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Driving Difficulties Among Patients with Alzheimer's Disease and Other Neurodegenerative Disorders

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Abstract.
Background/Objective: Neurodegenerative disorders impact fitness to drive of older drivers, but on-road driving studies investigating patients with different neurodegenerative disorders are scarce. A variety of driving errors have been reported in patients with Alzheimer's disease (AD), but it is unclear which types of driving errors occur most frequently. Moreover, patients with other neurodegenerative disorders than AD typically present with different symptoms and impairments, therefore different driving errors may be expected.
Methods: Patients with AD ($n = 80$), patients with other neurodegenerative disorders with cognitive decline (i.e., vascular dementia, frontotemporal dementia, dementia with Lewy bodies/Parkinson's disease, $n = 59$), and healthy older drivers ($n = 45$) participated in a fitness-to-drive assessment study including on-road driving.
Results: Patients with AD performed significantly worse than healthy older drivers on operational, tactical, visual, and global aspects of on-road driving. In patients with AD, on-road measures were significantly associated with 'off-road' measures. Patients with neurodegenerative disorders other than AD showed large overlap in the types of driving errors. Several driving errors were identified that appear to be characteristic for patients with particular neurodegenerative disorders.

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Conclusion: Patients from each group of neurodegenerative disorders commonly display tactical driving errors regarding lane positioning, slow driving, observation of the blind spot, and scanning behavior. Several other tactical and operational driving errors, including not communicating with cyclists and unsteady steering, were more frequently observed in patients with non-AD neurodegenerative disorders. These findings have implications for on-road and 'off-road' fitness-to-drive assessments for patients with neurodegenerative disorders with cognitive decline.

Keywords: Alzheimer's disease, automobile driving, cognitive decline, frontotemporal dementia, dementia with Lewy bodies, neurodegenerative diseases, Parkinson's disease, vascular dementia

INTRODUCTION

Driving is the preferred mode of transport of many older adults; however, late-life cognitive impairments resulting from neurodegenerative disorders may impair fitness to drive [1]. Fitness to drive of patients with neurodegenerative disorders is commonly examined by on-road driving assessments [2–8]. In a recent review, it was concluded that neurodegenerative disorders impair driving at all levels, i.e., at strategic, tactical, and operational levels [8, 9]. As denoted by Michon [9], the strategic level concerns non-immediate driving decisions, such as when to depart and which route to follow. At the tactical level, maneuvering during driving takes place, including speed adaptations and lane changes. The operational level requires the fastest responses in reacting to changing traffic situations and vehicle control such as lateral control and emergency braking. Accordingly, a variety of errors can be made during driving, and it is not entirely clear which types of driving errors are made most frequently by patients with neurodegenerative disorders [8]. In a study by Dobbs and colleagues [10] comparing patients with cognitive decline (most of them probably having Alzheimer's disease, AD) with an older and younger control group, it was found that patients with cognitive decline differed from both control groups in several error types, including hazardous errors, minor and turn positioning errors, scanning errors, and over-cautiousness. In another study, Withaar and colleagues examined on-road behavior of drivers with cognitive decline and demonstrated impaired performance for operating manual transmission, viewing behavior, and paying attention to other road users [11]. Notably, the population of patients with neurodegenerative disorders is very heterogeneous encompassing different types of diseases characterized by distinct symptoms and impairments. Consequently, it has been proposed that patients with different types of neurodegenerative diseases may differ in driving performance [12, 13].

On-road driving studies distinguishing multiple groups of patients with neurodegenerative disorders are scarce. Moreover, no on-road studies are available that include patients with dementia with Lewy bodies (DLB) or frontotemporal dementia (FTD). Fitten and colleagues [14] were the first to investigate patients with two different types of dementia on the road, i.e., patients with AD ($n = 13$) and patients with vascular dementia (VaD) ($n = 12$). In comparison to diabetic, older, and young control participants, both dementia groups made more serious driving errors (e.g., turning onto streets with 'do not enter' signs), especially during the more complex stages of the on-road assessment. Patients with AD scanned the environment less while driving than patients with VaD, and the latter group showed more between subject variability in overall driving performance [14]. In another study, Grace and colleagues [15] assessed driving performance of patients with AD ($n = 20$) and non-demented patients with Parkinson's disease (PD) ($n = 21$). Patients with AD made more driving errors than patients with PD, who in turn made more driving errors than healthy older drivers. Driving errors of patients with AD were found at the operational (such as timing), tactical (such as obeying rules, choice of travelling), and strategic (such as reasoning, judgment, or attention) level, with tactical errors being most common. Over half of the patients with AD made several errors associated with lane changes (i.e., merging, checking blind spot, smoothness of change), left turns, and pulling over. Patients with PD also made tactical driving errors, especially in scanning before merging, but they made relatively few operational and strategic driving errors. Tactical driving errors of patients with PD were often related to a deficiency in head turning [15]. These two studies indicate that most driving errors may be committed at the tactical level in different groups of patients with neurodegenerative disorders; however, the nature of these driving errors might differ between diagnostic groups.

