RESEARCH ARTICLE

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A re-examination of Montreal Cognitive Assessment (MoCA) cutoff scores

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Objective: The Montreal Cognitive Assessment (MoCA; Nasreddine *et al.*, 2005) is a cognitive screening tool that aims to differentiate healthy cognitive aging from Mild Cognitive Impairment (MCI). Several validation studies have been conducted on the MoCA, in a variety of clinical populations. Some studies have indicated that the originally suggested cutoff score of 26/30 leads to an inflated rate of false positives, particularly for those of older age and/or lower education. We conducted a systematic review and meta-analysis of the literature to determine the diagnostic accuracy of the MoCA for differentiating healthy cognitive aging from possible MCI.

Methods: Of the 304 studies identified, nine met inclusion criteria for the meta-analysis. These studies were assessed across a range of cutoff scores to determine the respective sensitivities, specificities, positive and negative predictive accuracies, likelihood ratios for positive and negative results, classification accuracies, and Youden indices.

Results: Meta-analysis revealed a cutoff score of 23/30 yielded the best diagnostic accuracy across a range of parameters.

Conclusions: A MoCA cutoff score of 23, rather than the initially recommended score of 26, lowers the false positive rate and shows overall better diagnostic accuracy. We recommend the use of this cutoff score going forward. Copyright © 2017 John Wiley & Sons, Ltd.

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Brief screening measures are commonly used to detect cognitive impairment in a range of clinical settings, including primary care (Iracleous *et al.*, 2010). An important aim of cognitive screening measures is to differentiate cognitive changes that are considered to be "normal" with aging from those that represent impairment. Mild Cognitive Impairment (MCI) is a condition characterized by cognitive changes greater than would be expected with normal aging, but that do not significantly impact functional independence. Mild Cognitive Impairment is considered a transitional stage preceding the development of dementia (Petersen *et al.*, 1999, Petersen, 2004).

The Mini-Mental State Exam (MMSE; Folstein *et al.*, 1975) is the most commonly used cognitive screening test (Ismail *et al.*, 2010; Mitchell, 2009; Shulman *et al.*, 2006). The Montreal Cognitive Assessment (MoCA; Nasreddine *et al.*, 2005) is a more recently developed cognitive screen that targets the differentiation between normal aging and MCI and has gained worldwide traction among healthcare professionals. Nasreddine *et al.* found the MoCA showed higher sensitivity for detecting MCI than the MMSE (.90 MoCA versus .18 MMSE) and acceptable specificity for the MoCA, albeit lower than the MMSE (.87 MoCA vs. 1.00 MMSE).

The MoCA test is straightforward to administer and easy to access (downloaded without cost from www.mocatest.org; Nasreddine, 2016). It is scored out of 30 points, with higher scores reflecting better performance. The MoCA examines the following cognitive abilities: visuospatial/executive function, naming, episodic memory, attention, language, abstraction, and orientation. Nasreddine *et al.* (2005) suggested a cutoff score of 26, with those scoring 25 or below suspected of having MCI. They also determined one point should be added to the total score to correct for the influence of education for individuals with 12 or fewer years of formal education.

The MoCA is widely used, with the current website listing 61 language variations of the test. Additionally, the test has been adapted for those with sensory loss that preclude standard MoCA screening, such as individuals with visual impairment (Wittich *et al.*, 2010). MoCA administration facilitates screening for cognitive function in primary care, where due to time constraints and limited options of referral to tertiary care, more extensive cognitive testing may not be available. Administration of the MoCA takes approximately 10 min, although abbreviated versions have been created in order to reduce administration time (e.g., Horton *et al.*, 2015; Larner, 2017; Roalf *et al.*, 2016).

The accessibility of the MoCA has facilitated a large number of studies investigating the diagnostic abilities of the test. The majority of studies report findings consistent with Nasreddine *et al.* (2005) showing the MoCA provides higher diagnostic accuracy for the detection of MCI than the MMSE (e.g. Dalrymple-Alford *et al.*, 2010; Damian *et al.*, 2011; Dong *et al.*, 2012; Freitas *et al.*, 2013; Larner, 2012; Markwick *et al.*, 2012; Tsai *et al.*, 2012). However, some studies have revealed that the originally recommended cutoff score of 26 leads to a higher rate of false-positives than found in Nasreddine *et al.*'s original study (Ahmed *et al.*, 2012; Cumming *et al.*, 2013; Freitas *et al.*, 2013; Kaya *et al.*, 2014; Lee *et al.*, 2008; Luis *et al.*, 2009; Memória *et al.*, 2013; McLennan *et al.*, 2011; Roalf *et al.*, 2013; Rossetti *et al.*, 2011; Tsai *et al.*, 2012). Indeed, our interest in the MoCA cutoff score was prompted by a discovery, in an unrelated normal aging study, in which we found eight of 24 older adult participants scored below the recommended cutoff (range 21–25) and yet scored within age and education expectations on a battery of standardized neuropsychological measures.

