Neuropsychological Test Performance of Cognitively Healthy Centenarians: Normative Data From the Dutch 100-Plus Study

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OBJECTIVES: The fraction of the population that reaches the age of 100 years is growing. At this age, dementia incidence is high and cognitive functioning is highly variable across individuals. Normative data for neuropsychological tests are lacking in centenarians, which hampers the ability to evaluate their cognitive functioning for both research and clinical practice. Here, we generated norms for neuropsychological tests in a sample of cognitively healthy centenarians while taking sensory impairments into account.

DESIGN: Cross-sectional cohort study.

SETTING: Centenarians who participate in the prospective 100-plus Study.

PARTICIPANTS: A total of 235 centenarians (71.5% female), who self-reported to be cognitively healthy, which was confirmed by an informant and a trained researcher.

MEASUREMENTS: We generated normative data for 15 cognitive tests, measuring global cognition (Mini-Mental State Examination [MMSE]), premorbid intelligence, attention, language, memory, executive function, and visuospatial function by multiple linear regressions and/or by reporting percentiles.

RESULTS: Normative data for global cognition resulted in a mean MMSE score of 25.6 ± 3.1 (range = 17-30; interquartile range = 24-28). Vision problems and fatigue often complicated the ability to complete tests, and these problems explained 41% and 22% of the missing test scores, respectively. In contrast, hearing problems (4%) and task incomprehension (6%) rarely complicated test performance. While educational level was associated with performance on the majority of the tests, sex and age were only weakly associated with test performance.

CONCLUSIONS: We generated normative data for 15 common neuropsychological tests in a large sample of cognitively healthy centenarians, while taking age-related sensory impairments into consideration. These normative data allow the detection of deficits across a wide range of cognitive domains. Our results suggest that, next to education level, vision ability and the level of fatigue should be taken into account when evaluating cognitive functioning in centenarians. **J Am Geriatr Soc 67:759–767, 2019.**

Key words: normative data; oldest-old; centenarians; neuropsychological tests; cognitive functioning

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In the next 30 years, the number of centenarians worldwide is expected to increase almost 20-fold to 3.2 million people.[1] Dementia incidence increases exponentially with age and reaches approximately 40% per year at the age of 100 years.[2] Previous studies indicated that, an estimated 25% of the centenarians have retained their cognitive health, while 25% have symptoms of cognitive impairment and 50% may be regarded as having dementia.[3,4] To evaluate cognitive impairment in this heterogeneous group, it is important to implement suitable instruments that consider the specific characteristics of centenarians.[5]

Cognitive test performance of centenarians is often evaluated relative to normative data generated in younger adults. However, norms derived in younger samples may not account for cognitive decline as part of the normal aging process.[6] Applying these norms to evaluate cognitive functioning in centenarians may lead to misclassifications of cognitive impairment.[7] Indeed, relative to 80 and 90 year olds, centenarians appear to have significantly lower test scores in multiple cognitive domains, while showing a larger variability in their performance.[8–10] This suggests that cognitive performance of the oldest-old can only be

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accurately assessed relative to norms generated in cohorts with narrow age bands.[11]

Thus far, normative data for centenarians is available for the Mini-Mental State Examination (MMSE),[9,12–15] which measures global cognitive functioning. However, to evaluate a broad spectrum of cognitive domains, application of additional tests is required.

The Georgia Centenarian Study evaluated test performance of centenarians across multiple cognitive domains, among which, the Controlled Oral Word Association Test, the Fuld Object Memory Evaluation and Severe Impairment Battery, and the Behavioral Dyscontrol Scale.[9,10,16,17] However, these norms were not adjusted for loss of hearing and sight and were generated in population-based samples, possibly including centenarians with cognitive impairment.[18] This may lead to lower norm ranges for cognitive tests, which complicates making a distinction between cognitive impairment and cognitive health in a clinical setting.[18]

Therefore, cognitive test performance of centenarians should be evaluated relative to normative data generated in a cognitively intact sample, while taking sensory disabilities into account. The 90+ Study previously included nondemented people from different age bands (90-91, 92-94, and 95 years and older) to provide suitable normative data.[19] Despite test adaptations that compensated for sensory losses, some tests could not be completed due to sensory impairments. This emphasizes that it is important to consider the decline of these faculties when establishing normative data.