There is a clear need for on-road driving studies comparing patients of different neurodegenerative disorders. Such a study could contribute to improving fitness-to-drive assessments for patients with different neurodegenerative disorders. In the current study, patients with AD, patients with other neurodegenerative disorders (VaD, mixed dementia, FTD, DLB/PD), and healthy older drivers were assessed on the road using the same protocol. Three objectives will be addressed in this study. The first objective of this study is to compare the differences in on-road driving errors of patients with AD with healthy older drivers using four subscales of the on-road driving assessment (TRIP). Driving errors at all levels of driving are expected in patients with AD. The second objective is to examine if there are differences in driving errors (as per the TRIP subscales) and outcomes of clinical interviews, neuropsychological assessments, and driving simulator rides ('off-road' measures) in patients with AD who failed versus patients with AD who passed the on-road assessment, and if the TRIP subscales and 'off-road' measures relate. The expectation is that more errors will be committed by patients with AD failing compared to those passing the on-road assessment. Given the high accuracy of 'off-road' measures to classify patients with AD passing or failing the on-road test [16], we expect large associations between TRIP subscales and 'off-road' measures in the present study which would be suggestive of the utility of 'off-road' measures for the prediction of different qualitative aspects of driving. Finally, the third objective of this study is to explore whether driving errors (as per TRIP categories) vary among patients with different neurodegenerative disorders (different types of dementia and no dementia [healthy older drivers]). Based on the different predominant symptoms and impairments in different neurodegenerative diseases, we expect that driving errors of patients with different neurodegenerative disorders will overlap only partially with driving errors of patients with AD. Implications for assessments of fitness to drive of patients with neurodegenerative disorders will be discussed, e.g., how to streamline on-road assessments in clinical practice.

METHODS

Participants

Patients with neurodegenerative disorders

In the present study, 139 patients with neurodegenerative disorders with cognitive decline participated. All over the Netherlands, patients were recruited via health care centers and from the general community by means of advertisements. Inclusion criteria for patients were an age over 30, a valid driving license, a desire to continue driving, and a diagnosis of a neurodegenerative disorder with cognitive decline in very mild to mild stages (Clinical Dementia Rating <2). Exclusion criteria were diagnoses of neurological or psychiatric conditions unrelated to dementia that may influence driving performance as well as use of medications legally prohibiting driving a car (ICADTS category III drugs). Furthermore, patients' visual functions were screened according to legal limits for driving, i.e., a minimum visual acuity of 0.5 and a minimum horizontal field of view of 120 degrees.

The diagnoses of the patients included AD, VaD, mixed dementia (AD + VaD), FTD, DLB, and PD. Patients with PD had self-reported cognitive decline. Generally, referring physicians established the diagnosis of AD with criteria of the NINCDS-ADRDA Work Group [17], the diagnosis of VaD by the NINDS-AIREN criteria [18], the diagnosis of FTD and its variants using criteria of the International bvFTD Criteria Consortium and the International PPA Consortium [19, 20], the diagnosis of DLB with criteria of the DLB consortium [21], and the diagnosis of PD by the UK PDS Brain Bank Criteria [22, 23]. Patients were aged 52 to 91 years (mean = 71.7; SD = 8.8 years) and 99 (71.2%) were men.

Healthy participants

Forty-five healthy older drivers participated in this study and served as a control group. Healthy participants were recruited from the general community by means of advertisements and the word of mouth. Inclusion criteria for healthy participants were an age over 70, a valid driving license, and a desire to continue driving. Exclusion criteria were diagnoses of psychiatric or neurological conditions, other diagnoses that would require referral to the Dutch driving license authority, and use of medications legally prohibiting driving a car. The lower age limit for healthy participants was higher than for patients to avoid recruiting a sample of healthy older drivers that was younger than the patient sample. Healthy participants were aged 70 to 87 years (mean = 76.3; SD = 4.7 years) and 24 (53.3%) healthy participants were men.

Measures

All participants were assessed in two sessions, in a clinical setting and on the road. The protocol used in the clinical setting has been described thoroughly by Piersma and colleagues [16]. In this study, predictor variables for on-road driving performance were derived from clinical interviews, neuropsychological assessment, driving simulator rides and these three methods combined ('off-road' measures). The predictor variables from 'off-road' measures were adopted from Piersma and colleagues [16] who identified predictor variables against the criterion fitness to drive as determined by a driving expert in an on-road test of patients with AD. The predictor equations were estimated based on a series of statistical calculations, i.e., point biserial correlation analyses, binary logistic regression analyses, and discriminant function analyses. The predictive accuracy of these equations were evaluated in receiver operating characteristics (ROC) by indicating the area under the curve (AUC) statistics. Predictive accuracy was good to excellent for each of the prediction equations, including clinical interviews (AUC = 83.5%), the neuropsychological assessment (AUC = 90.5%), driving simulator rides (AUC = 86.1%) and the three methods combined (AUC = 97.4%). Retained measures of clinical interviews comprised two sub-scores of the Clinical Dementia Rating [24] (i.e., Orientation and Judgment & Problem solving), the patients' judgments of their own driving safety, and recent driving experience. The neuropsychological predictors included the Mini-Mental State Examination (MMSE) [25, 26], the reaction time S2 [27, 28], the hazard perception test [16, 29], and a traffic theory test (see [16] for details). Driving simulator measures included the minimum speed when approaching an intersection with traffic lights, the number of collisions in a ride with intersections and two measures concerning a merging maneuver, namely the deceleration of the rear car after merging and the time headway directly after merging (see [16] for details).

