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A 4-item case-finding tool to detect dementia in older persons

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Abstract

Objectives—Brief cognitive tests are recommended in clinical services outside of specialized memory clinics, as case-finding tools to reduce the diagnostic gap of dementia. Although the Montreal Cognitive Assessment (MoCA) is among the most widely-used brief tests in specialized memory clinics, its length precludes routine use in non-specialty clinics. This study investigated whether a small subset of MoCA would suffice to match the performance of the full MoCA in detecting dementia, and hence may be useful in non-specialty clinics.

Design—Cross-sectional test research.

Setting—Alzheimer's Disease Centers across USA.

Participants—Participants aged ≥65 years (n=8,773).

Measures—Participants completed MoCA and were evaluated for dementia. The study sample was split into two – the derivation sample (n=4,386) was used to develop a short-variant of MoCA that best distinguish dementia (using the best-subset-approach with tenfold-cross-validation); while the validation sample (n=4,387) verified its actual performance using area-under-the-receiver-operating-characteristic-curve (AUC).

Results—A 4-item cognitive test was identified, comprising *Clock-drawing*, *Tap-at-letter-A*, *Orientation* and *Delayed-recall.* It demonstrated excellent performance in distinguishing dementia from non-dementia (AUC 94.2%), and was comparable to that of MoCA (AUC 93.8%) even across education subgroups. It explained 85.9% of the variability in MoCA, and had scores that could be mapped to MoCA with reasonable precision. At the optimal cut-off score of <10, it demonstrated 87.9% sensitivity and 87.6% specificity in detecting dementia.

Conclusions and Implications—Using rigorous methods, this study developed a brief cognitive test that is free-of-charge, takes <5 minutes to complete, covers the key cognitive domains, and has standardized instructions to allow its administration even by non-physicians. This brief test is well-suited as a case-finding tool in non-specialty clinics (such as in primary care

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CONFLICT OF INTEREST

None declared

and geriatric clinics), and may improve care-integration with specialized memory clinics that utilize MoCA.

Brief summary

This study developed a 4-item case-finding tool which can reduce the diagnostic gap of dementia in non-specialty clinics, as well as improve care-integration with specialized memory-clinics.

Keywords

Dementia; brief cognitive test; Montreal Cognitive Assessment; score mapping

INTRODUCTION

Dementia is often underdiagnosed across the world, with at least half of the older persons with dementia in USA not receiving any formal diagnosis of the condition.[1] Consequently, many of these older persons are deprived of dementia care which can be critical to their well-being, such as those pertaining to risk factor modification, cognitive training, symptomatic treatment of the cognitive and behavioral issues, caregiver support, and longer-term care planning.[2–4] The problem of undiagnosed dementia largely stems from the current healthcare systems whereby the diagnosis of dementia is primarily made in specialized memory clinics, even though majority of the older persons with undiagnosed dementia are often seen in non-specialty clinics (such as in primary care or geriatric clinics). The problem is also related to the challenge in making the diagnosis of dementia in non-specialty clinics, with previous studies demonstrating that up to 76% of patients with dementia would have been missed by primary care clinicians when the diagnostic process was based on routine history and physical examination alone.[5] To address this diagnostic gap, the International Association of Gerontology and Geriatrics (IAGG)[6] and the Gerontological Society of America[4] have separately emphasized the need for active case-finding in clinical services outside of specialized memory clinics, to improve the detection of dementia among those at high-risk of the condition. In particular, IAGG suggested the routine administration of *brief cognitive tests* among older persons ≥70 years, considering that age has been established as the strongest risk factor for dementia.[6]

