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CLINICAL INVESTIGATION

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Development and validation of the Montreal cognitive assessment for people with hearing impairment (MoCA-H)

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Abstract

Background: Hearing impairment is common among older adults and affects cognitive assessments for identification of dementia which rely on good hearing function. We developed and validated a version of the Montreal Cognitive Assessment (MoCA) for people with hearing impairment.

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Methods: We adapted existing MoCA 8.1 items for people with hearing impairment by presenting instructions and stimuli in written rather than spoken format. One Attention domain and two Language domain items required substitution by alternative items. Three and four candidate items respectively were constructed and field-tested along with the items adapted to written form. We used a combination of individual item analysis and item substitution to select the set of alternative items to be included in the final form of the MoCA-H in place of the excluded original items. We then evaluated the performance and reliability of the final tool, including making any required adjustments for demographic factors.

Results: One hundred and fifty-nine hearing-impaired participants, including 76 with normal cognition and 83 with dementia, completed the adapted version of the MoCA. A further 97 participants with normal hearing completed the standard MoCA as well as the novel items developed for the MoCA-H to assess score equivalence between the existing and alternative MoCA items and for independence from hearing impairment. Twenty-eight participants were retested between 2–4 weeks after initial testing. After the selection of optimal item set, the final MoCA-H had an area under the curve of 0.973 (95% CI 0.952–0.994). At a cut-point of 24 points or less sensitivity and specificity for dementia was 92.8% and 90.8%, respectively. The intraclass correlation for test–retest reliability was 0.92 (95%CI 0.78–0.97).

Conclusion: The MoCA-H is a sensitive and reliable means of identifying dementia among adults with acquired hearing impairment.

KEYWORDS
cognitive screening, dementia, hearing impairment, Montreal cognitive assessment

INTRODUCTION

Psychometric tests to identify cognitive impairment involve spoken items and rely on good hearing function. People with hearing impairment or under conditions of simulated hearing impairment do worse than people with good hearing.[1–4] The impact of hearing impairment may lead to false identification of dementia and/or overestimation of severity of cognitive impairment.[5] Hearing impairment is commonly comorbid with cognitive impairment; 94% of people with a cognitive impairment attending a memory clinic were reported having hearing impairment.[6] Cognitive tests have been adapted for people with hearing impairment by deleting or substituting written versions of hearing-dependent items.[7] But deleting hearing-dependent items can adversely affect sensitivity and specificity.[8] Substitution with written versions may change the cognitive demands of the item, meaning that written versions must be re-validated.

To address the need for a reliable cognitive screening test for people with hearing impairment, we developed and validated a version of the Montreal Cognitive Assessment (MoCA).[9] We chose the MoCA because it is widely used, freely available in over 100 languages, has good sensitivity and specificity for detection of dementia and mild cognitive impairment (MCI).[9,10] The MoCA is a one-page, 30-item test that indexes eight cognitive

Key points

- More than 75% of people aged over 75 years have hearing impairment.
- Hearing impairment impacts performance on cognitive screening tests, resulting in overestimation of cognitive impairment.
- We report the development and validation of a version of the Montreal Cognitive Assessment for adults with hearing impairment.

Why does this paper matter?

The MoCA-H is the first fully validated, sensitive, and reliable cognitive screening test for people with hearing impairment.

domains; visuospatial/executive, naming, memory, attention, language, abstraction, delayed recall, and orientation. Administration time is around 20 min.

There are three previous attempts to develop versions of the MoCA for people with hearing impairment.[7] Dupuis and colleagues adapted the MoCA for people with hearing impairment by deleting the spoken items (language repetition, attention to letters, digit span, and delayed recall).[2] They then examined performance of adults with hearing loss ($n = 43$) and adults with normal hearing ($n = 79$) on the standard versus the adapted MoCA. Using proportionately adjusted cut-off scores to account for deleted items, people with hearing impairment were more likely to be classed as cognitively normal on the adapted version, but still not as likely as people with normal hearing. Dupuis et al. concluded that the adapted MoCA reduced but did not eliminate the poorer performance of adults with hearing impairment. Deleting hearing-dependent items risks leaving some cognitive domains under- or un-represented and may reduce the sensitivity and specificity of the test. Al-Yawer and colleagues re-analyzed original MoCA validation data after deleting the hearing-dependent items.[8] Sensitivity for MCI was reduced (from 90% to 56%), although sensitivity for Alzheimer's dementia was not affected.

