

Normative Values of Cognitive and Physical Function in Older Adults: Findings from The Irish Longitudinal Study on Ageing

Rose Anne Kenny, MD,* Robert F. Coen, PhD,[†] John Frewen, MSc,* Orna A. Donoghue, PhD,* Hilary Cronin, MD,* and George M. Savva, PhD*

OBJECTIVES: To provide normative values of tests of cognitive and physical function based on a large sample representative of the population of Ireland aged 50 and older.

DESIGN: Data were used from the first wave of The Irish Longitudinal Study on Ageing (TILDA), a prospective cohort study that includes a comprehensive health assessment.

SETTING: Health assessment was undertaken at one of two dedicated health assessment centers or in the study participant's home if travel was not practicable.

PARTICIPANTS: Five thousand eight hundred ninety-seven members of a nationally representative sample of the community-living population of Ireland aged 50 and older. Those with severe cognitive impairment, dementia, or Parkinson's disease were excluded.

MEASUREMENTS: Measurements included height and weight, normal walking speed, Timed Up-and-Go, hand-grip strength, Mini-Mental State Examination (MMSE), Montreal Cognitive Assessment (MoCA), Color Trails Test, and bone mineral density. Normative values were estimated using generalized additive models for location shape and scale (GAMLSS) and are presented as percentiles, means, and standard deviations.

RESULTS: Generalized additive models for location shape and scale fit the observed data well for each measure, leading to reliable estimates of normative values. Performance on all tasks decreased with age. Educational attainment was a strong determinant of performance on all cognitive tests. Tests of walking speed were dependent on height. Distribution of body mass index did not change with age, owing to simultaneous declines in weight and height.

CONCLUSION: Normative values were found for tests of many aspects of cognitive and physical function based on

a representative sample of the general older Irish population. *J Am Geriatr Soc* 61:S279–S290, 2013.

Key words: geriatric assessment; reference values; cognition; gait; bone density; grip; body mass index

The comprehensive geriatric assessment (CGA) is now widely used as a multidomain assessment in clinical practice, with various validated tests used to measure medical, functional, psychological, and social domains.

The CGA informs evidence-based, goal-directed, patient-oriented interventions by multidisciplinary teams. In general, clinicians adapt the CGA for local use, and although there are recommended domains for assessment, the tests that are used depend on the setting, local practice, and experience. There is evidence that this targeted approach is superior to general medical assessment. In a recent Cochrane review,¹ CGA resulted in lower mortality, greater likelihood of independent living, better long-term cognitive outcomes, and lower rates of institutional care.

Interpretation of the tests used in the CGA relies on the availability of reliable, up-to-date reference or “normative” values that correspond to the range of test scores observed in the population and with which the individual can be compared.

This article provides normative values for a battery of tests that are typical of a CGA and were administered to a national population-representative sample as part of The Irish Longitudinal Study on Ageing (TILDA). These measures included the Mini-Mental State Examination (MMSE), the Montreal Cognitive Assessment (MoCA), executive function measured using the Color Trails Test, height, weight, body mass index (BMI), bone density measured according to heel bone ultrasound, the Timed Up-and-Go (TUG) test, walking speed, and grip strength.

From *The Irish Longitudinal Study on Ageing, Trinity College Dublin; and [†]Mercer's Institute for Research on Ageing, St James's Hospital, Dublin, Ireland.

Address correspondence to Dr. George Savva, The Irish Longitudinal Study on Ageing, Lincoln Gate, Trinity College Dublin, Dublin 2, Ireland. E-mail: george.savva@tcd.ie

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METHODS

Sample

The TILDA sample is described in detail in an accompanying article within this issue.² In brief, the TILDA cohort is a nationally representative sample of 8,175 adults aged 50 and older (4,431 women). The study sample was recruited based on the RANSAM sampling frame, which is based on the Irish national directory of all residential addresses.³ Geographic clusters were generated, and 640 of these were selected for use in the study, stratified according to area level socioeconomic status and geographical location. Forty addresses were selected within each cluster, and an interviewer visited each. All individuals aged 50 and older living in each selected household were invited to participate in the study. The household response rate was 62.0%. Further details of the study design can be found elsewhere.⁴

After the home interview, each participant was invited to undergo a comprehensive health assessment at one of two dedicated health assessment centers or in their own home if travel to a center was not practicable. Research nurses conducted assessments. Eight hundred sixty-one (10.5%) participants had a home assessment, and 5036 (61.6%) were assessed in a health assessment center. The home assessment did not include all of the measures included in the health assessment, so a total available sample of 5,897 individuals was available for some measures and 5,036 for others. Characteristics of the health center and home assessment samples are described elsewhere in this issue.⁵

Inclusion and Exclusion Criteria

Every member of the population of Ireland aged 50 and older living at a private residential address (not in a long-term care institution) was equally likely to be invited to participate in the study. At Wave 1 (baseline), TILDA did not include any participant who could not personally consent to the study, excluding individuals with severe cognitive impairment.

Those with diagnosed dementia, Alzheimer's disease, or Parkinson's disease or who scored less than 10 on the MMSE were also excluded from the present analysis ($n = 62$). The normative values are therefore applicable to the community-living population of Ireland without Parkinson's disease or severe cognitive impairment.

TILDA Health Assessment

Details of the rationale for the selection of tests included in the TILDA assessment and the standardized operational procedures and quality control processes under which they were conducted are described elsewhere.⁵ A brief description of the rationale for the test selection and the methods used to obtain the measures from which norms were calculated is given below.

