Reliability and validity of on-road driving tests in vulnerable adults: a systematic review

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The on-road driving test is considered a 'gold standard' evaluation; however, its validity and reliability have not been sufficiently reviewed. This systematic review aimed to map out and synthesize literature regarding on-road driving tests using the Consensus-based Standards for the Selection of Health Measurement Instruments checklist. Cochrane Library, PubMed, CINAHL, and Web of Science databases were searched from initiation through February 2018. All articles addressing reliability or validity of on-road driving tests involving adult rehabilitation patients were included. The search output identified 513 studies and 36 articles, which were included in the review. The Washington University Road Test/Rhode Island Road Test, performance analysis of driving ability, test ride for investigating practical fitness-to-drive, and K-score demonstrated high reliability and validity in regard to the Consensus-based Standards for the Selection of Health Measurement Instruments checklist. The Washington University Road Test/Rhode Island Road Test and test ride for investigating practical fitness-to-drive were analyzed based on Classical Test Theory techniques, and performance analysis of driving ability and K-score were analyzed based on Item Response Theory techniques. The frequency of studies were Washington University Road Test/Rhode Island Road Test (n=9), Test Ride for Investigating Practical fitness-to-drive (n=8), performance analysis of driving ability (n=4), and K-score (n=1). From the viewpoint of accuracy and generalization, the Washington University Road Test/Rhode Island Road Test, test ride for investigating practical fitness-to-drive, and performance analysis of driving ability were identified as highly qualified concerning on-road driving tests. However, the ability to assess real-world driving depends on various environmental conditions. *International Journal of Rehabilitation Research* 42: 289–299 Copyright © 2019 The Author(s). Published by Wolters Kluwer Health, Inc.

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Introduction

With technological advances, safe driving has become more possible, and the number of traffic accidents is decreasing. Simultaneously, however, the driver population has increased and changed with becoming an inclusive society. The number of elderly drivers has almost doubled since the 1990s, and people with disabilities, such as those post-stroke, hope to return to driving (Yu *et al.*, 2016). The evidence shows that driving cessation in these people contributes to a variety of health problems, particularly depression or functional limitation (Chihuri *et al.*, 2016; Shimada *et al.*, 2016). However, Azami-Aghdash *et al.* (2018) reported that the traffic-related mortality rate in elderly people is almost twice that of the non-elderly [odd = 2.57 (1.2–5.4 95% CI)]. Actually, 50% of countries recorded a rise in the number of road deaths among elderly people, and in 30% of countries, the elderly have the highest mortality rate in traffic of all age groups (Forum, 2018). Elderly people have become more mobile and more exposed to traffic risks. Therefore, it is of great importance to accurately evaluate the driving ability of these individuals.

There are two types of evaluations for testing driving skills: off-road and on-road tests. Off-road tests assess driving skills related to cognitive ability by paper-based or computer-based testing. Bliokas *et al.* (2011) demonstrated that some neuropsychological measures could predict the pass/fail classification of the on-road test with 73% sensitivity and 76% specificity. The Stroke Drivers Screening Test was developed to predict stroke patient's driving ability. It was determined to be useful for not only assessing cognitive ability but also for predicting on-road driving ability (Nouri and Lincoln, 1992; Edwards *et al.*, 2005). Neuropsychological measures are an important component of a multidisciplinary approach for evaluation of driving capacity (Wolfe and Lehockey, 2016).

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In the on-road study, Brooke *et al.* (1992) clarified that for closed head injury patients, off-road tests did not correspond to a pass/fail rating of an on-road test. Fox *et al.* (1998) showed that on-road driving assessments examined proficiency in operating a motor vehicle, but not the ability to drive in traffic, and, thus, were not an accurate prediction of safe driving. Marshall *et al.* (2007) reported on-road testing as the 'gold standard' of driving ability in his review because off-road tests are not always appropriate for understanding one's actual driving capabilities. These results show that it is important to evaluate vulnerable adults' driving ability using multiple perspectives (on-road and off-road). Several off-road tests have demonstrated their reliability and validity, and it is useful for predict patient's driving ability by systematic review and meta-analysis (Reger *et al.*, 2004; Devos *et al.*, 2011; Hird *et al.*, 2016). However, the reliability and validity of on-road tests have not been adequately researched. To the best of our knowledge, no prior systematic review has solely verified on-road test reliability and validity. Although some studies have assessed on-road test reliability and validity, it is still unclear which on-road tests are most reliable and valid. These problems of on-road tests cause ambiguity in testing the real driving ability. Therefore, the aim of the current systematic review was follows:

1. to map out and synthesize literature on on-road driving
2. to clarify which on-road tests are most reliable and valid

Method

Research design

This systematic review focuses on the reliability and validity of on-road tests in consideration of various health conditions and aging in relation to driving. A systematic review was conducted, focusing on reliability and validity of on-road tests in reference to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement (Liberati *et al.*, 2009; Moher *et al.*, 2009). The Consensus-based Standards for the Selection of Health Measurement Instruments (COSMIN) guidelines and recommendations for evaluating methodological quality were followed.

