The MoCA

Well-suited screen for cognitive impairment in Parkinson disease

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ABSTRACT

Objective: To establish the diagnostic accuracy of the Montreal Cognitive Assessment (MoCA) when screening externally validated cognition in Parkinson disease (PD), by comparison with a PD-focused test (Scales for Outcomes in Parkinson disease–Cognition [SCOPA-COG]) and the standardized Mini-Mental State Examination (S-MMSE) as benchmarks.

Methods: A convenience sample of 114 patients with idiopathic PD and 47 healthy controls was examined in a movement disorders center. The 21 patients with dementia (PD-D) were diagnosed using Movement Disorders Society criteria, externally validated by detailed independent functional and neuropsychological tests. The 21 patients with mild cognitive impairment (PD-MCI) scored 1.5 SD or more below normative data in at least 2 measures in 1 of 4 cognitive domains. Other patients had normal cognition (PD-N).

Results: Primary outcomes using receiver operating characteristic (ROC) curve analyses showed that all 3 mental status tests produced excellent discrimination of PD-D from patients without dementia (area under the curve [AUC], 87%–91%) and PD-MCI from PD-N patients (AUC, 78%–90%), but the MoCA was generally better suited across both assessments. The optimal MoCA screening cutoffs were <21/30 for PD-D (sensitivity 81%; specificity 95%; negative predictive value [NPV] 92%) and <26/30 for PD-MCI (sensitivity 90%; specificity 75%; NPV 95%). Further support that the MoCA is at least equivalent to the SCOPA-COG, and superior to the S-MMSE, came from the simultaneous classification of the 3 PD patient groups (volumes under a 3-dimensional ROC surface, chance = 17%: MoCA 79%, confidence interval [CI] 70%–89%; SCOPA-COG 74%, CI 62%–86%; MMSE-Sevens item 56%, CI 44%–68%; MMSE-World item 62%, CI 50%–73%).

Conclusions: The MoCA is a suitably accurate, brief test when screening all levels of cognition in PD. *Neurology*® 2010;75:1717–1725

GLOSSARY

ADAS-Cog = Alzheimer's Disease Assessment Scale–Cognition; **AUC** = area under the curve; **CDR** = Clinical Dementia Rating; **CI** = confidence interval; **DRS-2** = Dementia Rating Scale–2; **MDS** = Movement Disorders Society; **MMSE** = Mini-Mental State Examination; **MoCA** = Montreal Cognitive Assessment; **NPV** = negative predictive value; **PD** = Parkinson disease; **PD-D** = Parkinson disease with dementia; **PD-MCI** = Parkinson disease with mild cognitive impairment; **PD-N** = Parkinson disease with normal cognition; **R-IADL** = Reisberg instrumental activities of daily living; **ROC** = receiver operating characteristic; **S-MMSE** = standardized Mini-Mental State Examination; **SCOPA-COG** = Scales for Outcomes in Parkinson disease–Cognition; **VUS** = volume under a surface.

There is an 80%–90% cumulative prevalence of dementia and its complications in Parkinson disease (PD).[1-3] Screening for dementia (PD-D) and mild cognitive impairment (PD-MCI) is therefore needed to establish staging and track progression. The Montreal Cognitive Assessment (MoCA)[4] has become an increasingly popular cognitive screen,[5] which is easily administered by nonspecialist staff and could facilitate comparisons across PD studies and different neurodegenerative disorders. Two key issues require attention, however, before use of the MoCA

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becomes accepted practice in PD. First, the performance of the MoCA when assessing cognition needs to be compared with newly developed PD-focused instruments.[6-10] Secondly, additional validation is necessary to establish preference for the MoCA in PD when benchmarked against the commonly used Mini-Mental State Examination (MMSE).[11-14] Presently, the Movement Disorders Society (MDS) task force on PD-D has recommended continuation with the MMSE.[15]

We therefore compared the discriminant validity of the MoCA, the standardized MMSE (S-MMSE),[16] and the PD-focused Scales for Outcomes in PD–Cognition (SCOPA-COG).[6] Patients were classified as PD-D, PD-MCI, or with normal cognition (PD-N) on the basis of independent functional and cognitive tests that reflect the MDS task force criteria,[15] while assessment of healthy controls provided a baseline. For each mental status test, standard receiver operating characteristic (ROC) curve analyses compared the PD-D group with a single group of patients without dementia (PD-N and PD-MCI combined) and then the PD-MCI and PD-N groups after exclusion of the PD-D group. A supplementary 3D ROC approach assessed the discriminant validity of each screen for separating the 3 patient categories concurrently.[17,18]

METHODS

Subjects. Figure 1 is a flow diagram of participation[19] and table 1 summarizes demographic and clinical variables for the final inclusions. A convenience sample of patients with PD (n = 114, after exclusions), part of a longitudinal study, was contacted between March 2007 and December 2009 through a local database or were volunteers from consecutive cases evaluated at the Van der Veer Institute for Parkinson's Disease and Brain Research, Christchurch, New Zealand. Diagnosis of probable PD was made by T.J.A., a movement disorders neurology specialist. Patients with PD had experienced motor symptoms for at least 1 year, with a median of 12.5 years (range, 1–30 years) in PD-D cases, to exclude potential dementia with Lewy bodies. Most participants (88 PD and 33 control inclusions) underwent 3-T structural brain imaging concurrently with cognitive testing. None of the patients had undergone deep brain stimulation or other brain surgery. Atypical parkinsonian disorder or other neurologic or major medical conditions (e.g., head injury, stroke, early-life learning disability) provided a general exclusion. The healthy controls (n = 47, after exclusions) were community volunteers, contacted through local advertisements. Participants were tested in the morning and patients continued taking their medications (30 PD-N and 3 PD-MCI cases were drug-naïve).

Standard protocol approvals, registrations, and patient consents. The study was approved by the Upper South Ethics Committee of the New Zealand Ministry of Health and informed consent was provided by all participants with additional consent from a significant other when required.