A panel of experts devised the TILDA test battery with regard to several requirements: first, to incorporate the main elements of a CGA, in particular the domains of cognitive and physical function; second, to maintain a

degree of comparability with previous population-based studies and a relevance to clinical practice; third, to incorporate recent developments and novel elements; and finally, to be conducted within a reasonable time frame for a single health assessment center visit. The measures reported in the current article include well-known tests that are commonly applied but for which up-to-date normative values do not exist in the Irish population (e.g., TUG test), as well as those for newer tests that are becoming more widely adopted but for which normative values have been established in only a small number of cohorts worldwide (e.g., MoCA).

Measures

The Irish Longitudinal Study on Ageing participants are characterized according to the highest level of education attained at any point in their lives. None or primary education typically corresponds to fewer than 11 years of full-time education. Secondary education is regarded as completion of the junior certificate, group certificate, or leaving certificate and typically corresponds to between 11 and 13 years of full-time education. The final group includes those who completed tertiary education, including any diploma or degree at any time in their lives.

Height was measured using a wall-mounted measuring rod (SECA 240, SECA, Birmingham, UK). Height was dichotomized for stratification of grip strength, gait speed, and TUG normative values with the cutoff at the sex-specific median for the sample (173 cm for men and 160 cm for women). Weight was measured using electronic floor scales (SECA), and BMI was calculated as weight/height² with weight measured in kilograms and height in meters.

Functional mobility was measured using the TUG test. Participants were asked to stand from a seated position, walk 3 m at their usual pace, turn around, walk back to the chair, and sit down again. The time taken from the command "Go" to when the participant was sitting with their back resting against the back of the chair was recorded using a stopwatch. A chair with armrests and seat height of 46 cm was used in the health center. In the home assessment, an available chair that matched these dimensions as closely as possible was used (seat height 40–50 cm). Walking speed was measured using a 4.88-m electronic walkway with embedded pressure sensors (GAITRite, CIR Systems, Inc., Havertown, PA). Participants started and finished 2.5 m before and 2 m after the walkway to allow for acceleration and deceleration, respectively. Average walking speed was calculated from two walks performed at normal pace. Maximum grip strength was measured from four tests (2 on each hand) using a hydraulic hand dynamometer (Baseline, Fabrication Enterprises, Inc., White Plains, NY). Bone mass was measured using quantitative ultrasound (Achilles Heel Ultrasound, Lunar, Madison, WI). The instrument was calibrated and tested daily during the study. The Achilles apparatus for heel evaluation measures the broadband ultrasound attenuation and the speed of sound through bone which are combined to provide an index of bone stiffness. This has been shown to be a significantly better predictor of fractures than broadband ultrasound attenuation or speed of sound alone.

The MMSE and MoCA were used to assess global cognitive performance. The MMSE is a well-established⁶ test used to screen for cognitive impairment that includes measures of orientation, registration, attention, calculation, recall, and language. The MoCA⁷ is known to be more sensitive to mild cognitive deficits than the MMSE when applied in cognitively intact older adults. In addition to the domains that the MMSE measures, MoCA assesses executive function, abstraction, and visuospatial ability. MoCA and MMSE scores range from 0 to 30. Executive function was measured using the Color Trails Test.⁸ In Task 1, the participant was asked to draw a line connecting a series of 25 numbers that alternate between pink and yellow. In the second task, they were instructed to alternate between pink and yellow colored numbers, avoiding distractors. The completion times for both trail tasks were recorded.

Analysis

Generalized Additive Models for Location, Shape and Scale (GAMLSS)⁹ were used to estimate normative values. GAMLSS are a generalization of the more widely known

generalized linear models. In the current analysis, continuous measures are modelled using the Box Cox Power Exponential (BCPE) distribution, while discrete measures are modeled using the negative binomial distribution. The BCPE distribution has four parameters, corresponding to location, scale, skew, and kurtosis of the distribution.¹⁰ The negative binomial distribution has two parameters, corresponding to location and dispersion. GAMLSS allows all model parameters to be modelled as functions of the independent variables (e.g., allowing the standard deviation as well as the mean of a distribution to vary with age and sex). The package gamlss (<http://gamlss.org>) in statistical software R (R Foundation for Statistical Computing, Vienna, Austria) was used throughout.

Age was included as a continuous variable in each of the regression models. To account for the fact that many relationships with age are nonlinear, restricted cubic splines were calculated and used instead of age per se in regression models. This approach breaks age up into groups defined according to “knots” at their boundaries. Between each pair of knots, that is within each age group, the relationship between the outcome of interest and age

Table 1. Specific Tests and Measures Used and Numbers with Complete or Missing Data for Each Assessment

Assessment	Test or Measurement	Sample with Complete Data, n ^a	Reason for Missing Data (n)
Global cognitive function	Mini-Mental State Examination	5,842 (health center + home assessment)	Unable (5) Unwilling (7) No reason recorded (2)
Global cognitive function	Montreal Cognitive Assessment	5,802 (health center + home assessment)	Unable (29) Unwilling (5) No reason recorded (20)
Executive function (attention, processing)	Color Trail Task 1	5,732 (health center + home assessment)	Unable (71) Unwilling (48) Technical problem (1) No reason recorded (4)
Executive function (attention, processing, mental flexibility)	Color Trail Task 2	5,663 (health center + home assessment)	Unable (95) Unwilling (59) Technical problem (1) No reason recorded (38)
Weight	SECA electronic floor scales	5,836 (health center + home assessment)	Unable (12) Unwilling (3) Technical problem (2) No reason recorded (3)
Height	Wall-mounted measuring rod	5,834 (health center + home assessment)	Unable (14) Unwilling (2) Technical problem (2) No reason recorded (4)
Functional mobility	Timed Up-and-Go	5,791 (health center + home assessment)	Unable (43) Unwilling (18) No reason recorded (4)
Walking speed	4.88-m timed walk	4,931 (health center assessment only)	Unable (37) Unwilling (20) Technical problem (23) No reason recorded (2)
Grip strength	Baseline dynamometer	5,819 (health center + home assessment)	Unable (28) Unwilling (6) No reason recorded (3)
Bone density	Heel bone ultrasound	4,980 (health center assessment only)	Unable (11) Unwilling (5) Technical problem (11) No reason recorded (6)