To preserve the psychometric qualities of the MoCA, rather than deleting items it would be preferable to substitute visually-based items in the same cognitive domain, ideally of similar difficulty. Lin and colleagues developed a timed computerized visual version of the MoCA with written instructions.[11] There was no difference in performance of adults with severe-to-profound hearing loss ($n = 49$) compared to those with normal hearing ($n = 103$) on the computerized visual version of the MoCA. Utoomprurkporn and colleagues subsequently adapted Lin et al.'s computerized MoCA and examined performance in people with hearing impairment and a diagnosis of mild cognitive impairment (MCI; $n = 30$) or dementia ($n = 15$) versus those with normal cognition ($n = 30$).[12] A cut-point of ≤25 yielded 93.3% sensitivity with 80% specificity in distinguishing MCI from normal cognition. Comparing participants with dementia to 14 aged-matched participants with normal cognition, the authors reported that a cut-point of ≤21provided sensitivity of 93.3% and specificity of 100% in differentiating dementia from normal cognition but confidence intervals around the performance estimates were wide. Utoomprurkporn et al. reported higher educational level among the normal cognition group versus the MCI and dementia groups, which together with the small sample sizes and group differences in age raise issues of reliability around the sensitivity/specificity estimates and associated cut-points.

Our objective was to develop and validate a version of the MoCA (version 8.1) – the 'MoCA-H' - for people with hearing impairment. The MoCA-H development protocol is detailed in an earlier paper.[13] The intention was for the MoCA-H to be similar to the standard MoCA in terms of the cognitive domains assessed, number of items, scoring, and completion time. The content of the MoCA-H was determined by a combination of individual item analysis and model-based evaluation to determine the optimal combination of items with respect to sensitivity and specificity for dementia. The project was designed as a multinational study involving English-, French- and Greek-speaking people and sites, with participant data pooled across languages. Unfortunately, due to the Covid-19 pandemic, all activity was suspended in March 2020, with 67% of the target sample recruited. An interim analysis showed that the three language groups performed differently on the items in the MoCA-H and on the whole scale, making it not valid to pool the language groups into a single analysis. Recruitment recommenced in June 2021 and finished at the end of May 2022. The current paper reports on the development and validity of the English-language MoCA-H derived from the final dataset.

METHODS

Study design

The principal method used to adapt the existing MoCA 8.1 items for use with people with hearing impairment was to present instructions and stimuli for the MoCA items in written rather than spoken format.[13] Test-takers were asked to read the written instructions aloud to the examiner as a comprehension check. Three items—the 'attention to letters' item from the Attention domain and the two sentence repetition items from the Language domain—required substitution with more appropriate items (Table 1). Candidate alternative Attention items (labeled A1, A2, and A3) and Language items (L1, L2, L3, and L4) were constructed of varying anticipated difficulty. These were tested along with the remaining MoCA items adapted to written form. An aim of testing was to make a final selection of one alternative Attention item and two alternative Language items for inclusion on the MoCA-H, based on their evaluated performance.

Participants

Participants with age-related hearing impairment were recruited from sites across England (four sites), Ireland

TABLE 1 Adaptions to the Montreal Cognitive Assessment (MoCA; version 8.1) for hearing impaired (MoCA-H).

Attention domain[a]		
Standard MoCA	**Alternative items**	
Attention to letters. The participant listens to a string of 29 letters and taps his/her hand every time he/she hears the letter "A" (there are 12 "A"s; 1 point earned if <2 errors)[1]	A1	Numbers in WHITE CIRCLES, <2 ERRORS
	A2	Numbers in BLACK CIRCLES OR SQUARES, ≤2 ERRORS
	A3	Numbers in BLACK CIRCLES OR SQUARES, ≤3 ERRORS
Language domain[b]		
Standard MoCA items	**Alternative items**	
The participant listens to and repeats two short sentences[b]	L1	ball/kicked/the/Mary
	L2	cat/sleepy/the/very/ was
	L3	made/John/ tasty/cake/ a/chocolate
	L4	wear/decided/a/blue/ Julie/to/dress

[a]The MoCA 8.1 Attention domain item to be replaced, involved test-takers tapping their finger in response to hearing an 'A' in a string of letters that are read aloud. The first MoCA-H alternative item required participants to look at a string of numbers bordered by circles, squares or triangles and read out only those in a circle, with a point scored for making 1 error or less. The second alternative item was similar except that numbers in circles or squares were read out and the string was twice as long. A point was scored for 2 errors or less. The third alternative item was based on relaxing the criteria for achievement of this item to 3 errors or less.