Here, we aim to generate robust normative data for the evaluation of cognitive functioning in centenarians, while considering sensory impairments. For this, we used a large sample of cognitively healthy centenarians from the Dutch 100-plus Study.[20]

METHODS

Population

Subjects were part of the 100-plus Study, a longitudinal cohort study of people (1) aged 100 years or older, (2) who self-reported to be cognitively healthy, which was confirmed by the study partner. For this study, we implemented the following exclusion criteria: (1) cognitive impairment, as estimated by a trained researcher; and (2) no neuropsychological test scores available, which leaves a total sample of N = 235 (see flowchart in the supplementary). Furthermore, depending on the test requirements, we additionally excluded centenarians with poor-very poor vision and hearing.

Participants were recruited by searching different types of (online) media that mention centenarians and by mouth-to-mouth advertisement. A further description of inclusion and recruitment procedures can be found elsewhere.[20] This study was approved by the Medical Ethics Committee, and all participants provided informed consent.

Procedure

The centenarians were visited at home by researchers with neuropsychological and/or medical training. The researchers estimated the cognitive health of the centenarians based on semi-objective criteria. Centenarians were estimated to be cognitively impaired when they continually repeated themselves, had difficulty understanding or remembering questions, and had difficulty with naming and/or word finding. Vision and hearing were categorized into "good," "moderate," "poor," and "very poor" based on the observations of the study researcher and the self-reported rating of hearing and vision abilities (see supplementary). Centenarians with poor to very poor vision were excluded for the generation of normative data of the MMSE, the Key Search test, the Dutch Adult Reading Test (DART), the Visual Association Test (VAT), the Trail Making Test (TMT), Number Location, and the Clock Drawing Test (CDT). Centenarians with poor to very poor hearing were excluded from reporting normative data of the MMSE, Digit Span, and the Rivermead Behavioral Memory Test (RBMT).

Neuropsychological Testing

As some participants were frail and depended on help from caregivers or family members, we encouraged a close relation to be present during our visits. We requested the close relation to *not* interfere during test administration. The test battery took approximately 1.5 hours to complete, and we took short breaks whenever centenarians showed signs of fatigue. We encouraged participants to use all available devices to support their vision and/or hearing. Tests were aborted when sensory problems clearly interfered with test performance. Based on the observations of the study researcher and the self-report of the centenarians, we annotated the reasons for interference with test completion: physical, vision or hearing problems, fatigue, or incapable of understanding tasks or instructions.

Measures

Neuropsychological Tests

The neuropsychological test battery consisted of 15 tests measuring global cognition, premorbid intelligence, attention and/or concentration, language, memory, executive function, and visuospatial function. See supplementary data for more detailed information on properties of these tests. At the start of the study, the test battery was limited to the MMSE and CDT but expanded gradually over the course of the study with tests that allow the evaluation of specific cognitive domains. For this reason, not all centenarians were presented with the same battery or the same number of tests.

The MMSE was used to evaluate global cognition.[21] We addressed premorbid intelligence using the DART,[22–24] in which subjects are asked to read out loud 50 words with atypical phonemic pronunciation. These words were presented in an enlarged font size to take into account possible visual difficulties. The Digit Span was used to evaluate attention/concentration (*forward condition*) and working memory (*backward condition*).[25] The *forward condition* requires subjects to repeat sequences of digits that increase in length, whereas in the *backward condition*, sequences of digits have to be repeated in reverse order. We evaluated processing speed and attention using the TMT A, and mental flexibility using the TMT B, which respectively requires subjects to connect dots of numbers in numerical order and alternate between numbers and letters in numerical and alphabetical sequence.[26] If the centenarians were not determined to proceed after 180 seconds (TMT A) and 300 seconds (TMT B), the test was aborted and scores were extrapolated based on the last finished item (number or letter) and the time spent on the test. The Dutch version of the Controlled Oral Word Association Test (naming words from initial letters) and Category fluency (naming animals) were administered to evaluate executive functioning and language, the latter also assessing semantic memory.[27,28] To evaluate executive functioning, we administered the Key Search subtest of the Behavioral Assessment of the Dysexecutive Syndrome Test Battery[29] involving a problem-solving task instructing subjects to think of a strategy to find a lost key. Memory was measured with the story recall subtest of the Dutch version of the RBMT and the VAT.[30–32] The RBMT requires subjects to immediately repeat all items they remember from two stories read out loud, and again after a 15-minute interval. When necessary, a cue was given for helping them recall the story line, which was considered when calculating the total score. We made two adaptations to the test procedure: (1) two stories were read instead of one to improve reliability; (2) during recall, all remembered items were scored, whether they belonged to the appropriate story line or not. The VAT involves subjects to name two visual items shown in one picture (eg, a hedgehog on a chair), of which one item (hedgehog) needs to be recalled afterwards while the other (the chair *without* the hedgehog) is used as a cue. We used naming of the items as an additional measure of language functioning. Visuospatial orientation was assessed with the Number Location subtest of the Visual Object and Space Perception Battery,[33] which required subjects to indicate a specific number that corresponded with the exact location of a dot. For evaluating visuospatial construction, subjects were instructed to draw a clock with the hands at 10 past 11 (CDT). Because of common tremors in centenarians, the CDT was offered with a predrawn circle and was scored according to a method that does not consider the drawing of the circle.[34,35]