The present study mainly focuses on the on-road driving assessment. The on-road driving evaluations were carried out by approved experts on practical fitness to drive of the Dutch driving license authority (CBR). Experts were blind to the participants' diagnoses and test results, but they were instructed to use the standard CBR protocol for the assessment of drivers with cognitive impairment. Every on-road driving assessment was carried out in the participant's own car during daylight hours and lasted around 45 minutes.

Test ride investigating practical fitness to drive (TRIP)

The CBR experts rated driving behavior of participants using the Test Ride Investigating Practical fitness to drive (TRIP) [11, 30–32]. The TRIP consists of 59 items, concerning lateral positioning, gap distances, speed, visual behavior, responses to traffic signs, overtaking, anticipation, communication, turning left, merging, technical execution and perception and insight. Each item is rated as either insufficient (1), doubtful (2), or sufficient (3). Finally, a pass, doubtful or fail outcome was given by the experts. This outcome was recoded into a dichotomous item which indicates whether or not a participant is fit to drive, because pass outcomes indicated that participants could retain their driving license, whereas doubtful or fail outcomes indicated that participants would have lost their driving license if the on-road driving assessment would have been an official relicensing assessment. At the end of the TRIP, space was provided for the assessor to note any aspects of adverse driving.

Four subscales were calculated based on subsets of items as performed by De Haan and colleagues [30]. The operational subscale (OPER) comprised the average of 9 items on operational behavior, such as steering and braking. The tactical subscale (TACT) was calculated by averaging 15 items on tactical driving behavior, such as adapting speed and anticipation. The visual subscale (VIS) encompassed the average of 23 items related to visual scanning behavior. The final, global subscale (GLOB) included the average of three items regarding general impressions of *practical fitness to drive*, *mechanical operation*, and *traffic perception and traffic insight*.

Procedure

Participants were recruited and assessed consistent with the study protocol of Piersma and colleagues [16]. Participants were invited to take part in the study on a voluntary basis. The study was approved by the Medical Ethical Committee at the University Medical Center Groningen and the Ethical Committee Psychology at the University of Groningen, the Netherlands. Written informed consent was obtained from all participants. Healthy participants were rewarded 15 Euros for participation. Patients received

no direct reward for participation, but patients who passed the on-road driving assessment could use this outcome in an official relicensing procedure. Failing the on-road driving assessment did not lead to revocation of the participants' driving licenses.

Statistical analyses

Missing data

In 17% of the cases, participants were driving with automatic transmission, therefore values for operating the clutch and choosing the appropriate gear are missing in these cases. Other TRIP values were missing in less than 3% of cases per variable, either because a certain maneuver or situation did not occur in the on-road driving assessment or because experts did not judge the respective driving behavior. Missing values were not replaced.

Differences in on-road driving errors of patients with AD compared with healthy older drivers (study objective 1)

Data analysis was largely based on patients with AD as this is the most common form of dementia. To address the first study objective, patients with AD were compared with healthy older drivers (IV) on four subscales of the TRIP (OPER, TACT, VIS, and GLOB; DVs). Assumptions for parametric tests were violated, therefore Mann-Whitney U tests and effect sizes (Cohen's r) were used to compare the patients with AD with healthy older drivers. The significance level was Bonferroni adjusted and set to 0.01 in order to control for alpha error inflation in multiple testing. Furthermore, interpretations were mainly based on effect sizes. Effect sizes were classified into negligible effects ($r < 0.1$), small effects ($0.1 < r < 0.3$), medium effects ($0.3 < r < 0.5$), and large effects ($r > 0.5$) [33, 34].

Differences in on-road driving errors and 'off-road' measures between patients with AD who pass and those who fail the on-road driving assessment, and the association between on- and 'off-road' measures (study objective 2)

The same approach as explained for study objective 1 was used to compare patients with AD who passed the on-road driving assessment with patients with AD who failed the on-road driving assessments (IV) on TRIP subscales and 'off-road' measures (DVs). In order to examine the association between TRIP subscales and 'off-road' measures, Spearman rank correlations were computed using the data of the entire group of patients with AD to evaluate how the TRIP subscales relate to the predictor variables from 'off-road' measures (i.e., clinical interviews, neuropsychological assessment, driving simulator rides and these three methods combined). The significance level in correlation analyses was Bonferroni adjusted and set to 0.003 (=0.05/16 correlations). Effect sizes in correlation analyses were classified into negligible effects ($r < 0.1$), small effects ($0.1 < r < 0.3$), medium effects ($0.3 < r < 0.5$), and large effects ($r > 0.5$).