[b]The Language domain items in the MoCA 8.1 involved repetition of spoken sentences. The four alternative MoCA-H items involved re-arranging a randomly-ordered set of visually presented words into a meaningful sentence. The items varied in the number of words in the set, which ranged from 4 up to 7.

(one site), and Australia (two sites). A comparison sample of participants without hearing impairment was also recruited. Participants were recruited from audiology services, memory clinics, volunteer databases, and the general community. Participants were required to be over 60 years of age, resident in the general community and have capacity to provide written informed consent to participate. Those living in long term care facilities, who do not understand written and spoken English, with dual sensory impairment (both hearing and vision impairment), or who were culturally Deaf were excluded from the study. Hearing impairment status was based on pure-tone air conduction threshold testing. Those with a better-ear audiometric threshold ≥40 dB HL over 1, 2, and 4 kHz were allocated to the hearing-impaired groups. Those who reported fluctuating or recent changes in hearing or visual acuity with presenting visual acuity poorer than <6/12 were excluded.

Membership of the dementia group was based on a diagnosis of Alzheimer's, vascular or mixed dementia confirmed by a medical doctor. These dementia types account for approximately 90% of dementia diagnoses.[14] Less common dementia types, such as frontotemporal dementia, Parkinson's disease, and dementia with Lewy bodies were excluded. A change from the study protocol[13] was that participant scores on the General Practitioner Assessment of Cognition[15] (GPCOG) were not used to help decide on group membership: items on the GPCOG overlap with the MoCA and may be subject to similar hearing-impairment bias. Resulting mis-categorizations could potentially inflate agreement between MOCA-H item scores and group membership. We therefore assigned dementia group membership according to practitioner confirmation, or in cases where that was not available participant and study partner self-report. Compared with the main alternative (i.e., GPCOG), self-reported dementia status is a conservative approach in that use of self-report is likely to under-estimate the actually discriminative ability of the MoCA-H.

Sample size calculation

The original sample size calculation was based on generating estimates of the sensitivity to detect dementia and specificity to exclude normal cognition, with 95% confidence intervals no wider than plus/minus 9% regardless of their true values, for which samples of 132 people with dementia and hearing impairment and 132 people with normal cognition and hearing impairment would be required.[13] After the pause in recruitment in March 2020 and interim analysis of the data collected up to that point, the sample size requirement was recalculated for the revised aim of achieving a similar degree of precision on the English-language MoCA-H alone. The interim analysis indicated sensitivity and specificity close to 90%: to be conservative we assumed a true value of 80% and calculated that samples of 80 people with dementia and hearing impairment and 80 people with normal cognition and hearing impairment, would estimate this with a 95% confidence interval of −10% to +9%.

Consent and testing procedures

Data collection took place at participants' homes or testing rooms within research facilities. Capacity to consent was assessed at the start of the first visit, and written informed consent was obtained. All data collectors had received training in assessing capacity according to relevant local laws (e.g., the Mental Capacity Act (2005) in the UK). If more than one study visit was required, capacity to consent was re-assessed and willingness to continue was confirmed with the participant. After providing consent, participants completed hearing and vision assessment followed by the MoCA. Participants with hearing impairment undertook the MoCA-H including the candidate alternative MoCA-H Attention and Language domain items (see above). Participants with normal hearing completed the standard MoCA 8.1 and the candidate alternative MoCA-H items to provide a direct comparison between the original and alternative items. Participants were invited to return for a retest 2 to 4 weeks after the initial test, until a minimum of 30 participants for the hearing-impaired groups were retested. Administration of the MoCA and MoCA-H followed the standard MoCA testing procedure, and all data collectors received training in administration of the MoCA as mandated by the MoCA Clinic. Data were de-identified, encrypted, and transferred to the coordinating center in Manchester, UK. Data integrity checks were performed, with 5% of all data checked against data collection forms for accuracy. Data are available to researchers and held in the University of Manchester's institutional repository (https://figshare.manchester.ac.uk/). Pure tone audiometric hearing assessment was completed with a R07A Screening Portable Audiometer (Kamplex Limited, London), using audiocup headphones (Amplivox, Eden Prairie MN) to minimize interference from background noise. Testing took place in a 'quiet room'. Prior to testing, background noise levels were measured with a KM6 Sound level meter (Kamplex Limited, London) to ensure noise levels were below those recommended by American National Standards Institute standards.[16] Presenting visual acuity (i.e., with usually worn spectacles) was assessed with LED 930 illuminated 3-meter charts (Precision Vision, Woodstock IL).