Among the available *brief cognitive tests*, the Montreal Cognitive Assessment (MoCA)[7] is one of the most widely-used in specialized memory clinics.[8] In 2015, it has also been adopted by the Alzheimer's Disease Centers across USA, in replacement of the traditionally-popular Mini-Mental State Examination (MMSE).[9] The widespread adoption of MoCA is understandable, considering its many desirable features.[10] Compared to MMSE, MoCA is freely available at www.mocatest.org, has been translated into multiple languages, includes more robust measures of visuospatial and executive function, and has better performance in detecting early cognitive impairment.[7,8] Nevertheless, MoCA is not without its limitation. Its length of administration (10–15 minutes) often precludes its routine use in non-specialty clinics which typically have limited resources for test administration, despite the large volume of older persons at high-risk of dementia in these non-specialty clinics (due to the presence of multimorbity). Although several short-variants of MoCA have been developed to reduce the administration time of MoCA,[11–17] as shown in a recent comparative study,[10] all

of these short-variants did not perform as well as the original MoCA in detecting dementia. Notably, these short-variants can be especially limited by ceiling effects among those with higher educational attainment, with area under the receiver operating characteristic curve (AUC) of 88.9–91.0% which are significantly worse than that of MoCA (92.3%) in detecting dementia. While a 2–3% difference in AUC can appear marginal, they may not be inconsequential when used for case-finding purposes in a large population of patients. AUC estimates the probability of correctly discriminating cases (dementia) from controls (non-dementia) when a test is presented with pairs of case–control. Hence, when a test is intended for use in a large population (say, with one million people), a 2–3% difference in AUC will translate into an additional 20,000–30,000 people being misclassified with either dementia or non-dementia. Moreover, the prior short-variants of MoCA have also not been compared to, or shown to be better in performance than the other known case-finding tools, such as the Memory Impairment Screen,[18] Mini-Cog[19] and GPCOG[20] which have been recommended by the Gerontological Society of America for routine use in non-specialty clinics.[4]

This study aimed to develop a short-variant of MoCA (denoted as MoCA-Brief) that can rival the performance of the widely-used MoCA in detecting dementia, but is much shorter in length and better-suited for use outside of specialized memory clinics. Using a large sample and a newer, computationally-intensive method, this study sought to:

1. identify items in MoCA that have high utility in detecting dementia;
2. derive the new MoCA-Brief that can maintain the performance of MoCA, as well as has demonstrably better performance than the other brief case-finding tools;
3. verify that the scores of MoCA-Brief can be accurately mapped to those of MoCA, and hence are comparable to those of MoCA.

METHOD

Study population

This is a cross-sectional test research to distinguish between dementia and non-dementia. It involved participants recruited consecutively from the Alzheimer's Disease Centers across USA between September 2005 and May 2018, as available in the National Alzheimer's Coordinating Center (NACC) database.[21] The study included older participants who fulfilled the following criteria: (1) age ≥65 years; and (2) completed MoCA. Research using the NACC database was approved by the University of Washington Institutional Review Board.

Measures and diagnosis

MoCA comprises 13 individual tests which evaluate the cognitive performance across six different domains, namely Visuospatial/Executive, Language, Attention, Abstraction, Memory and Orientation. The test has a maximum score of 30 with higher scores corresponding to better cognition. MoCA was only introduced in the NACC database from March 2015 onwards, and hence was only available for participants who were in the NACC database since then.

The clinical diagnosis of dementia was made using the McKhann (2011) criteria,[22] based on findings from clinical history, physical examination and detailed neuropsychological testing. The detailed neuropsychological testing included 11 cognitive tests[9] which evaluated the domains of immediate memory (*Craft Story 21 Immediate Recall*),[23] visuospatial abilities (*Benson Complex Figure Copy*),[24] delayed memory (*Craft Story 21 Delayed Recall*[23] and *Benson Complex Figure Recall*),[24] language (*Multilingual Naming Test*,[25] *Verbal Fluency–Animal* and *Verbal Fluency–L-words*), attention (*Number Span Test Forward* and *Number Span Test Backward*), processing speed (*Trail Making Test Part A*) and executive function (*Trail Making Test Part B*).

Participants without dementia were further differentiated into normal cognition or mild cognitive impairment (MCI), with MCI diagnosed using modified Petersen criteria.[26] Most of the clinical diagnoses (82.6%) were made via consensus conference, with the remainder made by single clinicians.

Statistical analyses

The study samples were randomly split into two equal-halves (*derivation sample* and *validation sample*) – the *derivation sample* was used to develop a brief cognitive test that can best distinguish dementia from non-dementia, while the *validation sample* was used to evaluate the actual performance of this brief cognitive test in distinguishing dementia from non-dementia.