Exploratory analysis on driving errors specific to different neurodegenerative disorders (study objective 3)

Regarding the third study objective, i.e., an exploration of whether driving errors vary among patients with different neurodegenerative disorders, frequencies of driving errors in twelve TRIP categories (DVs) were calculated of the patients who failed the on-road assessment in each diagnostic group (IV). In the Supplementary Material, frequencies of specific driving errors (insufficient ratings on a TRIP item; DVs) were examined of the patients who failed the on-road driving assessment in each diagnostic group (i.e., IV) in order to investigate at a more detailed level whether patients with different neurodegenerative disorders made different driving errors. The groups failing the on-road driving assessments were of particular interest in this context as more incidences of driving errors can be expected that represent why the patients were no longer regarded fit to drive. For comparison, the data of the groups passing the on-road assessment are provided in the Supplementary Material as well.

RESULTS

Differences in on-road driving errors of patients with AD compared with healthy older drivers (study objective 1)

Characteristics of patients with AD were comparable with those of healthy older drivers, except for CDR and MMSE scores (Table 1). Of the 80 patients with AD, 46 failed the on-road driving assessment (41 fail and 5 doubtful outcomes). Of the 45 healthy older drivers, 5 failed the on-road driving assessment (2 fail and 3 doubtful outcomes). On average, patients with AD had lower scores on the TRIP subscales than healthy older drivers (Table 1). Addressing study objective 1, Mann-Whitney U tests indicated that patients with AD ($n = 80$) had significantly lower scores than healthy older drivers ($n = 45$) on all

Table 1
Characteristics and TRIP subscales of patients with Alzheimer's disease and healthy older drivers

Characteristics	Group		
	AD ($n=80$)	Healthy ($n=45$)	p (df)
Age [mean (SD)] (y)	71.8 (9.3)	76.3 (4.7)	0.047 (124) [a]
Male [n (%)]	51 (63.7)	24 (53.3)	0.262 (1)[b]
Education [mean of 7 stages (SD)]	5.1 (1.3)	5.2 (1.3)	0.398 (124)[a]
CDR-score [n (%)]			<0.001* (2) [c]
0	2 (2.5)	42 (93.3)	
0.5	67 (83.8)	3 (6.7)	
1	11 (13.8)	0 (0.0)	
MMSE-score [mean (SD)]	23.6 (3.7)	28.8 (1.1)	<0.001* (124)[a]
TRIP subscales	AD ($n=72$–80)	Healthy ($n=45$)	
OPER [mean (SD)]	2.83 (0.32)	2.95 (0.15)	0.006* (120)[a]
TACT [mean (SD)]	2.58 (0.43)	2.90 (0.15)	<0.001* (118)[a]
VIS [mean (SD)]	2.60 (0.46)	2.92 (0.14)	<0.001* (116)[a]
GLOB [mean (SD)]	2.33 (0.67)	2.93 (0.21)	<0.001* (124)[a]
Fail rate [n (%)]	46 (57.5)	5 (11.1)	<0.001* (1)[b]

*Significant at $p<0.01$. Education, Verhage scale for the Dutch educational level ranging from 1 (primary school not finished) to 7 (university level); CDR-score, Clinical Dementia Rating total score; MMSE-score, Mini-Mental State Examination sum score (range 0–30); TRIP, Test-Ride Investigating Practical fitness to drive; OPER, operational subscale; TACT, tactical subscale; VIS, visual subscale; GLOB, global subscale; AD, Alzheimer's disease; Healthy, healthy older drivers. [a]Mann-Whitney U test. [b]Fisher's exact test. [c]χ^2 test.

four TRIP subscales (OPER: U = 1279.5, $p=0.006$, $r=0.25$; TACT: U = 776.5, $p<0.001$, $r=0.45$; VIS: U = 803.5, $p<0.001$, $r=0.41$; GLOB: U = 884.0, $p<0.001$, $r=0.47$). For OPER, a small effect size was found, whereas TACT, VIS, and GLOB showed medium effect sizes.

Differences in on-road driving errors and 'off-road' measures between patients with AD who pass and those who fail the on-road driving assessment, and the association between on- and 'off-road' measures (study objective 2)

As presented in Table 2, comparing patients with AD who failed the on-road driving assessment ($n=46$) with those who passed the on-road assessment ($n=34$) revealed significantly lower scores in those who failed the on-road assessment on all four TRIP subscales (all $p<0.001$). In the pass/fail comparison, effect sizes were large for all TRIP subscales ($r=0.65-0.86$). When comparing the pass/fail groups on 'off-road' measures, effect sizes are of small to medium size with two variables of clinical interviews, all four of neuropsychological assessment, and two of driving simulator rides reaching significance ($p<0.01$) (Table 2).