Procedures and assessment criteria. Neuropsychological tests were conducted on 2 sessions with a fixed order that balanced verbal and nonverbal materials with breaks to avoid fatigue, using 4 research personnel trained by J.D.A. and G.P.C. These standardized tests examined the 4 cognitive domains proposed by the MDS Task Force, specifically executive function (Stroop interference; verb fluency; letter fluency; category fluency; category switching; Trails B), attention, working memory, and processing speed (map search; Wechsler digit span; digit ordering; Stroop word reading; Stroop color naming; Trails A), learning and memory (California Verbal Learning Test–Short Form; Rey Complex Figure recall), and visuoperceptual and visuospatial skills (Rey Complex Figure copy; Judgment of Line Orientation; fragmented letters). The MDS Task Force PD-D criteria were followed,[15] using significant impairment (−2.0 SD below normative data) in a neuropsychological test in at least 2 cognitive domains, supporting evidence from 2 dementia assessment tests (Dementia Rating Scale–2 [DRS-2], Alzheimer's Disease Assessment Scale–Cognition [ADAS-Cog]),[20,21] plus information pertinent to everyday function from a significant other (Reisberg instrumental activities of daily living [R-IADL], Clinical Dementia Rating [CDR], and Global Deterioration Scale).[22-24] All MCI cases failed to meet criteria for dementia and met the operationalized criterion of impairment at or worse than 1.5 SD below normative data on 2 variables from separate neuropsychological tests within at least 1 of the 4 cognitive domains. The remaining patients with PD (PD-N) and all control inclusions did not show evidence of MCI; for comparative purposes, 34/72 PD-N and 30/47 controls were also assessed on the DRS-2, ADAS-Cog, and everyday functional scales. The Neuropsychiatric Inventory[25] and the 15-item Geriatric Depression Scale[26] were also used to assess participants.

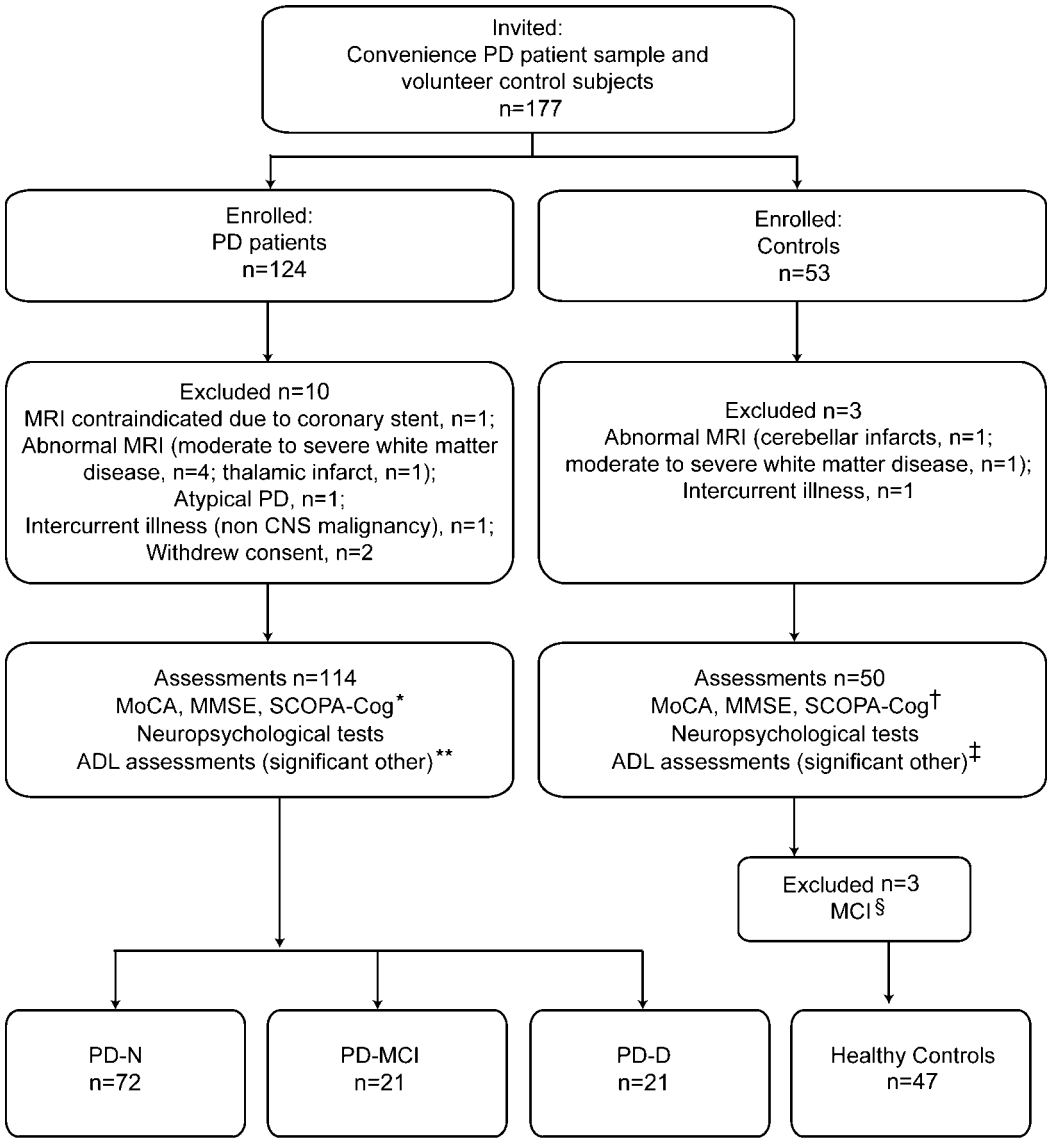
All participants were tested at the start of the first session on the S-MMSE protocol[16] to ensure optimal reliability of this benchmark screen. The item "world" spelled backwards was used during the test (MMSE-World),[16] but the reverse serial sevens item (MMSE-Sevens; item scores interchanged) was added at the end of the test, because the latter alternate is emphasized in PD.[15] One to 4 weeks later, the MoCA (www.mocatest.org for scoring criteria and details)[4] was administered at the start and the SCOPA-COG[6] at the end of the second session. Some cognitively normal participants (controls, n = 11/47; PD-N, n = 37/72) and 1 patient with PD-D did not receive the SCOPA-COG. Mental status tests were scored independently and none was employed to classify participants.

