

Cognitive Aging and Brain Health

A Comparison of Super Movers vs Nonsuper Movers

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Abstract

Background and Objectives

Super movers are individuals aged ≥ 80 years with gait speeds ≥ 1.5 SDs above age- and sex-adjusted means. Super movers tend to have lower prevalence of chronic medical conditions, healthier lifestyles, and younger biological age. The aim of this study was to examine their risk of incident cognitive impairment, trajectories of cognitive decline, and brain health.

Methods

This study used a retrospective study design using data from older adults aged ≥ 80 without Alzheimer disease or dementia enrolled in 5 Health and Retirement Study International Network of Studies (HRS-INS), the LonGenity Study, and the RUSH Memory Aging Project (RUSH MAP). HRS-INS data were used to assess incident cognitive impairment (>1.5 SD below the age-adjusted means on any cognitive test plus impaired Instrumental Activities of Daily Living) in super movers vs nonsuper movers. Age- and sex-adjusted hazard ratios (HRs) from Cox models were pooled in a meta-analysis to obtain risk of incident cognitive impairment. LonGenity data were used to examine (1) decline in cognitive domains using linear mixed-effects models adjusted for age, sex, education, and parental longevity; (2) trajectories of global cognition before and after age 80; and (3) brain structural differences (cortical thickness, hippocampal volume) between super vs nonsuper movers. RUSH MAP data were used to assess dementia-related pathology.

Results

HRS-INS study ($n = 3,989$, baseline age 83.6–84.4 years, 47%–65% females, 358 super movers), after excluding 274 adults with cognitive impairment at baseline, super movers had lower risk of incident cognitive impairment (HR 0.49, 95% CI 0.28–0.71) over follow-ups ranged between 3.4 and 5.4 years. In LonGenity ($n = 197$, baseline age 84.6 [SD 3.3], 57.8% women), super movers showed slower memory and non-memory-related cognitive decline and preserved hippocampal volume in specific subfields. In RUSH MAP ($n = 692$, baseline age 85.6 [SD 4.0], 68.9% women), super movers had better antemortem cognition and lower Alzheimer disease and dementia prevalence, but no differences in postmortem dementia-related pathologies.

Discussion

Super movers show slower cognitive aging—indicated as lower risk for cognitive impairment and slower cognitive decline—and preserved hippocampal volumes. Investigating their behavioral and biological traits may reveal novel protective mechanisms against cognitive decline and dementia.

Introduction

Better gait performance is a robust marker of health in older adults. Although typically gait slows with age, some individuals maintain gait speeds well into their ninth decade and beyond.

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Supplementary Material

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Glossary

A β = β -amyloid; **ADRD** = Alzheimer disease and related dementias; **CHARLS** = Chinese Health and Retirement Longitudinal Study; **DSST** = Digit Symbol Substitution Test; **ELSA** = English Longitudinal Study of Ageing; **HR** = hazard ratio; **HRS-INS** = Health and Retirement Study International Network of Study; **IADL** = Instrumental Activities of Daily Living; **MHAS** = Mexican Healthy Aging Study; **RBANS** = Repeatable Battery for the Assessment of Neuropsychological Status; **RUSH MAP** = RUSH Memory Aging Project; **SHARE** = Survey of Health, Ageing, and Retirement in Europe; **TMT** = Trail Making Test.

We introduced the concept of super movers—an exceptional aging phenotype characterized by adults aged ≥ 80 who maintain gait speeds of 1.5 SDs above age- and sex-adjusted means.¹ In our initial study, compared with age-matched older adults, super movers had lower prevalence of chronic medical conditions (i.e., cardiovascular disease burden, depression), healthier lifestyles (i.e., higher levels of physical activity, less smoking), and younger biological age (i.e., difference between chronological age and age predicted by accumulated physiology),¹ which have all been associated with preserved cognition in aging.^{2–5}

Based on our findings, we hypothesized that super movers would show lower risk for developing cognitive impairments, slower trajectories of cognitive decline, better-preserved brain structures, and lower Alzheimer disease and related dementias (ADRD) pathology compared with nonsuper movers. To examine these hypotheses, we leveraged data from nationally representative samples of 3,989 adults aged ≥ 80 enrolled in the Health and Retirement Study International Network of Studies (HRS-INS)^{6–10} and 2 separate cohorts of older adults aged ≥ 80 with data available for longitudinal cognitive assessments and brain MRI (the LonGenity study)¹¹ and ADRD pathology (RUSH Memory and Aging Project [RUSH MAP] autopsy sample).¹²