Inclusion and exclusion criteria

Peer-reviewed in current study, only academic papers describing on-road driving tests for individuals with various health conditions were assessed. Systematic literature reviews, study protocols, conference proceedings, commentary papers, studies with simulated on-road tests (excluded for the reliability and validity of on-road test), on-road tests developed by the authors for this study, the criterion based on a public institution (e.g. government), and studies without reliability or validity assessments were excluded (e.g. simply comparing pass or fail groups by using the result of on-road tests). Criterion validity usually means comparing on-road with on-road tests. However, many studies compared on-road with off-road tests. We included the off-road test studies that assessed criterion validity for comparison with on-road tests (e.g. combining several neuropsychological assessments, Useful Field of View Test), even if the aim of the study was not to investigate on-road tests. Therefore, we changed the check item of criterion validity to 'on-road to on-road' and 'on-road to off-road.' Only studies published in English were included.

Literature search

We searched the Cochrane Library, PubMed, CINAHL, and Web of Science databases using keywords (Table 1) for searching the relevant articles on 21 February 2018. Search words included driving, road, route, way, motor vehicles, automobile, measurement, outcome, test, and assessment. Disease terms included stroke, traumatic brain injury, mild cognitive impairment, dementia, Alzheimer's, cognitive dysfunction, physical dysfunction, spinal cord injury, and elderly (Table 1). We did not adopt the term 'reliability' or 'validity' because we tried to find as many on-road tests as possible. If eligible articles had studies on reliability or validity in their references, those references were checked in a manual search. In this case, only published research articles were adopted (e.g. excluding PhD theses).

Eligibility criteria

The titles and abstracts were first reviewed by two authors independently, following the removal of duplicates. If they were unsure whether the article met the criteria, the two authors independently screened the full-text papers and confirmed the articles that met include/exclude criteria. Differences of opinion were resolved through discussion with other reviewers. A structured abstract was then created considering the article objective, subject, method, and results.

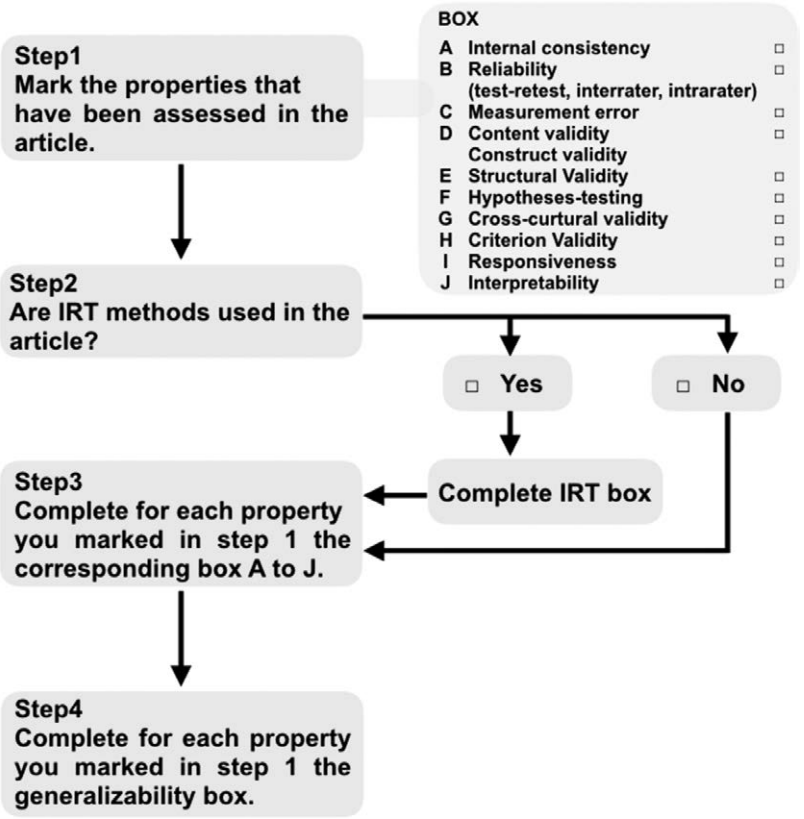
Methodological quality evaluation

The COSMIN is one valid methodology for determining study quality (Prinsen *et al.*, 2018). The COSMIN consists of 4 steps (Fig. 1). At first, measurement properties (Box A to I) are evaluated in each article (Step 1). Although the responsiveness and interpretability are neither reliability nor validity items, the COSMIN checklist adopted these items for standardization. There are three

Table 1 Search strategy

Search strategy
Driving AND ('road' or 'route' or 'way') AND ('motor vehicles' or 'automobile') AND ('stroke' or 'traumatic brain injury' or 'mild cognitive impairment' or 'dementia' or 'Alzheimer's' or 'cognitive dysfunction' or 'physical dysfunction' or 'spinal cord injury' or 'elderly') AND ('measurement' or 'outcome' or 'test' or 'assessment')

Fig. 1



COSMIN checklist process. COSMIN is standardized checklist methodology of the reliability and validity. It consists of four steps. COSMIN, Consensus-based Standards for the Selection of Health Measurement Instruments; IRT, item response theory.