Demographic and Clinical Measures

Education level was determined based on the International Standard Classification of Education 1997[36] and was divided into "low" (upper secondary education or less) and "high" (post-secondary non tertiary education or more). Independence in activities of daily living (ADLs) was evaluated with the Barthel Index.[37] Scores range from 0 to 20, with scores of 15 or greater indicating independence in ADLs. The 15-item version of the Geriatric Depression Scale (GDS) was administered to investigate depression.[38] Scores range from 0 to 15, with scores greater than 5 suggesting depressive symptoms.

Data Analysis

We generated normative data by applying multiple linear regression models to the data, and by representing test scores in percentiles. Regression analyses with age, sex, and education as independent variables and scores as dependent variables were performed for each test separately. TMT scores were log-transformed as they were not normally distributed and inverted, such that higher scores indicated better performance. Because of ceiling effects, the VAT, Number Location, and the CDT were not analyzed using regression models. For all tests, scores were standardized into z-scores to (I) correlate the number of tests the centenarians were able to complete with their overall mean z-score and (II) visualize the distribution of the scores using boxplots. $P < .05$ was considered significant. Statistical analyses were performed using SPSS 22.0 (IBM Corp., Armonk, NY) and R 3.4.2 (The R Foundation, https://www.r-project.org/).

RESULTS

Demographic and Clinical Characteristics

The 235 centenarians had a median age of 100.4 years (range = 100-107 years) and included 168 females (72%). The majority of the centenarians (59%) lived independently, 79% were independently mobile, and 54% were independent in ADLs. Most of the centenarians retained moderate-good vision (77%) and hearing capacities (88%). The majority (62%) had a basic-low education level. Most centenarians (92%) did not show depressive symptoms, as measured with the GDS. Clinical and demographic characteristics are summarized in Table 1.

Influence of Age-Related (Sensory) Impairments on Test Incompletion

Across all tests applied, an average of 79% of the tests were completed by the centenarians (Table 2). While greater than 95% of the centenarians completed both fluency tasks, only 45% were able to complete TMT B. Difficulties with vision (41%) and fatigue (22%) were the most common reasons for not being able to complete a test, whereas hearing impairment only rarely complicated test completion (4%). In some cases, not understanding the test and/or test instructions was a reason for not completing the Number Location (16%), Key Search (14%), and TMT B (23%). Overall, we found a positive correlation between the number of tests the centenarians were able to complete and the mean z-score across all completed tests (Pearson's correlation, $r = 0.35$, $P < .001$), see supplemental data.

Normative Data and Cognitive Test Performance In Centenarians

Per test, the number of centenarians whose test performance was used to generate normative data is shown in Table 2. Centenarians with poor to very poor vision (21%) and hearing (11%) were excluded for tests for which these faculties were required.

We present percentiles and means of all test scores stratified by education level to define the normative data (Table 3). Figure 1 shows the distribution of the performances on each test. Overall, most test scores showed wide distributions, while the VAT, Number Location, and the CDT had strong ceiling effects (Table 3). Correlations between the test scores are displayed in the supplement.

