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VIEWS & REVIEWS

Screening for fitness to drive after stroke

A systematic review and meta-analysis

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ABSTRACT

Objective: To identify the best determinants of fitness to drive after stroke, following a systematic review and meta-analysis.

Methods: Twenty databases were searched, from inception until May 1, 2010. Potentially relevant studies were reviewed by 2 authors for eligibility. Methodologic quality was assessed by Newcastle-Ottawa scores. The fitness-to-drive outcome was a pass–fail decision following an on-road evaluation. Differences in off-road performance between the pass and fail groups were calculated using weighted mean effect sizes (d_w). Statistical heterogeneity was determined with the I^2 statistic. Random-effects models were performed when the assumption of homogeneity was not met. Cutoff scores of accurate determinants were estimated via receiver operating characteristic analyses.

Results: Thirty studies were included in the systematic review and 27 in the meta-analysis. Out of 1,728 participants, 938 (54%) passed the on-road evaluation. The best determinants were Road Sign Recognition (d_w 1.22; 95% confidence interval [CI] 1.01–1.44; I^2, 58%), Compass (d_w 1.06; 95% CI 0.74–1.39; I^2, 36%), and Trail Making Test B (TMT B; d_w 0.81; 95% CI 0.48–1.15; I^2, 49%). Cutoff values of 8.5 points for Road Sign Recognition, 25 points for Compass, and 90 seconds for TMT B were identified to classify unsafe drivers with accuracies of 84%, 85%, and 80%, respectively. Three out of 4 studies found no increased risk of accident involvement in persons cleared to resume driving after stroke.

Conclusions: The Road Sign Recognition, Compass, and TMT B are clinically administrable office-based tests that can be used to identify persons with stroke at risk of failing an on-road assessment. *Neurology*® 2011;76:747–756

GLOSSARY

CI = confidence interval; **DMV** = Department of Motor Vehicles; **NOS** = Newcastle-Ottawa Scale; **RCT** = randomized controlled trial; **ROC** = receiver operating characteristic; **SDSA** = Stroke Drivers Screening Assessment; **TMT** = Trail Making Test; **UFOV** = Useful Field of View.

Approximately 50% of persons with stroke in developed countries wish to continue driving.[1] The majority (87%) of those who resume driving do not receive any formal driving assessment.[2] Nonetheless, legislation procedures across North America and most European countries require drivers with stroke to disclose their condition to the Department of Motor Vehicles (DMV), and to obtain a physician's certificate to confirm their fitness to drive.[3]

Although most countries exempt physicians from lawsuits for good faith reports to the DMV, signing the relicensing certificate still represents a complex conflict between physicians acting in their patients' best interests and public on-road safety.[3,4]

In the decision-making process, physicians may refer patients for an on-road evaluation.[4] On-road evaluations last approximately 45 minutes and cost between $300 and $400. Despite

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References e1 and e2 are available on the *Neurology*® Web site at www.neurology.org.

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the time and cost involved, on-road tests are the main criterion to determine licensing, given their ability to detect hazardous driving behavior and to identify precursors of car crashes.[4]

In practice, screening of fitness to drive is only rarely carried out due to time constraints and absence of an efficient assessment battery.[5,6] There is conflicting evidence regarding the accuracy of in-clinic screening tools to predict on-road performance after stroke. Some authors developed screening tools with a predictive accuracy of 95%,[5] while others found no such predictive tests.[7] In this systematic review and meta-analysis, we aimed to identify the best office-based determinants of fitness to drive, determine the proportion of persons with stroke who resume driving after a successful on-road evaluation, and investigate whether drivers with stroke are at an increased risk of car crashes.

METHODS

Data sources and searches. This systematic review adhered to the MOOSE guidelines.[8] Three investigators (H.D., A.N., W.D.W.) developed the search strategies. The literature search was performed using MeSH terms such as stroke, automobile driving, and their related entry terms. Case reports (n <10), editorials, guidelines, letters, and reviews were eliminated. The full list of search items can be found in the predefined protocol (available on request). Article databases were searched from inception of the database until May 1, 2010, in consecutive order: Medline, Embase, SCIRUS, CINAHL, Academic Search Premier, PsycINFO, AgeLine, Cochrane library, OT seeker, ISTP, and INSIDE. Databases for theses were searched in Index to Theses, Australian Digital Theses Program, Canadian Theses and Dissertations, Database of African Theses and Dissertations, and ProQuest Dissertation Express. Current trials were searched in National Research Register, Current Controlled Trials, Stroke Trials Registry, and ClinicalTrials.gov. Finally, a hand search of the reference list of candidate articles was also performed.

