Accuracy of the short form Montreal Cognitive Assessment – Systematic Review and Validation

Running title: The Montreal Cognitive Assessment Shortened

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ABSTRACT

Introduction: Short-form versions of the Montreal Cognitive Assessment (SF-MoCA) are increasingly used to screen for dementia in research and practice. We sought to collate evidence on the accuracy of SF-MoCAs and to externally validate these assessment tools.

Methods: We performed systematic literature searching across multidisciplinary electronic literature databases, collating information on the content and accuracy of all published SF-MoCAs. We then validated all the SF-MoCAs against clinical diagnosis using independent stroke (n=787) and memory clinic (n=410) data-sets.

Results: We identified 13 different SF-MoCAs (21 studies, n=6477 participants) with differing test content and properties. There was a pattern of high sensitivity across the range of SF-MoCA tests. In the published literature, for detection of post-stroke cognitive impairment, median sensitivity across included studies:0.88 (range:0.70-1.00); specificity:0.70 (0.39-0.92). In our independent validation using stroke data, median sensitivity:0.99 (0.80-1.00); specificity:0.40 (0.14-0.87). To detect dementia in older adults, median sensitivity:0.88 (0.62-0.98), median specificity:0.87 (0.07-0.98) in the literature and median sensitivity:0.96 (range:0.72-1.00); median specificity:0.36 (0.14-0.86) in our validation. Horton's SF-MoCA (delayed recall, serial subtraction, orientation) had the most favorable properties in stroke (sensitivity:0.90, specificity:0.87, PPV:0.55, NPV:0.93), whereas Cecato's 'MoCA reduced' (clock draw, animal naming, delayed recall, orientation) performed better in the memory clinic (sensitivity:0.72, specificity:0.86, PPV:0.55, NPV:0.93).

Conclusions: There are many published SF-MoCAs. Clinicians and researchers using a SF-MoCA should be explicit about the content. For all SF-MoCA,

sensitivity is high and similar to the full scale suggesting potential utility as an initial cognitive screening tool. However, choice of SF-MoCA should be informed by the clinical population to be studied.

Key words: Dementia, Cognitive Impairment, Montreal Cognitive assessment, sensitivity, specificity

Key Points:

- Many scales purport to be a short form of the MoCA (SF-MoCA).
- SF-MoCAs are not interchangeable; the scales differ in content, scoring and accuracy.
- SF-MoCAs generally have high sensitivity and lower specificity.
- Properties of SF-MoCAs make them suitable as an initial cognitive screening test, where a ‘positive’ result is followed by more detailed assessment (sometimes called a ‘rule out’ test).
- Optimal content of SF-MoCAs used in stroke may differ from that used in other settings.

Introduction

There is no consensus on how to approach screening older adults for cognitive impairment or dementia.[1] In non-specialist settings, the assessment of cognition often takes a two-stage approach, with initial screening or triage using a short test followed, where necessary, with more detailed testing. The Montreal Cognitive Assessment (MoCA) has gained traction as a short cognitive screening tool.[2] Although initially developed as a screen for mild cognitive impairment (MCI), the MoCA is now often used as a general cognitive screen and as a dementia assessment.[3]

Completion of the MoCA in the literature is generally quoted as around 10 minutes,[4] but in practice it can be much longer if the patient is medically unwell or has physical or cognitive impairments, a situation that is common in clinical practice.[5] While the MoCA is short compared to a comprehensive neuropsychological battery, it may still be too long for use as an initial screen in busy medical units. A shorter screen retaining diagnostic properties of the MoCA is attractive for both patients and clinicians. It could enable cognitive screening to be routinely integrated into greater clinical settings and reduce the assessment burden on patients.

Many multi-item assessments have some redundancy and certain component items can be removed to create a shorter version of the original. Short form versions of quality of life and activities of daily living assessments are commonly used in practice and research.[6,7] Short form versions of the MoCA (SF-MoCA) have also been described. While use of a SF-MoCA is intuitively attractive, validity of such an assessment should not be assumed. Even if the process of

developing the SF-MoCA is robust and the accuracy metrics favorable, it is still necessary to externally validate the new test in an independent data-set.

We used a two-stage process to describe the test properties of the SF-MoCA. First, we collated and reviewed the content and diagnostic accuracy of all published SF-MoCAs and then we externally validated these scales using independent data-sets.

Methods

Systematic review

We carried out a systematic review of the literature looking to describe the content and diagnostic properties of any short-form versions of the MoCA. We followed best practice in all aspects of design, conduct and reporting.[8,9] All searching, data extraction and quality assessment were performed by independent researchers (JM, GB, EE) with access to a third arbitrator (TQ) as needed. Our protocol is registered with the research registry database (http://www.researchregistry.com. UIN: reviewregistry298).