In the *derivation sample*, the best-subset approach[27] with tenfold cross-validation was employed to select items in the original MoCA which can best distinguish dementia from non-dementia. The best-subset approach has previously been shown to be an efficient method to derive brief tools that can have fewest items possible while maintaining their usefulness for routine clinical use.[28–30] It is a computationally-intensive method of variable selection[31] – using logistic regression to exhaustively evaluate all possible combinations of the test items from MoCA, and narrowing down to a list of top models that have the lowest prediction errors. Tenfold cross-validation was then conducted to identify the best model from this list of top models. Tenfold cross-validation is one of the recommended methods to avoid selecting models which are overfitted, and ensures that the identified model is replicable even in other independent samples.[31] It randomly divides the sample into 10 folds of equal size, cross-validates the prediction error within the 10 folds, and selects the most parsimonious model which is within one standard-error of the best model (commonly described as the ‘one-standard-error’ rule).[31] The best model, as identified through tenfold cross-validation, would then constitute the new, brief cognitive test (denoted as MoCA-Brief).

In the *validation sample*, AUC was computed to assess the actual performance of MoCA-Brief in distinguishing dementia from non-dementia, with the analyses further stratified by the education subgroups (≤12 years of education; and >12 years of education). AUC of MoCA-Brief were then compared to that of the original MoCA via a non-parametric approach proposed by DeLong et al,[32] to determine whether the AUC were significant different from those of the original MoCA. To contrast with the main results, we also included the prior short-variants of MoCA (which are shown in Supplementary Material 1

for reference purposes) as well as three known case-finding tools (Memory Impairment Screen,[18] Mini-Cog[19] and GPCOG)[20] in the comparison analyses with the original MoCA. Memory Impairment Screen, Mini-Cog and GPCOG were included in the analyses because they are the three brief cognitive tests which have been recommended by the Gerontological Society of America for case-finding purposes in nonspecialty clinics.[4] As these three brief tests had not been directly captured in the NACC database, their scores were approximated based on items from the original MoCA (the methods used to approximate the scores are presented in Supplementary Material 2). In the *validation sample*, three sensitivity analyses were also conducted to evaluate the performance of MoCA-Brief in distinguishing:

1. MCI and dementia from normal cognition;
2. dementia from MCI;
3. MCI from normal cognition.

In the *full sample*, the total scores of MoCA-Brief were further mapped to those of MoCA to demonstrate the comparability between MoCA-Brief and MoCA. The score mapping was conducted using the equipercentile equating method with log-linear smoothing.[33] Equipercentile equating is a non-parametric method to provide equivalent scores from one cognitive test to another on the basis of their corresponding percentile rankings.[34] Log-linear smoothing was applied to avoid an irregular distribution of the scores. The 95% confidence intervals (CI) of the mapped-scores were computed using 10,000 bootstrap samples.

Best-subset approach[27] and score-mapping[33] were performed in R (version 3.5.1), using the 'bestglm'[27] and the 'equate'[33] packages respectively. The other analyses were conducted in Stata (version 14).

RESULTS

A total of 8,773 participants were included in this study. The flow diagram related to participant selection is shown in Supplementary Material 3, while the participant characteristics are presented in Table 1. The participants had a mean age of 76.0 years and a mean education of 16.0 years. Among the participants, 23.3% had dementia, 21.0% had MCI and 55.7% had normal cognition.

In the *derivation sample* (n=4,386), the exhaustive search method identified a list of top models which are presented in Table 2. *Orientation* was the most useful test item in detecting dementia, followed by *Delayed-recall* and *Clock-drawing*; while *Digit-span* and *Trail-making* were among the less useful. Following tenfold cross-validation, the model with 4 items were identified as being the most parsimonious among the top models (Supplementary Material 4), and were then selected to constitute the new, brief cognitive test (MoCA-Brief). It included the following 4 items from the original MoCA: (1) ***Clock-drawing***; (2) ***Tap-at-letter-A***; (3) ***Orientation***; and (4) ***Delayed-recall***.