Study selection. All prospective or retrospective case series, comparative, case-control, cohort studies, and randomized controlled trials (RCT) were selected based on a number of inclusion criteria. Only studies that used a pass–fail outcome based on an on-road evaluation and included participants who were actively driving before stroke onset were considered. Subjects who successfully completed the on-road assessment were assigned to the pass category. Those who performed poorly and those who needed further driving lessons were assigned to the fail category. Any other outcome measures (expert opinions, voluntary driving cessation, psychometric or driving simulator tests) were not considered. Studies that based their decision on both on-road and off-road tests were also ineligible, unless separate data on on-road performance could be provided. Only English literature articles were considered. Studies that included samples of mixed etiology were eligible if they reported data of subjects with stroke separately.

Study and data extraction. Titles and abstracts were scanned for relevance by H.D. The full texts of candidate articles were then appraised independently by H.D. and A.E.A. to confirm the eligibility. Disagreement was resolved by W.D.W. Reviewers were not blinded to authors and study outcomes, because blinding has little effect on the outcome of systematic reviews.[9] To obtain full information regarding relevant missing details, the studies' authors were contacted by A.E.A.

Data extractors collected information about study characteristics, sample characteristics, and determinants. Determinants were categorized into descriptive variables or measures of driving ability, physical, visual, and cognitive function. The cognitive determinants were further categorized into perceptual, attention and memory, and executive and higher-order planning functions.[10]

Data analysis and synthesis. Agreement on eligibility was calculated with the κ statistic. For the comparison of on-road success rates between groups of studies, χ^2 tests were applied. $p < 0.05$ was set as the threshold for significance.

Effect sizes were calculated as the difference in performance of the pass and fail groups according to the formula derived by Hedges, which corrects for small sample size bias.[11] When means and standard deviations were not reported, t values, χ^2 statistics, Fisher correlation coefficients, or the natural logarithm of proportions and odds ratios were used.[12]

Data from randomized or cohort studies were pooled. Dependent effect sizes were averaged to a single effect size.[12]

Effect sizes (d) were calculated for each determinant identified in single studies. In case of multiple studies, effect sizes were weighted by the inverse of the variance and averaged to obtain a weighted mean effect size (d_w). In all cases of d and d_w, the 95% confidence interval (CI) was calculated and the Z statistic was used for significance testing.[12] Eighteen single effect sizes (d) and 36 mean effect sizes (d_w) were identified. To correct for multiple comparisons, the level of significance was reduced by taking the following formula: $1 - 0.95^{1/N}$.[13] Consequently, the significance value was $p < 0.003$ ($1 - 0.95^{1/18}$) for d and $p < 0.001$ ($1 - 0.95^{1/36}$) for d_w.

A positive effect size indicated that participants in the pass group were younger, were less severely affected, and performed better than those in the fail group. Only effect sizes higher than 0.80 with significant p values were considered to be clinically relevant.[14]

Area under the curve, sensitivity, specificity, and positive and negative predictive values for each clinically relevant d_w were identified using receiver operating characteristic (ROC) analyses.[15] We determined cutoff scores that were conservative in giving a pass judgment, since stroke drivers who are misclassified as pass may be at-risk drivers. Therefore, cutoff values with the highest sensitivity were selected at the expense of losing some specificity.

Heterogeneity across studies was assessed by the I^2 statistic.[12] I^2 is the percentage of overall variance in effect sizes that is due to heterogeneity rather than chance. Fixed-effect models were applied for d_w with I^2 <50%. Noniterative random-effects models were used for d_w with I^2 >50%.[12]

The quality of each study was rated independently by H.D. and A.E.A. using the Newcastle-Ottawa Scale (NOS).[16] The NOS allocates a total of 9 points to the quality of a study's participant selection, comparability of results, and quality of outcome variable. Interrater agreement on quality was calculated by the weighted kappa (κ_w) statistic.

Subgroup analysis per geographic area (North America, Europe, Australia) and study quality (below 5, 5 or higher) was specified in the protocol a priori. An additional subgroup analy-