Table 2 Step 2. Determining if the statistical method used in the article are based on classical test theory or item response theory

	Excellent	Good	Fair	Poor
1. Was the IRT model used adequately described? e.g. OPLM, Partial Credit Model, Graded Response Model	IRT model adequately described	IRT model not adequately described		
2. Was the computer software package used adequately described? e.g. RUMM2020, WINSTEPS, OPLM, MULTILOG, PARSCALE, BILOG, NLMIXED	Software package adequately described	Software package not adequately described		
3. Was the method of estimation used adequately described? e.g. conditional maximum likelihood, marginal maximum likelihood	Method of estimation adequately described	Method of estimation not adequately described		
4. Were the assumptions for estimating parameters of the IRT model checked? e.g. unidimensionality, local independence, and item fit (e.g. differential item functioning)	Assumptions of the IRT model checked	Assumptions of the IRT model partly checked	Assumptions of the IRT model not checked or unknown	

IRT, item response theory; OPLM, one-parameter logistic model.

types of reliability (test-retest, interrater, and intrarater) in Box B. If the statistical method used in the article was based on item response theory (IRT), it was evaluated by the IRT box (4 items) in Step 2 (Table 2). We performed the systematic review protocol in reference to a previous study methodology using a COSMIN 4-point modular checklist (Mokkink *et al.*, 2010; Wales *et al.*, 2016). Each checklist item in COSMIN is scored on a four-point ordinal rating scale to evaluate the methodological quality of each measurement item's property: excellent, good, fair, or poor. A score for a given box was obtained by using the lowest score for any item ('worst score counts method'). If one item is scored as 'poor,' the overall score for the study on that box will be 'poor' (Mokkink *et al.*, 2010). More than good was regarded as high quality. This scoring method is used in Steps 2 and 3. In Step 3, the evaluator completes the corresponding boxes marked in Step 1. Each corresponding box should be completed for each measurement property that was detected in Step 1. The researcher determines if the measurement properties were assessed according to the standards for methodological quality in Step 3. We showed the measurement property Box B as an example of method in Table 3. Finally, the generalizability box must be checked. Since there is

Table 3 Step 3. Determining if a study meets the standards for good methodological quality (Box A. Internal consistency)

1. Does the scale consist of effect indicators, i.e. is it based on a reflective model?	Item 1 is used to determine whether internal consistency is relevant for the instrument under study. It is not used to rate the quality of the study.			
Design requirements				
2. Was the percentage of missing items given?	Percentage of missing items described	Percentage of missing items NOT described		
3. Was there a description of how missing items were handled?	Described how missing items were handled	Not described but it can be deduced how missing items were handled	Not clear how missing items were handled	
4. Was the sample size included in the internal consistency analysis adequate?	Adequate sample size (≥ 100)	Good sample size (50–99)	Moderate sample size (30–49)	Small sample size (< 30)
5. Was the unidimensionality of the scale checked? i.e. was factor analysis or IRT model applied?	Factor analysis performed in the study population	Authors refer to another study in which factor analysis was performed in a similar study population	Authors refer to another study in which factor analysis was performed, but not in a similar study population	Factor analysis NOT performed and no reference to another study
6. Was the sample size included in the unidimensionality analysis adequate?	7 number of items and ≥ 100	5 number of items and ≥ 100 OR 6–7 number of items but < 100	5 number of items but < 100	< 5 number of items
7. Was an internal consistency statistic calculated for each (unidimensional) (sub)scale separately?	Internal consistency statistic calculated for each subscale separately			Internal consistency statistic NOT calculated for each subscale separately
8. Were there any important flaws in the design or methods of the study?	No other important methodological flaws in the design or execution of the study		Other minor methodological flaws in the design or execution of the study	Other important methodological flaws in the design or execution of the study
Statistical methods				
9. For CTT, continuous scores: Was Cronbach's alpha calculated?	Cronbach's alpha calculated		Only item-total correlations calculated	No Cronbach's alpha and no item-total correlations calculated
10. For CTT, dichotomous scores: Was Cronbach's alpha or KR-20 calculated?	Cronbach's alpha or KR-20 calculated		Only item-total correlations calculated	No Cronbach's alpha or KR-20 and no item-total correlations calculated
11. For IRT: Was a goodness of fit statistic at a global level calculated?	Goodness of fit statistic at a global level calculated			Goodness of fit statistic at a global level NOT calculated

CTT, classical test theory; IRT, item response theory.

no scoring system in this box, it was recommended by the previous study to use this box for extracting data on the characteristics of the study (Terwee *et al.*, 2012). We adopted this methodology.

Although COSMIN was developed for Patient-Reported Outcomes, a COSMIN checklist can be used for functional assessments, as has been done by occupational therapists for determining severe criteria within a systematic review (Wales *et al.*, 2016). As the present study assessed reliability and validity from a standard point of view, even if the assessment does not focus on patient-reported outcomes, COSMIN criteria are useful for on-road test investigations.

The authors also independently assessed specific properties of each on-road assessment. When results of this assessment were difficult to decipher, additional authors were included to arrive at a consensus.