Search strategy: We developed search terms using a concept-based approach. The first concept of interest was MoCA and its synonyms, including names of existing short-forms known to the researchers. The second concept was around short-form tests/item reduction. The vocabulary used for the second concept had been validated in a previous systematic review of short-form tests.[7] We searched a series of multidisciplinary electronic databases from 2005 (year of publication of original MoCA paper) to April 2017: MEDLINE (OVID), Embase (OVID), Health and Psychosocial Instruments (OVID), PsychINFO (EBSCO),

CINAHL (EBSCO). We included all studies in all languages, translating where necessary. We included published abstracts in initial data synthesis but these data sources were not assessed for reporting or risk of bias.

We screened all titles generated by initial searches for relevance. Abstracts were assessed and potentially eligible studies were reviewed as full manuscripts against inclusion criteria. We searched reference lists of included studies and relevant reviews, repeating the process until no new titles were found (Full search strategy available in Supplementary Methods 1).

Systematic review inclusion and exclusion criteria: Our index test of interest was any SF-MoCA. We defined the SF-MoCA as a test of more than one cognitive domain, derived from the original MoCA and designed to detect all-cause dementia or cognitive impairment. We did not include the 'MoCA-Basic', which is a MoCA designed for patients with limited education rather than a shortened form.[10] Included studies used a test accuracy design, where SF-MoCA was compared to a gold-standard clinical diagnosis of dementia, or cognitive impairment. We included studies where the comparator was the full MoCA or another multi-domain assessment. We included studies in any setting (community, primary, secondary care) and for any intended use of the test (research, screening, assessment).

Systematic review data extraction and assessments: We extracted data to a study specific proforma and created tables describing characteristics of included studies and characteristics of the index tests including the cognitive domains tested. Where possible, we created 2x2 contingency tables to allow us

to derive metrics of sensitivity, specificity and predictive values [11]. We contacted authors to obtain data or clarify methods, where needed.

We assessed methodological quality and risk of bias using the Quality Assessment for Diagnostic Test Accuracy Studies (QUADAS-2) tool (www.bris.ac.uk/quadas/quadas-2).[12] QUADAS-2 assesses four key domains; patient selection, application of index test, application of reference standard and patient flow/timing. We assessed quality of reporting using the dementia-specific extension to the Standards for Reporting of Diagnostic Accuracy (STARDdem) tool.[13]

External validation of SF-MoCA

We examined the properties of the MoCA and the different SF-MoCAs identified through systematic review by using independent data-sets that contained individual patient level data on MoCA (with scoring available for each individual component) and a reference standard comparator. We restricted our analyses to those SF-MoCAs designed to detect dementia. Our index tests were each differing SF-MoCA version found from our literature search. The SF-MoCA were derived from the full version of the test. To align with our systematic review, our reference standard was clinical diagnosis of dementia or scores on a validated multi-domain cognitive assessment.

Data-sets used for validation: As MoCA and SF-MoCA are often used in stroke settings, our first data-set had a stroke focus.[14] The data-set was derived from the Virtual International Stroke Trial Archive (VISTA), a not-for-profit repository of anonymised data from stroke trials or observational cohorts.[15] We included

any data-set that contained MoCA assessment and an appropriate reference standard. Recognizing the difficulty of applying a dementia label in an acute stroke setting, and to align with our literature review, we included data-sets where comparator was diagnosis of dementia and datasets where comparator was a multi-domain cognitive assessment other than MoCA. For this stroke cohort, impairment in memory was not mandatory to assign the clinical label. Our second data-set was taken from a memory clinic setting (the Walton Centre, Liverpool UK). The data-set has been described in detail previously.[16,17] In brief, MoCA is administered in clinic and then a clinical diagnosis was made by an independent clinician, masked to the MoCA score.

Validation analyses: We described the internal consistency (reliability) of the MoCA in each data-set using Cronbach's alpha. To identify potentially redundant items in the MoCA, we used spearman coefficient to describe the correlation between individual test items and total MoCA score and then described the effect on internal consistency if that item was removed. If internal consistency of the complete scale is unchanged when an item is removed, it suggests that the item is not contributing independent of other items and could potentially be removed without compromising test performance. We described rank correlation of each MoCA item with another. We used exploratory factor analysis and principle component analysis to assess the underlying structure of the MoCA i.e. how many differing constructs were being assessed by the scale. We assessed factor pattern and described factors that were positively loaded using standardized regression coefficients, where high loading was defined as >0.7.

We then described the test accuracy of the various SF-MoCAs. We described correlation of each SF-MoCA with the original MoCA. We derived sensitivity, specificity and negative/positive predictive values (NPV/PPV) for each SF-MoCA (using recommended threshold scores from the literature) against clinical reference standard. All analyses used SAS version 9.4 (SAS Institute, Cary) software.

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Results

Systematic review: After de-duplication, we screened 578 titles, reviewed 140 full papers and included 21 studies (18 full papers[17-34] and three conference abstracts [35-37]) (Figure 1). Numbers of participants included in studies ranged from n=59 to n=1850 (n=6477 participants in total). Included studies assessed diverse patient groups, with a majority having a cardio/cerebrovascular focus (n=9 studies; Table 2 and Supplementary Table 1).