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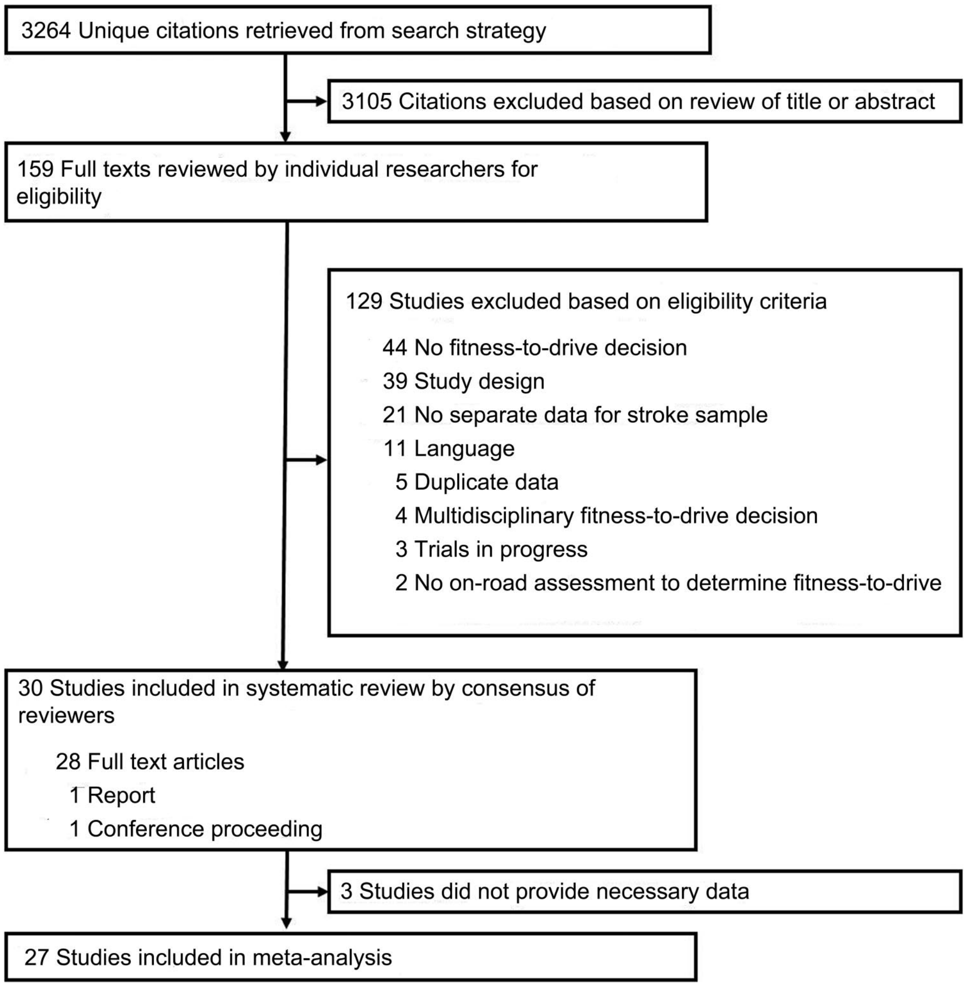
Figure 1 Review and selection of articles



sis was completed for studies that implemented driving training prior to testing. Subgroup analysis was performed using the analog to the analysis of variance procedure[12] and for a d_w composed of more than 5 studies.

Sensitivity analysis was conducted by excluding outliers from the meta-analysis.

To address the file-drawer problem, which indicates the effect of publication bias, we calculated the fail-safe number (Nfs). This is the theoretical number of unpublished studies with zero effect to change a significant effect size to a nonsignificant value (decrease Z to 2.83 for d or to 2.98 for d_w).[17] Determinants with Nfs higher than $2 \times N$ (N = number of studies) + 10 were considered not to be subject to publication bias.[17]

Statistical analyses were conducted with SPSS, version 16.0 (SPSS Inc., Chicago, IL).

RESULTS

Study selection. A flow chart of the included studies is detailed in figure 1. From the initial searches, 3,264 unique hits were obtained. The titles and abstracts were scanned for relevance. Of these, 159 passed the first screening. Thirty studies fulfilled the eligibility criteria.[5,7,18-45] The percentage of agreement between the 2 reviewers was 97% ($\kappa = 0.92$, $p < 0.0001$).

Study quality. Study characteristics are presented in table 1. Study participants were primarily recruited from rehabilitation hospitals and driving centers. Nine studies were conducted in North America, 17 in Europe, and 4 in Australia. Twelve prospective case series, 5 retrospective case series, 6 prospective comparative studies, 1 retrospective comparative study, 3 cohort studies, and 3 RCTs were included. Study quality ranged from 4 to 8 on the NOS. Most studies had explicit eligibility criteria, and used a standardized road test to determine fitness to drive. Subgroup analysis for study quality was not performed as 28 out of 30 obtained scores of 5 or higher. Interrater agreement on study quality was substantial ($\kappa_w = 0.69$, $p < 0.0001$).