Results

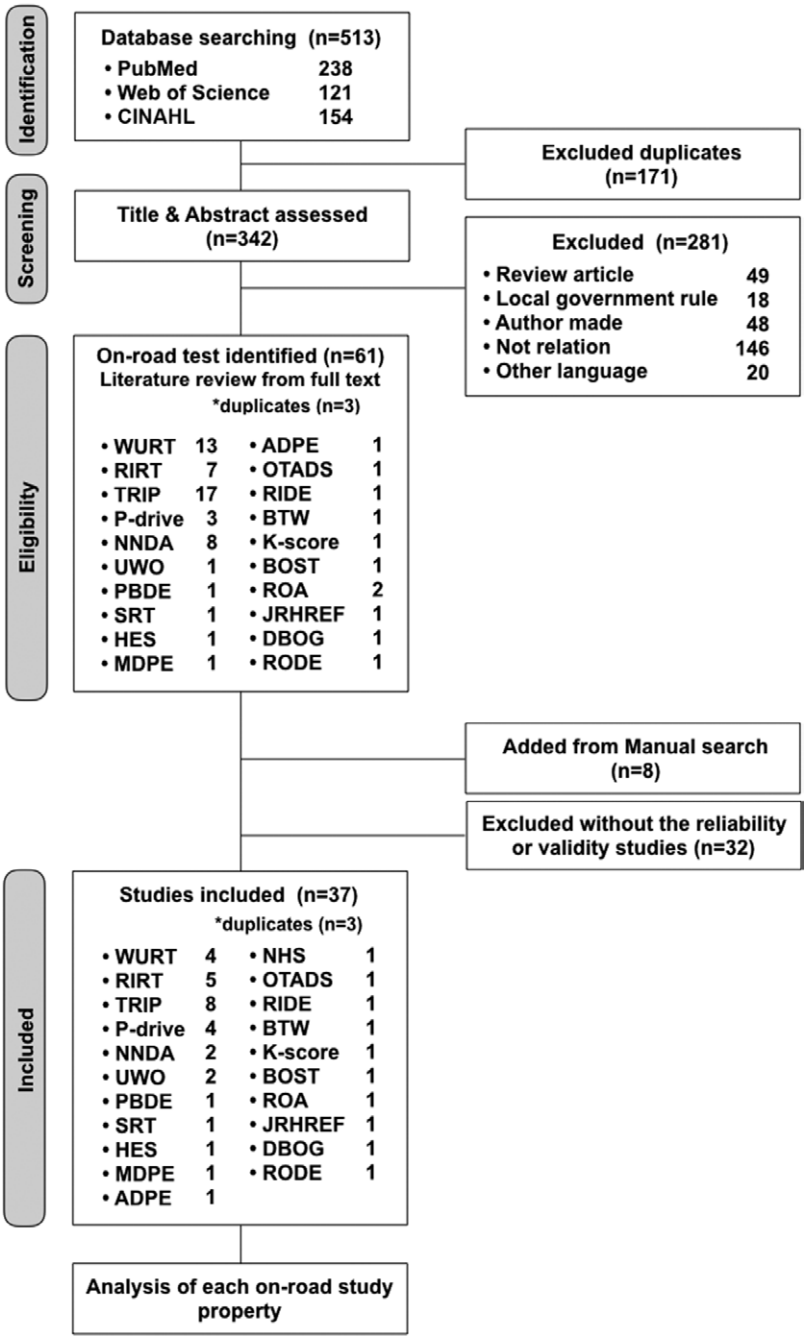
Study selection

A total of 513 papers were initially screened. A flow diagram depicting study selection is shown in Fig. 2. Initially, we selected 342 individual studies. We filtered this number down to 64 studies, excluding 282 studies that failed to meet criteria based on the titles and abstracts, as well as 171 duplicates. We then read full texts of these remaining papers. An additional 9 studies were included after a manual search. Next, we filtered down to studies that included reliability or validity assessments. This left us with 37 total studies (three duplicates).

Measurement properties for identified on-road assessments (Step 1)

Twenty-nine types of on-road tests were identified (Table 4). Some had various versions. For instance, the Test Ride for Investigating Practical fitness-to-drive (TRIP) Belgian Version 3 (named for purposes of the present review) was the most frequently assessed (Table 4). The Washington University Road Test (WURT) and the TRIP had the most versions (different number of items). There were 8 TRIP studies and 4 Rhode Island Road Test (RIRT) studies. However, the RIRT included the same items as the WURT to be applicable to Rhode Island (Brown *et al.*, 2005; Ott *et al.*, 2008). Therefore, we regarded these two on-road tests as the same one. When combining the WURT and RIRT, 9 studies were included.

Fig. 2



Systematic review process. ADPE, Area Driving Performance Evaluation; BOST, Basic Operator Skills Test; BTW, Behind-the-Wheel Driving Performance Assessment; DBOG, Driving Behaviors Observation Grid; HES, Hazardous Error Score; JRHREF, Jewish Rehabilitation Hospital Road Evaluation Form; MDPE, Modified Driving Performance Evaluation; NNDA, Nottingham Neurological Driving Assessment; OTADS, Occupational Therapy Assessment of Open-Road Driving Performance Score; P-drive, Performance Analysis of Driving Ability; PBDE, Performance-Based Driving Evaluation; RIDE, Rhode Island Driving Evaluation; RIRT, Rhode Island Road Test; ROA, Ryd On-road Assessment; RODE, Record of Driving Errors; SRT, Sepulveda Road Test; TRIP, test ride for investigating practical fitness-to-drive; UWO, University of Western Ontario's on-road assessment; WURT, Washington University Road Test.

Item response theory analysis of each on-road test (Step 2)

Performance Analysis of Driving Ability (P-drive) and K-score were analyzed by IRT method. These two on-road tests indicated good to excellent quality in IRT items (Table 5) (Patomella *et al.*, 2004; Kay *et al.*, 2008). Most studies used classical test theory.