There were 13 different published short versions of the MoCA with differing test items (range:2-8 items; total score 8-22); differing cut-offs to define 'test positive' and presented under different names (Table 1). The most frequently described SF-MoCA was the 5-minute protocol recommended by the National Institute of Neurological Disorders and Stroke and the Canadian Stroke Network (NINDS-CSN) (n=7 papers).

Content of each SF-MoCA differed. All SF-MoCAs retained the delayed recall item; the orientation and fluency items were also prevalent. Digit span was the item most likely to be omitted from a short form (Table 1).

Scoring in the short-forms was not always consistent with the original MoCA. For example, in one SF-MoCA version [24] immediate recall was scored; an item that is not scored in the original MoCA. In other SF-MoCAs, animal naming used one animal instead of three[17,27]. Cut-off scores employed to categorize patients varied across papers even where the same short-form was used (Table 1, Table 2).

The reported accuracy of the short-forms varied across the papers (Table 2 and Supplementary Table 1). In papers with a stroke focus, median sensitivity was 0.88 (range:0.70-1.00) and median specificity was 0.70 (range:0.39-0.92). Settings and timing of assessment using the index test (SF-MoCA) post-stroke varied: the majority of papers administered the tests >3 months' post-stroke, one paper used the SF-MoCA in the acute period following stroke (≤2 weeks),[31] and two papers in the setting of a stroke prevention clinic (therefore some non-stroke patients were also included)[22,37](Table 2).

In those papers where SF-MoCA was used to diagnosis dementia or MCI in older adults, median sensitivity was 0.85 (range:0.44-0.98), specificity was 0.74 (range:0.07-0.98). Restricting to dementia diagnosis only, median sensitivity:0.88 (range:0.62-0.98), median specificity:0.87 (range:0.07-0.98). We did not attempt meta-analyses to create summary estimates of SF-MoCA

test accuracy due to the significant heterogeneity in test content, thresholds and populations.

Using QUADAS-2, one study was considered to have a low risk of bias in all four areas.[17] Potential for bias in the other studies was generally around patient selection (n=17) (inappropriate exclusions, non-consecutive samples), use of index test (n=11) (no pre-specified cut-off) and the timing between the index test and reference standard not reported or ambiguous (n=9) (Supplementary Table 2). Eight papers were of particular concern (rated high or unclear risk of bas across three areas).[21,25-27,29,31,34,38] Study reporting was variable and no study reported all items recommended in STARDdem guidance. (Supplementary Table 3)

External validation of SF-MoCA: Our stroke analyses used data from 787 stroke patients with a median age of 70, median NIHSS of 4, median MoCA of 21 and 289 (37%) had dementia or post-stroke cognitive impairment. Assessments were performed in the acute period (first weeks) following stroke. Our memory clinic analyses used data from 410 patients, with median age of 60, median MoCA of 23 and 79 (19%) had dementia.

From 13 differing versions of SF-MoCA, we performed validation analyses on 11 tests. We excluded one SF-MoCA as it was designed to detect MCI rather than dementia.[25] We excluded one other SF-MoCA as it included additional content (immediate recall)[24] that is not part of the original MoCA scoring and we therefore could not retrospectively score it.

Internal consistency for the full MoCA was 0.88 for the stroke data-set and 0.82 for the memory clinic. In the stroke data-set clock drawing was the single item most correlated with total score, while sentence repetition was least correlated. In the memory clinic data-set, orientation questions were most correlated and a letter based attentional task least. In both data-sets item reduction did not suggest a redundant item (Supplementary Table 4). In both data-sets, correlation of one item with another did not suggest a redundant item (no correlation >0.6; Table 3). Exploratory factor analyses and principal components analysis suggested a unidimensional scale, with only clock drawing highly loaded (0.76) in the stroke data-set and no items highly loaded in the memory clinic data (Supplementary Table 5).

The test accuracy of the published SF-MoCAs varied when assessed in our independent data-sets. Test accuracy of the full MoCA was included for comparison at the usual threshold of <26. Accuracy was similar in the two data-sets; sensitivity:1.00 in both, specificity:0.22 in stroke, 0.26 in the memory clinic data-set. In both data-sets, the SF-MoCA versions were highly correlated with the full MoCA (all >0.80). For the stroke trial data-set, median sensitivity was:0.99 (range:0.80-1.00); median specificity:0.40 (range:0.14-0.87), PPV:0.48 (range:0.40-0.82), NPV:0.99 (range:0.88-1.00). The SF-MoCA with the most favorable balance of test properties (sensitivity, specificity, PPV, NPV) in stroke was Horton's SF-MoCA (comprising: delayed recall, serial subtraction, orientation).

For the memory clinic data-set, median sensitivity:0.96 (range:0.72-1.00); median specificity:0.36 (range:0.14-0.86), PPV:0.27 (range:0.24-0.55),

NPV:0.97 (range:0.93-1.00) (Figure 2). Cecato's 'MoCA reduced'[25] (comprising: clock draw, single animal naming, delayed recall, orientation) showed best performance in the memory clinic population.