The *regression-based norms* adjusted for sex, age, and education can be obtained from the β values derived from the linear-regression models (Table 4 and see supplementary

Table 1. Demographic and Clinical Characteristics of the Sample (n = 235)[a]

Characteristic	Value
Age, y	
Median (IQR)	100.4 (100.2-102)
Mean (SD)	101.1 (1.4)
Range	100-107
Female sex, No. (%)	168 (72)
Education, No. (%)[b]	
High level	90 (38)
Low level	145 (62)
Vision, No. (%)	
Good	153 (65)
Moderate	27 (12)
Poor	29 (12)
Very poor	22 (9)
Hearing, No. (%)	
Good	134 (57)
Moderate	73 (31)
Poor	21 (9)
Very poor	4 (2)
Living situation, No. (%)	
Independent without assistance, or in a residence with available service	138 (59)
In a residential care center	85 (36)
In a nursing home	2 (1)
With family	10 (4)
Barthel Index, No. (%)[c]	
≥15, Independent in ADLs	126 (54)
<15, Dependent in ADLs	80 (34)
GDS >5, depressive symptoms, No. (%)[d]	19 (8)
Mobility, No. (%)	
Able to walk independently[e]	185 (79)
Able to walk with help of another person	8 (3)
Able to move independently in a wheelchair	14 (6)
Not able to move independently in a wheelchair	12 (5)

Abbreviations: ADLs, activity of daily living; GDS, Geriatric Depression Scale; IQR, interquartile range; SD, Standard Deviation.

[a]There were 3 missing values for hearing, 4 for vision, 16 for mobility, 45 for the GDS, and 29 for the Barthel Index.

[b]High education level indicates post-secondary non tertiary education or higher; low education level, upper secondary education or lower.

[c]Scores range from 0 to 20.

[d]Scores range from 0 to 15.

[e]With or without help of a walking stick or walker.

for methods). In addition, we provide an Excel file in which these norms can be calculated (see supplementary).

Association of Education, Sex, and Age With Cognitive Test Performance

Across all tests, education level was positively associated with test performance when adjusted for age and sex. Exceptions to this are the RBMT delayed recall and TMT A and B. Males obtained higher scores on the Digit Span Forward (mean $\pm$ SD = 7.7 $\pm$ 1.8 vs 6.9 $\pm$ 1.8) and the Key Search (mean $\pm$ SD = 8.1 $\pm$ 4.1 vs 6.1 $\pm$ 3.3) relative to females. On the other hand, males performed worse on the Letter Fluency (mean $\pm$ SD = 22.9 $\pm$ 10.6 vs 25.0 $\pm$ 10.4). Age was only associated with the performance on the TMT A when adjusted for sex and education. The results of these analyses are presented in Table 4.

DISCUSSION

We generated normative data of 15 common neuropsychological tests in a sample of cognitively healthy centenarians, whilst taking sensory impairments into account. Vision impairments and fatigue complicated test completion, while hearing impairments or task incomprehension rarely did. Educational attainment was associated with the performance on almost all tests.

Cognitive Test Performance in Centenarians

Most scores were widely distributed, indicating heterogeneity in cognitive functioning among centenarians. This is in accordance with previous studies, which reported that the variability in cognitive test performance increased with age.[8,9] We observed ceiling effects in VAT, Number Location, and CDT scores, suggesting that these tests are relatively easy to complete, and might be limited in the ability to capture differences in cognitive functions. In line with previous studies, some centenarians had difficulty in completing executive functioning tests, supporting the theory that this domain is particularly vulnerable to decline with normal aging.[6,19] In contrast, almost all centenarians completed the fluency tests with varying results, implying that these are suitable tests for application.

The centenarians within our sample scored, on average, 25.6 $\pm$ 3.1 points on the MMSE, which is well above the cut-off score of 23 points for cognitive impairment in people aged 97 years or older.[39] The centenarians within our cohort scored considerably higher than centenarians from population-based studies, who scored on average between 12.5 to 20 points on the MMSE,[9,12,13,40–42] but similar to US cognitively intact centenarians, who scored on average 24 points.[14] Compared to nondemented people older than 95 years from the 90+ Study, the centenarians in our study acquired similar scores on the MMSE, Category and Letter Fluency, Digit Span Backward, and TMT B, while performing worse on the Digit Span Forward and TMT A.[19] This suggests that processing speed and attention may decline in the years between 95 and 100 and older, while other domains remain stable.