As previously noted, Nasreddine *et al.* (2005) reported an influence of education on the overall MoCA score. Others have shown that education along with age can impact the score (Freitas *et al.*, 2012a; Rossetti *et al.*, 2011; Larouche *et al.*, 2016); therefore, using a cutoff score as high as 26 particularly increases the risk of false positive results for those of older age and/or lower education (Malek-Ahmadi *et al.*, 2015). In fact, the recommended 1-point correction for individuals with ≤12 years of education has been debated as insufficient to compensate for educational differences (Malek-Ahmadi *et al.*, 2015) and in one study, contributed to a decrease in the sensitivity of the test (Gagnon *et al.*, 2013).

Defining a single, optimal MoCA cutoff score from the large number of validation studies is further limited by the fact that the majority of studies have been conducted in specific patient populations, such as those with cerebrovascular conditions (e.g., Cumming *et al.*, 2013; Dong *et al.*, 2010, 2012; Freitas *et al.*, 2012b; Godefroy *et al.*, 2011; Pendlebury *et al.*, 2012, 2013; Webb *et al.*, 2014; Wong, Lam, *et al.*, 2013a) cardiovascular conditions (Hawkins *et al.*, 2014; McLennan *et al.*, 2011), Parkinson's disease (e.g., Chen *et al.*, 2013; Dalrymple-Alford *et al.*, 2010; Gill *et al.*, 2008; Hoops *et al.*, 2009; Kasten *et al.*, 2010; Krishnan *et al.*, 2015; Ozdilek & Kenangil, 2014; Sobreira *et al.*, 2015), HIV (Koski *et al.*, 2011; Milanini *et al.*, 2014; Janssen *et al.*, 2015; Joska *et al.*, 2016; Overton *et al.*, 2013), Traumatic Brain Injury (Wong, Ngai, *et al.*, 2013b), psychiatric conditions (Gierus *et al.*, 2015; Musso *et al.*, 2014), Huntington disease (Bezdicek *et al.*, 2013), and Korsokoff syndrome (Oudman *et al.*, 2014; Wester *et al.*, 2013).

The original sample described in Nasreddine *et al.* (2005) was more homogeneous, with inclusion criteria for those with MCI specifying "the absence of obvious medical, neurological, or psychiatric explanation for the memory loss (with the exception of mild depression)" (p. 696). There has been little subsequent examination of the MoCA in similar samples without numerous comorbidities.

The current investigation used meta-analysis of MoCA validation studies to statistically determine the optimal cutoff score for differentiating normal aging from MCI. Included studies had samples similar to the original Nasreddine *et al.* (2005) article, in that they were without major medical, neurological, and psychiatric comorbidities.

Methods

Literature search

A systematic literature search for scholarly journal articles was conducted using databases PsycINFO

(1966 – April 2017), PubMed (1966 – April 2017), Web of Science (1900 – April 2017), and Embase (1974 – April 2017). The search strategy included the following: (Montreal Cognitive Assessment OR MoCA) AND (Mild Cognitive Impairment OR MCI OR Mild Neurocognitive Disorder) AND (sensitivity OR specificity OR accuracy OR screening OR validity OR diagnostic). Following deduplication, the initial search yielded 304 results.

Inclusion/exclusion criteria

Only diagnostic validity studies examining the ability of the MoCA to distinguish cognitively healthy individuals (controls) from those with MCI were included in the meta-analysis. Studies diagnosed MCI according to Petersen *et al.* (1999, 2001, 2004) criteria. These include (i) subjective memory complaint (or cognitive complaint, as per Petersen 2004 criteria), preferably corroborated by informant; (ii) impaired memory (or impairment in other cognitive domain(s)) for age and education level; (iii) preserved general cognitive function; (iv) functional independence in instrumental activities of daily living; (v) no evidence of dementia. Studies that diagnosed MCI according to updated National Institute on Aging-Alzheimer's Association criteria (Albert *et al.*, 2011) were also eligible; however, none of these studies were included in the final meta-analysis, as they failed to meet other inclusion criteria.