The clinical and neurobiological correlates of poor gait performance and its association with cognition are well established. Previous studies have shown that distinct gait measures (i.e., slow speed, greater variability) predict faster cognitive decline^{13,14} and poor gait shares similar neural correlates with cognitive functions.^{15,16} These findings support the view that structural and functional brain changes contribute to both gait and cognitive performance, and compensatory or resilience mechanisms may help some older adults maintain function despite age- or pathology-related brain changes.^{17,18} In contrast to the extensive literature on poor gait performance, far less is known about the antecedents of superior gait performance. It is important that superior gait is not simply the inverse of absence of poor gait—instead, it likely reflects distinct resilience factors and unique brain structures. Thereby, superior gait may serve as a marker of resilience against cognitive decline and ADRD. We aim to understand the cognitive and brain health of super movers to gain insights into resilience mechanisms that protect against age-related cognitive decline and ADRD.

Methods

Data from distinct studies were used to test our hypotheses: HRS-INS, the LonGenity study, and RUSH-MAP. Each study included subsets of adults aged ≥ 80 without a self-reported diagnosis of ADRD and was selected for its unique strengths and relevance to our investigation. HRS-INS provided harmonized data on cognitive impairment across nationally representative samples of adults from high-income and middle-income countries, making it ideal for assessing risk of cognitive impairment. The LonGenity study offered annual longitudinal cognitive assessments and a subset of participants with brain imaging data, enabling the examination of trajectories of cognitive decline and structural brain differences between super movers and nonsuper movers. RUSH MAP contributed ADRD pathology data and cognitive performance assessed clinically before death. Together, these datasets allowed for a comprehensive analysis of cognitive aging of super movers across multiple dimensions.

Risk for Developing Cognitive Impairment in Super Movers: HRS-INS

Study Population

To examine the risk for developing cognitive impairment in super movers, we accessed longitudinal data of older adults enrolled in the United States Health and Retirement Study (HRS), English Longitudinal Study of Ageing (ELSA), Survey of Health, Ageing, and Retirement in Europe (SHARE), Chinese Health and Retirement Longitudinal Study (CHARLS), and Mexican Healthy Aging Study (MHAS) on *Gateway to Global Aging Data*.^{6–9,19,20} HRS-INS studies received approval from local institutional review boards and obtained informed consent from participants before enrollment. We received ethical approval from the institutional review board of the Albert Einstein College of Medicine, New York for this analysis.

In each cohort, subsamples were created with adults aged ≥ 80 who completed gait assessments and had no clinical diagnosis of ADRD at baseline. Age- and sex-adjusted cut-scores for gait speeds of ≥ 1.5 SD were generated to identify super movers.¹ HRS-INS had harmonized gait assessments as time taken to walk a measured distance (2.5–4 m) at participants' preferred pace. Super movers were defined using cohort-specific cut-scores reducing variability across cohorts (eTable 1 provides definitions and information about years of data collection), mirroring approaches used to define normative cognitive

performance. This approach is preferable to using a single gait speed cut-score across cohorts, to avoid significant variation in prevalence estimates due to population differences in gait speed.^{21,22}

Cognitive Impairment

HRS-INS has harmonized cognitive assessments.⁶⁻⁹ Adopting from the definitions of previous HRS-INS studies, cognitive impairment was defined as scoring >1.5 SD below the age-adjusted cut-scores on at least one of the cognitive tests,²³ combined with any impairment in Instrumental Activities of Daily Living (IADL). Cognitive tests used to assess cognitive impairment included total recall, orientation, serial 7s, and counting backwards—ensuring harmonized definitions across cohorts (eTable 1). IADL impairment included self-reported data using standardized questionnaires on having difficulty in making phone calls, managing money and medication, reading a map, shopping for groceries, and preparing a hot meal. The date an individual first met criteria for cognitive impairment during the follow-up was considered as the date of incident cognitive impairment. For studies which reported follow-ups dates only by month and year, the date of first diagnosis was assumed to be the 15th day of the reported month.