Data analysis

Analysis was undertaken in two stages. Stage 1 used a combination of individual item analysis and item substitution to select the set of alternative items for the final MoCA-H in place of the excluded original items. Stage 2 focused on evaluating and refining the performance and reliability of the final tool, including adjustments for demographic factors. Analysis was conducted using Stata v16.

Stage 1 item analysis

Each MoCA-H item was assessed against five performance criteria. The first three criteria applied to individuals with hearing impairment only:

1. Group Discrimination: Maximum discrimination would be achieved by an item answered correctly by 100% of the hearing impairment-normal cognition group and 0% of the hearing impairment-dementia group.
2. Redundancy: Point-biserial correlation between the item and the remainder of the MoCA-H scale, where the latter refers to the total score across all items excluding the candidate alternatives. Correlations >0.75 are indicative of potentially redundant items.
3. Feasibility: No more than 5% missing responses.

Two further criteria also involved the comparison sample with normal cognition or dementia without hearing impairment who completed both the original MoCA 8.1 and alternative MoCA-H items:

4. Agreement with the original item. %'s of the normal cognition and dementia groups who responded identically to the original item and the corresponding alternative.
5. Independence from hearing impairment. Difference in the % of participants with and without hearing impairment answering the item correctly.

Scale items may perform differently in combination with other items than individually. We therefore also undertook an analysis of MoCA-H as a whole scale under different combinations of alternative items. The number of possible combinations was sufficiently limited to explore all options to identify the most efficient. We applied Receiver Operating Characteristic (ROC) analysis to each potential item set (i.e., the items adapted for presentation in written form, plus one alternative Attention item and two alternative Language items) and used the area under the curve (AUC) and sensitivity/specificity as measures of overall performance.

Based on the combined results from the individual item analyses and item-set substitution analysis we made a choice of one alternative attention item and two alternative language items to substitute for the corresponding original items.

TABLE 2 Participant demographics

	Hearing impairment				Normal hearing			
	Normal cognition ($n = 76$)		Dementia ($n = 83$)		Normal cognition ($n = 67$)		Dementia ($n = 30$)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Age (years)	75.1	7.9	79.6	6.5	69.0	6.0	73.8	6.2
Gender	*n*	%	*n*	%	*n*	%	*n*	%
Male	34	44.7	52	62.7	20	29.8	19	63.3
Female	42	55.3	31	37.3	47	70.1	11	36.7
Education								
≤12 years	30	39.5	50	60.2	20	29.9	13	46.3
≥13 years	46	60.5	33	39.8	47	70.1	17	56.7

TABLE 3 Summary of results from the substitution analysis; top five models based on Area Under the Curve (AUC)

Moca-H including the below new items	Mean (SD) for hearing impairment-normal cognition	Mean (SD) for hearing impairment-dementia	AUC	AUC l95	AUC U95	Sensitivity	Specificity	Cut-point for 90% sensitivity
A2 L2 L4	26.7 (2.8)	15.4 (5.8)	0.969	0.947	0.992	90.4	88.2	≤23
A2 L1 L2	26.6 (2.8)	15.5 (5.7)	0.969	0.946	0.991	90.4	88.2	≤23
A2 L2 L3	26.6 (2.8)	15.4 (5.8)	0.968	0.946	0.991	90.4	88.2	≤23
A2 L1 L4	26.6 (2.8)	15.4 (5.9)	0.968	0.945	0.991	90.4	88.2	≤23
A3 L2 L4	26.8 (2.8)	15.5 (5.9)	0.968	0.945	0.991	90.4	89.5	≤23

Stage 2 validation and reliability

The item set from Stage 1 constituted the MoCA-H. Mean scores and standard deviations for each MoCA-H domain for the hearing impairment-normal cognition and hearing impairment-dementia groups were computed and compared using the Wilcoxen ranked-sum test given the non-continuous and limited range of the domain scores.