^a N = 5,013 (health center) + 843 (home assessment) = 5,856.

varies as a third-order polynomial. These polynomials are constrained to join smoothly at each knot, creating a smooth continuous function, the complexity of which depends on the number of knots, k , used in its estimation. In practice, $k-1$ continuous variables, which when entered into a linear regression model yield the nonlinear relationship with age as described above, replace the continuous variable "age." The additional covariates considered for each model include sex, level of education (for cognitive tests), and height (for tests of walking speed and strength). Interaction terms between all covariates and between age and each covariate as well as higher-order interactions were also considered.

Selecting the model for each measure therefore involves selecting the covariates and interaction terms to be included and the number of knots to use for each spline. The BCPE distribution has four parameters, so four model equations need to be specified for each continuous measure. Each model was selected to minimize the Akaike Information Criterion (AIC). First, the equation for the location parameter was selected. The number of knots for the cubic spline was set between two (a straight line) and seven. A forward and backward stepwise selection was used for each number of knots to select which of the covariates and interactions was to be included, using the Generalized AIC calculated using the `gamlss` function

`stepGAIC()`. These models were then compared, and the number of knots that led to the model with the smallest AIC was selected. Once the equation for the location was selected, this process was repeated to select the equation for the scale parameter, given the location equation, and for the shape parameters, given the scale and location equations.

Inverse probability weights were then applied to the final model to ensure that estimates were applicable to the population. For each participant, the weight applied was the inverse of the probability that a member of the community-living older population of Ireland selected at random with his or her characteristics would have undergone the TILDA health assessment. Weights were calculated in a two-step procedure. First, the distribution of age, sex, and educational attainment among the TILDA home interview sample was compared with the distribution among the older Irish population reported in the Quarterly National Household Survey (2010) to calculate an initial probability weight. Second, the probability of completing a health assessment given participation in the home interview was calculated based on characteristics recorded in the interview. These probability weights were multiplied to create the final weight. Missing data are rare, so missing data with respect to individual measures was assumed to be missing completely at random.

Table 2. Mini-Mental State Examination Scores Stratified According to Highest Educational Attainment, Based on a Sample of 5,842 Individuals Aged 50 and Older Representative of the Community-Dwelling Population of Ireland without Known Dementia, Parkinson's Disease, or Severe Cognitive Impairment

Percentile	Age							
	50	55	60	65	70	75	80	85
Primary or no education								
P95	30	30	30	30	30	30	30	30
P90	30	30	30	30	30	30	29	29
P75	29	29	29	29	29	29	28	28
P50	28	28	28	28	28	27	27	26
P25	26	26	26	26	26	25	25	23
P10	24	24	25	24	24	23	22	20
P05	23	23	23	23	23	22	20	18
Mean \pm SD	27.5 \pm 2.4	27.5 \pm 2.3	27.5 \pm 2.2	27.4 \pm 2.3	27.2 \pm 2.4	26.7 \pm 2.7	26.1 \pm 3.0	25.2 \pm 3.6
Secondary education								
P95	30	30	30	30	30	30	30	30
P90	30	30	30	30	30	30	30	29
P75	30	30	30	30	30	29	29	28
P50	29	29	29	29	29	28	28	27
P25	28	28	28	28	28	27	26	25
P10	27	27	27	26	26	25	25	24
P05	26	26	26	25	25	24	23	22
Mean \pm SD	28.9 \pm 1.3	28.8 \pm 1.4	28.7 \pm 1.5	28.6 \pm 1.6	28.3 \pm 1.8	28.0 \pm 2.0	27.5 \pm 2.1	26.7 \pm 2.4
Tertiary or higher education								
P95	30	30	30	30	30	30	30	30
P90	30	30	30	30	30	30	30	30
P75	30	30	30	30	30	30	30	29
P50	30	30	30	29	29	29	29	28
P25	29	29	29	29	28	28	28	27
P10	28	28	28	28	27	27	26	26
P05	28	28	27	27	27	26	26	25
Mean \pm SD	29.5 \pm 0.8	29.4 \pm 0.9	29.3 \pm 1.0	29.1 \pm 1.1	29.0 \pm 1.3	28.7 \pm 1.4	28.4 \pm 1.5	28.0 \pm 1.6

Age corresponds to exact year of age; values for intermediate ages should be estimated by interpolation between supplied values.
SD = standard deviation.

For each measure, the 5th, 10th, 25th, 50th, 75th, 90th, and 95th percentiles are reported for every fifth year of age from age 50, stratified according to any covariates included in the final model. Although data from all participants aged 50 and older were used in the estimation of the normative values, the small numbers of participants aged 85 and older led to imprecise estimates of normative values at those ages, so estimates of normative values are provided only up to age 85. Because the distributions of many of the tests are nonnormal, it is not appropriate to use the means and standard deviations of test scores when comparing an individual with the population, although means and standard deviations are of interest, for example, when performing power calculations, so these values were extracted from each model and supplied along with quantiles.