Except for MHAS, other HRS-INS also included a self-reported question on whether participants had ever been diagnosed with a memory problem, Alzheimer disease, or dementia. Among the 701 participants who met criteria for incident cognitive impairment, 504 also reported a diagnosis of Alzheimer disease or dementia.

Covariates

Age and sex were used as covariates. Level of education, history of physician diagnosed medical conditions (i.e., cardiovascular risk factors and events), depression, obesity (calculated using body mass index), and self-reported behavioral factors (e.g., physical activity levels, sleep, smoking) were used to characterize the study samples²⁴ (see eTable 1 for cohort-specific definitions).

Statistical Analysis

All analyses were conducted in STATA version 18.5 (StataCorp LLC, College Station, TX). Cox proportional hazard models were used to evaluate the association of super mover status *at baseline* with the risk of incident cognitive impairment, adjusted for baseline age and sex. Poststratification sample weights that account for the variations in survey designs were applied to all models. Person-time variables were obtained by calculating time in days between the first assessment date and date meeting criteria for cognitive impairment for the first time or the last assessment date (for participants who did not develop cognitive impairment). Proportionality of the models was examined graphically and statistically and found to be adequately met. Hazard ratios (HRs) and standard errors from individual cohorts were extracted to perform a meta-analysis using STATA meta suite.

In the pooled sample, overall risk of developing cognitive impairment in super movers, using the Cochrane Q_b statistic, is reported.

Secondary Analyses

Self-Reported Alzheimer Disease and Dementia

To examine whether super movers demonstrate a lower risk of having self-reported diagnosis of Alzheimer disease or dementia, cohort-specific HR and standard errors were pooled in a meta-analysis.

Transformed Gait Speed–Based Super Mover Definition

As gait speed showed slight positive skewness in individual cohorts, age- and sex-adjusted cut-scores (1.5 SD above) from transformed gait speed (log or square-root transformation) were used to define an alternative super movers group, and their risk of incident cognitive impairment was assessed.

Adjustment for Previous Cognitive Performance

To further account for confounding from previous cognitive performance, the primary analyses were repeated adjusting for the overall cognitive performance in the wave before the baseline. Overall cognitive performance was derived from tests of total recall, counting, verbal fluency, and visual scanning (details in eTable 1).

Cognitive Trajectories and Differences in Brain Structure in Super Movers vs Nonsuper Movers: The LonGenity Study

Study Population

The LonGenity study is an ongoing community-based longitudinal study of Ashkenazi Jewish older adults aged ≥ 65 ,^{11,25} which aims to examine the genetic and biological mechanisms that promote successful aging in older adults with and without exceptional parental longevity (having at least 1 parent who lived to age ≥ 95). Participants are recruited through voter registration lists, Jewish newsletters, and contacts at synagogues. Ethical clearance was obtained from the Institutional Review Board of Albert Einstein College of Medicine, and written informed consent was obtained from all participants.

The LonGenity study provides up to 15 years of follow-up data on annual cognitive assessments and brain imaging data in a subset of participants, allowing us to examine longitudinal trajectories of cognitive functioning (rates of decline in specific cognitive domains and trajectories of global cognition before and after an individual turns 80 years) and differences in brain structure between super movers and nonsuper movers.

Gait Assessment

Gait was assessed with an 8.5-m computerized GAITRite walkway. Participants completed 1 straight walk at their comfortable walking speed—after a practice walk. The walks began 1.2 m before and ended 1.2 m after the walkway to

allow for initial acceleration and terminal deceleration effects. If participants used walking aids, gait was only assessed if they could complete a walk without the aid. Gait speed (meters/second [m/s]) was obtained from the GAITRite software.^{11,25,26} In our previous studies, we reported excellent reliability between gait speed assessed using the GAITRite and speed assessed with timed walk protocols.²⁷ Age- and sex-adjusted cut-scores for gait speed of 1.5 SD above mean were calculated to use in the definition of super movers *at baseline* (≥ 1.29 m/s for men and ≥ 1.27 m/s for women).