Table 4 Identified on-road test

On-road test	Author	Year	Object	n	Items	Total score	Age (range)	Female %	Setting	Country	
WURT	Pilot	Hunt et al	1993	Alzheimer's disease	38[a]	38	[b]	73.4 ± 6.2	55.3%	Designed route urban route including highway, daytime	United States
	Original	Hunt et al	1997	Alzheimer's disease	63–121[a]	54	108	[b]	[b]	9.6 km urban course	United States
	Modified	Carr et al	2011	Dementia	41	[b]	[b]	74.2 ± 9.0 (52–90)	37.0%	12 miles closed and open course	United States
	Modified	Barco et al	2014	Stroke	33	[b]	[b]	59.3 ± 13.0 (31–88)	46.0%	13 miles route including parking lot	United States
RIRT	Original	Brown et al	2005	Alzheimer's disease	20	54	108	73.2 ± 8.3	41.2%	Daylight hours under good condition	United States
	Original	Brown et al	2005	Very mild dementia	55[a]	54	108	72.0–76.9	45.5%	Daylight hours under good condition	United States
	Original	Ott et al	2008	Alzheimer's disease	20–121	54	108	[b](73.6–75.8)	45.1%	Daylight hours under good condition	United States
	Version 2	Ott et al	2012	Cognitive impairment	80[a]	28	960	73.1 ± 7.3	46.2%	6.5 miles of urban terrain without highway	United States
	Version 2	Davis et al	2012	Cognitive impairment	103[a]	28	960	73.9 ± 7.2 (60–90)	49.2%	6.5 miles of urban terrain without highway	United States
TRIP	Original	Tant et al	2002	Homonymous hemianopia	28	55	220	53.0 (24–76)	21.4%	[b]	Netherland
	Belgian version 1	De Raedt and Ponjaert-Kristoffersen, et al	2001	Old drivers	84	11	209	78.6 ± 6.8 (65–96)	28.6%	Standardized 35 km route including highway	Belgium
	Belgian version 1	Stapleton et al	2012	Stroke	11–32	11	209	63.5 ± 13.4 (29–83)	19.6%	Participant's own home town area	Ireland
	Belgian version 2	Akinwuntan et al	2003	Stroke	27	55	220	60.0 ± 2.6	18.5%	20 km including closed courses and highway	Belgium
	Belgian version 3	Akinwuntan et al	2005	Stroke	38	49	196	53.9 ± 12.8 (24–73)	18.4%	17 km including premise and highway	Belgium
	Belgian version 3	Akinwuntan et al	2006	Stroke	68	49	196	53.0 ± 13.0	16.2%	Standardized 20 km road	Belgium
	Belgian version 3	Devos et al	2014	Huntington's disease	30	49	196	50.2 ± 12.4	26.7%	Standardized 20 km road	Belgium
	Belgian version 3	Devos et al	2017	Multiple sclerosis	102	49	196	47.9 ± 8.7 (25–65)	86.0%	Country and urban route	United States
P-Drive	Original	Patomella et al	2004	Brain damage	31	21	84	57.0 ± 12.2 (22–77)	29.0%	Simulator fixed route	Sweden
	Version 2	Patomella et al	2010	Stroke, MCI, dementia	205	27	104	69.0 ± 11.0 (33–86)	16.0%	set route	Sweden
	Version 2	Selandera et al	2011	Old drivers	85	27	104	72.0 ± 5.3 (65–85)	47.0%	39.7 km fixed route	Sweden
	Version 3	Vaucher et al	2015	Old drivers	24	26	104	77 (75–85)	4.0%	21 km including highway	Switzerland
NNDA		Radford et al	2004	Parkinson's disease	49	25	[b]	64.4 ± 9.1 (44–85)	20.0%	Standard route	United Kingdom
		Lincoln et al	2012	Dementia	6	25	[b]	(73–85)	16.7%	Standard route	United Kingdom
UWO		Classen et al	2016	Multiple sclerosis	34[a]	41	[b]	48.3 ± 9.8	60.0%	Including parking lot, highway	Canada
		Classen et al	2017	Multiple sclerosis	34[a]	41	[b]	[b]	58.8%	23 miles fixed route including parking lot	Canada
PBDE		Odenheimer et al	1994	Dementia	26[a]–30[a]	75	[b]	72.2 (61–89)	13.0%	10 miles, week day	United States
SRT		Fitten et al	1995	Alzheimer's disease	8[a]–43[a]	[b]	41	[b]	[b]	2.7 miles including parking lot, Saturday morning	United States
HES		Dobbs et al	1998	Cognitive impairment	253[a]	37	[b]	72.7 ± 9.1	27.7%	Closed and open-road course	Canada
MDPE		Janke et al	1998	Old drivers	106	6	[b]	75.7 (60–91)	36.0%	Fixed route	United States
ADPE		Janke et al	1998	Old drivers	106	6	[b]	75.7 (60–91)	36.0%	Unstructural route	United States
NHS		Richardson et al	2003	Old drivers	26–357	36	72	[b]	[b]	20 miles including parking lot, highway	United States
OTADP		Mallon et al	2004	Old drivers	137[a]	106	100 (%)	70.6 ± 6.2	[b]	15 km predetermined course	United States

Table 4 (*continued*)