Overall scores on the standard MoCA are known to vary by patient characteristics, such as education and age, and adjustments applied. We conducted multivariable regression to determine whether MoCA-H scores varied by patient gender, age or education, and to determine appropriate adjustment factors. Overall scores were reasonably continuous and the sample large enough to be treated as normally distributed. The MoCA-H scores were subjected to ROC analysis to obtain the AUC and to estimate sensitivity and specificity for a range of threshold scores for dementia.

Test–retest reliability was calculated using the subsample of participants who repeated the test 2 to 4 weeks after the initial testing. We applied a two-way mixed-effects model (participant was a random effect) and derived an intraclass correlation coefficient (ICC) relating to absolute-agreement on individual scale scores.[17] Internal consistency was assessed using Cronbach's alpha computed on standardized item scores.

RESULTS

The dataset of hearing-impaired individuals included 76 people with normal cognition and 83 with dementia (Table 2). Compared with participants with normal cognition, those with dementia were slightly older (79.6 vs. 75.1), more likely to be male (62.7% vs. 44.7%), less likely to have 13 or more years of education (39.8% vs. 60.5%). The comparison groups of people with normal hearing were smaller: 67 in the normal cognition group and 30 in the dementia group. Similar demographic differences were observed between these two groups.

Stage 1 item analysis

The item analysis found mostly small differences in performance between the three alternative Attention items (Supplemental Material S1), except that A1 showed less independence from hearing impairment: the % of participants

with hearing impairment and dementia correctly answering A1 was almost 30% lower than for participants with dementia only. The four alternative Language items were considered acceptable options (Supplemental Material S1).

Substitution analysis

Table 3 summarizes the five most predictive models in which every possible combination of one of the three new attention items and two of the four new language items were substituted into the scale and total scores subjected to ROC analysis. For each model sensitivity and specificity is reported for the threshold at which sensitivity first exceeded 90%. All five models had very similar performance, with the AUC varying between 0.968 and 0.969 only and sensitivity and specificity unchanging. The most predictive model from this analysis incorporated items A2, L2, and L4. We therefore selected A2, L2, and L4 as the final alternative items for the MoCA-H.

Stage 2 validation and reliability

Demographic factors associated with MoCA-H scores

Multiple regression analysis of overall MoCA-H scores by dementia status, age, gender, and education found statistically significant relationships ($p < 0.05$) with gender, where females had a mean scores 1.9 (95%CI 0.52–3.25) points below males, and with education where those with ≤12 years of education had a mean score 3.2 (95%CI 1.80–4.59) points lower than those with ≥13 years of education. No relationship to age ≥80 years was found. Based on these findings, we explored the impact on the predictive performance of the MoCA-H of adjusting for education and gender (Table 4). We began by adding 1, 2, and 3 points to scores for those with ≤12 years of education. From ROC analysis for each of these scenarios we determined that a 2-point adjustment for education produced the best balance of sensitivity and specificity (Figure 1).

We next assessed whether additional improvement would come from boosting scores further by adding 1 or 2 points to the scores of female participants. Adding 1 point for female gender made a marginal improvement in the AUC, sensitivity, and specificity, but adding two points resulted in little additional gain. Adding points for gender is a diversion from current MoCA practice and given that the gain was small we opted to include a 2-point adjustment for education only. The final MoCA-H had an AUC of 0.973 (95% CI 0.952–0.994). At a cut-point of 24 points or less (one point less than the standard MoCA) sensitivity was 92.8% and specificity 90.8%. The hearing impairment-normal cognition group scored consistently significantly higher ($p < 0.001$) on all domains and on the whole scale (Supplemental Material S1). Group differences were smallest for the Naming domain and greatest for Delayed Recall, with standardized mean differences of 0.73 and 2.43 respectively. Including the adjustment for education, the hearing impairment-normal cognition group had a mean (SD) total score of 27.5 (2.6) compared with 16.6 (5.6) for the hearing impairment-dementia group. Internal consistency reliability based on Cronbach's alpha was 0.91. Twenty-eight individuals (10 hearing impairment-normal cognition and 18 hearing impairment-dementia) from across three sites were retested on the instrument between 2 and 4 weeks after initial testing. Using this data, we computed an ICC for the test–retest reliability of 0.92 (95%CI 0.78–0.97).