Studies with either single-domain or multi-domain MCI participants (amnestic and non-amnestic) were included in the meta-analysis. Study groups of normal controls and individuals diagnosed with MCI were required to be well defined according to neuropsychological findings and clinical judgment. Results must have been presented separately for each group, with the number of individuals in each group explicitly stated, and the mean years of education in each group specified. Diagnoses of normal aging versus MCI must have been made independently of MoCA performance. The sensitivity and specificity associated with at least one cutoff point differentiating normal controls from MCI must have been reported. Finally, included studies must have corrected for education (as recommended in Nasreddine *et al.* 2005). In cases where any of these criteria were not explicitly stated in the article (and where no exclusion criteria were met), corresponding authors were contacted to verify that inclusion criteria were met. Language of MoCA administration was not considered a factor for study inclusion/exclusion. Only published articles were included in the meta-analysis. The quality of each study included in the meta-analysis was evaluated according to the Standards for Reporting of Diagnostic Accuracy (STARD) criteria (Bossuyt *et al.*, 2003), which have been further specified by Noel-Storr *et al.* (2014) to include issues pertinent to diagnostic accuracy studies relating to dementia and cognitive impairment (STARDdem).

Studies were excluded from the analysis if they investigated the MoCA in specific patient populations with known medical problems (e.g., cerebrovascular, cardiovascular). Other exclusion criteria included: lack of a distinct normal control group free of psychiatric, neurological, or medical comorbidities, groups not well-defined in the presentation of results (e.g. MCI and dementia groups combined as a "cognitively impaired group"), and diagnosis based on non-standardized neuropsychological tests.

Results of search

Abstracts of the 304 articles identified by the literature search were appraised to determine which papers warranted further investigation. Figure 1 depicts the literature search through a flow chart. Nine studies were confirmed to meet criteria for inclusion in the meta-analysis (see Table 1 for details).

Statistical analysis

Data extracted from each study included the sample sizes of healthy individuals, and of individuals with MCI, the *sensitivity* (proportion of individuals diagnosed with MCI who tested positive on the MoCA) and *specificity* (proportion of individuals indicated as normal controls who tested negative on the MoCA) for each cutoff point provided in each article. From this data, the following calculations (see Appendix A for equations) were made for each cutoff provided in each of the included studies: *true positives*, *true negatives*, *false positives*, and *false negatives*, as well as *Positive Predictive Accuracy (PPA)*, the proportion of individuals who test positive on the MoCA who are diagnosed with MCI, *Negative Predictive Accuracy (NPA),* the proportion of individuals who test negative on the MoCA who are diagnosed as healthy, and *prevalence*, the proportion of individuals diagnosed with MCI in the overall sample.

Likelihood ratios were also calculated for each cutoff point. The *Likelihood Ratio for Positive Result (LRPR)* represents the odds that an individual who is diagnosed with MCI will test positively on the MoCA compared to the odds that a healthy control will test positively. The *Likelihood Ratio for Negative Result (LRNR)* represents the odds that an individual diagnosed with MCI will test negatively on the MoCA compared to the odds that a healthy control will test negatively. Likelihood ratios that are greater than 10 or less than 0.1 have the greatest influence on the post-test probability of a disease (Hawkins, 2005, Jaeschke, Guyatt & Sackett, 1994).

Further calculations included *classification accuracy*, the proportion of individuals classified accurately as healthy control or MCI by the MoCA, *chi square,* to determine the association between categorical assignment, *phi*, a measure of binomial effect size, and *Youden index*, an estimate of the optimal threshold at which true positives (sensitivity) are maximized and false positives (1 − specificity) are minimized, uninfluenced by prevalence rates (Fluss *et al.*, 2005; Youden, 1950). After obtaining each measure listed earlier, data were aggregated across studies according to cutoff point. Diagnostic accuracy was examined at each MoCA cutoff score by evaluating the following parameters: sensitivity,