RESULTS

Of the 5,013 participants who attended the health assessment center, 2,720 (54%) were female, and the mean age was 62.0. Including the additional 843 who had a health assessment in their own home, 3,176 (54%) were female, and the mean age was 63.1. The sample was ethnically homogeneous, with 98% of the Irish population aged 50 and older describing themselves as white (census data

available from the Central Statistics Office at www.cso.ie). A full description of the socioeconomic and health status of both cohorts is described elsewhere in this issue.⁵

Table 1 shows numbers of individual participants who provided valid measurements for each test. The numbers with missing data were small, with the highest rate of missing data arising from the second color trail task (N = 193, 3.3% of the sample). Tables 2–9 show modeled 5th, 10th, 25th, 50th, 75th, 90th, and 95th percentiles along with the mean and standard deviation for each of the measures described above reported every fifth year of age from 50 to 85. Values for intermediate ages should be estimated using linear interpolation between the supplied values; for example, an individual aged 62 will have scores two-fifths of the way between those for individuals aged 60 and 65.

Mini-Mental State Examination (Table 2), MoCA (Table 3), and time to complete the trail tasks (Table 4) varied according to highest educational attainment and so are stratified according to education; differences between men and women, although statistically significant, were relatively minor, so cognitive test scores are not stratified according to sex. The simultaneous decline in weight and height (Table 5) with age means that the distribution of BMI in the population did not change substantially with age, so a table for BMI is not provided. Median BMI was

Table 3. Montreal Cognitive Assessment Scores Stratified According to Highest Educational Attainment, Based on a Sample of 5,802 Individuals Aged 50 and Older Representative of the Community-Dwelling Population of Ireland without Known Dementia, Parkinson’s Disease, or Severe Cognitive Impairment

Percentile	Age							
	50	55	60	65	70	75	80	85
Primary or no education								
P95	29	29	29	28	28	28	27	27
P90	28	28	28	28	27	27	26	26
P75	27	26	26	26	26	25	24	23
P50	24	24	24	24	23	22	21	20
P25	22	22	21	21	20	19	18	16
P10	19	19	19	18	17	16	14	12
P05	17	17	17	16	15	13	12	9
Mean ± SD	24.0 ± 3.5	23.8 ± 3.6	23.5 ± 3.7	23.1 ± 3.9	22.5 ± 4.1	21.7 ± 4.5	20.7 ± 4.9	19.3 ± 5.5
Secondary education								
P95	29	29	29	29	29	29	28	28
P90	29	29	29	29	28	28	27	27
P75	27	28	27	27	27	26	26	25
P50	26	26	26	26	25	24	23	22
P25	24	24	24	23	23	22	20	18
P10	22	22	21	21	20	19	17	15
P05	20	20	20	19	19	17	15	12
Mean ± SD	25.4 ± 2.9	25.4 ± 2.9	25.3 ± 2.9	25.1 ± 3.0	24.6 ± 3.2	23.8 ± 3.6	22.7 ± 4.1	21.1 ± 4.7
Tertiary or higher education								
P95	30	30	30	30	29	29	29	29
P90	30	29	29	29	29	29	28	28
P75	29	29	28	28	28	27	27	27
P50	28	27	27	27	26	26	25	24
P25	26	26	25	25	24	24	23	22
P10	25	24	24	23	22	21	20	19
P05	24	23	22	22	21	20	19	17
Mean ± SD	27.3 ± 2.0	27.0 ± 2.1	26.7 ± 2.3	26.3 ± 2.5	25.8 ± 2.7	25.3 ± 2.9	24.7 ± 3.2	23.9 ± 3.5

Age corresponds to exact year of age; values for intermediate ages should be estimated by interpolation between supplied values. SD = standard deviation.

Table 4. Time (Seconds) to Complete the Color Trail 1 Task (N = 5,732) and the Color Trail 2 Task (N = 5,663) Stratified According to Highest Educational Attainment, Based on a Sample Aged 50 and Older Representative of the Community-Dwelling Population of Ireland without Known Dementia, Parkinson's Disease, or Severe Cognitive Impairment