Table 3 shows results regarding the Spearman rank correlations between the four TRIP subscales (OPER, TACT, VIS, and GLOB) and four predictor variables derived from the 'off-road' assessments (clinical interviews, neuropsychological assessment, driving simulator rides, and these three methods combined) using the entire group of patients with AD. All four 'off-road' predictor variables correlated significantly with all four TRIP subscales ($p<0.003$), with the exception of the association between the variable of the driving simulator ride and OPER ($p=0.004$) and TACT ($p=0.010$). However, an inspection of the size of the correlations revealed medium to large effects for all 16 correlation coefficients, including the ones not reaching significance on a Bonferroni adjusted significance level of $p<0.003$. Large effects ($r>0.5$) were found for the predictor variable based on neuropsychological assessment with TACT, VIS, and GLOB, for the predictor variable based on driving simulator rides with VIS and GLOB, and for the predictor variable based on the three methods combined with OPER, VIS, and GLOB.

Exploratory results on driving errors specific to different neurodegenerative disorders (study objective 3)

To describe the driving errors made by patients with different neurodegenerative disorders, only those participants who failed the on-road driving assessment were selected. These were 46 of 80

Table 2
Results of patients with Alzheimer's disease failing and passing the on-road assessment

	Group				
	AD fail ($n = 46$)	AD pass ($n = 34$)	Z	p	ES
TRIP subscales					
OPER	2.64 (0.45)	2.97 (0.10)	–5.0	<0.001*	0.73
TACT	2.43 (0.44)	2.90 (0.15)	–5.6	<0.001*	0.65
VIS	2.33 (0.50)	2.93 (0.12)	–6.0	<0.001*	0.71
GLOB	1.88 (0.55)	2.98 (0.08)	–7.7	<0.001*	0.86
Clinical interviews	AD fail ($n = 46$)	AD pass ($n = 34$)			
CDR Orientation	0.8 (0.6)	0.5 (0.5)	–2.1	0.036	0.23
CDR Judgement & Problem solving	0.8 (0.8)	0.4 (0.3)	–3.2	0.002*	0.36
Judgement driving safety[a]	1.2 (0.4)	1.0 (0.2)	–1.8	0.072	0.20
Recent driving experience[b]	2.3 (1.1)	3.0 (1.0)	–2.9	0.004*	0.32
Neuropsychological assessment	AD fail ($n = 45$–46)	AD pass ($n = 34$)			
MMSE score	22.5 (4.1)	25.1 (2.3)	–2.9	0.003*	0.32
RT S2 RT (ms)	345.3 (141.3)	267.9 (49.3)	–3.0	0.003*	0.34
Hazard perception, correct trials	12.1 (3.0)	15.0 (3.0)	–3.7	<0.001*	0.41
Traffic theory, RT (s)	7.9 (1.0)	7.1 (0.9)	–3.3	0.001*	0.37
Driving simulator rides	AD fail ($n = 27$)	AD pass ($n = 29$)			
Minimum speed at intersection (km/h)[c]	17.3 (23.9)	7.2 (16.8)	–1.1	0.268	0.15
Number of collisions	0.9 (0.9)	0.3 (0.5)	–2.5	0.012	0.33
Deceleration rear car after merging (km/h)	–2.0 (2.4)	–0.3 (0.8)	–3.0	0.002*	0.40
Time headway after merging (s)	1.4 (0.7)	0.9 (0.6)	–2.7	0.007*	0.36

*Significant at $p < 0.01$. [a]Judgment of own driving safety by the participant with (1) still driving as safely as when the participant was middle aged, (2) is driving less safely compared with when the participant was middle aged, or (3) drives unsafely. [b]Kilometers driven in the previous 12 months: (1) <1.000 km, (2) 1.000 to 5.000 km, (3) 5.000 to 10.000 km, (4) 10.000 to 20.000 km, (5) 20.000 to 30.000 km, (6) 30.000 to 50.000, (7) >50.000 km. [c]Intersection with need to give right of way, the traffic lights at this intersection turn yellow and subsequently red. TRIP, Test-Ride Investigating Practical fitness to drive; OPER, operational subscale; TACT, tactical subscale; VIS, visual subscale; GLOB, global subscale; AD, Alzheimer's disease; ES, effect size indicated by Cohen's r.