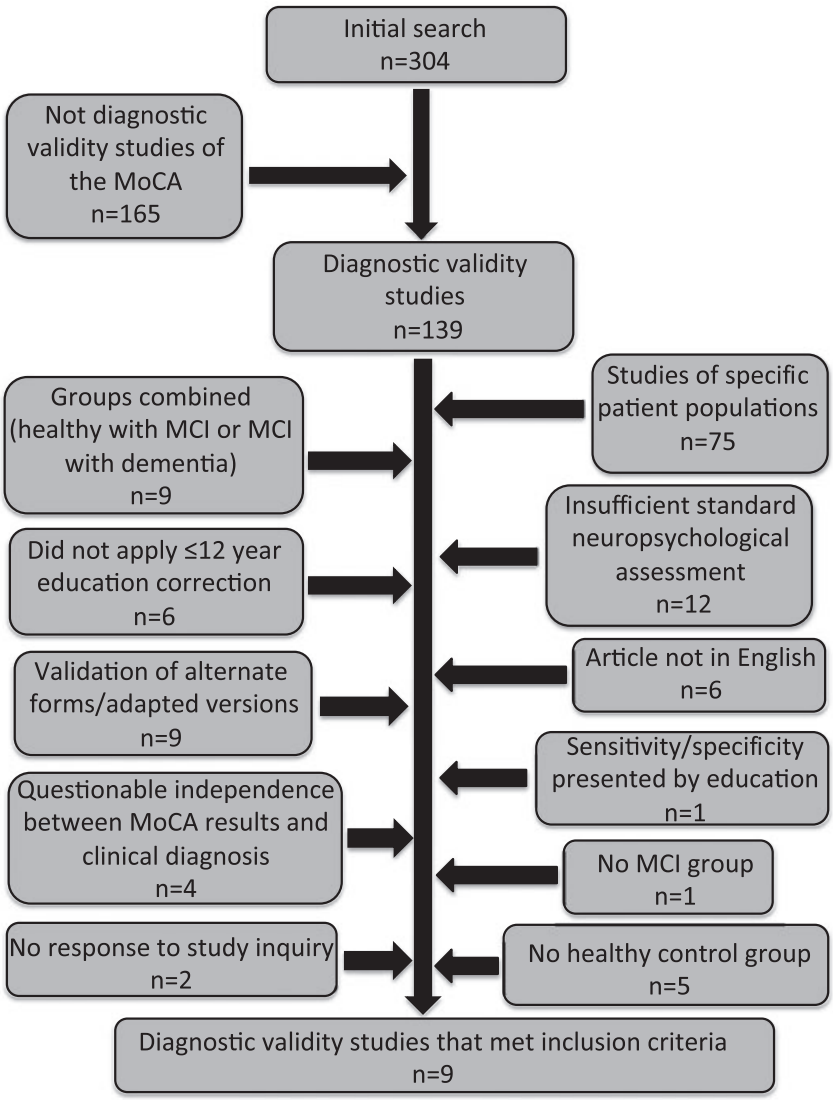

Figure 1 Flow chart describing literature search for studies to include in meta-analysis.

Table 1 Studies included in meta-analysis

Study	Language of MoCA	Cutoffs presented	Control sample					Clinical sample					
			n	Age	Education (years)	% female	MoCA score	n	Age	Education (years)	% female	MCI subtype	MoCA score
Fujiwara *et al.*, 2010	Japanese	13–30	36	76.4 (3.3)	12.3 (2.3)	72	~27 (~4)	30	77.3 (6.3)	11.5 (3.1)	77	unspec.	~22 (~5)
Lee *et al.*, 2008	Korean	19–27	115	69.1 (6.1)	8.0 (3.5)	81	25 (2.6)	37	71.3 (5.9)	8.3 (3.8)	23	unspec.	18.5 (3.7)
Goldstein *et al.*, 2014	English	22–26	16	65.8 (7.7)	13.4 (3.1)	69	25.1 (2.9)	38	71.9 (8.9)	10.9 (2.4)	71	sd + md	19.8 (4.2)
Luis *et al.*, 2009	English	23, 27	74	78.9 (3.7)	14.2 (2.5)	51	25.9 (1.8)	24	78.9 (5.3)	14.4 (4.1)	38	aMCI	20.5 (2.4)
Tsai *et al.*, 2012	Taiwanese	24	38	77.7 (6.0)	10.1 (4.4)	35	25.5 (2.3)	71	79.2 (6.8)	8.9 (5.1)	51	sd + md	20.5 (4.0)
Ahmed *et al.*, 2012	English	23.5	20	77.4 (4.0)	14.7 (2.9)	45	27.1 (2.8)	15	80.9 (7.2)	13.1 (3.0)	66	aMCI	21.7 (3.3)
Memoria *et al.*, 2013	Portuguese	25, 26	41	71.7 (4.6)	13.4 (4.5)	80	26.3 (2.61)	43	74.3 (5.6)	11.4 (4.2)	67	sd + md	22.6 (2.8)
Roalf *et al.*, 2013	English	25	140	71.2 (9.2)	15.9 (3.0)	67	26.8 (2.64)	126	72.3 (8.1)	14.9 (4.2)	49	unspec.	20.9 (4.5)
Nasreddine *et al.*, 2005	English, French	26	90	72.8 (7.0)	13.3 (3.4)	60	27.5 (~4)	94	75.2 (6.3)	12.3 (4.3)	44	sd + md	22.0 (~6)