Percentile	Color Trail 1 Task										Color Trail 2 Task									
	50	55	60	65	70	75	80	85	90	95	50	55	60	65	70	75	80	85	90	95
Primary or no education																				
P95	27	29	31	34	38	42	47	51	64	70	72	75	81	81	90	100	111	111	111	111
P90	30	32	35	38	43	48	53	58	71	77	80	83	90	90	99	110	123	123	123	123
P75	37	39	42	47	52	59	66	74	83	91	94	98	106	106	118	131	146	146	146	146
P50	47	50	54	60	67	77	88	99	101	110	115	120	130	130	144	161	180	180	180	180
P25	61	65	70	78	89	103	119	138	124	136	142	149	162	162	180	202	226	226	226	226
P10	79	84	91	101	116	136	161	191	152	167	174	183	200	200	223	251	282	282	282	282
P05	93	99	106	119	137	163	195	236	172	190	199	210	230	230	256	288	325	325	325	325
Mean ± SD	52 ± 22.1	55.2 ± 23.3	59.6 ± 25.2	66 ± 28.5	75 ± 33.8	86.4 ± 41.6	100.2 ± 52.5	116.3 ± 68.1	107.2 ± 35	117.7 ± 39	122.6 ± 41.2	128.3 ± 43.8	139.7 ± 48.4	155 ± 54.6	173.4 ± 62	194.4 ± 70.6	194.4 ± 70.6	194.4 ± 70.6	194.4 ± 70.6	194.4 ± 70.6
Secondary education																				
P95	26	27	28	31	34	39	43	48	54	60	63	66	72	72	81	91	102	102	102	102
P90	29	30	31	34	38	43	49	54	59	66	69	72	79	79	89	100	113	113	113	113
P75	34	36	38	41	46	52	60	68	69	77	81	85	93	93	104	118	133	133	133	133
P50	43	44	47	51	58	66	77	88	83	93	97	103	113	113	127	144	163	163	163	163
P25	54	56	59	65	74	86	100	118	102	114	119	126	139	139	157	178	202	202	202	202
P10	67	69	73	81	93	109	130	156	123	138	145	154	170	170	192	219	249	249	249	249
P05	77	80	84	93	107	128	154	187	139	156	164	174	193	193	219	250	285	285	285	285
Mean ± SD	46 ± 16.8	47.5 ± 17.2	50.2 ± 18.2	55.1 ± 20.3	62.7 ± 24.1	72.6 ± 29.6	84.8 ± 37.3	99.1 ± 47.9	88.4 ± 27.2	98.7 ± 30.8	103.5 ± 32.8	109.2 ± 35.1	120.4 ± 39.3	135.6 ± 44.9	153.8 ± 51.7	174.5 ± 59.6	174.5 ± 59.6	174.5 ± 59.6	174.5 ± 59.6	174.5 ± 59.6
Tertiary or higher education																				
P95	23	25	27	29	32	36	40	44	50	55	58	62	69	69	78	88	100	100	100	100
P90	25	27	29	31	34	38	43	48	55	61	64	68	75	75	85	97	110	110	110	110
P75	30	31	33	35	39	44	50	56	63	71	75	79	87	87	99	113	128	128	128	128
P50	37	38	40	43	48	55	63	73	75	84	89	94	104	104	118	135	154	154	154	154
P25	46	48	50	54	60	68	79	91	90	102	107	114	126	126	144	165	188	188	188	188
P10	57	59	62	67	75	85	98	114	107	121	128	136	152	152	173	199	228	228	228	228
P05	65	68	71	76	84	95	110	129	119	135	143	153	171	171	195	224	257	257	257	257
Mean ± SD	39.6 ± 13.5	41.5 ± 14.5	43.4 ± 15.5	46.1 ± 16.5	50.1 ± 18.5	55.1 ± 20.5	62.7 ± 24.5	72.6 ± 29.5	62.7 ± 24.5	72.6 ± 29.5	84.8 ± 37.5	99.1 ± 47.5	88.4 ± 27.5	98.7 ± 30.5	103.5 ± 32.5	109.2 ± 35.5	120.4 ± 39.5	135.6 ± 44.5	153.8 ± 51.5	174.5 ± 59.5

Age corresponds to exact year of age; values for intermediate ages should be estimated by interpolation between supplied values. SD = standard deviation.

Table 5. Height (n = 5,834) and Weight (n = 5,836) Based on Samples of Individuals Aged 50 and Older Representative of the Community-Dwelling Population of Ireland without Dementia, Parkinson's Disease or Severe Cognitive Impairment

Percentile	Height, cm										Weight, kg									
	50	55	60	65	70	75	80	85	90	95	50	55	60	65	70	75	80	85	90	95
Male																				
P95	186	185	184	184	182	181	180	178	178	177	116	115	113	111	109	106	102			
P90	184	182	181	180	179	178	177	176	176	175	108	107	106	105	102	100	97			
P75	179	179	178	177	176	175	174	172	172	171	97	97	96	95	93	91	88			
P50	175	175	174	173	172	171	170	168	168	167	87	87	86	85	84	82	80			
P25	171	170	169	168	167	166	165	164	164	163	79	78	78	77	75	73	71			
P10	167	166	165	164	163	162	161	160	160	159	71	71	70	69	67	66	64			
P05	165	164	163	162	160	159	158	157	157	156	67	66	65	64	63	61	59			
Mean ± SD	175.4 ± 6.6	174.4 ± 6.4	173.6 ± 6.4	172.8 ± 6.6	171.6 ± 6.7	170.4 ± 6.8	169.3 ± 7.1	168.2 ± 6.4	168.2 ± 6.4	168.2 ± 6.4	89.0 ± 15.4	88.8 ± 15.1	87.5 ± 14.7	86.2 ± 14.3	84.4 ± 14.0	82.4 ± 13.6	80.0 ± 13.2			
Female																				
P95	172	170	170	169	168	167	165	164	164	163	101	100	99	97	95	93	90			
P90	169	168	168	167	166	165	163	162	162	161	92	92	91	90	88	86	84			
P75	165	165	164	163	162	161	160	158	158	157	80	80	80	79	78	77	75			
P50	162	161	160	159	158	157	156	155	155	154	71	71	71	70	69	68	67			
P25	158	157	156	155	154	153	152	151	151	150	63	63	63	63	62	60	59			
P10	154	153	153	152	150	149	148	147	147	146	57	57	57	56	55	54	52			
P05	152	151	151	150	148	146	146	145	145	144	53	53	53	52	51	50	48			
Mean ± SD	161.8 ± 6.1	160.8 ± 5.9	160.0 ± 5.9	159.2 ± 6.0	158.0 ± 6.2	156.9 ± 6.2	155.7 ± 6.1	154.6 ± 5.8	154.6 ± 5.8	154.6 ± 5.8	73.2 ± 15.8	73.2 ± 15.2	72.7 ± 14.8	71.9 ± 14.0	70.6 ± 13.6	69.2 ± 13.1	67.5 ± 12.7			

Age corresponds to exact year of age; values for intermediate ages should be estimated by interpolation between supplied values. SD = standard deviation.

between 28.0 and 29.0 kg/m² in men at all ages and between 27.0 and 28.0 kg/m² in women. There were substantial and statistically significant differences according to sex and height for TUG (Table 6), usual walking speed (Table 7), and grip strength (Table 8). Normative values for heel bone mineral density measured according to the stiffness index (Table 9) are stratified according to sex.