On-road test	Author	Year	Object	n	Items	Total score	Age (range)	Female %	Setting	Country	
RIDE		Whelihan et al	2005	Questionable dementia	23–46[a]	31	570	78.2 ± 9.3	47.8%	4 miles city street	United States
BTW		Justiss et al	2006	Old drivers	10–33	91	273	[b]	44.0%	Approximately 15 miles, late afternoon	United States
K-score		Kay et al	2008	Senior drivers	100	19	99	69 ± 6.3 (60–86)	36.3%	9 km standard route including parking	Australia
BOST		Zook et al	2009	Old drivers	37	13	97	74.0 ± 6.5 (62–92)	51.3%	15 miles fixed route including freeway	United States
ROA		Selandera et al	2011	Old drivers	85	34	68	72.0 ± 5.3 (65–85)	47.0%	39.7 km fixed route	Sweden
JRHREF		Stapleton et al	2012	Stroke	30	46	170	65.3 ± 13.4 (29–83)	24.3%	Participant's own home town area	Ireland
DBOG		Ferreira et al	2012	Old drivers	50	50	100	73.1 ± 7.0 (65-88)	[b]	10 km predetermined route during off-peak period	Portugal
RODE		Barco et al	2015	Dementia	24	[b]	No limit	69.1 ± 9.3	29.2%	13 miles including park	United States

ADPE, Area Driving Performance Evaluation; BOST, Basic Operator Skills Test; BTW, Behind-the-Wheel Driving Performance Assessment; DBOG, Driving Behaviors Observation Grid; HES, Hazardous Error Score; JRHREF, Jewish Rehabilitation Hospital Road Evaluation Form; MDPE, Modified Driving Performance Evaluation; NHS, New Haven Score; NNDA, Nottingham Neurological Driving Assessment; OTADP, Occupational Therapy Assessment of Open-Road Driving Performance; PBDE, Performance-Based Driving Evaluation; P-drive, Performance Analysis of Driving Ability; RIDE, Rhode Island Driving Evaluation; RIRT, Rhode Island Road Test; ROA, Ryd On-road Assessment; RODE, Record of Driving Errors; SRT, Sepulveda Road Test; TRIP, Test Ride for Investigation Practical fitness-to-drive; UWO, University of Western Ontario's on-road assessment; WURT, Washington University Road Test.

[a]Including control.

[b]None identified.

Confirming for each property of box (Step 3)

Reliability

In the number of studies, interrater reliability was tested most frequently (13 on-road tests), followed by internal consistency (seven on-road tests), and test-retest reliability (three on-road tests). There were no studies regarding intrarater reliability and measurement error. In total, WURT/RIRT and Behind-the-Wheel Driving Performance Assessment had the most COSMIN checklist reliability items (3 items).

In the quality of item, five on-road tests (Ott *et al.*, 2012), TRIP (De Raedt and Ponjaert-Kristoffersen, 2001), P-drive (Patomella *et al.*, 2010), Behind-the-Wheel Driving Performance Assessment (Justiss *et al.*, 2006), and K-score (Kay *et al.*, 2008) indicated high quality of internal consistency items (good or excellent). Only WURT indicated high quality in the interrater and test-retest items (Table 5).

WURT/RIRT had the highest quality items (two good and one excellent) in COSMIN reliability.

Validity

In a number of studies, criterion validity was examined most frequently. There were 9 studies comparing on-road tests to on-roads test in existence (Selander *et al.*, 2011; Vaucher *et al.*, 2015) and there were 14 studies comparing on-road tests to off-road tests (Hunt *et al.*, 1993). Structural validity was studied in P-drive (two studies) and K-score (one study) using IRT. Hypotheses testing was studied in TRIP (De Raedt and Ponjaert-Kristoffersen, 2001) and Sepulveda Road Test (Fitten *et al.*, 1995) (each one study). Content validity was examined only in one study (University of Western Ontario's on-road assessment) (Classen *et al.*, 2017). There were no studies that verified cross-cultural validity, responsiveness, and interpretability.

In the quality of items, WURT/RIRT (Ott *et al.*, 2008; Hunt *et al.*, 1997), Hazardous Error Score (Dobbs *et al.*, 1998), Occupational Therapy Assessment of Open-Road Driving Performance (Mallon and Wood, 2004), and Ryd On-road Assessment had high quality (good) in criterion validity items. In the structural validity items, P-drive and K-score showed high quality. TRIP (De Raedt and Ponjaert-Kristoffersen, 2001) had good quality in the hypotheses testing items.

P-drive had the highest quality items (one good and one excellent) in COSMIN validity.

Generalizability (Step 4)

Some on-road tests had more than two studies: WURT/RIRT (9), TRIP (8), P-drive (4), Nottingham Neurological Driving Assessment (2), University of Western Ontario's on-road assessment (2); others had only one. Although the subjects' age in some studies was unclear because of extracting a part of the article, the average age of the

Table 5 Synthesis of evidence for on-road tests

			Reliability					Validity							
												Criterion validity			
On-road test	Number of articles	IRT	Internal consistency	Intrarater reliability	Interrater reliability	Retest reliability	Measurement error	Hypotheses testing	Content validity	Structural validity	Cross-cultural validity	On-road	Off-road	Responsiveness	Interpretability
WURT															
Pilot	1				+								+		
Original	1				++	++						++			
Modified	2				+, +										
RIRT															
Original	3				±, ±								±		
Version 2	2		++		±							++	±		
TRIP															
Original	1												±		
Belgian Version 1	2		++		±, ±			++							
Belgian Version 2	1				±										
Belgian Version 3	4				+							+	+, ++, ++		
P-Drive															
Original	1	+++	±							±					
Version 2	2	+++	+++		+					+++		++			
Version 3	1	++			±							±			
NNDA	2				±								++		
UWO	2				+				±						
PBDE	1		±		±							±			
SRT	1				±	±		+							
HES	1											++			
MDPE	1														
ADPE	1														
NHS	1		+		+								+		
OTADP	1											++			
RIDE	1												±		
BTW	1		++		+	±						±			
K-score	1	+++	++							++					
BOST	1												+		
ROA	1												++		
JRHREF	1												+		
DBOG	1				±								±		
RODE	1				±										