Cognitive Assessment

Cognitive performance was assessed with a comprehensive battery of neuropsychological tests. Episodic memory was assessed using Free Recall on Free and Cued Selective Reminding Test, and subdomains of executive functions were assessed with Trail Making Tests (TMT) A and B and Digit Span (working memory) of the Wechsler Adult Intelligence Scale-III test, and Repeatable Battery for the Assessment of Neuropsychological Status (RBANS) Figure Copy test (visuospatial function). Processing speed was assessed with the Digit Symbol Substitution Test (DSST). Global cognition was assessed as a standardized composite score from 10 individual subtests as previously described.¹¹

Brain Structure

Brain images were obtained from a single Philips 3T MRI scanner (Achieva Quasar TX; Philips Medical Systems, Best, the Netherlands), in a subset of participants. The standard protocol of MRI acquisition has been previously described.^{28,29} T1-weighted images were processed using FreeSurfer version 6.0—an open source, automated pipeline for analysis of structural and function neuroimaging data. Data for cortical thickness in 68 brain regions (34 per hemisphere) and volume in 12 hippocampal subfields per hemisphere (tail, subiculum, presubiculum, parasubiculum, hippocampal fissure, molecular layer, CA1, CA3, CA4, fimbria, GCMLDG, and HATA) were extracted.

Covariates

Age, sex, education levels, and parental longevity were self-reported. Similar to the HRS-INS, physician diagnosed medical conditions, depression, obesity, and self-reported behavioral factors (e.g., current smoking [yes, no], sedentary behavior [engaging in moderate physical activity at least 3 times per week]) were used to characterize the study samples.

Statistical Analysis

To estimate the rates of decline in specific cognitive domains between super movers and nonsuper movers, linear mixed effect models were used with an interaction between super mover status at baseline and centered age. Centered age was calculated with the sample mean as the reference point to create meaningful intercepts in the models. Models were adjusted to a priori selected covariates (baseline age, sex, education, parental longevity). In our previous studies from

the LonGenity study, we observed nonlinear decline in cognitive domains in aging.¹¹ Hence, in the current dataset, models incorporating a quadratic term for centered age (i.e., super movers $\times$ centered age $\times$ centered age) were fitted. After model comparisons (with and without quadratic terms), using the likelihood ratio test, we present the results from the models without the quadratic term due to better model fit and ease of clinical interpretation.

In a secondary analysis to examine whether super movers experience slower cognitive decline before and after age 80, we categorized individuals as super movers or nonsuper movers based on their gait speed *when they turned age 80* (≥ 1.31 m/s for men and ≥ 1.27 m/s for women). Plotted piecewise trajectories of global cognitive function with separate slopes for the periods before and after age 80 were used to visually compare the trajectories between the 2 groups.

In the subset of participants with brain MRI, linear regression analyses—adjusted for age, sex, education, parental longevity, and total intracranial volume—were used to estimate associations between super mover status and mean cortical thickness and mean hippocampal volume, with models run separately for the right and left hemispheres. When significant group differences were observed in these global brain metrics, follow-up multivariate regression analyses were conducted to examine regional differences in cortical thickness and/or hippocampal subfield volumes between super movers and nonsuper movers.

ADRD Pathology in Super Movers: RUSH MAP

RUSH MAP is a longitudinal clinical-pathologic study of chronic age-related conditions. The study goals and procedures, including autopsy procedures, have been previously described.^{12,30} We used data from 692 participants who were aged ≥ 80 *at baseline*, had gait speed data, and consented to brain autopsy, to examine the differences in ADRD pathology between super movers vs nonsuper movers (defined using gait speed data at baseline; ≥ 0.87 m/s men; ≥ 0.80 m/s women). ADRD pathology was characterized as (1) global Alzheimer pathology, (2) β -amyloid-immunoreactive (A β plaques), (3) density of paired helical filament tau tangles, (4) Lewy body, and (5) cerebrovascular pathology. Global Alzheimer pathology was the average of neuritic plaques, diffuse plaques, and neurofibrillary tangles from 5 brain regions (midfrontal gyrus, inferior parietal gyrus, middle temporal gyrus, entorhinal cortex, and hippocampus [CA1/subiculum]) stained, visualized, and counted by a neuropathologist blinded to clinical data. A β plaques and tau tangles were derived from 8 brain regions (hippocampus, entorhinal cortex, midfrontal cortex, inferior temporal, angular gyrus, calcarine cortex, anterior cingulate cortex, and superior frontal cortex) using immunohistochemistry and image analyses. Lewy body was examined as 4 stages of distribution of α -synuclein in the brain using immune staining. Cerebrovascular pathologies were examined as a summary index of gross

infarcts, micro infarcts, cerebral amyloid angiopathy, atherosclerosis, or arteriolosclerosis.