DISCUSSION

Summary of Findings

This study provides normative values for many of the tests undertaken as part of a geriatric assessment, based on a sample representative of the community-living Irish population aged 50 and older without known dementia, Parkinson's

son's disease, or severe cognitive impairment. Values were calculated based on the health assessment conducted during Wave 1 of TILDA.

Strengths and Weaknesses of the Study

This study was based on a large population-representative sample who underwent a comprehensive health assessment including many tests typical of a geriatric assessment. The sample included those who attended a health assessment center and those who opted for a home-based health assessment. Inverse probability weights were applied to all estimates to correct for possible selection bias to the TILDA sample.

Individuals with severe cognitive impairments or a doctor's diagnosis of dementia or Parkinson's disease were

Table 6. Time to Complete Timed Up-and-Go (seconds) Test Based on a Sample of 5,791 individuals Aged 50 and Older Representative of the Community Dwelling Population of Ireland without Dementia, Parkinson's Disease, or Severe Cognitive Impairment

Percentile	Age							
	50	55	60	65	70	75	80	85
Male								
<173 cm								
P95	6	6	6	7	7	7	8	8
P90	6	6	7	7	7	8	9	9
P75	7	7	7	8	8	9	10	11
P50	8	8	8	9	9	10	11	13
P25	9	9	9	10	11	12	13	15
P10	10	10	10	11	13	14	17	20
P05	11	11	12	13	14	17	20	25
Mean ± SD	7.9 ± 1.8	8.2 ± 2.1	8.6 ± 2.5	9.1 ± 3.4	10 ± 5.1	11.5 ± 8.1	14.1 ± 12.6	18.4 ± 18.9
≥ 173 cm								
P95	6	6	6	7	7	7	7	8
P90	7	7	7	7	7	8	8	8
P75	7	7	7	8	8	9	9	10
P50	8	8	8	9	9	10	10	11
P25	9	9	9	10	10	11	12	14
P10	10	10	10	11	12	13	15	18
P05	10	11	11	12	14	15	18	21
Mean ± SD	7.8 ± 1.3	8 ± 1.4	8.3 ± 1.6	8.8 ± 1.8	9.4 ± 2.3	10.3 ± 3.5	11.6 ± 6.2	13.3 ± 11.9
Female								
<160 cm								
P95	6	6	6	7	7	8	8	9
P90	6	6	7	7	7	8	9	10
P75	7	7	7	8	8	9	10	11
P50	8	8	8	9	9	10	12	14
P25	9	9	9	10	11	12	14	17
P10	10	10	11	11	13	15	18	24
P05	12	12	12	13	14	17	22	31
Mean ± SD	8.1 ± 3.2	8.3 ± 2.9	8.6 ± 2.9	9.1 ± 3.4	10.0 ± 4.7	11.4 ± 7.4	13.9 ± 12.1	18.4 ± 18.9
≥ 160 cm								
P95	6	6	6	7	7	7	8	8
P90	6	6	7	7	7	8	8	9
P75	7	7	7	8	8	9	10	10
P50	8	8	8	8	9	10	11	12
P25	9	9	9	9	10	11	13	15
P10	10	10	10	11	12	13	16	20
P05	11	11	11	12	13	15	19	25
Mean ± SD	7.9 ± 1.6	8.1 ± 1.6	8.4 ± 1.7	8.8 ± 1.8	9.4 ± 2.2	10.3 ± 3.2	11.5 ± 5.8	13.3 ± 12.0

Age corresponds to exact year of age; values for intermediate ages should be estimated by interpolation between supplied values. Standard deviations (SDs) are imprecise at older ages because of the influence of few large values.

Table 7. Usual Walking Speed (seconds) Based on Sample of 4,931 Individuals Aged 50 and Older Representative of the Community-Dwelling Population of Ireland without Dementia, Parkinson’s Disease, or Severe Cognitive Impairment

Percentile	Age							
	50	55	60	65	70	75	80	85
Male								
<i><173 cm</i>								
P95	170	169	166	162	157	152	147	142
P90	164	163	160	155	151	145	140	134
P75	155	152	150	145	140	135	129	123
P50	144	142	139	135	129	123	117	110
P25	133	130	127	123	118	111	104	96
P10	122	119	115	111	105	98	90	80
P05	114	111	107	103	97	89	80	69
Mean ± SD	143.6 ± 17.0	141.0 ± 17.7	137.8 ± 18.0	133.7 ± 17.9	128.5 ± 18.3	122.4 ± 19.1	115.5 ± 20.5	108.1 ± 22.1
<i>≥ 173 cm</i>								
P95	174	173	170	166	161	156	151	146
P90	168	166	164	159	155	149	144	139
P75	158	156	153	149	144	139	133	126
P50	148	145	142	138	133	127	120	113
P25	137	134	130	126	121	114	107	98
P10	125	121	118	114	108	101	92	83
P05	117	113	110	106	100	92	82	72
Mean ± SD	147.0 ± 17.4	144.4 ± 18.2	141.2 ± 18.4	137.1 ± 18.4	131.9 ± 18.7	126.0 ± 20.0	119.0 ± 21.0	111.0 ± 23.0
Female								
<i><160 cm</i>								
P95	170	168	165	160	154	147	140	133
P90	163	161	158	153	147	140	133	125
P75	152	150	147	142	135	128	121	113
P50	141	138	135	130	124	117	108	99
P25	130	127	123	118	112	104	96	86
P10	119	115	111	107	100	92	83	72
P05	111	107	104	99	93	84	74	64
Mean ± SD	141.1 ± 17.8	138.2 ± 18.5	134.7 ± 18.6	129.8 ± 18.4	123.6 ± 18.5	116.2 ± 19.1	108.0 ± 20.0	99.1 ± 21.1
<i>≥ 160 cm</i>								
P95	175	173	170	165	159	152	146	139
P90	168	166	163	158	152	145	138	130
P75	157	154	151	146	140	133	125	117
P50	145	143	139	134	128	121	112	104
P25	134	130	127	122	116	108	99	90
P10	122	118	115	110	104	95	86	75
P05	115	111	107	102	96	87	77	66
Mean ± SD	145.2 ± 18.3	142.3 ± 19.0	138.7 ± 19.2	133.9 ± 19.0	127.7 ± 19.1	120.3 ± 19.8	112.1 ± 20.8	103.1 ± 22.0