Fitness-to-drive decisions. In total, 1,919 participants were included in the systematic review (table 1). The median of the mean ages was 61.1 years (mean range 51.4–71.0). The median of the mean time intervals between stroke onset and examination was 8.8 months (mean range 1.9–18.5). Fitness-to-drive de-

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Table 1 Characteristics of the 30 studies included in the systematic review

First author's name and reference	Year	Country	Design	Recruitment center	Sample size, n	Gender, M/F	Age, y	Time since stroke, m	On-road outcome	Pass, n	Fail, n	Quality score, mean[a]
Quigley[18]	1983	USA	Retrospective case series	Medical center	50	NA	NA	NA	NA	31	19	4
Nouri[5]	1987	UK	Prospective case series	Stroke unit Referral	39	36/3	59	NA	Standardized reliable[b]	22	17	5
Cimolino[19]	1988	USA	Cohort	Rehabilitation center	41[c]	34/7	NA	>4	NA	25	12	7
Nouri[20]	1988	UK	Prospective case series	Stroke unit Referral	38	36/2	59	NA	Standardized reliable[b]	22	16	5
Nouri[21]	1992	UK	Prospective case series	Referral	40	36/4	61.1	8.2	Standardized reliable[b]	12	28	5.5
Simms[22]	1992	UK	Prospective comparative study	Mobility center	50	46/4	53.5	NA	Standardized	40	10	5
Nouri[23]	1993	UK	Cohort	Stroke unit	52	46/6	NA	>8	Standardized reliable[b]	19	33	7
Klavora[24]	1995	Canada	Prospective case series with follow-up	Rehabilitation center	10[d]	8/2	63.1	9.8	NA	6	4	6
Mazer[25]	1998	Canada	Prospective case series	Rehabilitation center	84	63/21	60.8	10.4	Standardized	33	51	5
Klavora[26]	2000	Canada	Prospective case series	Driving center	56	46/10	60.2	>6	Standardized	NA	NA	5
Korner-Bitensky[27]	2000	Canada, USA	Retrospective case series	Driving center	269	215/54	63.6	6.9	NA	145	124	5
Lundqvist[28]	2000	Sweden	Prospective comparative study	University hospital	30[c]	21/9	68.3	8.6	Standardized reliable	14	14	6
Akinwuntan[29]	2002	Belgium	Retrospective case series	Driving center	104	82/22	56.8	18.5	Standardized	41[e]	63[e]	5
Lundberg[30]	2003	Norway, Sweden	Retrospective case series	Rehabilitation center, university department	97	87/10	63	13	Standardized reliable	64	33	6
Mazer[31]	2003	Canada	Randomized controlled trial	Rehabilitation center	97[c]	70/27	64	>3	Standardized reliable	30	54	7.5
Akinwuntan[32]	2005	Belgium	Prospective case series	Rehabilitation center	38	31/7	53.9	4[f]	Standardized reliable,[g] valid[g]	9	29	5
Akinwuntan[33]	2005	Belgium	Randomized controlled trial	Rehabilitation center	83[c]	65/18[f]	54[f]	7.2[f]	Standardized reliable,[g] valid[g]	30[e]	22[e]	8
Patomella[34]	2005	Sweden	Prospective case series	Stroke registry	27	24/3	57.7	7.5	Standardized	10	17	4.5
Akinwuntan[35]	2006	Belgium	Prospective case series	Driving center	68	57/11	53	15	Standardized reliable,[g] valid[g]	40[e]	28[e]	5
Bouillon[36]	2006	Canada	Retrospective comparative study	Driving center	48	28/20	NA	NA	Standardized reliable	24	24	5
Smith-Arena[37]	2006	USA	Prospective case series	Stroke unit	39[c]	29/10	71	NA	NA	23	3	5
Söderström[7]	2006	Sweden	Cohort	Stroke unit	34	32/2	54	6.2	Standardized	19	15	6.5
Akinwuntan[38]	2007	Belgium	Prospective case series	Driving center	43	39/4	55	9[f]	Standardized reliable,[g] valid[g]	30[e]	13[e]	5
George[39]	2007	Australia	Prospective comparative study	Rehabilitation center	81[c]	60/21	67.4	NA	Standardized[h]	14	20[f]	5.5
George[40]	2008	Australia	Prospective case series	Rehabilitation center	26[c]	24/2	65.6	5.1[f]	Standardized[h]	8	16	5