Discussion

Our systematic review found many cognitive tests that purport to be a shorter form of the MoCA. The available SF-MoCA are not interchangeable as they have differing test items, application and test properties. Our external validation of the SF-MoCA confirmed differences in test properties. Accepting this heterogeneity, in general the SF-MoCA had a pattern of high sensitivity and lower specificity, with corresponding high negative predictive value and lower positive predictive value.

Various approaches to developing short versions of longer tests are described [39]. The processes used to develop the various published SF-MoCA varied. In terms of psychometrics, it is debatable whether the MoCA content should be reduced at all. Our analyses suggest no obviously redundant item in the original MoCA. Indeed, our factor and components analyses would not necessarily favor the creation of a shorter form. In spite of whether it is considered 'correct' to shorten tests, certain scenarios, such as test administration by telephone[23] necessitate that certain items from the original scale are discarded, effectively creating a short form assessment. We note that the team who developed the original MoCA are working on a shortened, 5-minute version. Although this official short MoCA is not released at the time of writing, the developers state that the tool will predominantly assess memory and executive functions.

The terminology used to describe the short versions of the MoCA is potentially confusing. Some of the short-form tests were presented under the same name, yet contained different items, for example there were two versions of the "mini-MoCA"[22,37] and two of the "MoCA reduced".[25] Conversely, some SF-MoCA had identical content and scoring but had a different title, for example the "new short MoCA" and "mini-MoCA" were the same test.[18,20] Abbreviations also potentially add to the confusion with 'MoCA-B' being used to describe both the 'MoCA Basic' and 'MoCA Blind' tests.[10,28] We would encourage researchers and clinicians to be explicit about the test content and scoring when using a SF-MoCA.

The SF-MoCA was used in a variety of patient populations. Many of the populations assessed represented neurodegenerative diseases where patients are likely to have mixed physical and cognitive impairments (multiple sclerosis, Parkinson's disease, stroke). In these settings a short cognitive test may have particular utility as patients may struggle to complete a longer test battery.[5] More specifically the choice of SF-MoCA could be tailored, for example removing questions requiring drawing for patients with limb weakness. The MoCA test items that were most discriminating differed between stroke and memory clinic patients. This finding has biological plausibility as the predominant dementia pathologies will also differ in these patient groups, with greater impairment of executive function in the stroke group.[14] This suggests that the optimal short form may depend on the population to be tested. The NINDS-CSN recommended a 5-minute protocol specifically for VCI, however this was also the choice of test in those papers that studied test performance in non-vascular groups e.g. MS and PD populations.

Across the different SF-MoCA, a general pattern emerges of high sensitivity and lower specificity with corresponding high NPV and lower PPV. These results are not surprising since the MoCA was designed to detect milder cognitive impairment and we focused on dementia. There is no 'acceptable' value for test accuracy and the preferred trade off of NPV and PPV will vary with the purpose of the test.[11] The test accuracy findings for SF-MoCA suggest that the test is useful for 'rule-out' i.e. a negative or normal SF-MoCA makes it unlikely that a person has important cognitive issues. With specificity being low across many of the SF-MoCAs, a positive or abnormal SF-MoCA is less helpful (many false positives) and will need to be followed by further assessment. In this regard the properties of SF-MoCA are similar to the original MoCA, where sensitivity for a dementia diagnosis is around 94% and specificity less than 60%.[3]

There are limitations in our work. For our systematic review we were constrained by the methodology and reporting of the original research. Many of the original papers had substantial risk of bias. We adopted an inclusive approach and accepted papers where SF-MoCA was compared only to the original MoCA. This is a less useful analysis than comparison against a clinical diagnosis, since the MoCA itself is an imperfect cognitive assessment. In our external validation we derived SF-MoCA data from the original MoCA test data. We recognize that the properties of a SF-MoCA may differ if used directly rather than if retrospectively derived. We also used a mixed reference standard of clinical diagnosis and multi-domain assessment. We felt that this approach was representative of real-world practice where a diagnosis of post stroke dementia may not be made in the acute period. We also acknowledge that using a neurology-led memory clinic population for validation has some limitations.

These patients are likely to be selected and may have already been triaged using a cognitive screen, and brief tests are less useful in this specialist setting. These factors all potentially limit the generalisability of our findings. The different accuracy found in our validation analyses compared to studies included in our review are likely due to methodological limitations, differing case-mix and differing comparator groups. Finally, due to our validation being a secondary analysis, we were unable to adjust our results for education, which would usually be done in practice. Strengths of our approach include the use of a comprehensive search strategy and validated assessments of reporting and bias. By externally validating the tests in a large sample we were able to test their performance in a real-world setting.