Age corresponds to exact year of age; values for intermediate ages should be estimated by interpolation between supplied values. SD = standard deviation.

excluded, as were those living in long-term care institutions, but the sample included individuals with chronic diseases that would potentially affect their test scores, so the results should be taken to be representative of the general community-living older population and not the healthy older population. Identifying a healthy cohort, that is separating the pathological from the physiological age-related change in the older population, is difficult, and removing all of those with a chronic condition that might in some way affect their performance would result in a small, highly atypical sample.

The models fit the observed data well, and the sample size was adequate for estimating the models. The modeled values were also compared with those generated using quantile regression and with basic descriptive statistics across age groups to validate the approach. Using

GAMLSS models with the BCPE distribution for continuous measures is a well-validated approach to producing reference curves and is recommended by the World Health Organization Multicentre Growth Reference Study Group after a comprehensive comparison of methods for the creation of child growth curves.¹¹ As with all modeling approaches, there is a danger of overfitting models to data, as well as producing results that are model driven as opposed to data driven. The study did not include sufficient individuals aged 85 and older, so normative values are provided only up to age 85. Less than 4% of data were missing for all tests, and most cases arose from participants being unable to complete the test. Those with missing data were excluded from the analyses, so estimated normative values are applicable to those willing and able to complete each assessment.

Table 8. Maximum Grip Strength (kg) from Two Trials of Each Hand, Based on a Sample of 5,819 Individuals Aged 50 and Older Representative of the Community-Dwelling Population of Ireland without Known Dementia, Parkinson's Disease, or Severe Cognitive Impairment

Percentile	Age							
	50	55	60	65	70	75	80	85
Male								
<i><173 cm</i>								
P95	51	49	48	46	43	40	37	34
P90	48	46	45	43	40	37	35	32
P75	43	41	40	38	36	34	31	28
P50	38	36	35	34	32	29	27	24
P25	33	32	30	29	27	25	22	20
P10	29	27	26	25	23	21	19	16
P05	27	24	24	23	21	18	16	16
Mean ± SD	38.4 ± 7.5	36.4 ± 7.4	35.3 ± 7.2	34.0 ± 7.0	31.8 ± 6.7	29.2 ± 6.5	26.6 ± 6.3	23.8 ± 6.1
<i>≥ 173 cm</i>								
P95	56	53	53	51	48	45	42	40
P90	53	51	49	48	45	42	40	37
P75	48	46	45	43	41	38	35	32
P50	42	41	39	38	36	34	31	28
P25	37	36	35	33	31	29	26	24
P10	33	31	30	29	27	25	22	20
P05	30	28	27	27	24	22	20	18
Mean ± SD	42.7 ± 7.8	40.7 ± 7.7	39.7 ± 7.6	38.4 ± 7.4	36.1 ± 7.1	33.6 ± 7.0	30.9 ± 6.8	28.2 ± 6.7
Female								
<i><160 cm</i>								
P95	31	29	28	27	26	24	23	23
P90	29	27	26	26	24	23	22	21
P75	26	24	24	23	22	20	19	18
P50	23	21	21	20	19	18	17	16
P25	20	18	18	18	17	16	14	13
P10	17	15	15	15	14	13	12	10
P05	16	13	13	14	13	11	10	9
Mean ± SD	23.0 ± 4.6	21.3 ± 4.7	20.7 ± 4.5	20.3 ± 4.2	19.1 ± 3.9	17.9 ± 3.9	16.8 ± 4.1	15.7 ± 4.5
<i>≥ 160 cm</i>								
P95	34	32	32	31	29	27	27	27
P90	32	30	30	29	27	26	25	25
P75	29	27	26	26	24	23	22	21
P50	25	24	23	23	22	21	19	18
P25	22	21	20	20	19	18	16	15
P10	19	17	17	17	16	15	13	12
P05	17	15	15	15	14	13	11	10
Mean ± SD	25.5 ± 5.1	23.7 ± 5.2	23.2 ± 5.0	22.7 ± 4.6	21.6 ± 4.4	20.4 ± 4.4	19.2 ± 4.7	18.2 ± 5.2

Age corresponds to exact year of age; values for intermediate ages should be estimated by interpolation between supplied values.
SD = standard deviation.

Comment on Specific Measures

This is the first study to provide population-based normative data for the TUG test performed at a normal pace. Men performed the TUG test slightly faster than women, and TUG times were faster in taller participants. Variation in TUG time increased with age, with large differences between the fastest and slowest participants at the oldest ages. TUG times were slower than those reported in a recent meta-analysis,¹² although that analysis included studies with differing inclusion criteria, varying test protocols, and small convenience samples, making a direct comparison difficult. Another study¹³ reported faster TUG times in a Spanish population, but these were calculated for TUG performed at fast pace.