—*Continued*

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Table 1 Continued												
First author's name and reference	Year	Country	Design	Recruitment center	Sample size, n	Gender, M/F	Age, y	Time since stroke, m	On-road outcome	Pass, n	Fail, n	Quality score, mean[a]
Ponsford[41]	2008	Sweden	Retrospective case series	Mobility center	200	152/48	62	12	Standardized	87[e]	113[e]	5.5
Crotty[42]	2010	Australia	Randomized controlled trial	Rehabilitation center	26	24/2	65.6	2.8	Standardized[h]	8	18	6.5
George[43]	2010	Australia	Prospective comparative study	Rehabilitation center	66[c]	52/14	65.9	1.9	Standardized[h]	36	7	5
Selander[44]	2010	Sweden	Prospective comparative study	Driving center	76	68/8	65.3	>6	Standardized	50	26	5
Sommer[45]	2010	Austria, Germany	Prospective comparative study	Rehabilitation center, specialist consultants	109	88/21	51.4	12.4	Standardized reliable	85	24	6
Total					1,919[i]					938	790	

Abbreviation: NA = data not available.
[a] Methodologic quality was assessed using the Newcastle-Ottawa Scale[16] by 2 independent reviewers. Average scores are displayed.
[b] The reliability of the on-road test was reported in the study by Wilson and Smith.[6]
[c] Number of participants at intake was not the same as number of participants from whom driving decisions were obtained due to reasons such as dropouts.
[d] All 10 participants received on-road therapy after initially failing the on-road assessment.
[e] The original study reported success rates based on both on-road and off-road tests. Success rates presented herein may therefore deviate from those in the original study.
[f] New data.
[g] The reliability and validity of the on-road test were reported in the studies by Akinwuntan et al.[32,46]
[h] The standardization of the on-road test was reported in the study by Lister et al.[47]
[i] Nouri and Tinson,[20] Akinwuntan et al.,[32] and Crotty and George[42] were excluded from the calculation of the total sample size because they included the same participants as reported in other studies.

cisions were obtained from 1,728 participants. Of those, 938 (54%) passed the on-road evaluation.

The geographic area did not account for differences in success rates ($\chi^2 = 1.91$, $p = 0.38$). Six studies reported some sort of driving therapy prior to assessment.[7,18,24,31,33,42] Success rates of participants in studies that offered contextual therapy such as on-road[7,18] or simulator-based driving training[33] were significantly higher than those using a remedial approach through visuoperceptual[24,31,42] or cognitive rehabilitation therapy.[33] Out of 108 participants who received contextual driving therapy after stroke,[7,18,33] 82 (76%) passed the on-road evaluation, while only 52 out of 124 (42%) passed after noncontextual therapy ($\chi^2 = 27.33$, $p < 0.0001$).[24,31,33,42]

Determinants of fitness to drive. Study authors were contacted when the reported data were insufficient to calculate effect sizes. Additional data were retrieved from 9 studies.[28,29,31-35,38,40] Data necessary for the calculation of effect sizes could not be retrieved after contacting the authors of 3 other studies,[5,37,41] leaving 27 studies to be included in the meta-analysis (figure 1).

In the deduction process to reveal the best determinants, all potentially relevant determinants were considered. Tables e-1 and e-2 on the *Neurology*® Web site at www.neurology.org display the effect sizes ordered by category and effect size magnitude of 18 determinants identified in single studies and 36 identified in multiple studies. The results show that the fitness-to-drive decision was not influenced by clinical characteristics (e.g., age, driving experience, side of lesion), physical symptoms, or visual deficits.

Only 5 cognitive determinants met the criteria for a large (>0.80) and significant effect ($p < 0.003$ for d and $p < 0.001$ for d_w; table 2): Cube Copy, Road Sign Recognition, Compass, Stroke Drivers Screening Assessment (SDSA), and Trail Making Test part B (TMT B). The figure of Rey and Useful Field of View (UFOV) were only moderately predictive of on-road performance. Visual Recognition and Cognitive Behavioral Driver's Inventory had effect sizes higher than 0.80, but their CIs were too large (table e-2).

Cube Copy had the highest effect size among the 5 most accurate determinants. Yet this d was derived from one study and should be considered as less solid than the d_w derived from multiple studies. The Road Sign Recognition and Compass components of the SDSA were more successful in discriminating between pass and fail than the full test. Therefore, only ROC curves for Road Sign Recognition and Compass along with TMT B were plotted (figure e-1). The cumulative ROC curve of the 3 tests could not

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Table 2 Characteristics of the 5 clinically relevant screening tools of fitness to drive after stroke