DISCUSSION

The MoCA-H is a sensitive and reliable version of the MoCA 8.1 for the identification of dementia within populations of adults with acquired hearing impairment. The MoCA-H draws on the diagnostic strength of the previously well-validated MoCA.[9,10] Our approach in developing the MoCA-H was through item substitution rather than item deletion, yielding superior validity and reliability compared with previous measures.[7] We constructed and substituted novel items that met criteria for individual item performance and that together maximized the ability of the MOCA-H to distinguish dementia from normal cognition.

The MoCA-H closely matches the standard MoCA regarding the cognitive domains assessed, number of items, and completion time, but differs slightly in scoring. Whereas the standard MoCA gives a 1-point score uplift to persons with ≤12 years of education, the MoCA-H includes a 2-point uplift for improved overall discrimination. Our recommended cut-point for dementia of ≤24 points maximizes the balance of sensitivity and specificity, but is one point lower than the standard MoCA cut-point of ≤25. However, users should select a cut-point that suits their purposes. At a cut-point of ≤25, the MoCA-H has 98% sensitivity and 82% specificity, which compares well to 100% and 87% respectively for the standard MoCA[9,10] and which may be preferred where avoiding false negatives is a priority. We observed that female participants on average scored two points lower on the MoCA-H compared with males after controlling for cognitive group, education, and age. This is a finding not

TABLE 4 Receiver Operating Characteristic (ROC) analysis with score adjustments for education and gender

	No adjustment			Adding 2 points for ≤12 years of education			Adding 2 points for ≤12 years of education and 1 point for female gender		
Cut-point for dementia	**Sensitivity**	**Specificity**	**Youden Index**	**Sensitivity**	**Specificity**	**Youden Index**	**Sensitivity**	**Specificity**	**Youden Index**
≤30	100.0%	0.0%	0.0%	100.0%	0.0%	0.0%	100.0%	0.0%	0.0%
≤29	100.0%	9.2%	9.2%	100.0%	23.7%	23.7%	100.0%	34.2%	34.2%
≤28	100.0%	27.6%	27.6%	100.0%	43.4%	43.4%	100.0%	50.0%	50.0%
≤27	100.0%	44.7%	44.7%	100.0%	54.0%	54.0%	100.0%	60.5%	60.5%
≤26	100.0%	67.1%	67.1%	98.8%	71.1%	69.9%	97.6%	77.6%	75.2%
≤25	100.0%	77.6%	77.6%	97.6%	81.6%	79.2%	96.4%	89.5%	85.9%
≤24	95.2%	85.5%	80.7%	92.8%	90.8%	83.6%	91.6%	93.4%	85.0%
≤23	90.4%	88.2%	78.5%	86.7%	94.7%	81.5%	86.8%	94.7%	81.5%
≤22	86.7%	92.1%	78.9%	83.1%	96.1%	79.2%	80.7%	96.1%	76.8%
≤21	83.1%	94.7%	77.9%	78.3%	96.1%	74.4%	75.9%	97.4%	73.3%
≤20	79.5%	96.1%	75.6%	71.1%	97.4%	68.4%	71.1%	98.7%	69.8%
≤19	74.7%	96.1%	70.7%	67.5%	98.7%	66.2%	67.5%	98.7%	66.1%
≤18	65.1%	97.4%	62.4%	61.4%	98.7%	60.1%	57.8%	98.7%	56.5%
≤17	60.2%	98.7%	58.9%	53.0%	98.7%	51.7%	51.8%	100.0%	51.8%
≤16	56.6%	98.7%	55.3%	47.0%	100.0%	47.0%	43.4%	100.0%	43.4%
≤15	49.4%	98.7%	48.1%	42.2%	100.0%	42.2%	37.3%	100.0%	37.3%
AUC (95%CI)	0.969 (0.947–0.992)			0.973 (0.952–0.994)			0.976 (0.957–0.995)		