Grip strength was greater in men than women. Grip strength declines from age 50 onward and declines faster

after the age of 65. In general, the TILDA population had weaker grip strength than in several other studies,¹⁴⁻¹⁶ including normative data provided in the Baseline dynamometer manual,¹⁷ although because none of these studies used population-representative samples, they may reflect healthier, more-robust groups. Many of these studies used the Jamar dynamometer, which has excellent interinstrument reliability with the Baseline dynamometer¹⁸ used in the current study.

Walking speed declined with increasing age and was faster in men than women and in taller than smaller participants of both sexes. The decline was slightly curvilinear, with the most pronounced decline after age 65. The walking speed of the TILDA population was faster than or similar to that of community-dwelling adults of a comparable age in other studies using the GAITRite walkway.¹⁹⁻²¹ This may be because of the long acceleration period available to par-

Table 9. Heel Bone Stiffness Index Based on a Sample of 4,980 Individuals Aged 50 and Older Representative of the Community-Dwelling Population of Ireland without Known Dementia, Parkinson’s Disease, or Severe Cognitive Impairment

Percentile	Age							
	50	55	60	65	70	75	80	85
Male								
P95	134	131	128	126	124	124	124	126
P90	126	124	121	119	117	117	117	118
P75	113	111	109	107	106	105	105	106
P50	100	99	97	95	94	93	92	92
P25	88	87	85	83	82	81	80	79
P10	77	77	75	73	71	70	68	66
P05	72	71	69	67	65	63	61	59
Mean ± SD	100.9 ± 19.0	99.5 ± 18.5	97.7 ± 18.0	95.6 ± 17.7	94.0 ± 17.9	93.0 ± 18.4	92.5 ± 19.3	92.3 ± 20.4
Female								
P95	129	118	111	108	105	102	97	92
P90	120	109	103	101	98	95	90	86
P75	106	97	92	90	87	84	80	76
P50	93	86	81	79	77	74	70	65
P25	82	76	72	70	68	65	61	56
P10	74	68	64	62	60	57	53	49
P05	69	64	60	58	56	53	49	44
Mean ± SD	95.3 ± 18.6	87.6 ± 16.7	82.8 ± 15.6	80.7 ± 15.2	78.4 ± 15.1	75.1 ± 14.9	71.1 ± 14.8	66.5 ± 14.6

Age corresponds to exact year of age; values for intermediate ages should be estimated by interpolation between supplied values. SD = standard deviation.

Participants before the timed walk, highlighting the importance of standardization of every aspect of such a test.

BMI does not appear to decline with age in the community-living older population of Ireland. Previous studies have shown varying patterns of BMI change with age in older adults but have tended to show a similar distribution of BMI in those aged 60 to 69 and 70 to 79, with lower BMI in those aged 80 and older.^{22,23}

In interpreting the cognitive test scores, it is worth re-emphasizing that, although the sample excluded those with known dementia or severe cognitive impairment, it is likely that a significant proportion of the sample had disease that might have impaired their cognitive function, particularly in the oldest age groups. This approach of excluding individuals with dementia or severe cognitive impairment while including those with possible mild impairment is commonly taken when supplying normative values for cognitive tests^{24,25} because it is difficult to distinguish between age-related and mild pathological decline in cognitive ability.

Mini-Mental State Examination scores declined with age, and this decline was more pronounced at lower education levels, as previously reported.²⁵ Normative data for MMSE has been stratified according to sex in some previous studies, with differences between men and women in the oldest age groups and at the lowest percentiles,²⁶ but no substantial effect of sex on MMSE score was found in the current study, possibly because individuals in long-term care institutions were excluded. The MMSE does not discriminate cognitive function well in cognitively intact individuals, as the overlapping MMSE percentiles demonstrate, but can identify the lowest performing 5th and 10th percentiles in most subgroups. MoCA scores in this study declined with age, and similar to MMSE, this decline was

more pronounced with lower education levels. The median values for MoCA reported here are 1 to 2 points higher than those reported recently in 2,653 ethnically diverse participants of the Dallas Heart Study.²⁴ This, along with the previous finding that the cutoff score of 26 originally proposed for the MoCA lacks specificity in many populations,²⁷ highlights the need for population-specific norms. Educational attainment strongly affect MoCA and MMSE scores. Using the recently suggested cutoff of 20 for indication of cognitive impairment on the MoCA,²⁸ half of those aged 85 with primary education or less would be categorized as impaired, compared with only 10% of those aged 85 with third-level or higher education. Limited normative data exist for the Color Trails Test. The trend of longer completion time with age is demonstrated, and the greater effect of education on the Trails 2 norms is similar to that reported previously.^{8,29-31}

Bone mineral density (BMD) declines with age, particularly in women. Although many normative studies of BMD exist in middle-aged and older populations, the majority use dual-energy X-ray absorptiometry,^{32,33} which is considered to be the criterion standard for osteoporosis diagnosis. Heel bone ultrasound provides a complementary measure of bone density that is also useful as a low-cost, portable screening measure for osteoporosis, and this study is one of the first to provide normative values for heel bone ultrasound measurements derived from an unselected sample from a middle-aged and older population.

CONCLUSION

This study reports a comprehensive range of up-to-date normative values for many measures currently indicated for use in CGA. The population used was representative of

community-dwelling individuals aged 50 and older living in the Republic of Ireland. Up-to-date population-specific normative values are essential to enable clinicians to compare the performance of their patients with that observed in the general community-living older population, guiding better diagnosis and management of older adults.

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