Determinant and references	Studies, N	Sample size, n	Effect size (95% CI)[a]	*p* Value, *Z* test	I^2 (%)	Nfs[b]
Perceptual functions						
Cube Copy[21]	1	40	1.54 (0.77–2.32)[c]	<0.0001	NA	1
Executive and higher-order planning functions						
Road Sign Recognition[21,30,33,35,38,44]	6	374	1.22 (1.01–1.44)[d]	<0.0001	58	81
Perceptual, executive, and higher-order planning functions						
Compass[21,30,33,35,38,44]	6	374	1.06 (0.74–1.39)[d]	<0.0001	36	22
Perceptual, attention and memory, executive, and higher-order planning functions						
SDSA[7,21,23,29,35,38,43]	7	395	1.03 (0.61–1.46)[d]	<0.0001	0	11
Trail Making Test B[25,31]	2	168	0.81 (0.48–1.15)[e]	<0.0001	49	3

Abbreviations: CI = confidence interval; NA = not applicable; Nfs = fail-safe number; SDSA = Stroke Drivers Screening Assessment.
[a] Positive effect size indicates that the pass group performed better than the fail group.
[b] Number of zero-effect studies that are needed to change the effect size to a nonsignificant result.
[c] No pooling method was used because effect size was obtained from a single study.
[d] Random-effects pooling method was applied when the initial $I^2 > 50\%$.
[e] Fixed-effects pooling method was applied when $I^2 < 50\%$.

be calculated because different datasets of raw scores were used. There was a substantial overlap between the Road Sign Recognition and the Compass curves with predictive accuracies of 76% and 75%. The TMT B curve showed an inferior, more erratic pattern with a predictive accuracy of 65% (table 3).

Cutoff scores of 8.5 (out of 12) on the Road Sign Recognition test, 25 (out of 32) on the Compass test, and 90 seconds for the TMT B were determined to obtain a sensitivity of at least 80%. The TMT B cutoff value showed different predictive abilities than the Road Sign Recognition and Compass. Its specificity and positive predictive power was higher, despite its lower predictive accuracy. The Road Sign Recognition and Compass tests had similar predictive abilities (table 3).

Subgroup analysis and publication bias. Subgroup analysis for differences in geographic area and the use of driving training did not show differences in effect size magnitude (data not shown). When the formula for publication bias of $2 \times N + 10$ was applied,[17] critical values of 12 for Cube Copy, 22 for Road Sign Recognition and Compass, 24 for SDSA, and 14 for TMT B were obtained. Only the publication bias value of the Road Sign Recognition test exceeded its critical value, which indicates that the magnitude of effect size of the Road Sign Recognition test was not subject to publication bias. Publication bias in the other tests could not be excluded (table 2).

Predictive validity of the on-road evaluation against crash risk involvement after stroke. Twelve studies reported data on crash risk involvement of post-stroke drivers (table 4).[48-59] One study was excluded because it combined records of self-reported strokes and TIAs.[48] Eight studies found that drivers with stroke did not exhibit more car crashes than controls.[49-52,54,56,58,59] Three out of 4

Table 3 Predictive abilities of Road Sign Recognition (n = 163), Compass (n = 163), and Trail Making Test B (n = 97) to detect unsafe on-road performance

Determinant and references	Sample size, n	Area under the curve (95% CI)	Sensitivity, n (%)[a]	Specificity, n (%)[b]	PPV, n (%)[c]	NPV, n (%)[d]
Road Sign Recognition,[33,35,38] cutoff score = 8.5 out of 12	163[e]	0.76 (0.68–0.84)	52/62 (84)	49/90 (54)	52/93 (56)	49/59 (83)
Compass,[33,35,38] cutoff score = 25 out of 32	163[e]	0.75 (0.67–0.83)	53/62 (85)	49/90 (54)	53/94 (56)	49/58 (84)
Trail Making Test B,[31] cutoff score = 90 seconds	97[f]	0.65 (0.53–0.78)	40/50 (80)	18/29 (62)	40/58 (69)	11/21 (52)

Abbreviations: CI = confidence interval; NPV = negative predictive value; PPV = positive predictive value.
[a] Proportion of participants correctly classified to fail the on-road assessment.
[b] Proportion of participants correctly classified to pass the on-road assessment.
[c] Proportion of participants correctly predicted to fail the on-road assessment.
[d] Proportion of participants correctly predicted to pass the on-road assessment.
[e] Missing data: n = 11.
[f] Missing data: n = 18.