In the *validation sample* (n=4,387), the new MoCA-Brief had excellent performance in distinguishing dementia from non-dementia (AUC 94.2%), which was not significantly different (p=1.000) from that of MoCA (AUC 93.8%). Table 3 compares the performance of

the various brief tests to that of the original MoCA, stratified by educational attainment. Notably, among participants with >12 years of education, MoCA-Brief was the only brief test that had comparable performance (AUC 94.0%) to MoCA (AUC 94.5%); while the other brief tests had relatively lower performance (AUC 87.8–93.5%) than MoCA, albeit by a small margin. The detailed results on the sensitivity and specificity statistics of MoCA-Brief are presented in Table 4. MoCA-Brief had 88.2% sensitivity and 85.9% specificity at its optimal cut-off score of <10 (out of the maximum score of 15). The sensitivity and specificity remained similar even across education subgroups, although participants with ≤12 years of education had the optimal cut-off score which was one point lower (<9).

In the three sensitivity analyses, MoCA-Brief consistently maintained the performances which were comparable to those of MoCA, even across educational subgroups (the AUC statistics are presented in Supplementary Material 5 to 7; while the sensitivity and specificity statistics are presented in Supplementary Material 8 to 10). In particular, MoCA-Brief demonstrated comparable performance to MoCA in distinguishing MCI and dementia from normal cognition (AUC of 89.1% for MoCA-Brief, and 89.2% for MoCA) (Supplementary Material 5). At the optimal cut-off score of <12, MoCA-Brief had 83.3% sensitivity and 79.0% specificity in identifying MCI and dementia (Supplementary Material 8).

In the full sample (n=8,773), MoCA-Brief was further mapped in its total score to that of the original MoCA. Despite being much briefer, the 4-item MoCA-Brief still explained 85.9% of variance in the original MoCA (based on the results from R-squared), and had scores that can be mapped to those of MoCA with a precision of approximately ±1 in the 95% CI. The conversion table between MoCA-Brief and MoCA is further presented in Table 5.

DISCUSSION

Summary of findings

This study developed a 4-item, brief cognitive test based on rigorous methods – using a large sample (n=8,773); utilizing an exhaustive-search approach to identify test items that are most useful for detecting dementia (from the widely-used MoCA); and following the well-established processes of derivation, cross-validation and independent validation. As a result, the new MoCA-Brief (comprising *Clock-drawing*, *Tap-at-letter-A*, *Orientation* and *Delayed-recall*) demonstrated excellent performance in distinguishing dementia from non-dementia. Despite its brevity, this 4-item MoCA-Brief still inherited the key properties of the original MoCA – it had comparable performance to MoCA even across education subgroups; explained most of the variability in MoCA; and had scores which can be mapped to MoCA with reasonable precision. It had good sensitivity and specificity to distinguish dementia from non-dementia at the optimal cut-off score of <10 (out of the maximum score of 15), and can also be as useful to distinguish MCI and dementia from normal cognition at the optimal cut-off score of <12.

Interpretation of findings

Although many of the brief tests demonstrated comparable performance to MoCA among the participants with lower educational attainment, their performance was relatively lower

among participants with higher educational attainment. Such finding is understandable because brief tests have fewer test items to detect more subtle decline in cognition, and hence may be limited by ceiling effects among those with better cognitive function. This finding has similarly been demonstrated in another recent study,[10] and suggests that the choice of brief tests may be more critical in older persons with higher education compared to their counterparts with lower educational attainment. The finding can have research implications, highlighting the need for future studies to validate the performance of brief cognitive tests among highly educated individuals and to rule out any ceiling effect that may potentially limit the utility of brief cognitive tests.

Among the test items in the original MoCA, this study identified several of them which can be more useful in the detection of dementia (Table 2), including *Orientation*, *Delayed-recall* and *Clock-drawing*. Such findings are not inconsistent with extant literature, with available brief case-finding tools often comprising some or most of these items – For example, the Memory Impairment Screen[18] comprises *Delayed-recall*; while the Mini-Cog[19] comprises *Delayed-recall* and *Clock-drawing*; and the GPCOG[20] comprises *Delayed-recall*, *Clock-drawing* and *Orientation*. While these brief tools primarily concentrate on the top three items in Table 2, the current study suggested that the addition of another item (Attention – *Tap-at-letter-A*) can noticeably improve the performance in detecting dementia (as shown in Table 3). Notwithstanding this finding, further studies are needed to directly compare these known brief tools with MoCA-Brief, considering that the three brief tools had not been directly captured in the current study and that their results were based on scores approximated from items in the original MoCA. In particular, future research should conduct such comparisons among those with higher education, in the light of current findings on the prominent ceiling effects of brief cognitive tests in this group of individuals.