Covariates

Data from standard clinical evaluations including demographics, medical history, and neurologic examination were used as covariates. Cognitive status—determined through a 3-stage diagnostic process involving computerized scoring of cognitive tests, clinical judgment of a neuropsychologist, and final diagnostic classification by a clinician—was used to identify cases of Alzheimer disease and other dementias as previously described.³¹

Statistical Analysis

Linear regression models and multivariate logistic regression models (for Lewy body pathology) were used to examine the differences in ADRD pathology between super movers and nonsuper movers in separate models. Models were adjusted for potential confounding effects of age at last visit, sex, and time from last visit to death. The 2-sample *t* test was used to assess differences in the overall cognitive performance (measured as a composite *z*-score of 19 neuropsychological tests) between super movers vs nonsuper movers at the last available visit, and the χ^2 test was used to compare the presence of Alzheimer disease and other dementias.

Data Availability

Data for this study are publicly available at *Gateway to Global Aging Data* for HRS-INS and at Rush Alzheimer's Disease Center Resource Sharing Lab for RUSH MAP. Access to the LonGenity data is available upon request to the study investigators, subject to ethics approval.

Results

Risk for Cognitive Impairment: HRS-INS

Table 1 provides participant characteristics at baseline in individual HRS-INS, using raw sample sizes and weighted percentages. The mean age of the 3,989 participants (pooled) varied between 83.6 and 84.4 years (range 80–101 years). Except for MHAS (47%), other studies had a greater proportion of females. Older adults in HRS had the highest proportion of individuals with higher levels of education. The prevalence of cardiovascular risk factors such as hypertension and diabetes was greater in the HRS, MHAS, and SHARE compared with other HRS-INS, whereas the prevalence of heart problems and stroke was greater in the HRS, ELSA, and SHARE.

Prevalence of super movers ranged between 6.4% (in SHARE) and 9.8% (in MHAS). In individual Cox proportional hazard models, adjusted for age and sex, super movers showed significantly lower risks of developing cognitive impairment in ELSA (HR 0.31, 95% CI 0.16–0.60) and SHARE (HR 0.49, 95% CI 0.26–0.89) (Table 2). When HRS-INS data were pooled in the meta-analysis (*n* = 352/3,715

super movers; after excluding 274 adults who met cognitive impairment at baseline), followed up for 3.4–5.4 years, super movers showed an overall lower risk of incident cognitive impairment (HR 0.49, 95% CI 0.28–0.71). Table 3 and Figure 1 show the risks of developing incident cognitive impairment in the pooled sample.

Secondary Analyses

Self-Reported Alzheimer Disease and Dementia

In the pooled data from HRS, ELSA, SHARE, and CHARLS, super movers had a significantly lower risk of developing Alzheimer disease or dementia (HR 0.40, 95% CI 0.22–0.58) based on self-reported diagnoses (eTable 2).

Transformed Gait Speed–Based Super Mover Definition

When cut-scores based on transformed gait speed were used, prevalence of super movers ranged from 3.8 in MHAS to 7.3 in HRS. In age- and sex-adjusted Cox proportional hazard models in each cohort, super movers showed lower risks of developing cognitive impairment in HRS (HR 0.67, 95% CI 0.45–0.99), ELSA (HR 0.24, 95% CI 0.11–0.54), and SHARE (HR 0.47, 95% CI 0.26–0.87) (eTable 3). When HRS-INS cohorts were pooled in the meta-analysis, super movers showed an overall lower risk of incident cognitive impairment (HR 0.40, 95% CI 0.22–0.58).

Adjustment for Previous Cognitive Performance

Adjustment for cognitive performance in the wave prior made the associations between super mover status and incident cognitive risk nonsignificant in SHARE study; however, the pooled data showed a lower risk of incident cognitive impairment among super movers (Table 2).