Statistical analyses. MedCalc version 10.4.8.0 (www.medcalc.be) was used for group comparisons and ROC curve analyses. One-way analysis of variance or Kruskal-Wallis tests (when nonparametric required), with post hoc tests (Newman-Keuls or Conover; MedCalc), examined differences among the 4 groups on demographic, clinical, functional, and neuropsychological variables. Age- and education-adjusted scores were used.

The primary ROC curve analyses tested the criterion validity and diagnostic performance of the mental status tests across pairs of groups. For the analysis relevant to dementia, the PD-N and PD-MCI groups were treated as a single no-dementia group and compared with the PD-D group. To specify performance detecting MCI, the PD-MCI group was compared with the PD-N group.

Supplementary 3-D ROC analyses (Matlab 7.0) addressed the performance of the mental status tests when making 3 simul-

Figure 1 Flow diagram of participation



*A total of 38 patients with Parkinson disease (PD) did not undergo Scales for Outcomes in Parkinson disease–Cognition (SCOPA-COG) assessment. **A total of 38 patients with PD (all PD-N) did not undergo activities of daily living (ADL) assessment. †A total of 11 controls did not undergo SCOPA-Cog assessment. ‡A total of 17 controls did not undergo ADL assessment. §Controls diagnosed with mild cognitive impairment (MCI) on neuropsychological assessment. MMSE = Mini-Mental State Examination; MoCA = Montreal Cognitive Assessment; PD-D = Parkinson disease with dementia; PD-MCI = Parkinson disease with mild cognitive impairment; PD-N = Parkinson disease with normal cognition.

taneous classifications (PD-D, PD-MCI, and PD-N).[17,18] Whereas the area under the ROC curve (AUC) assesses a single threshold for 2 ordinal diagnostic possibilities (e.g., no dementia > PD-D or PD-N > PD-MCI), the 3-D ROC analysis produces a volume under a surface (VUS within a cube). The VUS was generated by varying 2 ordered decision thresholds concurrently (PD-N > PD-MCI and PD-MCI > PD-D) instead of the conventional single threshold. There were 3 possible correct classifications and 6 possible incorrect classifications (for example, when the MoCA score for a PD-MCI case is misclassified as either PD-N or PD-D). A perfect diagnosis in a 3-D ROC analysis yields a VUS = 1.0 for PD-N > PD-MCI > PD-D (chance VUS = 1/6), in a similar manner to a perfect AUC of 1.0 (chance AUC of 0.5) for the ROC curve. This 3-D ROC approach controls for multiple comparisons and is superior to averaging the corresponding ROC curves.[18]

RESULTS **Demographics.** The PD-N group had a younger mean age than the other 3 groups (table 1), but age showed no significant association with any of the mental status tests across cognitively normal participants (Spearman r, all <0.2; n = 119, controls and PD-N combined). There were no group differences in years of education, but premorbid IQ estimates were significantly higher in the 2 cognitively normal groups than the PD-MCI and PD-D groups.

Table 1 Demographic and clinical comparison of the 4 groups[a]

	HC (n = 47)	PD-N (n = 72)	PD-MCI (n = 21)	PD-D (n = 21)	ANOVA/Kruskal-Wallis	Adjacent pairwise comparisons[b]
M/F	31/16	50/22	15/6	18/3		
Age, y	67.3 ± 9.3	64.5 ± 8.4	71.5 ± 5.4	73.4 ± 6.7	$H(3) = 22.6$, $p < 0.001$	Con > PD-N < PD-MCI = PD-D
Education, y	13.7 ± 3.0	13.2 ± 3.0	12.3 ± 3.1	12.9 ± 3.0	$F_{3,160} = 1.1$, $p > 0.30$	Con = PD-N = PD-MCI = PD-D
Premorbid IQ (WTAR)	112.5 ± 9.5	112.2 ± 8.1	106.7 ± 9.8	107.6 ± 11.4	$F_{3,160} = 3.2$, $p < 0.03$	Con = PD-N > PD-MCI = PD-D
Geriatric Depression Scale (15-item)	0.2 ± 0.1	1.0 ± 0.2	1.2 ± 2.3	3.5 ± 3.3	$H(3) = 30.8$, $p < 0.001$	Con = PD-N = PD-MCI = PD-D
Neuropsychiatric Inventory	N/A	3.9 ± 7.9[c]	5.5 ± 8.6	10.3 ± 8.4	$F_{2,75} = 3.9$, $p < 0.03$	PD-N = PD-MCI = PD-D
Duration of symptoms, y	N/A	4.6 ± 3.9	7.3 ± 5.2	12.6 ± 8.1	$H(3) = 23.2$, $p < 0.001$	PD-N < PD-MCI < PD-D
Hoehn & Yahr Stage	N/A	1.9 ± 0.7	2.6 ± 0.9	3.4 ± 0.8	$F_{2,112} = 32.1$, $p < 0.001$	PD-N < PD-MCI < PD-D

Abbreviations: ANOVA = analysis of variance; Con = controls; HC = healthy age- and education-matched controls; PD-D = patients with Parkinson disease with dementia; PD-MCI = patients with Parkinson disease with mild cognitive impairment; PD-N = patients with Parkinson disease with normal cognition; WTAR = Wechsler Test of Adult Reading.