Potential clinical implications

MoCA-Brief fulfilled many of the desirable features of brief cognitive tests as described in the consensus guideline by the Gerontological Society of America.[4] It is free-of-charge, takes <5 minutes to complete and covers the key cognitive domains that are germane to the diagnosis of dementia (including Visuospatial/Excutive function, Attention, Orientation and Memory), which makes MoCA-Brief a potentially useful tool to narrow the diagnostic gap of dementia in clinical services outside of specialized memory clinics (such as in primary care and geriatric clinics). As MoCA-Brief was developed from the well-established MoCA, its test items already have clearly-prescribed and standardized instructions that can be easily followed (available at www.mocatest.org), and may potentially be administered even by trained non-physicians in clinical services. Equally pertinent, the scores of MoCA-Brief can be easily mapped to that of MoCA (using the conversion table as shown in Table 5), which can improve the integration of care between non-specialty clinics (that utilize MoCA-Brief) and specialized memory clinics (that not-uncommonly utilize MoCA). The MoCA-Brief scores from non-specialty clinics can then be captured as the baseline scores by specialist memory clinics, and used as the reference points to substantiate the subsequent development of cognitive decline.

Limitations

Several limitations should be considered. First, although the Alzheimer's Disease Centers have the strength of providing rigorous diagnoses, their participants are based on those who volunteered and may not necessarily be similar to patients in other healthcare settings. As such, the findings from this study will benefit from further validation in naturalistic settings to confirm the usefulness of MoCA-Brief, especially in non-specialty clinics where MoCA-Brief is likely to be used. Second, the MoCA-Brief in this study was administered as part of the original MoCA. Future research is needed to validate whether MoCA-Brief, when administered alone, will maintain similar performance to what have been reported in this study. Third, MoCA-Brief has fewer test items than the original MoCA, which may potentially lead to a shorter *time gap* between the word list registration and the recall task. Future research is needed to evaluate whether a shorter *time gap* would have sufficed to maintain the overall performance of MoCA-Brief, or whether it is still necessary to keep to a time gap of at least 5 to 10 minutes before administering the recall task in MoCA-Brief (similar to that in the original MoCA). This can have implications to clinical practice, considering that a shorter *time gap* may potentially be more feasible, as well as more likely to be adopted, in non-tertiary clinics with high volume of older patients. Fourth, majority of the participants were highly educated, with an average education of 16 years. This limitation was addressed by further stratifying the results by educational attainment, which also demonstrated that the choice of brief tests was less consequential among those with lower educational attainment. Fifth, in a small proportion of the participants (17.4%), the diagnoses of cognitive impairment were made primarily by single clinicians. They may not necessarily be as accurate as those made via consensus conference. Sixth, as the other case-finding tools (Memory Impairment Screen, Mini-Cog and GPCOG) were not directly captured in the NACC database, their approximated scores were used (based on responses from the original MoCA) to provide an indication of their performance in the current cohort of participants. As there can be differences in the test administration between these case-finding tools and MoCA, the approximated scores may not fully reflect the actual test scores and hence this part of the results should only be treated as exploratory. Seventh, MoCA or MoCA-Brief may not perform as well in distinguishing between normal cognition and MCI (as seen in Supplementary Material 7), which conventionally is assessed using detailed neuropsychological assessments and is not an expected strength of brief cognitive tests. As such, brief cognitive tests such as MoCA or MoCA-Brief may not be the appropriate substitutes for detailed neuropsychological assessments in the context of diagnostic uncertainties related to differentiating between normal cognition and MCI.