Cognitive Decline and Differences in Brain Structure: The LonGenity Study

In 197 adults aged ≥ 80 (mean age 84.6, SD 3.3, 57.8% women) followed up for an average of 4.4 years (SD 3.7), we identified 14 (7.1%) super movers, who were younger and, as expected, had faster gait speeds than nonsuper movers (eTable 4). A higher proportion of super movers had parents with exceptional longevity (*p* = 0.05; nonsignificant) and were more likely to engage in regular physical activities (*p* < 0.001).

Compared with nonsuper movers, super movers showed a slower decline in memory (total recall) (difference of 0.14 points per year, 95% CI 0.02–0.25, *p* = 0.016), and non-memory-related cognitive tests (DSST [0.78 points per year, 95% CI 0.24–1.31, *p* = 0.004], TMT-A time [–1.31 seconds per year, 95% CI –2.44 to –0.17, *p* = 0.024] and TMT-B time [–4.66 seconds per year, 95% CI –7.54 to –1.79, *p* = 0.001]) and global cognition (difference in *z*-score of 0.04 per year, 95% CI 0.01–0.08, *p* = 0.009). There was no difference in the rates of decline in digit span (β = 0.08, 95%

Table 1 Characteristics of Participants at Baseline in Health and Retirement Studies International Network of Studies

	HRS US	ELSA UK	SHARE Europe	CHARLS China	MHAS Mexico
Wave (baseline)	8 (2006–2007)	2 (2004–2005)	2 (2006–2007)	1 (2011–2012)	3 (2012)
No. of older adults ≥80 y	n = 876	n = 874	n = 1,800	n = 303	n = 136
% of super movers among older adults ≥80 y	9 (79/876)	8.8 (81/874)	6.4 (152/1,800)	7.3 (25/303)	9.8 (21/136)
% of older adults ≥80/adults ≥65 y	25 (876/3,915)	23.13 (874/4,128)	49 (1,800/3,940)	12 (303/3,170)	13 (136/746)
Demographic factors					
Age (y) ^a	84.4 (3.5)	84.0 (3.0)	83.6 (3.1)	83.7 (3.1)	83.6 (4.5)
Female ^b	527 (62)	538 (65)	974 (64)	170 (62)	77 (47)
Higher levels of education ^b	665 (77)	284 (32)	609 (28)	13 (4.4)	12 (22)
Medical conditions					
Hypertension ^b	543 (61)	426 (49)	888 (51)	105 (37)	88 (72)
Diabetes ^b	160 (18)	84 (9.3)	241 (17)	18 (5.9)	27 (13)
Heart problems ^b	320 (37)	280 (32)	544 (30)	39 (14)	13 (11)
Stroke ^b	90 (11)	83 (9.3)	147 (7.7)	16 (5)	8 (2.9)
Depression ^b	185 (22)	279 (33)	542 (34)	87 (32)	91 (61)
Obesity ^b	123 (14)	123 (18)	188 (10)	42 (17)	16 (8)
Lifestyle factors					
Physical activity ^b	442 (50)	477 (54)	1,268 (69)	29 (21)	38 (19)
Smoking ^b	460 (53)	560 (63)	681 (32)	116 (37)	53 (37)
Sleep ^b	174 (20)	346 (40)	594 (37)	119 (43)	66 (42)
Gait performance					
Gait speed (m/s) ^a	6.45 (2.23)	6.16 (2.31)	6.08 (3.18)	4.39 (1.89)	4.69 (1.94)

Abbreviations: CHARLS = Chinese Health and Retirement Longitudinal Study; ELSA = English Longitudinal Study of Ageing; HRS = Health and Retirement Study; MHAS = Mexican Healthy Aging Study; N/A = not applicable; SHARE = Survey of Health, Ageing, and Retirement in Europe.

Across 7 cohorts, except for demographic and gait speed variables, values are based on all available data and sample sizes vary because not all participants had data for every variable.

^aValues are reported with weighted *M* (SD).

^bValues are reported with *n* (%). Characteristics are reported with *raw sample n and weighted sample %*. Raw sample *n* show the number of observations the estimates are based on and the weighted percentages represent the population estimates of the proportions).