[a] Values are mean ± SD.

[b] $p < 0.05$ for post hoc test.

[c] A subset of PD-N participants was administered this test to provide comparisons with PD-D and PD-MCI.

Education showed a weak correlation with MMSE-Sevens scores only ($r = 0.20$, $p < 0.03$; uncorrected for multiple comparisons), and estimated premorbid IQ showed weak associations (p values uncorrected) with the MoCA ($r = 0.19$, $p < 0.05$), MMSE-Sevens ($r = 0.24$, $p < 0.01$), and SCOPA-COG ($r = 0.24$, $p < 0.05$). Geriatric Depression Scale items were more frequently endorsed by patients with PD than in the control group, especially by patients with PD-D. Higher Neuropsychiatric Inventory scores were more evident in the PD-D group than the PD-N group. The patients with PD-D had longer disease duration and more severe motor impairments than the patients with PD-MCI; in turn, disease duration and severity were lower in the PD-N group.

Cognitive assessments. The MoCA, MMSE, and PD-focused SCOPA-COG scores were lower in the PD-D group than all other groups, and lower in the PD-MCI group than the PD-N and control groups (table 2). There was a small but significant difference between the PD-N and control groups on the SCOPA-COG, but they did not differ on either the MoCA or the MMSE.

The neuropsychological and functional variables established valid classifications of patients with PD (table 2). As expected, functional status (IADL; CDR; Global Deterioration Scale), dementia test scores (DRS-2 and ADAS-Cog), and neuropsychological domain scores were poor in the PD-D group compared to all other groups. The PD-MCI group had worse neuropsychological test scores in all 4 cognitive domains compared to the PD-N group. The PD-MCI group also had similar (R-IADL) or slightly worse (CDR; Global Deterioration Scale) functional status, and worse dementia test scores (DRS-2, ADAS-COG), when compared to the PD-N subgroup that was administered these tests. The PD-N patients obtained mean scores at or above the mean of normative data on the standardized neuropsychological tests, but their scores were significantly lower than the control group's scores in all 4 domains.

ROC analyses of mental status tests. All 3 tests accurately discriminated patients with PD-D from those without dementia (PD-N and PD-MCI combined; see AUC for the ROC curves, table 3). Both the MoCA and the SCOPA-COG approached perfect separation between patients with and without dementia and were significantly superior in this regard compared to the AUC for MMSE-Sevens scores (AUC difference of 7% for the MoCA, $p = 0.008$; and AUC difference of 8% for the SCOPA-COG, $p = 0.011$). When discriminating dementia, the AUC difference between the MMSE-World and the MoCA (AUC difference of 3%, $p = 0.09$) and the SCOPA-COG (AUC difference of 5%, $p = 0.10$) did not reach significance.

When discriminating patients with PD-MCI from patients with PD-N, all 3 tests again produced high AUCs, but in this instance the MoCA appeared to perform better than all 3 other measures (table 3). The AUC for the MoCA was significantly higher than that shown by the SCOPA-COG (AUC difference of 12%, $p = 0.045$), the MMSE-Sevens (AUC difference of 12%, $p = 0.016$), and the MMSE-World (AUC difference of 10%, $p = 0.039$).

Table 3 also shows 3 standard cutoff options for each mental status test. ROC curve diagnostics are provided for 1) optimal screening value (the lowest value with >80% for both sensitivity [detection of true positive cases] and negative predictive value [probability of an accurate negative test]), 2) optimal

Table 2 Mental status tests, dementia assessment, and neuropsychological test domains[a]

	HC (n = 47)	PD-N (n = 72)	PD-MCI (n = 21)	PD-D (n = 21)	ANOVA/Kruskal-Wallis	Adjacent pairwise comparisons[b]
Mental status tests (maximum)						
MoCA (30)	27.2 ± 1.9	26.7 ± 2.1	23.2 ± 2.5	16.9 ± 4.0	$H(3) = 81.9$, $p < 0.001$	Con = PD-N > PD-MCI > PD-D
MMSE-Sevens (30)	28.6 ± 1.6	28.1 ± 1.8	25.9 ± 2.6	22.9 ± 2.9	$H(3) = 59.5$ (66.2), $p < 0.001$	Con = PD-N > PD-MCI > PD-D
MMSE-World (30)	(29.0 ± 1.0)	(28.9 ± 1.1)	(27.4 ± 1.8)	(24.1 ± 2.9)		
SCOPA-COG (43)	33.9 ± 4.3[c]	31.5 ± 4.7[c]	26.0 ± 4.4	15.6 ± 5.3	$F_{3,111} = 75.6$, $p < 0.001$	Con > PD-N > PD-MCI > PD-D
Dementia assessment (maximum)						
R-IADL (4)	0.2 ± 0.2[c]	0.5 ± 0.7[c]	0.6 ± 0.5	2.0 ± 0.5	$H(3) = 51.0$, $p < 0.001$	Con = PD-N < PD-MCI < PD-D
CDR Sum of boxes (18)	0.02 ± 0.01[c]	0.5 ± 1.3[c]	1.5 ± 1.1	7.3 ± 2.6	$H(3) = 79.8$, $p < 0.001$	Con < PD-N < PD-MCI < PD-D
GDS (7)	1.00 ± 0.0[c]	1.13 ± 0.4[c]	2.23 ± 0.7	4.31 ± 0.7	$H(3) = 69.6$, $p < 0.001$	Con = PD-N < PD-MCI < PD-D
ADAS-Cog (70)	4.9 ± 2.2[c]	6.0 ± 2.3[c]	10.4 ± 3.7	22.5 ± 8.0	$H(3) = 70.0$, $p < 0.001$	Con < PD-N < PD-MCI < PD-D
DRS-2 (AEMSS)	13.1 ± 2.3[c]	12.3 ± 1.7[c]	10.0 ± 2.0	4.7 ± 2.7	$F_{3,111} = 73.9$, $p < 0.001$	Con = PD-N > PD-MCI > PD-D
Neuropsychological domains (z score)[d]						
Executive function	0.83 ± 0.5	0.37 ± 0.6	−0.86 ± 0.6	−2.06 ± 0.5	$F_{3,160} = 145.0$, $p < 0.001$	Con > PD-N > PD-MCI > PD-D
Attention, working memory, and processing speed	0.36 ± 0.5	−0.04 ± 0.4	−0.89 ± 0.5	−1.92 ± 0.6	$F_{3,160} = 138.7$, $p < 0.001$	Con > PD-N > PD-MCI > PD-D
Learning and memory	0.91 ± 0.8	0.28 ± 0.7	−0.72 ± 0.6	−1.72 ± 0.7	$F_{3,160} = 74.7$, $p < 0.001$	Con > PD-N > PD-MCI > PD-D
Visuospatial/visuoperceptual	0.53 ± 0.5	0.35 ± 0.4	−0.32 ± 0.7	−1.27 ± 0.8	$H(3) = 67.1$, $p < 0.001$	Con > PD-N > PD-MCI > PD-D
Aggregate mean score across the 4 domains	0.66 ± 0.4	0.24 ± 0.4	−0.70 ± 0.4	−1.74 ± 0.5	$F_{3,160} = 209.4$, $p < 0.001$	Con > PD-N > PD-MCI > PD-D