CONCLUSIONS AND IMPLICATIONS

Using rigorous methods, this study developed a 4-item brief cognitive test that is free-of-charge, takes <5 minutes to complete, covers the key cognitive domains that are material to the diagnosis of dementia, and has standardized instructions to allow its administration even by non-physicians. This brief test is well-suited as a case-finding tool to reduce the diagnostic gap of dementia in non-specialty clinics, such as in primary care and geriatric clinics. It has comparable performance to MoCA (which is an assessment tool often used in

many of the memory clinics), and has scores that can be mapped to MoCA to facilitate integration with specialized memory clinics that utilize the full version of MoCA.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Table 1.

Characteristics of the study participants (n=8,773)

Variable	Overall sample (n=8,773)	Derivation sample (n=4,386)	Validation sample (n=4,387)
Age, mean (SD)	76.0 (7.2)	75.7 (7.1)	76.2 (7.2)
Female sex, n (%)	5,043 (57.5)	2,503 (57.1)	2,540 (57.9)
Years of education, mean (SD)	16.0 (3.0)	16.0 (3.0)	16.0 (2.9)
Ethnicity, n (%)			
White	7,202 (82.1)	3,599 (82.1)	3,603 (82.1)
African American	1,063 (12.1)	538 (12.3)	525 (12.0)
Others/Unknown	508 (5.8)	249 (5.7)	259 (5.9)
MoCA total score, mean (SD)	22.5 (6.1)	22.5 (6.1)	22.5 (6.0)
Diagnosis, n (%)			
Dementia	2,042 (23.3)	1,005 (22.9)	1,037 (23.6)
Mild cognitive impairment	1,845 (21.0)	942 (21.5)	903 (20.6)
Normal cognition	4,886 (55.7)	2,439 (55.6)	2,447 (55.8)

SD, standard deviation; MoCA, Monteral Cognitive Assessment.

Table 2.

Items in the original MoCA, and the top models which best discriminate dementia from non-dementia (as identified by the best-subset approach) in the derivation sample (n=4,386).

Items in the original MoCA, *rearranged* by their usefulness in detecting dementia [a]	**Number of items in the top models**												
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
13. Orientation	●	●	●	●	●	●	●	●	●	●	●	●	●
12. Memory – Delayed-recall		●	●	●	●	●	●	●	●	●	●	●	●
3. Visuospatial/Executive – Clock-drawing			●	●	●	●	●	●	●	●	●	●	●
7. Attention – Tap-at-letter-A				●	●	●	●	●	●	●	●	●	●
5. Memory – Registration					●	●	●	●	●	●	●	●	●
10. Language – Fluency						●	●	●	●	●	●	●	●
8. Attention – Serial 7s							●	●	●	●	●	●	●
4. Language – Naming								●	●	●	●	●	●
11. Abstraction									●	●	●	●	●
9. Language – Repetition										●	●	●	●
2. Visuospatial/Executive – Cube-copying											●	●	●
6. Attention – Digit-span												●	●
1. Visuospatial/Executive – Trail-making													●

MoCA, Montreal Cognitive Assessment.

[a] the numbering in the first column reflects the item sequence in the original MoCA.

Table 3.

Performance of MoCA-Brief in distinguishing dementia from non-dementia in the validation sample (n=4,387), and a comparison with the performance of the original MoCA. Prior short-variants of MoCA and three known case-finding tools (MIS, Mini-Cog and GPCOG) were also included in the comparison with the original MoCA.