Table 2 Risks of Incident Cognitive Impairment (Based on Cognitive Test Scores and Impairment in Instrumental Activities of Daily Living) in Super Movers vs Nonsuper Movers in Individual Studies in Health and Retirement Studies International Network of Studies

Study (n of aged ≥80)	HRS (n = 876)	ELSA (n = 874)	SHARE (n = 1,800)	CHARLS (n = 303)	MHAS (n = 136)	Overall
Hazard ratio (95% CI), <i>p</i> value	0.767 (0.475–1.237), 0.271	0.312 (0.161–0.604), 0.001	0.490 (0.267–0.899), 0.021	0.678 (0.249–1.849), 0.448	0.457 (0.055–3.764), 0.467	0.499 (0.285–0.713), <0.001
Hazard ratio (95% CI), <i>p</i> value Adjusted for previous cognitive performance	0.825 (0.520–1.308), 0.407	0.355 (0.180–0.699), 0.003	0.541 (0.287–1.022), 0.058	Data not available	0.555 (0.069–4.426), 0.578	0.543 (0.291–0.795), <0.001
Mean survival time (95% CI)	5.474 (5.087–5.861)	4.435 (4.142–4.727)	4.361 (4.021–4.702)	3.408 (3.076–3.741)	3.731 (3.012–4.451)	
Number of events	229	163	233	57	19	

Abbreviations: CHARLS = Chinese Health and Retirement Longitudinal Study; ELSA = English Longitudinal Study of Ageing; HRS = Health and Retirement Study; MHAS = Mexican Healthy Aging Study; SHARE = Survey of Health, Ageing, and Retirement in Europe.

Table 3 Risks for Developing Cognitive Impairment in Super Movers vs Nonsuper Movers in the Meta-Analysis

	Hazard ratio (95% CI)	% Weight
HRS	0.767 (0.408 to 1.126)	22.04
ELSA	0.313 (0.106 to 0.519)	37.64
SHARE	0.491 (0.193 to 0.788)	27.34
CHARLS	0.679 (−0.002 to 1.359)	8.44
MHAS	0.457 (−0.506 to 1.421)	4.54
Overall	0.499 (0.285 to 0.713) to $p < 0.001$	

Abbreviations: CHARLS = Chinese Health and Retirement Longitudinal Study; ELSA = English Longitudinal Study of Ageing; HRS = Health and Retirement Study; MHAS = Mexican Healthy Aging Study; SHARE = Survey of Health, Ageing, and Retirement in Europe.

CI −0.08 to 0.26, $p = 0.323$) and RBANS figure test ($\beta = 0.06$, 95% CI −0.07 to 0.19, $p = 0.365$).

eFigure 1 shows the estimated piecewise trajectories of global cognition in super movers and nonsuper movers before and after the age of 80. Super movers showed better cognitive scores up to age 80 and a steeper decline after (these patterns are interpreted descriptively, based on the magnitude and direction of the observed effects, rather the statistical significance of $p < 0.05$). Brain structural data from 64 participants (age 84.8 years SD 3.6; $n = 35$, 54.6% women) showed that super movers ($n = 6$) had significantly greater mean hippocampal volume (cubic millimeters) in the right hemisphere ($\beta = 314.4$, 95% CI 28.9–599.8, $p = 0.032$) and a nonsignificant trend in the left hemisphere ($\beta = 245.2$, 95% CI −37.6 to 528.0, $p = 0.088$). In the hippocampal subfield analysis, right fimbria, molecular layer, pre-subiculum, and CA1 and left subiculum showed differences between super movers and nonsuper movers (Table 4). No

differences were observed in mean cortical thickness between groups.