Abbreviations: ADAS-Cog = Alzheimer's Disease Assessment Scale–Cognition[21]; ANOVA = analysis of variance; CDR = Clinical Dementia Rating[23]; Con = controls; DRS-2 = Dementia Rating Scale–2, using age- and education-adjusted standard scores[20]; GDS = Global Deterioration Scale[24]; HC = healthy age- and education-matched controls; MMSE = Mini-Mental State Examination; MoCA = Montreal Cognitive Assessment; PD-D = patients with Parkinson disease with dementia; PD-MCI = patients with Parkinson disease with mild cognitive impairment; PD-N = patients with Parkinson disease with normal cognition; R-IADL = Reisberg instrumental activities of daily living[22]; SCOPA-COG = Scales for Outcomes in Parkinson disease–Cognition.

[a] Values are means ± SD.

[b] $p < 0.05$ for post hoc test.

[c] A subset of PD-N and control participants was administered these tests to provide comparisons with PD-D and PD-MCI.

[d] Domain age- and education-adjusted *z* scores, based on individual average of test scores within each domain.

diagnostic value (the highest value with >80% for both specificity [detection of true negatives] and positive predictive value [probability of an accurate positive test]), and 3) maximum accuracy (Youden Index). The diagnostic cutoffs are generally used for a supplementary test, after a patient is identified through screening cutoffs in a first test (e.g., the MoCA). Screening cutoffs are the primary interest for mental status tests. For PD-D, all 3 tests provided good to excellent sensitivity and negative predictive value at the identified screening cutoffs, although the MMSE values (MMSE-Sevens <27/30; MMSE-World <28/30) were close to ceiling and thus of limited practical value, unlike those for the MoCA (<21/30) and the SCOPA-COG (<19/43). For PD-MCI, however, the MoCA provided a more suitable screening cutoff (<26/30), because 1) the MMSE screening values were at or close to the maximum score (<29 and <30) and 2) sensitivity (90% vs 80%) and negative predictive value (95% vs 86%) were superior for the MoCA vs the SCOPA-COG.

These ROC curve analyses suggested better performance by the MoCA compared to the MMSE and equal (PD-D) or better (PD-MCI) performance even when compared to a PD-focused cognitive instrument.

Figure 2 depicts the 3-D ROC surface for the MoCA and the MMSE-Sevens, which visualizes the tests' ability to discriminate 3 diagnostic categories concurrently. The volume under the ROC surface (VUS) quantifies the ordered discrimination of PD-N > PD-MCI > PD-D, which was well above chance (17%) for all mental status test scores ($p < 0.001$). This analysis produced supplementary evidence for the superiority of the MoCA (VUS of 79%, 95% confidence interval [CI] 70%–89%) over the MMSE-Sevens (VUS of 56%, CI 44%–68%, bootstrap comparison for VUS difference, $p = 0.006$) and the MMSE-World scores (VUS of 62%, CI 50%–73%, VUS difference, $p = 0.03$). The SCOPA-COG also produced a large VUS (74%, CI 62%–86%), which was significantly greater than for the MMSE-Sevens (VUS difference, $p = 0.048$) but not MMSE-World (VUS difference, $p = 0.161$).

DISCUSSION The current study provides convincing evidence that the MoCA produces excellent dis-

Table 3 Diagnostic performance of the mental status tests for PD-D and PD-MCI

	Optimal screen values[a]					Optimal diagnostic values[b]					Maximum accuracy (Youden Index)				
Test (AUC, 95% CI)	Cutoff	Sensitivity	Specificity	PPV[c]	NPV[c]	Cutoff	Sensitivity	Specificity	PPV[c]	NPV[c]	Cutoff	Sensitivity	Specificity	PPV[c]	NPV[c]
MoCA															
PD-D[d] (97%, 92%–99%)	<21	81	95	87	92	<22	90	91	82	96	<23	95	87	76	98
PD-MCI[e] (90%, 82%–95%)	<26	90	75	61	95	<24	62	94	79	85	<26	90	75	61	95
MMSE-Sevens															
PD-D (91%, 84%–95%)	<27	86	75	60	93	<24	62	95	83	85	<25	71	90	76	88
PD-MCI (78%, 68%–86%)	<29	90	51	44	93	<24	19	99	85	74	<29	90	51	44	93
MMSE-World															
PD-D (94%, 88%–98%)	<28	100	77	66	100	<26	62	95	83	85	<28	100	77	66	100
PD-MCI (80%, 71%–88%)	<30	95	38	30	100	<27	29	99	90	76	<28	57	88	66	83
SCOPA-COG															
PD-D (97%, 90%–99%)	<19	80	98	95	92	<22	85	93	84	94	<20	85	96	91	94
PD-MCI (81%, 68%–90%)	<31	80	51	42	86	<25	33	94	71	77	<30	76	74	56	88