Cognitive tests	All education subgroups		<12 years of education		>12 years of education	
	AUC, % (95% CI)	P-value [a]	AUC, % (95% CI)	P-value [a]	AUC, % (95% CI)	P-value [a]
Original MoCA	93.8 (93.0–94.6)	Ref	91.1 (88.9–93.3)	Ref	94.5 (93.6–95.4)	Ref
MoCA-Brief [b]	94.2 (93.3–95.1)	1.000	94.9 (93.2–96.7)	**<0.001**	94.0 (93.0–95.0)	0.997
Prior short-variants of MoCA [c]						
Mai 2013	91.4 (90.4–92.3)	**<0.001**	89.1 (86.7–91.4)	0.123	91.7 (90.6–92.7)	**<0.001**
Horton 2015	93.4 (92.5–94.3)	1.000	93.5 (91.5–95.5)	**0.014**	93.4 (92.3–94.4)	**0.006**
Dong 2016	93.6 (92.8–94.5)	1.000	94.3 (92.5–96.1)	**<0.001**	93.4 (92.4–94.4)	**0.016**
Wong 2015	93.3 (92.4–94.1)	0.956	91.4 (89.2–93.5)	1.000	93.5 (92.6–94.5)	**0.034**
Bocti 2013	90.9 (90.0–91.8)	**<0.001**	87.3 (84.8–89.8)	**<0.001**	91.5 (90.5–92.5)	**<0.001**
Bezdicek 2018	91.9 (91.0–92.8)	**<0.001**	87.2 (84.6–89.8)	**<0.001**	92.9 (92.0–93.9)	**<0.001**
Roalf 2016	92.7 (91.8–93.5)	**<0.001**	89.3 (86.9–91.7)	**0.008**	93.4 (92.4–94.3)	**<0.001**
Other case-finding tools (approximated scores) [a]						
MIS	89.4 (88.3–90.4)	**<0.001**	88.0 (85.5–90.5)	0.097	89.4 (88.2–90.6)	**<0.001**
Mini-Cog	87.6 (86.5–88.7)	**<0.001**	85.3 (82.5–88.0)	**<0.001**	87.8 (86.6–89.0)	**<0.001**
GPCOG	92.3 (91.4–93.3)	**<0.001**	92.6 (90.6–94.6)	0.563	92.1 (91.1–93.2)	**<0.001**

MoCA, Montreal Cognitive Assessment; MoCA-Brief, Montreal Cognitive Assessment–Brief version; MIS, Memory Impairment Screen; GPCOG, General Practitioner Assessment of Cognition; AUC, area under the receiver operating characteristics curve; CI, confidence interval; Ref, reference.

[a] Bonferroni-adjusted p-values in the comparisons of AUC between the original MoCA and the respective brief tests. Bold-faced p-values are ≤0.05 and indicate that the AUC of the respective brief tests were significantly different from that of the original MoCA.

[b] MoCA-Brief included 4 items from the original MoCA, namely *Clock-drawing*, *Tap-at-letter-A*, *Orientation* and *Delayed-recall*.

[c] Items in the respective short-variants of MoCA are presented in Supplementary Material 1.

[d] As these other known case-finding tools had not been directly captured in the NACC database, their scores were approximated based on items from the original MoCA (the methods used to approximate the scores are presented in Supplementary Material 2).

Table 4.

The sensitivity and specificity of MoCA-Brief in identifying the diagnosis of dementia in the validation sample (n=4,387). Bold-faced values indicate the sensitivity and specificity at the optimal cut-off scores.

Cut-off score	All education subgroups		≤12 years of education		>12 years of education	
	Se, %	Sp, %	Se, %	Sp, %	Se, %	Sp, %
< 7	52.5	99.3	63.1	98.7	49.3	99.4
< 8	65.8	97.6	76.4	96.4	62.6	97.8
< 9	79.3	93.8	**88.8**	**88.6**	76.4	94.7
< 10	**87.9**	**87.6**	94.2	80.3	**85.9**	**88.9**
< 11	93.3	77.9	96.3	65.0	92.3	80.0
< 12	96.0	66.1	97.9	50.2	95.4	68.7
< 13	97.5	50.4	98.8	32.6	97.1	53.3
< 14	98.7	31.1	99.2	16.7	98.5	33.5
< 15	99.6	13.3	100.0	5.5	99.5	14.6

Se, sensitivity; Sp, specificity.

Table 5.

Equivalent MoCA score for a given MoCA-Brief score, as derived based on the equipercentile equating method.

MoCA-Brief	Equivalent MoCA (95% CI)
0	2 (2–3)
1	4 (4–5)
2	6 (5–7)
3	8 (7–9)
4	10 (10–11)
5	12 (12–13)
6	15 (14–15)
7	17 (16–17)
8	19 (18–19)
9	20 (20–20)
10	22 (21–22)
11	23 (23–23)
12	25 (25–25)
13	26 (26–26)
14	28 (28–28)
15	29 (29–29)

MoCA, Montreal Cognitive Assessment; MoCA-Brief, Montreal Cognitive Assessment–Brief version; CI, confidence interval.