Our findings have implications for research and practice. The test properties of certain SF-MoCA and the original scale are comparable and so in some situations the SF-MoCA may be preferred to the full MoCA for initial screening. The choice of SF-MoCA should also be informed by other test properties such as feasibility and reduced test burden. Although this is the obvious advantage to a short form, few studies have reported metrics such as time taken for assessment or percentage test completion. Further research that describes these properties would help guide choice of SF-MoCA. As the short versions have a theoretical advantage of greater feasibility, in any future research the test population should be an unselected cohort that includes participants with physical, language and sensory impairments that may complicate cognitive assessment.

Conclusion

The cognitive tests named ‘mini-MoCA’; ‘short-form MoCA’; ‘5 minute-MoCA’ etc. describe a variety of differing cognitive assessments with differing content and test properties. The psychometric properties of the MoCA do not suggest preferred content of a shorter version and so choice of SF-MoCA should be based on accuracy and feasibility. Test accuracy of the various published SF-MoCA suggests that these tests may be best used as initial cognitive screening tests, if the purpose of testing is to rule out dementia. However, such an approach should be prospectively validated in an independent sample before being used in a clinical setting.

Data Availability

The data that inform the analyses included in this paper are available from the authors upon reasonable request.

References

1. Harrison JK, Noel-Storr AH, Demeyere N, Reynish EL, Quinn TJ. Outcomes measures in a decade of dementia and mild cognitive impairment trials. *Alzheimer's Research & Therapy.* 2016;8(1):48.
2. Nasreddine ZS, Phillips NA, Bedirian V, et al. The Montreal Cognitive Assessment, MoCA: a brief screening tool for mild cognitive impairment. *Journal of the American Geriatrics Society.* 2005;53(4):695-699.
3. Davis DH, Creavin ST, Yip JL, Noel-Storr AH, Brayne C, Cullum S. Montreal Cognitive Assessment for the diagnosis of Alzheimer's disease and other dementias. *Cochrane Database Syst Rev.* 2015(10):CD010775.
4. Julayanont P, Phillips N, Chertkow H, Nasreddine ZS. Montreal Cognitive Assessment (MoCA): Concept and Clinical Review. In: Larner AJ, ed. *Cognitive Screening Instruments: A Practical Approach.* London: Springer London; 2013:111-151.
5. Lees RA, Hendry Ba K, Broomfield N, Stott D, Larner AJ, Quinn TJ. Cognitive assessment in stroke: feasibility and test properties using differing approaches to scoring of incomplete items. *International journal of geriatric psychiatry.* 2017;32(10):1072-1078.
6. Jenkinson C, Fitzpatrick R, Crocker H, Peters M. The Stroke Impact Scale: validation in a UK setting and development of a SIS short form and SIS index. *Stroke.* 2013;44(9):2532-2535.
7. MacIsaac RL, Ali M, Taylor-Rowan M, et al. Use of a 3-Item Short-Form Version of the Barthel Index for Use in Stroke: Systematic Review and External Validation. *Stroke.* 2017;48(3):618-623.
8. Davis DHJ, Creavin ST, Noel-Storr A, et al. Neuropsychological tests for the diagnosis of Alzheimer's disease dementia and other dementias: a generic protocol for cross-sectional and delayed-verification studies. *Cochrane Database of Systematic Reviews.* 2013(3):Art No: CD010460.
9. McInnes MDF, Moher D, Thombs BD, et al. Preferred Reporting Items for a Systematic Review and Meta-analysis of Diagnostic Test Accuracy Studies: The PRISMA-DTA Statement. *Jama.* 2018;319(4):388-396.
10. Julayanont P, Tangwongchai S, Hemrungrojn S, et al. The Montreal Cognitive Assessment-Basic: A Screening Tool for Mild Cognitive Impairment in Illiterate and Low-Educated Elderly Adults. *Journal of the American Geriatrics Society.* 2015;63(12):2550-2554.
11. Takwoingi Y, Quinn TJ. Review of Diagnostic Test Accuracy (DTA) studies in older people. *Age and Ageing.* 2018;47:349-355.
12. Whiting PF, Rutjes AW, Westwood ME, et al. QUADAS-2: a revised tool for the quality assessment of diagnostic accuracy studies. *Annals of internal medicine.* 2011;155(8):529-536.
13. Noel-Storr AH, McCleery JM, Richard E, et al. Reporting standards for studies of diagnostic test accuracy in dementia: The STARDdem Initiative. *Neurology.* 2014;83(4):364-373.
14. Lees R, Selvarajah J, Fenton C, et al. Test accuracy of cognitive screening tests for diagnosis of dementia and multidomain cognitive impairment in stroke. *Stroke.* 2014;45(10):3008-3018.
15. Ali M, Bath P, Brady M, et al. Development, expansion, and use of a stroke clinical trials resource for novel exploratory analyses. *International journal of stroke : official journal of the International Stroke Society.* 2012;7(2):133-138.
16. Larner AJ. Screening utility of the Montreal Cognitive Assessment (MoCA): in place of--or as well as--the MMSE? *International psychogeriatrics.* 2012;24(3):391-396.
17. Larner AJ. Short Montreal Cognitive Assessment:Validation and Reproducibility. *Journal of Geriatric Psychiatry and Neurology.* 2017;30(2):104-108.