Abbreviations: AUC = area under the 2-D receiver operating characteristic curve; CI = confidence interval; MMSE = Mini-Mental State Examination, with World item and with Sevens item (maximum score = 30)[15,16]; MoCA = Montreal Cognitive Assessment (maximum score = 30)[4]; NPV = negative predictive value; PD-D = Parkinson disease with dementia; PD-MCI = Parkinson disease with mild cognitive impairment; PD-N = Parkinson disease with normal cognition; PPV = positive predictive value; SCOPA-COG = Scales for Outcomes in Parkinson disease–Cognition (maximum score = 43).[6]

[a] Lowest value with sensitivity and NPV at ~80%.

[b] Highest value with specificity and PPV at ~80% when available.

[c] For PPV and NPV, estimated population base rates were 30% for PD-D vs no dementia and 30% for PD-MCI vs PD-N.[1,35–37]

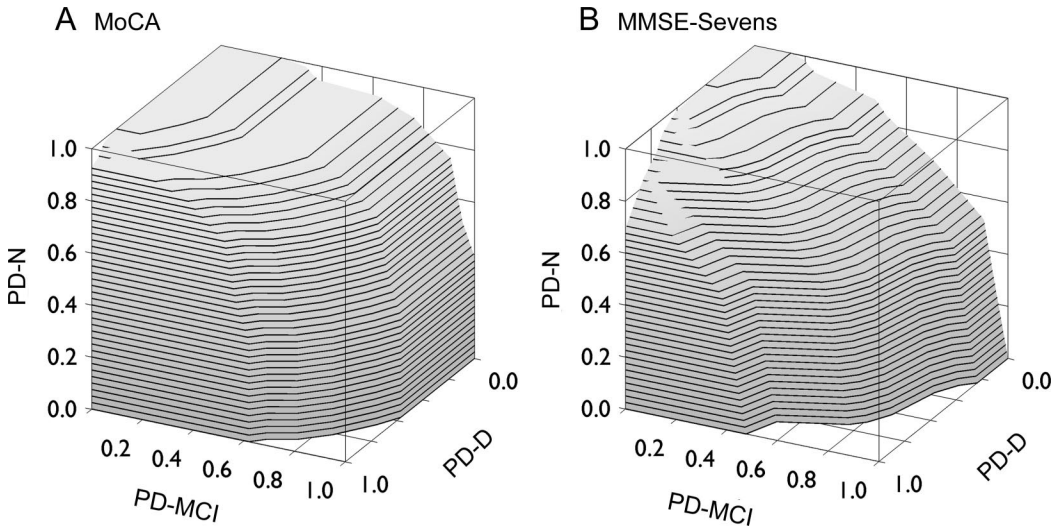
[d] Patients without dementia (PD-N and PD-MCI), n = 93, and PD-D, n = 21.

[e] PD-N, n = 72, and PD-MCI, n = 21.

crimination for both dementia and MCI in PD. ROC curve analyses showed that the MoCA exhibited more useful diagnostic indicators than the S-MMSE, although the latter was also a good discriminator for cognitive impairment. Three-dimensional ROC analyses,[17] which directly examined concurrent discriminations for PD-D, PD-MCI, and PD-N, also confirmed a clear benefit for the MoCA relative to the MMSE. Previous studies have provided either no or uncertain validation of cognitive status in patients with PD and the relative value of the MoCA and MMSE has been unclear.[11-14] For example, one small study identified cognitively impaired patients with PD on the basis of scoring 1.5 SD below the mean of normative data on an independent test of memory or executive function, but equal performance by the MoCA and the MMSE in identifying impairment perhaps reflected the inclusion of patients with dementia as several low scores were evident.[11] The relatively modest performance by the MoCA and MMSE in screening cognition in the largest previous study, with 23 patients with PD-MCI, 17 patients with PD-D, and 92 other patients with PD, may have been due to the inclusion of self-report for cognitive decline and limited testing to classify impairments.[13] The present study established well-validated cognitive classifications, including everyday functional status based on interview with a significant other and cognitive evaluation based on a large independent battery of neuropsychological tests. In addition, brain imaging was undertaken in 75% of participants, minimizing the influence of non-PD brain factors on the suggested cutoffs reported here. Our study has also shown that patients with normal cognition (PD-N) performed as well on the MoCA as do healthy controls, even though they obtained slightly but significantly poorer scores on the SCOPA-COG and specific neuropsychological tests.

One major issue is that disease-focused tests may be better than nonspecific mental status tests when screening cognition in PD.[27] The 20- to 25-minute SCOPA-COG is one of several options devised for patients with PD,[11-14] whereas the 10-minute MoCA is shorter and simpler for front-line health professionals. Among other options, the PDD-Short Screen also appears highly accurate for PD-D, but the utility of this test for PD-MCI is unknown.[10]

Figure 2 Three-dimensional receiver operating characteristic surfaces



The larger volume under the surface for the Montreal Cognitive Assessment (MoCA) (A) reflects its superiority over the Mini-Mental State Examination (MMSE)-Sevens (B), based on the true classification rate for patients in the 3 groups when concurrently classified using 2 ordered decision thresholds (Parkinson disease with normal cognition [PD-N] > Parkinson disease with mild cognitive impairment [PD-MCI] and PD-MCI > Parkinson disease with dementia [PD-D]).