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Table 4 Characteristics of the 11 studies that evaluated crash risk after stroke

First author's last name and reference	Year	Country	Design	Case	Control	Follow-up period	Outcome measure	Crash risk	Authors' conclusion
Kumar[49]	1991	USA	Prospective case series	16 participants with stroke; 13 obtained driver's license after on-road assessment	No control group	6 months and 2 years after stroke	Nonreported accidents	Crash rate at 6 months: 0/13 (0%); crash rate at 2 years: 1/12[a] (8%)	Not significant
Koepsell[50]	1994	USA	Case-control	4 (0.7%) drivers with stroke out of 234 drivers injured in car crashes	10 (2.2%) drivers with stroke out of 446 drivers not injured in car crashes	NA	Police reported injury crashes	OR[b] (95% CI) case vs control: 0.8 (0.2–2.5)	Not significant
Johansson[51]	1996	Sweden	Case-control	2 (5%) drivers with stroke out of 37 drivers with cardiovascular disease	0 (0%) out of 37 controls matched for age, sex, education, and mileage	NA	Police reported crashes	Crash rate case vs control: 2/23 (9%) vs 0/37 (0%)	Not significant
Haselkorn[52]	1998	USA	Case-control	1,910 drivers with stroke	3,732 controls matched for age, gender, and location	2 years (1 year before to 1 year after stroke)	State crash records	RR[c] (95% CI) case vs control: 0.8 (0.6–1.2)	Not significant
Salzberg[53]	1998	USA	Case-control	21 drivers with stroke who passed on-road evaluation	449 controls matched for age, gender, and location	5 years (1.75 years before to 3.75 years after exam)	State crash records per 100 drivers per year	Pre-exam crash rate case vs control: 5.44 vs 3.82; post-exam crash rate case vs control: 4.4 vs 1.2	Significant
McGwin[54]	2000	USA	Case-control	Case 1: 18 (7.3%) drivers with stroke out of 249 at-fault drivers; case 2: 14 (6.9%) drivers with stroke out of 198 not-at-fault drivers	19 (4.1%) drivers with stroke out of 454 drivers not involved in crashes	NA	State crash records	OR[d] (95% CI) case 1 vs control: 1.9 (1.0 to 3.9) OR[e] (95% CI) case 1 vs control: 1.8 (0.9 to 3.6) OR[d] (95% CI) case 2 vs control: 1.1 (0.5 to 2.4)	Significant Not significant Not significant
Sagberg[55]	2006	Norway	Case-control	36 (1.6%) drivers with stroke out of 2,226 at-fault drivers	13 (0.7%) drivers with stroke out of 1,840 not-at-fault drivers	NA	Car crashes reported to insurance company	OR[f] (no 95% CI provided) case vs control: 1.93 (p = 0.007)	Significant
Lafont[56]	2008	France	Case-control	9 drivers with stroke	975 drivers without stroke	5 years	Self-reported accidents	Crash rate case vs control: 3/9 (33%) vs 237/740 (32%)	Not significant
Lundqvist[57]	2008	Sweden	Case-control	14 drivers with stroke; 9 were driving at follow-up	22 controls matched for age, gender, education, and mileage	10 years after stroke	Car crashes reported to insurance company	Crash rate case vs control: 3/9 (33%) vs 1/22 (4%)	Significant
Schanke[58]	2008	Norway	Case-control	68 drivers with stroke who passed on-road evaluation	Norwegian normative data	9 years after stroke	Reported and nonreported car crashes per million kilometers driven	Crash rate case vs control: 5.2 vs 6.49	Not significant
Devos[59]	2010	Belgium	Prospective case series	34 drivers with stroke of which 33 passed the on-road evaluation	No control group	10 years (5 years before to 5 years after stroke)	Self-reported car crashes per million kilometers driven	Crash rate poststroke vs prestroke: 1.29 vs 0.90	Not significant

Abbreviations: CI = confidence interval; NA = data not available; OR = odds ratio; RCT = randomized controlled trial; RR = relative risk.
[a] One person died.
[b] Adjusted for age, gender, race, and mileage.
[c] Adjusted for age, gender, and crash outcome 12 months prior to event.
[d] Adjusted for age, gender, race, and mileage.
[e] Adjusted for age, gender, race, mileage, and relevant classes of medication.
[f] Adjusted for age and mileage.

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studies found no increased crash involvement of poststroke drivers who were cleared to resume driving following an on-road evaluation.[49,58,59]

No significant off-road tests could be found to determine crash risk at follow-up.[57,59]

DISCUSSION In developed countries, more than half of persons with stroke are fit to drive following a successful on-road examination. The likelihood of passing is even higher for those who receive driving therapy prior to assessment. However, driving therapy success depends on the type of training program. Contextual therapy in a car or driving simulator appears to be superior to noncontextual training of driving-related cognitive skills.[33]

This study reduced an extensive list of 54 determinants to 5 clinically relevant determinants of fitness to drive: Cube Copy, SDSA, Road Sign Recognition, Compass, and TMT B. All 5 tests assess cognitive functions. Clinical characteristics and motor symptoms did not predict on-road performance. This is not surprising considering the extensive range of in-vehicle adaptive devices available (e.g., automatic transmission, steering knob, left-foot accelerator pedal). Though commonly affected after stroke, visual deficits did not predict on-road success either because legislation criteria in many countries preclude persons with visual problems from driving.[7,25,26,28,30,31,45]