Influence of Age-Related (Sensory) Impairments on Test Incompletion

Overall, the ability to complete tests associated with the performance on tests. This emphasizes the importance of considering factors that interfere with test completion when assessing cognitive functions in centenarians. In agreement with previous reports, visual impairment, more so than hearing loss, was the most common reason for test incompletion.[19] Hence, we caution that tests that require intact vision ability are not fully applicable in centenarians. Also, fatigue commonly led to test incompletion, suggesting that our battery may have been too extensive for a subset of the centenarians. Therefore, to prevent fatigue from interfering with test performance, tests and test batteries for the oldest-old should be kept as short as possible.[19,43]

Table 2. Overview of Number of Tests Used for Generating Normative Data[a]

Tests	No. of Tests Presented	No. (%) of Tests Completed	Reasons for Test Incompletion, %						No. of Tests After Exclusion for Sensory Losses
			No Compr.	Fatigue	Hearing	Vision	Several	Other[b]	
MMSE	235	177 (75)	0	0	9	60	12	19	151[cd]
RBMT	201	175 (87)	0	23	42	0	0	35	167[d]
Number Location	201	152 (76)	16	10	0	63	0	10	142[c]
Key Search	209	152 (73)	14	19	0	47	4	16	138[c]
Clock Drawing Test	234	181 (77)	0	13	0	60	6	21	162[c]
Letter Fluency	226	214 (95)	0	50	0	0	0	50	214
Animal Fluency 1 min	203	196 (97)	0	43	0	0	0	57	196
Animal Fluency 2 min	204	196 (96)	0	50	0	0	0	50	196
VAT Memory	229	178 (78)	0	22	0	57	0	22	156[c]
VAT Naming	206	153 (74)	0	19	0	53	0	28	132[c]
Digit Span Forward	218	178 (82)	0	40	13	0	3	45	163[d]
Digit Span Backward	218	180 (83)	0	47	13	0	3	37	165[d]
TMT A	202	133 (66)	1	26	0	49	7	16	127[c]
TMT B	202	91 (45)	23	19	0	32	8	19	90[c]
DART	228	169 (74)	0	24	0	58	2	17	153[c]
Average	214	168 (79)	6	22	4	41	4	23	

Abbreviations: DART, Dutch Adult Reading Test; MMSE, Mini-Mental State Examination; No Compr., no comprehension of tests and/or test instructions; RBMT, Rivermead Behavioral Memory Test; TMT, Trail Making Test; VAT, Visual Association Test.

[a]Columns represent, respectively: total number of tests that the centenarians were subjected to, total number of tests that could be completed, reasons for inability to complete tests, and total number of tests used for generating normative data after exclusion for sensory losses.

[b]Other includes problems with test equipment, reasons were not reported, physical impairments (tremor or motor), or when there was no time left to finish the whole test battery.

[c]Centenarians with poor to very poor vision were excluded.

[d]Centenarians with poor to very poor hearing were excluded.

Influence of Education, Sex, and Age on Cognitive Test Performance

Consistent with previous findings, education was associated with performance on almost all tests, except for the delayed recall and the TMT.[7,19] Accordingly, we assume that scores of centenarians who attained lower levels of education are represented in the lower range of test scores. Previous studies showed that older adults with lower educational attainment often scored below cut-off scores on cognitive screening tests, causing an overestimation of cognitive impairment.[44–46] This might explain that some centenarians, while appearing cognitively healthy during study visits, scored less than 23 points on the MMSE, or had lower scores on tests on which the majority obtained high scores. To evaluate cognitive impairment in centenarians, performance on individual tests should be interpreted in context of other test scores on several cognitive domains.

Population-based centenarian studies indicated that males had an overall better performance on cognitive tests,[16,47] possibly reflecting the higher dementia prevalence in centenarian females.[48,49] Our inclusion criteria may introduce a selection bias for cognitively healthy males and females, which might explain why we observed no clear sex difference in test performance.

Likewise, whereas age is seen to have a major effect on cognitive decline, age was not predictive for cognitive performance in our sample. We expect that, in combination with our inclusion criteria of cognitive health, the interquartile age range of 100 to 101 years was too narrow to identify an effect of age on cognitive performance.

Strengths, Limitations, and Recommendations for Future Research

The availability of a relatively large sample of centenarians allowed us to select centenarians based on cognitive health and to consider sensory difficulties.