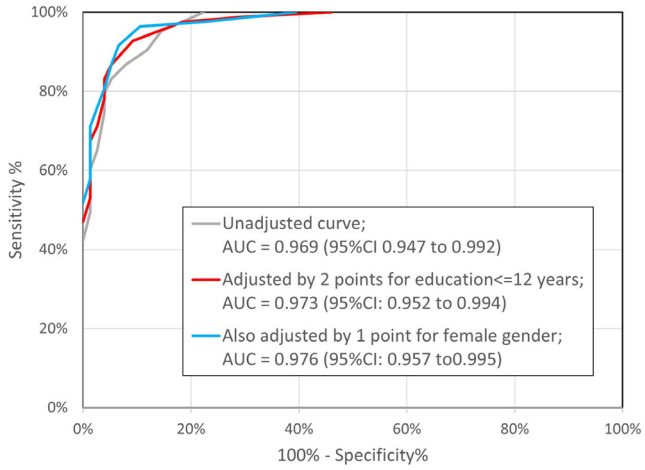

FIGURE 1 Receiver operating characteristic (ROC) curve analysis of the Montreal Cognitive Assessment for people with hearing impairment (MoCA-H), with and without adjustment for years of education and female gender. AUC, area under the ROC curve.

previously reported to our knowledge but which requires further investigation as it suggests a possible gender bias in the instrument.

We had planned to combine data across three languages (English, French, Greek) to validate the MoCA-H. But we discovered that MoCA-H and the MoCA 8.1 items performed differently across languages and were unable to pool data for analysis. Variability in sensitivity and specificity of the MoCA in different languages has been reported.[18] Data collection in our project followed the same protocol across the three languages, suggesting that (i) differences in dementia diagnosis between countries and/or (ii) cultural or language differences may be responsible for the differences in performance we observed. This supports the conclusion[18] that translations of the MoCA-H should be re-validated in each language.

A strength of the MoCA is its ability to discriminate MCI.[19] Unfortunately due to the complexity of design and the large numbers of participants with specific combinations of cognitive and sensory impairments required, we did not include a group of participants with mild cognitive impairment (MCI). In addition, the MoCA-H is not suitable for people with dual sensory impairment, which affects between 9% and 21% of those over 70.[20] A version of the MoCA for people with vision impairment is in development (MoCA-V),[13] though this also is not suitable for people with dual sensory impairment. Appropriate cognitive screening tests for people with dual sensory impairment include those based on, for example, touch[21,22] or smell.[23]

The MoCA-H is a sensitive and reliable means of identifying dementia among adults with acquired hearing impairment, which is comparable to the standard MoCA and freely available to appropriately qualified persons.

AUTHOR CONTRIBUTIONS

Iracema Leroi and Piers Dawes are responsible for the overall development of an ethically sound protocol. Piers Dawes, Kathleen Gallant, Antonis Politis, Saima Sheikh, Wai Kent Yeung, and Ziad Nasreddine developed the MoCA-H. Piers Dawes, Antonis Politis and David Reeves designed the validation study. David Reeves planned the analyses, which was conducted by Fiona Holland and David Reeves. Iracema Leroi, Catherine Helmer, Chyrssoula Thodi, Antonis Politis, Renaud David, Marie-Josée Sirois, and Hamid R. Sohrabi were leads for each site. All authors contributed to the drafting, critical revision, and final approval of the document. The investigators would like to thank Milena Spoa, Angus Sturrock, Olga Clark, Kimberley Evans, Zoe Simpkin, Jo Shaw, JP Connelly, Alexandra Konig, Evangelina Stamouli, Sophie Auriacombe, Charlotte Riom, Roxanne Villeneuve and Juliana Prokopiou for assistance with recruitment and data collection.

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CONFLICT OF INTEREST

Ziad Nasreddine is the Copyright Owner of the MoCA Test.

SPONSOR'S ROLE

The sponsors had no role in the design, methods, subject recruitment, data collections, analysis, or preparation of the article.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

Supplemental Material S1. Stage 1 Analysis. Summary of item analysis for alternative Attention and Language items.

Supplemental Table. MoCA-H individual domain and total scores for the hearing impairment-normal cognition and hearing impairment-dementia groups respectively.

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