The 18 effect sizes derived from single studies (table e-1) need to be considered as less solid than the 36 effect sizes derived from multiple studies (table e-2). They are however worthy of exploration in subsequent studies, particularly Cube Copy, which reached an effect size higher than 1.50. The full SDSA was less predictive than the Road Sign Recognition and Compass subtests separately, most likely due to the poor discriminative abilities of the Dot Cancellation and Directions subtests. We therefore recommend shortening the SDSA to its 2 most predictive components. The Road Sign Recognition test assesses traffic knowledge and visual comprehension.[5,21,23] It involves matching 19 road signs to 12 traffic situations.[e1] The Compass task examines visuoperceptual and visuospatial abilities, divided attention, mental speed, and executive functions.[5,21,23] This test involves matching 16 out of 27 cue cards, each displaying 2 cars driving away from a roundabout, to the indicated driving directions of the compass cards arranged in a 4 × 4 matrix.[e1] The TMT B evaluates visuomotor tracking, visual scanning, and executive functions.[31] This task requires participants to connect 25 consecutive circles on a sheet of paper, alternating between numbers and letters (e.g., 1, A, 2, B).[e2]

Subjects with stroke who score below 8.5 out of 12 on the Road Sign Recognition test, below 25 out of 32 on the Compass test, and perform slower than 90 seconds on the TMT B should be referred for further on-road assessment. The Road Sign Recognition, Compass, and TMT B are readily available and can be administered within 15 minutes. They each correctly classified 80% to 85% of unsafe drivers. Yet the specificity of both tests was poor, indicating that the cutoff values are very conservative in giving a pass judgment. Despite its lower predictive accuracy, the TMT B had better specificity and positive predictive power than the 2 other tests. It is reasonable to assume that a combination of the 3 tests will provide a better model to predict on-road performance. A prospective multicenter study should therefore be conducted to determine the multivariate predictive accuracy.

In an earlier systematic review, the figure of Rey, TMT A, and UFOV were additionally recommended as screening tools.[10] These 3 tests were not retained in our meta-analysis, although the figure of Rey and UFOV had moderate effect sizes. A possible reason for this discrepancy might be that the authors of the previous systematic review did not base their conclusion on quantitative data. Additionally, they covered material up until 2005 and included 11 studies on determinants of on-road evaluation.[10] Since 2005, the number of studies on fitness to drive after stroke has increased substantially. Despite the broad search strategy in abstract and article databases, absence of publication bias could not be excluded. This represents a limitation of the current study.

Our results indicate that stroke survivors applying for a license reinstatement are younger than the general stroke population and are recovered to their full potential. The in-clinic tests therefore only apply to a subgroup of stroke survivors without severe deficits in the late rehabilitation phase.

The levels of evidence of the included studies ranged from case series to Class II RCTs.[60] The inclusion of RCTs that offered contextual driving therapy prior to testing influenced the on-road success rates but not the effect size magnitude of the clinical variables. The majority of studies were case series. This research design is appropriate to investigate determinants of fitness to drive after stroke. Furthermore, 28 studies received ratings of 5 or higher on the NOS, which indicates acceptable quality.

The on-road assessment is a practical method of evaluation and recognized in most countries as the de facto standard to determine relicensing.[3,23,29,39] Most studies used standardized on-road assessments with high to perfect interrater agreement[6,28,30-32,36,45,46] and

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concurrent validity.[32] Still, there were considerable differences in terms of geographic area, vehicles used, and professional background of on-road assessors.

Physicians may be reluctant to refer stroke survivors for on-road testing because of the limited evidence supporting the view that clinical screening and subsequent on-road testing actually reduces their potential accident proneness. There were too few studies to conclude that stroke drivers who pass an on-road evaluation do not exhibit an increased risk of motor vehicle accidents.[49,58,59] More epidemiologic studies are needed to optimize the predictive validity of on-road tests by comparing self-reported accidents and state records of drivers who were cleared to resume driving after stroke with those of healthy peers. So far, no in-clinic tests have been identified to predict crash risk involvement poststroke. Further research is warranted to determine predictors of accident proneness after stroke and similar studies are recommended to identify office-based screening tools for drivers with Alzheimer dementia, Parkinson disease, multiple sclerosis, and traumatic brain injury.

AUTHOR CONTRIBUTIONS

Statistical analysis was conducted by H. Devos and Dr. S. Truijen.

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Screening for fitness to drive after stroke : A systematic review and meta-analysis
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