Considering the high risk of cognitive impairment in centenarians, we selected the cognitively healthy centenarians based on three semi-objective criteria. For this, we relied (1) on self-reported cognitive health, which was (2) confirmed by the study partner and (3) a study researcher. The value of using the clinical impression of the study researcher as a selection criterion was evidenced by previous results of the 100-plus Study. Centenarians who were estimated to be cognitively impaired by the study researcher had significantly lower test scores compared to those who were regarded cognitively healthy.[20]

As a result, our cohort represents a high-performing subselection of centenarians, which is therefore not representative for the general population of centenarians. This may result in higher norm ranges for cognitive tests compared to norm ranges determined in a population-based sample. The advantage of using these normative data is that they will be more sensitive and robust in distinguishing between cognitively healthy and cognitively impaired centenarians.

Besides sensory impairments, we suggest that fatigue should be considered in the cognitive evaluation of centenarians. In addition, we speculate that some centenarians were anxious for the cognitive assessment, which may have further influenced test performance, especially for the first few tests. We propose that future normative data should be

Table 3. Percentiles and Means for Cognitive Test Scores for the Total Sample and Stratified by Education Level[a]

					Percentiles						
Test	Group	No.	Mean	SD	5th	10th	25th	50th	75th	90th	95th
MMSE	Total	151	25.6	3.1	20	21	24	26	28	29	30
	HE	51	26.5	3.0	20	22	25	27	29	30	30
	LE	100	25.2	3.1	19	20	23	26	28	29	30
RBMT Immediate Recall	Total	167	8.8	4.7	2	3.5	5	8	12	15	18
	HE	64	10.0	5.2	2	4	6	9	12.5	18.5	21
	LE	103	8.0	4.1	2	3	5	7	11	13.5	16
RBMT Delayed Recall	Total	167	5.3	4.4	0	0	2	4.5	7.5	11.5	14
	HE	64	6.3	5.0	0	1	2.5	6	9	13	16.5
	LE	103	4.6	3.9	0	0	1.5	3.5	7	11	12.5
Number Location	Total	142	8.5	2.0	4	5	8	9	10	10	10
	HE	47	9.0	1.2	6	7	9	9	10	10	10
	LE	95	8.2	2.2	4	4	7	9	10	10	10
Key Search	Total	138	6.7	3.6	2	3	4	5	9	13	14
	HE	44	8.4	3.3	4	4	6	9	11	13	15
	LE	94	5.8	3.5	2	3	3	5	7	12	14
Clock Drawing Test	Total	162	3.4	1.3	1	2	2	3	5	5	5
	HE	55	3.8	1.3	1	2	3	5	5	5	5
	LE	107	3.2	1.3	1	2	2	3	4	5	5
Letter Fluency (letters D-A-T)	Total	214	24.4	10.5	9	11	17	24	32	38	43
	HE	79	29.2	10.8	10	16	21	28	35	45	47
	LE	135	21.6	9.3	7	9	14	21	30	33	38
Animal Fluency 1 min	Total	196	11.4	4.3	6	6	8	11	15	17	19
	HE	71	12.2	4.7	5	6	8	12	16	19	20
	LE	125	10.9	3.9	6	6	8	11	14	16	18
Animal Fluency 2 min	Total	196	17.2	6.7	8	9	12	17	21	26	30
	HE	70	18.6	7.9	7	8	12	18	24	30	33
	LE	126	16.4	5.7	8	9	12	17	20	25	27
VAT Memory	Total	156	9.0	3.3	2	4	7	10	12	12	12
	HE	50	9.9	2.9	2	5	9	11	12	12	12
	LE	106	8.6	3.4	2	4	6	10	12	12	12
VAT Naming	Total	132	11.5	1.1	10	10	11	12	12	12	12
	HE	43	11.7	0.6	11	11	12	12	12	12	12
	LE	89	11.4	1.2	9	10	11	12	12	12	12
Digit Span Forward *score*	Total	163	7.1	1.8	4	5	6	7	8	10	10
	HE	64	8.0	1.8	4	6	7	8	9	10	11
	LE	99	6.6	1.6	4	5	5	6	8	9	10
Digit Span Forward *span*	Total	160	5.1	1.1	3	4	4	5	6	6	7
	HE	63	5.5	1.0	3	4	5	6	6	7	7
	LE	97	4.8	1.0	3	4	4	5	6	6	6
Digit Span Backward *score*	Total	165	4.6	1.4	2	3	4	5	5	6	8
	HE	64	5.0	1.4	3	3	4	5	6	7	8
	LE	101	4.4	1.4	2	3	3	4	5	6	7
Digit Span Backward *span*	Total	163	3.8	0.9	2	3	3	4	4	5	5
	HE	64	3.9	0.7	3	3	3	4	4	5	5
	LE	99	3.7	1.0	2	3	3	4	4	5	5
TMT A *time*	Total	127	113.1	66.9	258	199	134	92	70	58	51
	HE	40	104.8	63.9	260	202	109	85	65	56	55
	LE	87	116.9	68.3	266	199	140	98	70	60	49
TMT B *time*	Total	90	310.9	171.9	753	567	376	286	178	130	113
	HE	34	267.0	154.6	591	436	299	258	162	122	92
	LE	56	337.5	177.7	763	628	417	303	221	132	118
DART *IQ score*	Total	153	98.4	13.9	75	79	87	99	108	118	122
	HE	52	110.6	9.9	94	98	104	112	119	124	126
	LE	101	92.1	11.3	74	78	84	92	101	106	110