Note. Data for age, years of education, MoCA score presented as means (SDs). Data for MoCA score represented with ~ sign indicates an approximate value discerned from a graph. sd = single domain; md = multi domain; aMCI = amnestic mild cognitive impairment.

specificity, PPA, NPA, LRPR, LRNR, classification accuracy, chi square, phi, and Youden index.

Results

Table 2 shows data relating to the full meta-analysis. Chi square values for cutoff scores 18 and below did not show a significant relationship between MoCA test outcome and MCI diagnosis; therefore, these cutoff scores were not further analyzed. Sensitivity was highest for cutoff scores of 28, 29, and 30 (1.00), and specificity was highest for cutoff scores of 19 and 20 (.98). The optimal score, which maximized true positives while minimizing false positives, was a cutoff of 23 (Youden index = .71). Four studies (Fujiwara *et al.*, 2010; Goldstein *et al.*, 2014; Lee *et al.*, 2008; Luis *et al.*, 2009) contributed to the data analyzed using a cutoff of 23, revealing an overall sensitivity of .83 and specificity of .88. The PPA was .79, indicating that 79% of individuals who achieve a lower score than 23 on the MoCA are accurately diagnosed with MCI, and the NPA was .91, indicating that 91% of individuals who achieve a score of 23 or higher on the MoCA are accurately diagnosed as healthy. These PPA and NPA values are based on an aggregate prevalence of MCI of 35% in the four studies. The LRPR at a cutoff of 23 indicates that an individual who scores below 23 is 7.09 times more likely to have MCI than not and the LRNR indicates that an individual with MCI is .19 times as likely to obtain a score 23 or above than an individual without MCI. At a cutoff score of 23, our analysis indicated that 86% of individuals were correctly classified as either with MCI or healthy. The chi square test was significant at $\chi^2 = 183.37$, $p < .05$, and phi = .70 is considered a large effect size (Cohen, 1988).

The current meta-analysis indicated that a cutoff score of 23 on the MoCA offered better diagnostic accuracy than the originally recommended cutoff score of 26. Refer to Table 2. Although sensitivity was lower at 23 (.83) than at 26 (.94), specificity was higher (.88 vs. .66) and the balance between true positive and false positive results was better at a cutoff of 23 (Youden index = .71) than 26 (Youden index = .59). Independent proportion analysis further indicated that classification accuracy was significantly higher at 23, with 86% of individuals correctly classified, than at 26, with 78% of individuals correctly classified ($z = 3.12$, $p = .002$).

Given the especially widespread use of the English version of the MoCA, we also conducted the meta-analysis using only validity studies of the English

