressed five cognitive domains: attention, executive function, mental status, memory, visuospatial ability. COGSTAT uses eight measures, and examines three domains: executive function, memory, visuospatial skills.[33] A battery used in another study[37] uses three measures that examine executive function, mental status, and visuospatial ability, and another[38] contains four measures and examined attention and executive function.

DISCUSSION

The current systematic review was the first to examine studies that had results isolated to individuals with dementia and examined the relationship between cognitive testing and driving performance. The results demonstrated considerable variability in findings regarding the relationship between cognitive test scores and driving performance in individuals with dementia. Quality assessment did not yield a systematic bias in study results, suggesting that there is a lack of consistency in the results of the articles reviewed for measures of a single cognitive domain and individual cognitive tests that cannot be explained in terms of methodological differences.

From the pattern of results evidenced by this review, single tests, such as the MMSE, should not be used as indicators of fitness to drive because they are not sufficient to obtain a reliable picture of driving ability for individuals with dementia. Similarly, no single cognitive domain was found to be the most reliable when determining driver ability. These results are in line with previous findings that effect sizes for the different cognitive domains range from weak to moderate.[11] The combination of these findings indicates that deficits in a single cognitive ability are not a reliable predictor of driving performance. Caution is therefore warranted when trying to make driving determinations on the basis of tests from a single cognitive domain.

It appears that using a composite battery that combines multiple individual tests of different cognitive domains has greater potential to predict driving performance. Considering that driving requires input from multiple cognitive domains, it would be logical to assess all of the individual domains that affect driving performance. It has been concluded that in addition to the individual tests, a composite battery that assessed the multiple cognitive domains required to be an efficient driver was the best predictor of driving performance in individuals with Alzheimer's disease (AD).[33]

One of the primary aims of this study was to establish whether previous research has developed an objective assessment of driving ability of individuals with a diagnosis of dementia that can be practically implemented. The review demonstrated that there is still a gap between research findings and clinical application. As a result, there are a number of limitations that investigators must overcome. First, research has typically grouped mixed etiologies and levels of severity into one "dementia" group, which means that the cohorts being compared across the studies are not necessarily equivalent. This could potentially explain the mixed findings evidenced by this review, because different dementia diagnoses or levels of severity could be skewing results. The cognitive profile is different for each of the severity levels; for instance, MMSE scores would be worse for individuals with a moderate rating then those with a mild rating.[41] Therefore, the results of studies that grouped individuals with different severity ratings together could potentially be different if those groups were analyzed separately. Investigations into the differences between dementia with Lewy bodies (DLB) and AD have found that perceptual and spatial deficits are worse in those diagnosed with DLB.[42] As such, if individuals with DLB and AD were analyzed together, the DLB cohort might be responsible for the relationship between scores on measures of visuospatial ability and driving performance, and that relationship might not exist for the AD cohort. To determine the effect that different etiologies and severity levels might have, researchers should distinguish these categories in their analyses. As a result, there may be a need to determine different assessments for each dementia etiology and severity category.

Research conducted in this area has overwhelmingly been a series of single stand-alone studies using a variety of driving outcome measures. As such, little is known about the reliability and validity of the individual tests, tests of a single cognitive domain, or the composite batteries as predictors of driving performance for individuals with dementia. Although composite batteries show promising findings, reliability and validity of the proposed batteries in determining driving performance for individuals with dementia needs to be investigated more thoroughly. Furthermore, this research should be conducted using standardized on-road assessments because these are the criterion standard approach for assessing driving performance. Finally, this investigation of reliability and validity will need to be spread over a range of sites to account for potential differences in samples. This will ensure the applicability of any composite test battery and its scoring to the broader population of drivers with dementia.

An important criticism of prior research was that cutoff scores were not provided and, as such, results were not useful in a clinical context. It remains the case that the majority of research does not include cutoff scores.[10] Several studies in which new composite batteries were used[30,35,37] used predictive equations to determine whether a driver could be classed as safe or unsafe based on test performance. Only two of these studies[30,35] developed cutoff scores that could be used clinically, and only these studies are close to providing a battery that will enable clinical determinations regarding driver safety to be made, but in its current form, it is not appropriate. The 2010 study[35] was a validation study of the original prediction equation that the same authors produced in 2006.[30] Although the findings of the 2006 study held true, the authors found that adding more tests and altering the cutoff score from 5 to 0 improved the classification accuracy of the battery to 77.8%. Because changes were made to the battery, predictive equation, and cutoff scores, further validation studies are required. Also, although the classification percentage increases, almost one-quarter of drivers are still incorrectly being deemed safe or unsafe to drive. Current recommendations are that screening measures should accurately classify with certainty 80% to 90% of all drivers.[43] As a result, any proposed composite battery should have a classification percentage of a minimum of 80% over several samples to ensure it can consistently predict driver safety for individuals with a diagnosis of dementia.

Similarly, divisions of drivers into safe or unsafe is in contrast to recommendations of previous researchers who proposed that, rather than dichotomizing drivers as safe or unsafe, trichotomization should be employed.[10] Trichotomization of cutoff scores would mean that there would be an upper score and a lower score that would divide drivers into three groups; safe, indeterminate, and unsafe. The benefit of trichotomization is that it will allow individuals who fall into the indeterminate category to be more closely monitored or to undergo another form of assessment, such as an on-road driving test, which will mean more certainty that the correct clinical decision regarding driver safety has been made.

It is not sufficient to produce a screening assessment that is a reliable and valid with usable cutoff scores. It is also important to make sure it can be implemented practically in an everyday clinical setting. It is therefore necessary for researchers to produce a battery that is complete in its assessment but also balanced with an appropriate administration time. The current method of conducting the cognitive assessments by hand, scoring them, and then running complex equations is a complicated process that requires expert training. To alleviate this problem, researchers should investigate developing an electronic application style of an appropriately validated battery. Computerizing the battery would remove the need to administer tests by paper and pen, hand score, and determine category membership, and therefore the need for the costly training associated with it. Such a tool would enable this form of assessment to be conducted at licensing offices, removing the burden from clinicians.

Because driving is an essential aspect of everyday life for many individuals in the early stages of dementia, examining driving ability it is of great importance to balance individual independence with overall road safety. By using a composite battery of multiple cognitive tests from various cognitive domains, a more-holistic picture of an individual's driving performance is gained, as opposed to using individual measures or tests from a single cognitive domain. As a result, researchers need to focus on the development of a composite battery that can accurately classify a minimum of 80% of drivers with dementia using the trichotomization approach. This tool will need to be validated at a variety of sites to ensure that it is effective for the broader population with dementia. Ideally, this battery will be able to be computerized to allow for easy administration at licensing authority locations nationwide, reducing the burden on clinicians. The development of a composite battery will enable policy-makers nationally to put in place a practical, objective determinant of driving performance for individuals with dementia.

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SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article:

Table S1. Composite Batteries.

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