Table 3
Spearman rank correlations between on-road TRIP subscales and predictor variables of 'off-road' methods in patients with Alzheimer's disease ($n = 49$–80)

	OPER	TACT	VIS	GLOB
Clinical interviews[a]	–0.408*	–0.350*	–0.412*	–0.487*
Neuropsychological assessment[b]	0.438*	0.506*	0.544*	0.644*
Driving simulator rides[c]	–0.390	–0.358	–0.504*	–0.638*
Complete approach[d]	–0.531*	–0.469*	–0.632*	–0.812*

*Significant at $p < 0.003$ (=0.05/16 correlations). TRIP, Test-Ride Investigating Practical fitness to drive; OPER, operational subscale; TACT, tactical subscale; VIS, visual subscale; GLOB, global subscale. Prediction equations (see [16]): [a]Prediction equation for fitness to drive (clinical interviews) = CDR Orientation × 0.675 + CDR Judgement & Problem Solving × 1.036 + Judgement driving safety × 1.250 + Recent driving experience × 0.576. [b]Prediction equation for fitness to drive (neuropsychological assessment) = MMSE × 0.129 + RT S2 RT × –0.003 + Correct trials of Hazard Perception × 0.206 + Response time of traffic theory × –0.310. [c]Prediction equation for fitness to drive (driving simulator rides) = Minimum speed intersection 2 × 0.021 + Number of collisions × 0.738 + Deceleration rear car × –0.367 + Time headway × 0.732. [d]Prediction equation for fitness to drive (complete approach) = Clinical interviews × 0.328 + Neuropsychological assessment × –0.620 + Driving simulator rides × 0.483.

patients with AD, 9 of 13 patients with VaD, 6 of 9 patients with mixed dementia, 7 of 14 patients with FTD, 8 of 23 patients with DLB/PD, and 5 of 45 healthy older drivers. Characteristics of these groups are reported in Table 4.

Table 5 presents the frequencies of participants failing the on-road driving assessment with one or more insufficient ratings per TRIP category. All drivers with neurodegenerative disorders who failed the on-road driving assessment had at least one insufficient rating on a TRIP item related to turning left. Insufficient ratings were also common in TRIP categories Position on the road, Speed, Observation and Merging with a fast moving stream of traffic (e.g., a motorway), and general impressions. The frequencies of insufficient ratings per TRIP category differ somewhat between diagnostic groups (Table 5). For a further exploration regarding possible differences in driving errors between patients with different neurodegenerative disorders, results at TRIP item level are presented and discussed in the Supplementary Material.

Table 4
Characteristics of participants who failed the on-road driving assessment per diagnostic group

Characteristics	Group*					
	AD ($n=46$)	VaD ($n=9$)	AD+VaD ($n=6$)	FTD ($n=7$)	DLB/PD ($n=8$)	Healthy ($n=5$)
Age [mean (SD)] (y)	73.8 (9.0)	76.8 (3.9)	76.7 (5.1)	69.0 (13.1)	71.5 (8.9)	76.2 (5.8)
Male sex [*n* (%)]	26 (56.5)	8 (88.9)	4 (66.7)	4 (57.1)	6 (75.0)	1 (20.0)
Education [mean of 7 stages (SD)]	4.8 (1.3)	5.0 (1.3)	4.0 (1.7)	5.3 (0.8)	5.4 (1.8)	5.6 (0.9)
CDR-score [*n* (%)]						
0	1 (2.2)	0 (0.0)	0 (0.0)	1 (14.3)	2 (25.0)	4 (80.0)
0.5	35 (76.1)	8 (88.9)	3 (50.0)	4 (57.1)	5 (62.5)	1 (20.0)
1	10 (21.7)	1 (11.1)	3 (50.0)	2 (28.6)	1 (12.5)	0 (0.0)
MMSE-score [mean (SD)]	22.5 (4.1)	22.8 (3.0)	21.0 (2.8)	25.3 (3.5)	25.6 (3.1)	29.0 (1.0)

*Participants who failed the on-road driving assessment were selected in each diagnostic group, these were 46/80 (58%) patients with AD, 9/13 (69%) patients with VaD, 6/9 (66%) patients with mixed dementia, 7/14 (50%) patients with FTD, 8/23 (35%) patients with DLB/PD, and 5/45 (11%) healthy older drivers. Education, Verhage scale for the Dutch educational level ranging from 1 (primary school not finished) to 7 (university level); CDR-score, Clinical Dementia Rating total score; MMSE-score, Mini-Mental State Examination sum score (range 0–30); AD, Alzheimer's disease; VaD, vascular dementia; FTD, frontotemporal dementia; DLB, dementia with Lewy bodies; PD, Parkinson's disease; Healthy, healthy older drivers.

Table 5
Frequencies of participants failing the on-road driving assessment with one or more insufficient ratings per TRIP category