Table 2 Evaluation of MoCA cutoff scores

Studies	Test cutoff	Control n	MCI n	Sensitivity (95% CIs)	Specificity (95% CIs)	tp	tn	fp	fn	Prevalence	PPA	NPA	LRPR	LRNR	Classification accuracy (95% CIs)	Chi sqr	phi	Youden index
1	13,14, 15,16, 17,18	36	30	.10 (−.01, .20)	1.00 (1.00, 1.00)	3	36	0	27	.45	1.00	.57	undef.	.90	.59 (.47, .71)	3.77	.24	.10
1, 2	19	151	67	.37 (.26, .49)	.98 (.96, 1.00)	25	148	3	42	.31	.88	.78	16.35	.64	.79 (.74, .85)	50.27	.48	.35
1, 2	20	151	67	.45 (.33, .57)	.98 (.96, 1.00)	30	148	3	37	.31	.90	.80	19.58	.57	.81 (.77, .87)	64.42	.54	.42
1, 2	21	151	67	.54 (.42, .66)	.95 (.92, .99)	36	144	7	31	.31	.84	.82	11.77	.48	.83 (.78, .88)	71.11	.57	.49
1, 2, 3	22	167	105	.72 (.63, .80)	.92 (.88, .96)	75	154	13	30	.39	.85	.84	8.90	.31	.84 (.80, .89)	118.37	.66	.63
1, 2, 3, 4	23	241	129	.83 (.76, .89)	.88 (.84, .92)	107	213	28	22	.35	.79	.91	7.09	.19	.86 (.83, .90)	183.37	.70	.71
1, 2, 3, 5, 6	24	225	191	.90 (.86, .94)	.77 (.72, .83)	172	174	51	19	.46	.77	.90	4.00	.13	.83 (.80, .87)	189.38	.67	.68
1, 2, 3, 7, 8	25	348	274	.89 (.85, .92)	.73 (.68, .77)	243	253	95	31	.44	.72	.89	3.25	.16	.80 (.77, .83)	232.29	.61	.61
1, 2, 3, 7, 9	26	298	242	.94 (.91, .97)	.66 (.60, .71)	227	196	102	15	.45	.69	.93	2.73	.10	.78 (.75, .82)	197.89	.61	.59
1, 2, 4	27	225	91	.98 (.95, 1.00)	.39 (.32, .45)	89	87	138	2	.29	.39	.98	1.59	.06	.56 (.50, .61)	42.28	.37	.36
1	28	36	30	1.00 (1.00, 1.00)	.47 (.31, .64)	30	17	19	0	.45	.61	1.00	1.89	0	.71 (.60, .82)	18.96	.54	.47
1	29	36	30	1.00 (1.00, 1.00)	.39 (.23, .55)	30	14	22	0	.45	.58	1.00	1.64	0	.67 (.55, .78)	14.86	.47	.39
1	30	36	30	1.00 (1.00, 1.00)	.17 (.05, .29)	30	6	30	0	.45	.50	1.00	1.20	0	.55 (.43, .67)	5.62	.29	.17

Note. Studies represented by numbers. 1 = Fujiwara *et al.*, 2010; 2 = Lee *et al.*, 2008; 3 = Goldstein *et al.*, 2014; 4 = Luis *et al.*, 2009; 5 = Tsai *et al.*, 2012; 6 = Ahmed *et al.*, 2012; 7 = Memória *et al.*, 2013; 8 = Roalf *et al.*, 2013; 9 = Nasreddine *et al.*, 2005. tp = true positives; tn = true negatives; fp = false positives; fn = false negatives; PPA = positive predictive accuracy; NPA = negative predictive accuracy; LRPR = Likelihood Ratio for Positive Result; LRNR = Likelihood Ratio for Negative Result; chi sqr = chi square statistic.

MoCA. Five of nine studies included in the overall meta-analysis investigated the English MoCA (Ahmed *et al.*, 2012; Goldstein *et al.*, 2014; Luis *et al.*, 2009; Nasreddine *et al.*, 2005; Roalf *et al.*, 2013). However, these studies unfortunately provided the data for few cutoff points. We were able to calculate parameters for cutoffs 23–26, including data from two studies at each of these cutoff scores. See Table 3. Overall, when investigating the English version of the MoCA separately, it remained evident that a cutoff of 23 offered the highest classification accuracy (90%) and balance between true positive rate and false positive rate (Youden index = .79).

Discussion

Meta-analytic evaluation of validation studies including data from the original MoCA study revealed an optimal cutoff score of 23/30. Together the studies provided an increased sample size, permitting confirmatory evidence for the diagnostic usefulness of the MoCA. The cutoff of 23 optimally balanced sensitivity and specificity and provided the highest classification accuracy.

Similar to the original study by Nasreddine *et al.* (2005), the studies included in the meta-analysis were from samples without known medical, neurological, or psychiatric comorbidities; they were however more culturally and educationally heterogeneous. These studies included data from multiple cultural backgrounds, speaking different languages, and with a range of access to formal education. This undoubtedly contributed to the outcome of the meta-analysis and potentially to the lower cutoff score than recommended in the original study (26), which included a more culturally homogenous sample of participants with relatively high education.