Abbreviations: DART, Dutch Adult Reading Test; HE, high education; IQ, intelligence quotient; LE, low education; MMSE, Mini-Mental State Examination; RBMT, Rivermead Behavioral Memory Test; TMT, Trail Making Test; VAT, Visual Association Test.

[a]Score range of the MMSE, 0 to 30; Digit Span Forward and Backward, 0 to 16 (raw score) and 0 to 8 (span); RBMT, 0 to 42 (both Immediate and Delayed Recall); VAT, 0 to 12 (trial 1 + 2); Key Search, 0 to 16 (no time limit); Number Location, 0 to 10; and Clock Drawing Test, 0 to 5. Higher scores indicate better performance, except for the TMT.

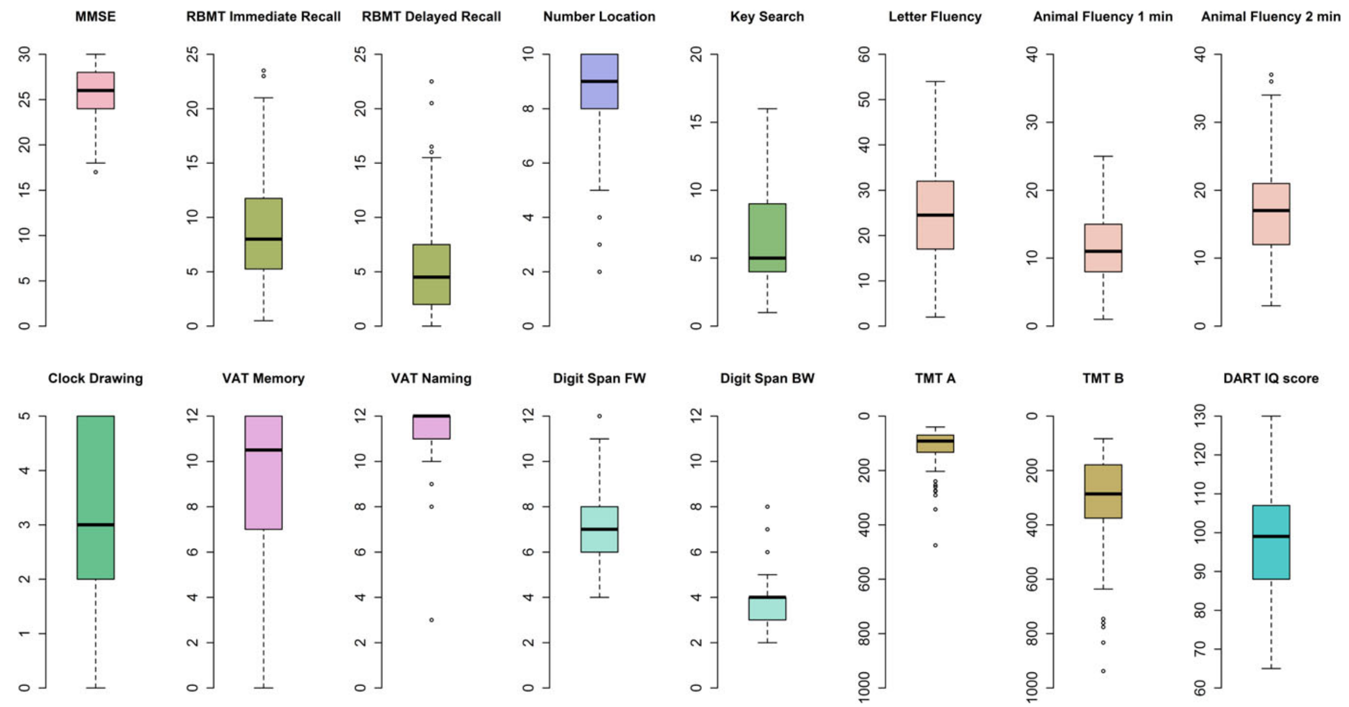

Figure 1. Distribution of test scores. Boxplots represent raw test scores. See footnote in Table 3 for possible range of scores for each test.
BW, backward; DART, Dutch Adult Reading Test; FW, forward; IQ, intelligence quotient; MMSE, Mini-Mental State Examination; RBMT, Rivermead Behavioral Memory Test; TMT, Trail Making Test; VAT, Visual Association Test.

adjusted for symptoms of fatigue and nervousness as they may differentially influence test performance according to the order in which tests are administered. Our finding that impaired vision is the most prevalent reason for test incompletion indicates that new tests should be designed to be applicable regardless of vision impairments.

CONCLUSION

The normative data generated in the current study allow clinicians and researchers to distinguish between cognitively healthy and cognitively impaired centenarians. When assessing cognitive functioning in centenarians, vision impairment, fatigue, and education level should be considered.

Table 4. Multiple Linear Regression Analyses With Sex, Age, and Education as Independent Variables and Cognitive Test Outcome as Dependent Variable

		Sex			Age			Education		