TRIP category (number of items)	Group*					
	AD	VaD	AD+VaD	FTD	DLB/PD	Healthy
Position on the road (11)	30/46 (65%)	5/9 (56%)	4/6 (67%)	4/7 (57%)	7/8 (88%)	1/5 (20%)
Car following (3)	11/46 (24%)	1/9 (11%)	2/6 (33%)	1/7 (14%)	2/8 (25%)	0/5 (0%)
Speed (3)	26/46 (57%)	5/9 (56%)	5/6 (83%)	5/7 (71%)	3/8 (38%)	0/5 (0%)
Observation (Head and eye movements) (11)	31/46 (67%)	6/9 (67%)	6/6 (100%)	6/7 (86%)	7/8 (88%)	1/5 (20%)
Traffic signals (Lights and signs) (2)	20/45 (44%)	3/9 (33%)	2/6 (33%)	3/7 (43%)	1/8 (13%)	0/5 (0%)
Overtaking and passing by (2)	12/43 (28%)	3/9 (33%)	1/6 (17%)	4/7 (47%)	1/8 (13%)	1/5 (20%)
Anticipation (at a tactical level) (2)	14/45 (31%)	2/9 (22%)	3/6 (50%)	3/7 (43%)	2/8 (25%)	0/5 (0%)
Communication (2)	15/45 (33%)	4/9 (44%)	1/6 (17%)	4/7 (47%)	3/8 (38%)	0/5 (0%)
Turning left on a priority road or no traffic lights (11)	46/46 (100%)	9/9 (100%)	6/6 (100%)	7/7 (100%)	8/8 (100%)	1/5 (20%)
Merging with a fast moving stream of traffic (e.g., motorway) (5)	27/45 (60%)	4/8 (50%)	3/5 (60%)	4/6 (67%)	6/8 (75%)	1/5 (20%)
Mechanical operation (4)	5/38 (13%)	1/7 (14%)	1/5 (20%)	1/4 (25%)	1/5 (20%)	0/4 (0%)
General impressions (3)	36/46 (78%)	8/9 (89%)	5/6 (83%)	6/7 (86%)	4/8 (50%)	0/5 (0%)

*Participants who failed the on-road driving assessment were selected in each diagnostic group, these were 46/80 (58%) patients with AD, 9/13 (69%) patients with VaD, 6/9 (66%) patients with mixed dementia, 7/14 (50%) patients with FTD, 8/23 (35%) patients with DLB/PD, and 5/45 (11%) healthy older drivers. TRIP, Test-Ride Investigating Practical fitness to drive; AD, Alzheimer's disease; VaD, vascular dementia; FTD, frontotemporal dementia; DLB, dementia with Lewy bodies; PD, Parkinson's disease; Healthy, healthy older drivers.

DISCUSSION

The first objective of the current study was to compare the differences in on-road driving errors of patients with AD with healthy older drivers using four subscales of the TRIP. In correspondence with previous studies [4, 14, 15, 35, 36], patients with AD performed worse than healthy older drivers with regard to operational, tactical, and visual aspects as well as global outcomes of the on-road driving assessment. AD patients scored significantly lower on all subscales, with largest differences on subscales TACT, VIS, and GLOB. This may indicate that patients with AD are more impaired at the tactical level than at the operational level in comparison to healthy older drivers. Nonetheless, patients with AD passing the on-road assessment showed very similar scores compared to healthy older drivers. However, group differences must be interpreted with caution, as causal relationships are difficult to derive from quasi-experimental designs, as the groups may also differ in other, potentially important variables. In the present study, demographic characteristics including age, gender, and educational level did not differ significantly between patients with AD and healthy older drivers, and may presumably not represent influential confounding variables. Yet, differences in the frequency of driving errors could possibly also be attributed to differences in driving habits between groups, and not solely to diagnostic status.

The second objective was to examine if there are differences in driving errors (as per the TRIP

subscales) and outcomes of clinical interviews, neuropsychological assessments, and driving simulator rides ('off-road' measures) in patients with AD who failed versus patients with AD who passed the on-road assessment, and if the TRIP subscales and 'off-road' measures relate. Importantly, a comparison of patients with AD who failed the on-road driving assessment with those who passed revealed large effect sizes for all four TRIP subscales, suggesting that driving errors at all levels of driving could lead to failing the on-road driving assessment. A clinical assessment of practical fitness to drive of patients with AD should therefore be designed broadly in the sense that it considers all critical aspects of driving in which the individual may show adverse behavior. In addition, lower scores on the four on-road TRIP subscales (OPER, TACT, VIS, and GLOB) were significantly associated with lower 'off-road' scores on clinical interviews, neuropsychological assessment, and with respect to VIS and GLOB also to driving simulator rides. Of note, one may consider each of the correlations as meaningful, as indicated by medium to large effect size, including the ones not reaching significance on a Bonferroni adjusted significance level. These observed associations indicate clinical relevance as it underlines the utility of 'off-road' clinical instruments not only for the dichotomous decision on practical fitness to drive [16], but also for the prediction of different qualitative aspects of real world driving. More specifically, various approaches in the clinical assessment appear to serve this purpose, including clinical interviews, a neuropsychological assessment using cognitive tests, as well as driving simulator rides.

The third objective was to explore whether driving errors (as per TRIP categories) vary among patients with different neurodegenerative disorders (different types of dementia and no dementia [healthy older drivers]). In neurodegenerative disorders in general, difficulties with turning left, positioning on the road, speed, observation and merging with a fast moving stream of traffic (e.g., a motorway) were common, and more profound than for healthy older drivers. Despite the variety of tactical driving errors found in all diagnostic groups, several other tactical and operational driving errors may occur particularly frequently in specific diagnostic groups (for results and discussion, see the Supplementary Material).