18. Campbell N, Rice D, Friedman L, Speechley M, Teasell RW. Screening and facilitating further assessment for cognitive impairment after stroke: application of a shortened Montreal Cognitive Assessment (miniMoCA). *Disabil Rehabil.* 2016;38(6):601-604.
19. Horton DK, Hynan LS, Lacritz LH, Rossetti HC, Weiner MF, Cullum CM. An Abbreviated Montreal Cognitive Assessment (MoCA) for Dementia Screening. *The Clinical neuropsychologist.* 2015;29(4):413-425.
20. Bocti C, Legault V, Leblanc N, et al. Vascular cognitive impairment: most useful subtests of the Montreal Cognitive Assessment in minor stroke and transient ischemic attack. *Dementia and geriatric cognitive disorders.* 2013;36(3-4):154-162.
21. Lin HF, Chern CM, Chen HM, et al. Validation of NINDS-VCI Neuropsychology Protocols for Vascular Cognitive Impairment in Taiwan. *PLoS One.* 2016;11(6):e0156404.
22. Mai LM, Oczkowski W, Mackenzie G, et al. Screening for cognitive impairment in a stroke prevention clinic using the MoCA. *The Canadian journal of neurological sciences Le journal canadien des sciences neurologiques.* 2013;40(2):192-197.
23. Pendlebury ST, Welch SJ, Cuthbertson FC, Mariz J, Mehta Z, Rothwell PM. Telephone assessment of cognition after transient ischemic attack and stroke: modified telephone interview of cognitive status and telephone Montreal Cognitive Assessment versus face-to-face Montreal Cognitive Assessment and neuropsychological battery. *Stroke.* 2013;44(1):227-229.
24. Wong A, Nyenhuis D, Black SE, et al. Montreal Cognitive Assessment 5-minute protocol is a brief, valid, reliable, and feasible cognitive screen for telephone administration. *Stroke.* 2015;46(4):1059-1064.
25. Cecato JF, Martinelli JE, Izbicki R, Yassuda MS, Aprahamian I. A subtest analysis of The Montreal Cognitive Assessment (MoCA): which subtests can best discriminate between healthy controls, mild cognitive impairment and Alzheimer's disease? *Int Psychogeriatr.* 2016;28:825-32.
26. Xu X, Chan QL, Hilal S, et al. The Diagnostic Utility of the NINDS-CSN Neuropsychological Battery in Memory Clinics. *Dementia and geriatric cognitive disorders extra.* 2016;6(2):276-282.
27. Roalf DR, Moore TM, Wolk DA, et al. Defining and validating a short form Montreal Cognitive Assessment (s-MoCA) for use in neurodegenerative disease. *J Neurol Neurosurg Psychiatry.* 2016;87(12):1303-1310.
28. Wittich W, Phillips N, Nasreddine SZ, Chertkow H. Sensitivity and Specificity of the Montreal Cognitive Assessment Modified for Individuals Who Are Visually Impaired. *Journal of Visual Impairment & Blindness.* 2010;104(6):360-368.
29. Kaur D, Kumar G, Singh AK. Quick screening of cognitive function in Indian multiple sclerosis patients using Montreal cognitive assessment test-short version. *Annals of Indian Academy of Neurology.* 2013;16(4):585-589.
30. Cameron JD, Gallagher R, Pressler SJ, et al. Sensitivity and Specificity of a Five-Minute Cognitive Screening Test in Patients With Heart Failure. *Journal of cardiac failure.* 2016;22(2):99-107.
31. Lim JS, Oh MS, Lee JH, et al. Prediction of post-stroke dementia using NINDS-CSN 5-minute neuropsychology protocol in acute stroke. *Int Psychogeriatr.* 2017;29(5):777-784.
32. Freitas S, Batista S, Afonso AC, Simoes MR. The Montreal Cognitive Assessment (MoCA) as a screening test for cognitive dysfunction in multiple sclerosis. *Appl Neuropsychol Adult.* 2018;25(1):57-70.
33. Dong Y, Koay WI, Yeo LL, et al. Rapid Screening for Cognitive Impairment in Parkinson's Disease: A Pilot Study. *Parkinson's disease.* 2015;2015:348063.
34. Panenková E, Kopecek M, Lukavsky J. Item analysis and possibility to abbreviate the Montreal Cognitive Assessment. *Ceska a Slovenska Psychiatrie* 112: 63-69

35. Bocti C, Cossette P, Fulop T, Lacombe G, Létourneau C. Designing an abridged Montreal Cognitive Assessment for more efficient cognitive screening. *Alzheimer's & Dementia.* 2012;8(4):P539.
36. Dong C, Xu K, Chen C. An ultra-short cognitive screening test to detect significant post-stroke vascular cognitive impairment. Circulation; 2015.
37. Davies LM, Oczkowski W, MacKenzie G, Sahlas DJ. Detection of cognitive impairment in a stroke prevention clinic using the moca: Rationale for prospective validation of a mini-MoCA. 2nd Canadian Stroke Congress; 2011; Canada.
38. Cameron JD, Gallagher R, Pressler SJ, et al. Sensitivity and Specificity of a Five-Minute Cognitive Screening Test in Patients with Heart Failure. *Journal of Cardiac Failure.* 2016;22(2):99-107.
39. Goetz C, Coste J, Lemetayer F, et al. Item reduction based on rigorous methodological guidelines is necessary to maintain validity when shortening composite measurement scales. *Journal of clinical epidemiology.* 2013;66(7):710-718.