Criterion validity regarding on-road means comparing on-road test with on-road test and off-road means comparing on-road tests with off-road tests. ADPE, Area Driving Performance Evaluation; BOST, Basic Operator Skills Test; BTW, Behind-the-Wheel Driving Performance Assessment; DBOG, Driving Behaviors Observation Grid; HES, Hazardous Error Score; IRT, item response theory; JRHREF, Jewish Rehabilitation Hospital Road Evaluation Form; MDPE, Modified Driving Performance Evaluation; NHS, New Haven Score; NNDA, Nottingham Neurological Driving Assessment; OTADP, Occupational Therapy Assessment of Open-Road Driving Performance; P-drive, Performance Analysis of Driving Ability; PBDE, Performance-Based Driving Evaluation; RIDE, Rhode Island Driving Evaluation; RIRT, Rhode Island Road Test; ROA, Ryd On-road Assessment; RODE, Record of Driving Errors; SRT, Sepulveda Road Test; TRIP, Test Ride for Investigation Practical fitness-to-drive; UWO, University of Western Ontario's on-road assessment; WURT, Washington University Road Test; +++, excellent; ++, good; +, fair; ±, poor.

subject in available studies was 65.2 (47.9–78.6; lowest to highest average age).

WURT/RIRT has mostly studies from dementia subjects (one of stroke patients), while TRIP has four studies of stroke patients and four studies with other patient groups (homonymous hemianopia, elderly drivers, Huntington's disease, and Multiple Sclerosis). Also, other tests included fewer female subjects (less than 40 %—Record of Driving Errors, Jewish Rehabilitation Hospital Road Evaluation Form, K-score, Area Driving Performance Evaluation, Modified Driving Performance Evaluation, Hazardous Error Score, PDBE, and Nottingham Neurological Driving Assessment). In the setting of on-road tests, standardized route was 60.0%, fixed distance was 55.0% and both of them was 40% (Table 4). Nottingham Neurological Driving Assessment, Hazardous Error Score, Occupational Therapy Assessment of Open-Road Driving Performance, Behind-the-Wheel Driving Performance Assessment, and Ryd On-road Assessment had high-quality items, but they also consisted of only one item.

Detail of high-quality on-road tests

WURT/RIRT and P-drive had four high-quality COSMIN items, followed by K-score and TRIP (three items). However, K-score was conducted in only one study.

In the WURT study, interrater reliability was high (κ = 0.85 to 0.96), and test-retest reliability correlations were 0.53 to 0.76. In the criterion validity, the quantitative score from the investigator and the global rating from the driving instructor were highly positively correlated (Kendall T-b = 0.60; $P < 0.001$) (Hunt *et al.*, 1997). One RIRT study examined internal consistency reliability. Results revealed a homogeneous cluster of 21 RIRT items with a strong intraclass correlation (ICC = 0.40) and high internal consistency (Cronbach's α = 0.93). Furthermore, Spearman rank correlation between the RIRT and the Composite Driving Assessment Scale ($P = 0.62$, $P < 0.001$) indicated criterion validity (Ott *et al.*, 2012).

A Rasch analysis (IRT analysis) has been previously employed to develop the P-drive test. The first study to use this test observed adequate internal consistency and structural validity for the 21 items analyzed (infit mean square = 0.6–1.3; z = −1–1), while also demonstrating unidimensionality (structural validity) (Patomella *et al.*, 2004). The P-drive Version 2 included additional items 27). This version demonstrated adequate structural validity and internal consistency, as well as unidimensionality (Patomella *et al.*, 2010). Combined sensitivity/specificity curves crossed at 85, providing an optimal cutoff value for the P-drive protocol. In terms of criterion validity, P-drive scores were related to driving instructors' subjective evaluations (R^2 = 0.44) (Vaucher *et al.*, 2015).

The TRIP showed Cronbach's α reliabilities were high (range = 0.86 to 0.97) in internal consistency (De Raedt and Ponjaert-Kristoffersen, 2001). TRIP demonstrated hypotheses testing items, using accidents ratio (De Raedt and Ponjaert-Kristoffersen, 2001). Criterion validity is based on correlations between the tremendous driving assessment (e.g. Useful Field of View Test, Trail Making Test) and TRIP scores (Devos *et al.*, 2017). Another study revealed very similar results in that TRIP produced significant correlations (test for attentional performance, Stroke Drivers' Screening Assessment; –0.36 to 0.39) (Akinwuntan *et al.*, 2006).

Discussion

To our knowledge, this is the first systematic review of studies regarding on-road driving tests. From the 513 studies, 37 were extracted and evaluated for quality by the COSMIN checklist. Most studies could not meet COSMIN checklist criteria. However, WURT/RIRT, P-drive, and TRIP have met on many items of the COSMIN checklist. These on-road tests have good reliability, validity, and generalizability of the on-road tests.