Tactical driving errors occurred in all patient groups, which concurs with previous studies [14, 15], and strategic driving errors were found at a lower frequency than operational and tactical driving errors. An explanation would be that strategic driving errors did not occur often in the on-road driving assessments with patients with neurodegenerative disorders. However, getting lost has been reported in earlier studies as a common problem of driving of patients with AD [35, 37], but occurs less likely in driving assessments in which the driving expert is navigating large parts of the ride. As an alternative explanation, one could speculate that the TRIP items provide little information about the strategic level of driving. In order to get a better grasp of this issue within the present study, qualitative reports that the CBR experts delivered with the TRIP form were explored for indications of strategic driving errors (data not shown). Strategic driving errors concerning difficulty with decision-making, orientation, and remembering tasks were observed in patients with AD, VaD, AD + VaD, and DLB, which negatively influenced driving performance. Moreover, three patients with AD, one patient with FTD, and one patient with PD were easily distracted while driving. In conclusion, even though on small samples only, the analysis of the qualitative reports revealed strategic driving errors in all diagnostic groups.

Strengths and limitations

This is the first study in which patients with various neurodegenerative disorders with cognitive decline were included and assessed using a uniform on-road driving assessment. The on-road driving assessments were similar to those used in official licensing relicensing procedures in the Netherlands, in which the representativeness of individual driving behavior is ensured by allowing all participants to drive in their own car (except for novice drivers). For a thorough and standardized monitoring and scoring of driving behavior, the TRIP was used. The TRIP is an accepted tool to evaluate on-road driving performance [11, 30–32, 38, 39]. Nevertheless, it is remarkable that several healthy older drivers did not pass the on-road assessment and that the fail rate is relatively high in the group of patients with mild dementia, which could indicate that the on-road assessment might not only assess fitness to drive, but sometimes also unsafe driving habits or a lack of recent driving experience (e.g., no recent experience with merging on the motorway).

The small sample sizes of diagnostic groups with non-AD neurodegenerative disorders limit the generalizability of the results. Demographics of the diagnostic groups showed some variation (e.g., patients with VaD were older than patients with FTD;

Table 4) which complicates data interpretation. The driving errors that were common in specific neurodegenerative disorders, therefore, require further study in larger samples, preferably in combination with neuropsychological assessments that may add explanatory value to the interpretation of the nature of observed driving errors.

Conclusions and implications

Patients with AD showed a poorer on-road driving performance than healthy older drivers with regard to operational, tactical, and visual aspects of driving, and were more likely to fail an on-road driving assessment. The patients with AD who failed the on-road driving assessment performed significantly poorer on operational, tactical, and visual aspects of driving compared to patients with AD who passed the on-road driving assessment. Having AD does not suffice as a reason to stop driving, however, the findings above imply that drivers with AD need to be assessed on fitness to drive. Findings in clinical interviews, neuropsychological assessments, and driving simulator rides were significantly associated with various aspects of on-road driving. Therefore, 'off-road' methods have the potential to be of value in addition to the 'gold standard' on-road driving assessment [16].

A lack of traffic perception and insight was common in patients with neurodegenerative disorders who failed an on-road driving assessment. Tactical driving errors were found frequently in all diagnostic groups, including lane positioning errors, slow driving, no observation of the blind spot, and insufficient looking in mirrors and sideways when approaching intersections or when merging on the motorway. Knowledge about particular driving errors that are typical for patients with specific neurodegenerative disorders could be used to streamline on-road assessments, and also to improve diagnostic sensitivity of 'off-road' methods for the prediction of fitness to drive in patients with neurodegenerative disorders with cognitive decline [40]. In the current study, only 16.8% of the patients with any neurodegenerative disorder were driving a car with automatic transmission, corresponding with low rates of using cars with automatic transmission in the Netherlands. Nonetheless, automatic transmission is advisable for older drivers [41], in particular for patients with VaD or DLB/PD because of motor impairments, but also for patients with AD as some of them forgot to shift gears in the current study (Supplementary Material; Supplementary Table 1). In addition, in qualitative reports, strategic driving errors were found in all diagnostic groups, in particular when patients with neurodegenerative disorders were asked to navigate themselves in complex traffic situations, and when they were driving for a longer period of time. The latter findings indicate that the on-road driving assessment should last at least around 40–45 minutes and must include complex traffic situations and navigation by the patient to assess fitness to drive [6, 42, 43]. The large variety of driving errors committed by patients with neurodegenerative disorders suggests that many different driving behaviors, at all levels of driving, must be judged during on-road driving assessments before grounded pass/fail decisions can be made.

DISCLOSURE STATEMENT

Authors' disclosures available online (https://www.j-alz.com/manuscript-disclosures/18-1095r3).

SUPPLEMENTARY MATERIAL

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