Table 1. Content and scoring of published, named short-form versions of Montreal Cognitive Assessment

Name of short-form MoCA	Number of test items	Description of test items included and scoring	Cut offs suggested by each paper
Abbreviated MoCA	2	Clock draw (3) Delayed recall (5) /8	Panenkova 2016: <4
NINDS-CSN 5 min protocol *T-MoCA short	3	Delayed recall (5) Fluency (1) Orientation (6) /12	Bocti 2013a: <10 Cameron 2016: <10 Dong 2015 (PD): <13 Kaur 2013: <11 Lim 2017: <7 Lin 2016: Not stated *Pendlebury 2013: <10 Xu 2016: Not stated
Mini-MoCA	3	Clock draw (3) Delayed recall (5) Abstraction (2) /10	Mai 2013: <7 Davies 2011: Not stated
SF MoCA	3	Delayed recall (5) Serial 7 (3) Orientation (6) /14	Horton 2015: <9
MoCA 5 min protocol	4	Immediate recall (5) Delayed recall (10)* Fluency (9)** Orientation (6) /30 ** 2 points for each word free recall. 1 point for cued recall/recognition* *** Animal fluency. 0.5 point for each word*	Wong 2015: <15
MoCA reduced	4	Clock draw (3) Animals (rhino) (1) Delayed recall (5)	Cecato 2016 (AD): <9

		Orientation (6) /15	
Four item mini-MoCA	4	Cube copy (1) Delayed recall (5) Serial 7 (3) Fluency (1) /10 *(paper states total is 11)*	Bocti 2012: <9
New short MoCA *Mini-MoCA	5	Trails (1) Cube copy (1) Delayed recall (5) Fluency (1) Abstraction (2) /10	Bocti 2013b: <7 Campbell 2016: <7
5 min MoCA	5	Clock draw (3) Delayed recall (5) Serial 7 (3) Fluency (1) Orientation (6) /18	Dong 2015 (stroke): <13
EM-MoCA	7	Trails (1) Cube copy (1) Clock draw (3) Delayed recall (5) Fluency (1) Abstraction (2) Orientation (6) /19	Freitas 2018: <17
MoCA reduced	7	Animals (rhino) (1) Delayed recall (5) List letters (1) Sentence repetition (2) Fluency (1) Abstraction (2) Orientation (6) /18	Cecato 2016 (MCI): <14

S-MoCA	8	Trails (1) Clock Draw (3) Animals (rhino) (1) Delayed recall (5) Serial 7 (3) Fluency (1) Abstraction (measurement) (1) Orientation (place) (1) /16	Larner 2017: <12 Roalf 2017: <12
T-MoCA *MoCA-Blind	8	Delayed recall (5) Digit span (2) List letters (1) Serial 7 (3) Sentence repetition (2) Fluency (1) Abstraction (2) Orientation (6) /22	Pendlebury 2013: <18 *Wittich 2010: <19

Table 2. Characteristics of stroke and older adults' studies included in systematic review