Tests	R^2	Unstandardized β	SE	*P* Value	Unstandardized β	SE	*P* Value	Unstandardized β	SE	*P* Value
MMSE	0.08	−0.60	0.58	.30	−0.28	0.23	.23	0.51	0.17	**<.001**
RBMT Immediate Recall	0.05	−0.64	0.79	.42	−0.10	0.31	.73	0.61	0.24	**.01**
RBMT Delayed Recall	0.03	−0.70	0.76	.36	−0.10	0.29	.73	0.45	0.23	.05
Key Search	0.16	−1.71	0.65	**.01**	−0.04	0.26	.86	0.75	0.19	**<.001**
Letter Fluency	0.16	3.74	1.50	**.01**	−0.01	0.51	.98	2.66	0.43	**<.001**
Animal Fluency										
1 min	0.05	1.24	0.67	.06	−0.17	0.23	.46	0.54	0.20	**.01**
2 min	0.05	1.72	1.05	.10	−0.26	0.36	.47	0.94	0.31	**<.001**
Digit Span Forward										
Score	0.16	−0.59	0.29	**.04**	0.09	0.12	.43	0.41	0.09	**<.001**
Span	0.11	−0.15	0.18	.40	0.03	0.07	.64	0.23	0.05	**<.001**
Digit Span Backward										
Score	0.06	0.20	0.24	.42	0.01	0.10	.92	0.23	0.07	**<.001**
Span	0.04	0.12	0.16	.44	−0.04	0.06	.52	0.12	0.05	**.01**
TMT A *time*[a]	0.07	0.05	0.09	.63	−0.10	0.04	**.01**	0.05	0.03	.09
TMT B *time*[a]	0.07	0.23	0.12	.06	−0.05	0.05	.38	0.06	0.03	.08

Abbreviations: MMSE, Mini-Mental State Examination; RBMT, Rivermead Behavioral Memory Test; TMT, Trail Making Test.
[a]TMT scores were log transformed.
Significant values ($P < .05$) are marked in bold.

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SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article.

Table S1. Categorization of Vision and Hearing.

Table S2. Measurement Properties of the Neuropsychological Tests.

Table S3. Regression Coefficients for Sex, Age, and Education.

Table S4. Regression Formulas to Calculate Regression-Based Norms.

Table S5. Pearson Correlations Among Cognitive Test Scores.

Figure S1. Flowchart of study inclusion.

Figure S2. Associations between the number of completed tests and overall cognitive test performance.

Supplementary Data. Calculating regression-based normative data.