Due to the nature of cutoff scores, it is difficult to statistically control for potential effects of age or education on MoCA scores in a meta-analysis. Only two of the nine studies reported performing correlations between age and MoCA score. Luis *et al.* (2009) reported no significance (but no *r* value given) and Roalf *et al.* (2013) reported a significant but weak correlation, $r = -.20$, $p < .001$, between age and MoCA score. Two studies reported correlations between education and MoCA scores. Luis *et al.* (2009) reported a correlation at $p = .05$ (no *r* value given). Memória *et al.* (2013) reported significance of education only on selected components (clock drawing, $r = .33$, $p = .02$, verbal fluency $r = .31$,

Table 3 Evaluation of English version MoCA cutoff scores

Studies	Test cutoff	Control n	MCI n	Sensitivity (95% CIs)	Specificity (95% CIs)	tp	tn	fp	fn	Prevalence	PPA	NPA	LRPR	LRNR	Classification accuracy (95% CIs)	Chi sqr	phi	Youden index
3, 4	23	90	62	.89 (.81, .97)	.90 (.84, .96)	55	81	9	7	.41	.86	.92	9.21	0.13	.90 (.85, .94)	94.20	.79	.79
3, 6	24	36	53	.94 (.88, 1.0)	.65 (.48, .80)	50	23	13	3	.60	.80	.87	2.69	0.10	.82 (.74, .90)	35.17	.63	.59
3, 8	25	156	164	.88 (.83, .93)	.75 (.69, .82)	144	118	38	20	.50	.79	.85	3.57	0.16	.82 (.78, .86)	129.90	.64	.63
3, 9	26	106	132	.93 (.89, .97)	.79 (.70, .86)	123	83	23	9	.55	.84	.90	4.33	0.10	.86 (.82, .91)	126.15	.73	.71

Note. Studies represented by numbers. 3 = Goldstein *et al.*, 2014; 4 = Luis *et al.*, 2009; 6 = Ahmed *et al.*, 2012; 8 = Roalf *et al.*, 2013; 9 = Nasreddine *et al.*, 2005. tp = true positives; tn = true negatives; fp = false positives; fn = false negatives; PPA = positive predictive accuracy; NPA = negative predictive accuracy; LRPR = Likelihood Ratio for Positive Result; LRNR = Likelihood Ratio for Negative Result; chi sqr = chi square statistic.

$p = .028$, verbal abstraction $r = .39$, $p = .0006$) for MCI but no significance for controls.

Out of the nine validation studies included in the current meta-analysis, five used the English version of the MoCA and four involved translated versions into Korean, Japanese, Taiwanese, and Portuguese. Although these studies adhered to procedures common in the cross-cultural translation of psychological measures (for example, consensus translation and back translation interpreted by a blind reviewer of the test), changes to the tests that make them more culturally relevant (for example, in the Japanese version of the MoCA, the words to be remembered "velvet", "church", and "daisy" are replaced with "silk", "shrine", and "lily") may also affect the similarity between tests and therefore the appropriateness of including them within one meta-analysis. Inclusion of culturally and educationally diverse validation studies may be a limitation to the interpretation of the findings presented here. That said, in a sub-analysis of the five studies of the English version of the MoCA (Ahmed *et al.*, 2012; Goldstein *et al.*, 2014; Luis *et al.*, 2009; Nasreddine *et al.*, 2005; Roalf *et al.*, 2013), a cutoff of 23 was still found to provide the highest diagnostic accuracy.

A recent meta-analysis by Ciesielska *et al.* (2016) used similar methods to analyze the sensitivity and specificity of the MoCA at different cutoff scores. Results indicated that a cutoff of 24 was optimal, with a sensitivity of 0.80 and specificity of 0.81. It is encouraging that similar to the current meta-analysis, this study found that a lower cutoff score than the originally recommended score of 26 showed better diagnostic accuracy across studies. Importantly, many of the studies included in the Ciesielska *et al.* meta-analysis are of concern due to their heterogeneity. For example, different educational adjustments were used across studies, standard neuropsychological testing was not universally employed to determine objective cognitive decline in the diagnosis of MCI, and healthy control groups with apparent comorbidities (for example, psychiatric) were included. The rigor of the inclusion/exclusion criteria employed in the assessment of validity studies in the present study, along with the range of diagnostic parameters calculated in addition to sensitivity and specificity, provides confidence in the current optimal cutoff score obtained.