Study ID	Subjects (n)	Target Condition	Index Test	Setting/timing of index test post-stroke	Reference Standard	Cut-off	Sensitivity In study	Specificity In Study
Stroke								
Bocti 2013	386	CI	New Short MoCA	3 months	MoCA	<7/10	91%	83%
			NINDS-CSN 5 min protocol			<10/12	87%	74%
Campbell 2016	72	CI	Mini-MoCA	Rehab unit	Cognistat	<7/10	93%	92%
Davies 2011 (CA)	102	CI	Mini-MoCA	Stroke prevention clinic	MoCA	not reported	not reported	not reported
Dong 2015 (CA)	327	CI	5 min MoCA	3-6 months	NPB	<13/20	70%	87%
Lim 2017	308	Dementia	NINDS-CSN 5 min protocol	≤2 weeks	NPB	<7/12	82%	67%
Lin 2016	83	CI	NINDS-CSN 5 min protocol	3-18 months	MDT Consensus	<15/30	81%	55%
Mai 2013	102	CI	Mini-MoCA	Stroke prevention clinic	MoCA	<7/10	99%	78%
Pendlebury 2013	68	Multi-domain MCI	T-MoCA	>1 year post stroke	NPB	<18/22	100%	52%
			T-MoCA Short (NINDS-CSN)			<10/12	83%	48%
Wong 2015	104	CI	MoCA 5 min protocol	39 days	CDR (0.5 or 1)	<15/30	84%[a]	73%[a]
Older Adults								
Horton 2015	Derivation Group =317	AD vs MCI+HC	SF-MoCA		MDT Consensus	Unknown	95%[b]	87%[b]
	Validation Group = 91					unknown	80%[b]	95%[b]
Cecato 2016	97	AD vs MCI	Reduced MoCA		DSM IV	<8.5/18	85%	87%
Larner 2017	cohort 1:150, cohort 2:260	Dementia vs MCI	S-MoCA		DSM IV	<12/16	cohort 1:94%, cohort 2: 98%	cohort 1: 25%, cohort 2: 7%
Panenkova 2016	540	CI	Abbreviated MoCA		MoCA	<4/8	89%	64%
Roalf 2017	1850	All cause dementia vs HC	s-MoCA		DSM IV	<12/16	62%	86%
Wittich 2010	277	AD	MoCA-Blind		NPB	Absolute ≤17/22	87%	98%
Xu 2016	405	CIND, dementia	NINDS-CSN 5 min protocol		MDT Consensus	Not reported	Not reported	Not reported

[a]Data obtained through contacting authors
[b]Data obtained from ROC curve
Where multiple cut-offs were presented, we chose the optimal cut-off as specified by the author. Where various reference standards were described, we describe the comparator closest to clinical diagnosis of dementia. Full Characteristics of included studies table is available in Supplementary Table 1.

Abbreviations: CA, conference abstract; CDR, Clinical Dementia Rating; CI, Cognitive Impairment; CIND, Cognitive Impairment, no dementia; DSM, Diagnostic and Statistical Manual; HC, Healthy Control; MCI, Mild Cognitive Impairment; MDT, Multidisciplinary Team Assessment; NPB, Neuropsychological battery; NINDS-CSN, National Institute of Neurological Disorders and Stroke and the Canadian Stroke Network

Table 3. Rank correlation between individual domains of the Montreal Cognitive Assessment

	TRAILS	CUBE	CLOCK	NAMING	DIGITS	LETTERS	SUBTRACTION	REPEAT	FLUENCY	ABSTRACTION	RECALL	ORIENTATION
TRAILS	1	0.48	0.50	0.39	0.38	0.38	0.46	0.17	0.38	0.30	0.38	0..40
CUBE	0.40	1	0.46	0.31	0.30	0.28	0.35	0.14	0.29	0.35	0.36	0.31
CLOCK	0.38	0.38	1	0.53	0.46	0.44	0.54	0.27	0.43	0.31	0.45	0.51
NAMING	0.23	0.24	0.23	1	0.39	0.40	0.41	0.20	0.39	0.28	0.37	0.42
DIGITS	0.27	0.17	0.19	0.23	1	0.33	0.49	0.27	0.31	0.26	0.36	0.35
LETTERS	0.24	0.16	0.23	**0.15**	0.30	1	0.42	0.21	0.36	0.28	0.34	0.42
SUBTRACTION	0.37	0.33	0.40	0.38	0.31	0.27	1	0.22	0.44	0.30	0.38	0.51
REPEAT	0.27	0.15	0.34	**0.22**	0.36	0.23	0.26	1	0.18	0.11	0.21	0.20
FLUENCY	0.30	0.24	0.21	**0.14**	0.33	0.23	0.26	0.26	1	0.25	0.44	0.20
ABSTRACTION	0.29	0.32	0.28	0.29	0.23	0.21	0.32	0.33	0.19	1	0.31	0.27
RECALL	0.32	0.30	0.28	0.19	0.24	**0.16**	0.26	0.23	0.20	0.36	1	0.41
ORIENTATION	0.38	0.31	0.46	0.23	0.26	0.19	0.39	0.29	0.26	0.31	0.45	1

Grey cells are the stroke data and white cells are the memory clinic data. Those items where correlation was not significant at <0.0001 are in bold type

Figure 1. PRISMA flow diagram

Figure 2. Correlation and test accuracy of short forms of the Montreal Cognitive Assessment

Supplementary Appendix 1. Virtual International Stroke Trial Archive (VISTA) - Cognition Steering Committee

Supplementary Methods 1. Search syntax used across electronic databases

Supplementary Table 1. Characteristics of studies included in systematic review

Supplementary Table 2. Risk of bias and applicability concerns for papers describing short form Montreal Cognitive Assessment using the QUADAS-2 tool

Supplementary Table 3. Quality of reporting for papers describing short form Montreal Cognitive Assessment using the STARDdem tool

Supplementary Table 4. Correlation of each item with total Montreal Cognitive Assessment (MoCA) and internal consistency (Cronbach's alpha) if that item removed (Data from independent stroke and memory clinic data-sets)

Supplementary Table 5. Factor pattern for all items of Montreal Cognitive Assessment (MoCA)