Importantly, the MoCA (90% correct diagnosis at the screening cutoff for PD-D, table 2; 77% correct for PD-MCI) was not inferior to the SCOPA-COG (PD-D, 93% correct; PD-MCI, 75% correct). AUC and screening value diagnostics, however, suggested that the MoCA was superior to the SCOPA-COG when assessing PD-MCI. The optimal MoCA cutoffs for a positive screen for PD-D (<21/30) and PD-MCI (<26/30) therefore provide a suitable and valid basis for assessment and follow-up diagnostic tests. Additional measurement of functional impairments caused by cognitive change is necessary to confirm a diagnosis of probable PD-D vs PD-MCI and detailed neuropsychological testing is needed to show areas of strength or weakness in individual patients.

The PD-D diagnosis used here was based on current internationally accepted standards,[15] but no consensus has yet been reached for PD-MCI criteria.[28-30] Some researchers propose that while PD initially results in faulty basal ganglia-thalamic-frontal loops related to cognition, later dementia reflects the addition of posterior cortical changes and decline in learning and memory, semantic networks, and visuoperceptual skills.[27,28,31] This perspective implies that deficits reflecting frontal cortex dysfunction may be less relevant when identifying MCI that leads to dementia in PD. Other evidence, however, suggests that deteriorating performance on tests sensitive to frontal dysfunction is also a significant predictor of PD-D.[32-35] Consistent with the latter evidence, the PD-MCI criteria used in our study produced a sample that showed impairments across all 4 cognitive domains. A similar but more severely impaired profile was evident in the PD-D group. Variability in the criteria for PD-MCI currently exists, however, with some groups requiring only a single measure in any domain that is scored at 1.5 SD or more below the mean of normative data, while other groups have used −1 SD or −2 SD as a criterion for impairment, some a clinical dementia rating of 0.5, and some the inclusion of subjective memory complaints.[11,13,31,35-38] Clearly, different MCI criteria would have impact both on the composition of the PD-MCI group and that of the healthy control group. For example, 57% of our PD-N group would be classified as PD-MCI if we had required only a single neuropsychological test score to fall below −1.5 SD. We consider this alternative to be inappropriate because 32% of our healthy control group would also then be labeled MCI despite their otherwise intact, above average cognition. Such evidence emphasizes the value of including a healthy control group when establishing MCI. Moreover, objective evidence of poor scores on multiple neuropsychological variables as used in this study is supported by the wider MCI literature, suggesting our approach is likely to predict persistent impairment and clinically relevant decline.[39,40]

The primary limitation of the current study is that it is unknown whether the MoCA and the specific criteria used to define PD-MCI in our study are predictive of decline to PD-D. This cohort will comprise part of a longitudinal study to address those questions. The base rate for PD-MCI used to calculate positive and negative predictive value is uncertain and will depend on the specific criteria used.

Larger sample sizes of patients with PD-MCI and PD-D would help verify the cutoff values proposed here, but the current samples included only well-validated cases and the study sample size was high. Also, the influence of PD medications on the MoCA is not known and would have to be considered when using the cutoffs suggested here.

By comparison with the SCOPA-COG and the MMSE, the current study found the MoCA to be an excellent, brief screening tool for well-validated PD-MCI and PD-D cases relative to patients with normal cognition and healthy controls. Our results suggest that MoCA cutoffs of <21 for dementia and <26 for MCI are the most appropriate when screening cognition in PD.

AUTHOR CONTRIBUTIONS

Statistical analysis was conducted by Dr. J.C. Dalrymple-Alford, Dr. C.T. Nakas, and Dr. M.R. MacAskill.

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REFERENCES

1. Buter TC, van den Hout A, Matthews FE, Larsen JP, Brayne C, Aarsland D. Dementia and survival in Parkinson disease: a 12-year population study. Neurology 2008; 70:1017–1022.
2. Hely MA, Reid WG, Adena MA, Halliday GM, Morris JG. The Sydney multicenter study of Parkinson's disease: the inevitability of dementia at 20 years. Mov Disord 2008;23:837–844.
3. Aarsland D, Larsen JP, Tandberg E, Laake K. Predictors of nursing home placement in Parkinson's disease: a population-based, prospective study. J Am Geriatr Soc 2000;48:938–942.
4. Nasreddine ZS, Phillips NA, Bedirian V, et al. The Montreal Cognitive Assessment, MoCA: a brief screening tool for mild cognitive impairment J Am Geriatr Soc 2005;53: 695–699.
5. Ismail Z, Rajji TK, Shulman KI. Brief cognitive screening instruments: an update. Int J Geriatr Psychiatry 2010;25: 111–120.
6. Marinus J, Visser M, Verwey NA, et al. Assessment of cognition in Parkinson's disease. Neurology 2003;61:1222–1228.
7. Kalbe E, Calabrese P, Kohn N, et al. Screening for cognitive deficits in Parkinson's disease with the Parkinson neuropsychometric dementia assessment (PANDA) instrument. Parkinsonism Relat Disord 2008;14:93–101.
8. Pagonabarraga J, Kulisevsky J, Llebaria G, Garcia-Sanchez C, Pascual-Sedano B, Gironell A. Parkinson's disease-cognitive rating scale: a new cognitive scale specific for Parkinson's disease. Mov Disord 2008;23:998–1005.
9. Riedel O, Klotsche J, Spottke A, et al. Cognitive impairment in 873 patients with idiopathic Parkinson's disease: results from the German Study on Epidemiology of Parkinson's Disease with Dementia (GEPAD). J Neurol 2008;255:255–264.
10. Pagonabarraga J, Kulisevsky J, Llebaria G, et al. PDD-Short Screen: a brief cognitive test for screening dementia in Parkinson's disease. Mov Disord 2010;25:440–446.
11. Gill DJ, Freshman A, Blender JA, Ravina B. The Montreal cognitive assessment as a screening tool for cognitive impairment in Parkinson's disease. Mov Disord 2008;23: 1043–1046.
12. Zadikoff C, Fox SH, Tang-Wai DF, et al. A comparison of the mini mental state exam to the Montreal cognitive assessment in identifying cognitive deficits in Parkinson's disease. Mov Disord 2008;23:297–299.
13. Hoops S, Nazem S, Siderowf AD, et al. Validity of the MoCA and MMSE in the detection of MCI and dementia in Parkinson disease. Neurology 2009;73:1738–1745.
14. Nazem S, Siderowf AD, Duda JE, et al. Montreal cognitive assessment performance in patients with Parkinson's disease with "normal" global cognition according to mini-mental state examination score. J Am Geriatr Soc 2009;57: 304–308.
15. Dubois B, Burn D, Goetz C, et al. Diagnostic procedures for Parkinson's disease dementia: recommendations from the movement disorder society task force. Mov Disord 2007;22:2314–2324.
16. Molloy DW, Standish TI. A guide to the standardized Mini-Mental State Examination. Int Psychogeriatr 1997; 9(suppl 1):87–94.
17. Nakas CT, Alonzo TA. ROC graphs for assessing the ability of a diagnostic marker to detect three disease classes with an umbrella ordering. Biometrics 2007;63:603–609.
18. Yiannoutsos CT, Nakas CT, Navia BA. Assessing multiple-group diagnostic problems with multi-dimensional receiver operating characteristic surfaces:

application to proton MR Spectroscopy (MRS) in HIV-related neurological injury. Neuroimage 2008;40:248–255.
19. Bossuyt PM, Reitsma JB, Bruns DE, et al. Towards complete and accurate reporting of studies of diagnostic accuracy: the STARD Initiative. Ann Intern Med 2003;138:40–44.
20. Jurica SJ, Leitten CL, Mattis S. Dementia Rating Scale: Professional Manual. Odessa, FL: Psychological Assessment Resources; 2001.
21. Harvey PD, Ferris SH, Cummings JL, et al. Evaluation of dementia rating scales in Parkinson's disease dementia. Am J Alzheimers Dis Other Demen 2009;25:142–148.
22. Reisberg B, Finkel S, Overall J, et al. The Alzheimer's disease activities of daily living international scale (ADL-IS). Int Psychogeriatr 2001;13:163–181.
23. Morris JC. The Clinical Dementia Rating (CDR): current version and scoring rules. Neurology 1993;43:2412–2414.
24. Reisberg B, Ferris SH, de Leon MJ, Crook T. The Global Deterioration Scale for assessment of primary degenerative dementia. Am J Psychiatry 1982;139:1136–1139.
25. Cummings JL, Mega M, Gray K, Rosenberg-Thompson S, Carusi DA, Gornbein J. The Neuropsychiatric Inventory: comprehensive assessment of psychopathology in dementia. Neurology 1994;44:2308–2314.
26. Weintraub D, Oehlberg KA, Katz IR, Stern MB. Test characteristics of the 15-item geriatric depression scale and Hamilton depression rating scale in Parkinson disease. Am J Geriatr Psychiatry 2006;14:169–175.
27. Kulisevsky J, Pagonabarraga J. Cognitive impairment in Parkinson's disease: tools for diagnosis and assessment. Mov Disord 2009;24:1103–1110.
28. Troster AI. Neuropsychological characteristics of dementia with Lewy bodies and Parkinson's disease with dementia: differentiation, early detection, and implications for "mild cognitive impairment" and biomarkers. Neuropsychol Rev 2008;18:103–119.
29. McKinlay A, Grace RC, Dalrymple-Alford JC, Roger D. Cognitive characteristics associated with mild cognitive impairment in Parkinson's disease. Dement Geriatr Cogn Disord 2009;28:121–129.
30. Aarsland D, Bronnick K, Larsen JP, Tysnes OB, Alves G. Cognitive impairment in incident, untreated Parkinson disease: the Norwegian ParkWest study. Neurology 2009;72:1121–1126.
31. Williams-Gray CH, Evans JR, Goris A, et al. The distinct cognitive syndromes of Parkinson's disease: 5 year follow-up of the CamPaIGN cohort. Brain 2009;132:2958–2969.
32. Jacobs DM, Marder K, Cote LJ, Sano M, Stern Y, Mayeux R. Neuropsychological characteristics of preclinical dementia in Parkinson's disease. Neurology 1995;45:1691–1696.
33. Levy G, Jacobs DM, Tang MX, et al. Memory and executive function impairment predict dementia in Parkinson's disease. Mov Disord 2002;17:1221–1226.
34. Woods SP, Troster AI. Prodromal frontal/executive dysfunction predicts incident dementia in Parkinson's disease. J Int Neuropsychol Soc 2003;9:17–24.
35. Janvin CC, Larsen JP, Aarsland D, Hugdahl K. Subtypes of mild cognitive impairment in Parkinson's disease: progression to dementia. Mov Disord 2006;21:1343–1349.
36. Caviness JN, Driver-Dunckley E, Connor DJ, et al. Defining mild cognitive impairment in Parkinson's disease. Mov Disord 2007;22:1272–1277.
37. Mamikonyan E, Moberg PJ, Siderowf A, et al. Mild cognitive impairment is common in Parkinson's disease patients with normal Mini-Mental State Examination (MMSE) scores. Parkinsonism Relat Disord 2009;15:226–231.
38. Gagnon JF, Vendette M, Postuma RB, et al. Mild cognitive impairment in rapid eye movement sleep behavior disorder and Parkinson's disease. Ann Neurol 2009;66:39–47.
39. Jak AJ, Bondi MW, Delano-Wood L, et al. Quantification of five neuropsychological approaches to defining mild cognitive impairment. Am J Geriatr Psychiatry 2009;17:368–375.
40. Saxton J, Snitz BE, Lopez OL, et al. Functional and cognitive criteria produce different rates of mild cognitive impairment and conversion to dementia. J Neurol Neurosurg Psychiatry 2009;80:737–743.