Although the meta-analytic results reported here identified an optimal cutoff of 23, the diagnostic accuracy of the MoCA at this cutoff score could still be improved. Studies of brief cognitive screening tests, such as the MMSE, have shown that diagnostic accuracy can be greatly enhanced by using normative

data that is stratified by age and education (e.g., Crum *et al.*, 1993; Heeren *et al.*, 1990; Magni *et al.*, 1996; Uhlmann & Larson, 1991). Normative data for the MoCA has also begun to appear in the literature, with Rosseti *et al.* (2011, 2017) and Malek-Ahmadi *et al.* (2015) publishing norms stratified by age and education for the English version of the MoCA, and other authors publishing normative data for Quebec-French (Larouche *et al.*, 2016), Portuguese (Freitas *et al.*, 2011), Italian (Santangelo *et al.*, 2015), Czech (Kopecek *et al.*, 2017) and Japanese (Hawkins, 2005) versions. Given that MoCA performance has been shown to be influenced by age, years of formal education, and cultural background, it would be wise to consult normative data to improve accuracy when interpreting MoCA cutoff scores. It is also crucial to consider the sensory functioning (vision, hearing) of individuals when interpreting MoCA scores as these factors have been shown to influence performance on the test (Dupuis *et al.*, 2016; Lin *et al.*, 2017; Wittich *et al.*, 2010). It has been noted that other types of sensory loss, such as change in olfactory functioning, similar to poor MoCA score, may be considered a supplemental indicator of neurodegenerative disease (see Quarmley *et al.*, 2017). Future research examining MoCA normative data stratified by age and education and with consideration to culturally based translations will certainly assist in confirming an optimal general cutoff score for this valued screening tool.

The MoCA is a screening measure and cannot replace comprehensive neuropsychological testing that improves diagnostic accuracy when investigating cognitive changes. Performance on the MoCA speaks to one aspect of the clinical criteria for the diagnosis of MCI (objective evidence of cognitive decline); therefore, MCI diagnosis should never be made based solely on this one piece of evidence. It is the responsibility of the clinician to ensure that other clinical criteria (reviewed by Petersen *et al.*, 2014) are satisfactorily met before giving a diagnosis of MCI.

Conclusion

The MoCA is a widely used cognitive screening instrument introduced by Nasreddine *et al.* in 2005. Our meta-analysis did not replicate the originally recommended cutoff of 26 but instead indicated that a cutoff score of 23 offers the highest classification accuracy and Youden index. Interpreting the MoCA at this cutoff reduces the rate of false positives, which is an area of concern when using higher cutoff scores to distinguish healthy aging from MCI with the MoCA. We therefore recommend that that a cutoff of 23 be used when interpreting the MoCA. Consultation of demographically corrected norms is recommended, where available, as this will further increase the diagnostic accuracy of the test.

Conflict of interest

None of the authors declare a conflict of interest in regards to their authorship or the publication of this manuscript.

Key points

- The Montreal Cognitive Assessment (MoCA) is a cognitive screening measure that was published by Nasreddine *et al.* (2005) as a tool to distinguish normal cognitive aging from Mild Cognitive Impairment (MCI)
- Several validation studies have found that the recommended cutoff score of 26/30 is too high and increases false positive test results
- The present study used meta-analysis to compare diagnostic accuracy of a range of cutoff scores from nine studies that evaluated validity of the MoCA
- Results showed that a cutoff score of 23/30 has better diagnostic accuracy across parameters than the originally recommended 26/30 cutoff score

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Appendix A

Sensitivity = true positives / (true positives + false negatives)
Specificity = true negatives / (true negatives + false positives)
True Positives = sensitivity × clinical sample size
True Negatives = specificity × control sample size
False Positives = control sample size − true negatives
False Negatives = clinical sample size − true positives
Positive Predictive Accuracy (PPA) = true positives / (true positives + false positives)
Negative Predictive Accuracy (NPA) = true negatives / (true negatives + false negatives)
Prevalence = clinical sample size / total sample size
Likelihood Ratio for Positive Result (LRPR) = sensitivity / (1 − specificity)
Likelihood Ratio for Negative Result (LRNR) = (1 − sensitivity) / specificity
Classification Accuracy = (true positives + true negatives) / total sample size
Chi square = ((total sample size) × ((true positives × true negatives) − (false positives × false negatives))^2) / ((true positives + false negatives) × (false positives + true negatives) × (true positives + false positives) × (false negatives + true negatives))
Phi = square root(chi square / total sample size)
Youden index = (sensitivity + sensitivity) − 1