In recent years, a shift has occurred from the use of traditional statistical methods of Classical Test Theory to the recommended use of newer statistical methods of IRT or Rasch Measurement Theory analyses for developing and evaluating outcome measurement instruments. It is difficult to decide which is superior between IRT and Classical Test Theory (Kohli *et al.*, 2015; Jabrayilov *et al.*, 2016), however, the test using IRT method tends to have high quality according to the COSMIN checklist (Prinsen *et al.*, 2018).

Although it is difficult to gain high quality by the IRT method (e.g. sample size issues), the studies using the IRT method solved this problem and had relatively high quality in this review. In fact, our review showed that P-drive and K-score using IRT have high reliability and validity. Our finding indicates that the use of IRT is still low. Therefore, we suggest the use of IRT methodology in future studies. Although K-score also had high-quality items, there was only one study about its reliability and validity. Thus, we did not include it in the recommendation list.

On the other hand, more classical test theory method studies were reviewed than IRT studies. The WURT/RIRT and TRIP assessments included several verified items, and many reliability and validity studies were conducted. One could argue that these tests are of adequate quality given the repeated assessments undertaken for determining reliability and validity. Together, our findings suggest that WURT/RIRT, P-drive, and TRIP are useful on-road tests for drivers.

Next, we describe focusing on each item of reliability and validity. Interrater reliability was the most frequent item

assessed based on the checklist. Medical assessments, such as off-road tests (e.g, Trail Making Test, Stroke Drivers Screening Assessment), were usually conducted by medical staff, while on-road tests were typically administrated by driving instructors (Hunt *et al*., 1997; De Raedt and Ponjaert-Kristoffersen, 2001; Akinwuntan *et al*., 2006; Ott *et al*., 2012). Therefore, it might be easy for the researchers to check the interrater reliability.

Another examiner such as an occupational therapist might be added to further simplify the research process. Interrater reliability means that regardless of who evaluates the test, it is possible to generalize these reliabilities. However, no prior studies verified measurement error of on-road driving tests. Measurement error is important for a decision whether the changing score is due to interventional effect or error (bias). Our results suggest that further study is needed to confirm the measurement error item. In the items of validity, we included the criterion validity study that was conducted to test the 'off-road' comparing to 'on-road.' Because these studies used a cross-sectional study design, the gold standard test of on-road driving tests had been unclear. After this study, WURT/RIRT, P-drive, and TRIP would be expected to be uses as a gold standard test.

Moreover, some studies (De Raedt and Ponjaert-Kristoffersen, 2001; Fitten *et al*., 1995) demonstrated validity items based on drivers' accident ratios. It is important to consider for what purpose the on-road test is to be conducted, and what it intends to predict in the end. It is recommended that future studies clarify actual on-road behavior, especially in cases where there is no goal-standard on-road test. The current review also observed that few studies verified content and structural validity. These forms of validity assume that a theoretical rationale underlies the test instrument. Such verifications are related to construct validity and are the highest form of empirical evidence for an instrument's utility (Rice and Cutler, 2012). Therefore, it is better for future studies developed for road tests to verify content and structural validity. No prior studies verified responsiveness and interpretability. Since patients with some neurological diseases (e.g. traumatic brain injury, stroke) may improve their driving performance in the future, these components are important for determining effectiveness of any training, exercise, or treatment of driving performance.

Many researchers are more focused on predicting driving skills of subjects than training effectiveness. In fact, there is no strong evidence for training effectiveness when engaging in driving interventions within these populations. For instance, randomized control trial studies show that there was some effectiveness in the subgroup (Mazer *et al*., 2003; Mazer *et al*., 2015). Mazer *et al*. (2003) clarified that participants with moderate impairment who received simulator training were more likely to pass the driving test compared with those in the control group (86% versus 17%). However, they were unable to demonstrate the effectiveness of a driving training program in the main group/outcome. Furthermore, only one Cochran review report has assessed driving rehabilitation among stroke patients, and results indicated insufficient evidence for reaching conclusions regarding improved on-road driving skills post-stroke (George *et al*., 2014). Our result showed that the COSMIN checklist items for the effect of interventions have not been demonstrated. These items will be demonstrated in the near future because more researchers are becoming interested in the effect of driving rehabilitation.

Limitations

The study has several limitations. First, we reviewed only studies published in the English literature. Therefore, we could not learn about the on-road tests performed in non-English-speaking countries. Second, we adopted the COSMIN methodology in the current study, but there are some limitations in confirming the validity. For example, some studies reported on construct validity (Classen *et al*., 2017) and ecological validity (Vlahodimitrakou *et al*., 2013). Although these methods were used to assess on-road test reliability and validity, their analysis methods did not fit for the COSMIN. In the different items, a cross-cultural validity item is present on the COSMIN checklist. This item deals predominantly with language (e.g. back translation). The ability to assess real-world driving depends on various environmental conditions. For instance, some countries require motorists to drive on the left, others on the right. Therefore, cross-cultural validity of on-road tests should not only depend on language but also on various contexts. Along these lines, the RIRT was created by adapting the WURT, but it did not match with the cross-cultural validity items of COSMIN methodology. From these reasons, without verification from the COSMIN checklist, some of the on-road tests reviewed may be of limited quality. Future studies assessing on-road test validity within various environments are recommended.

Conclusion

The WURT/RIRT, P-drive, and TRIP were identified as highly qualified on-road driving tests. Future studies should confirm measurement error, content validity, structural validity, responsiveness, and interpretability of these tools.

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Conflicts of interest

There are no conflicts of interest.

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