ADRD Pathology in Super Movers: RUSH-MAP

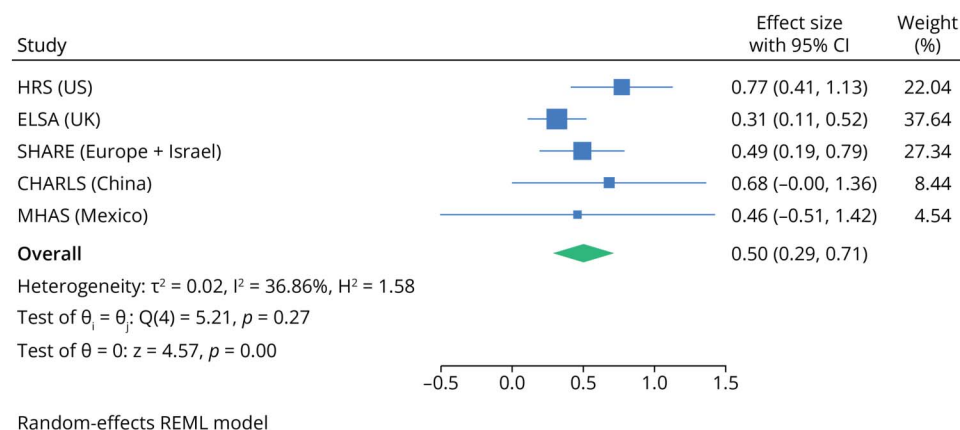
Prevalence of super movers was 12.1% ($n = 84$) among the 692 participants aged ≥ 80 at baseline. The average age at death was 94.8 years (SD 4.9) for super movers and 92.8 years (SD 4.8) in nonsuper movers ($p < 0.001$). At their last clinical assessment, super movers showed better global cognition (mean z score −0.79 vs −0.81, $p = 0.86$) and lower prevalence of clinically diagnosed Alzheimer disease and other dementias (86.7% vs 13.2%, $p = 0.65$) compared with nonsuper movers (although not statistically significant). There were no differences in any of the ADRD pathologies examined.

Discussion

In this study, we adopted a novel perspective on gait and cognitive performances by examining these associations through the lens of super movers—adults aged ≥ 80 with exceptional gait performance. Using multiple datasets—each selected based on the availability of specific data on cognitive functioning, brain structure, and ADRD pathology—we present a unified summary of the findings. Super movers showed a lower risk of incident cognitive impairment and having a self-reported diagnosis of Alzheimer disease and dementia. They demonstrated slower decline in specific memory and non-memory-related cognitive domains and better or preserved hippocampal volumes in several subfields. However, there were no differences in overall cortical thickness or ADRD pathology between super movers and nonsuper movers.

Although we expected that super movers would show lower ADRD pathology—based on reported associations between higher ADRD pathology and slow gait speed^{32–35}—this was not supported. Nevertheless, super movers showed trends of

Figure 1 Forest Plot of the Risks for Developing Cognitive Impairment in Super Movers in Health and Retirement Studies International Network of Studies



CHARLS = Chinese Health and Retirement Longitudinal Study; ELSA = English Longitudinal Study of Ageing; HRS = Health and Retirement Study; MHAS = Mexican Healthy Aging Study; SHARE = Survey of Health, Ageing, and Retirement in Europe.

Table 4 Brain Structural Differences in Super Movers vs Nonsuper Movers in the LonGenity Study (n = 64)

	Right hemisphere			Left hemisphere		
	Coefficient	95% CI	p Value	Coefficient	95% CI	p Value
Hippocampal tail	45.61	−10.30 to 101.54	0.108	47.18	−14.13 to 108.51	0.129
Subiculum	45.41	−0.74 to 91.56	0.054	44.19	2.75 to 85.62	0.037
CA1	68.08	4.46 to 131.71	0.036	49.19	−7.83 to 106.22	0.089
Hippocampal fissure	2.53	−25.14 to 30.21	0.855	11.37	−19.25 to 42.01	0.460
Presubiculum	33.71	3.99 to 63.43	0.027	22.04	−10.98 to 55.07	0.186
Parasubiculum	7.76	−1.37 to 16.90	0.094	−0.93	−12.52 to 10.65	0.872
Molecular layer	52.70	0.96 to 104.44	0.046	38.49	−10.12 to 87.11	0.118
GCMLDG	16.49	−10.83 to 43.82	0.232	14.94	−7.85 to 37.75	0.194
CA3	10.10	−13.04 to 33.26	0.385	4.77	−14.73 to 24.29	0.625
CA4	9.72	−13.27 to 32.73	0.400	13.02	−6.74 to 32.80	0.192
Fimbria	18.27	2.95 to 33.58	0.020	7.39	−13.59 to 28.38	0.483
HATA	6.52	−2.23 to 15.27	0.141	4.87	−3.25 to 13.00	0.235

better cognitive performance and lower rates of ADRD diagnosis compared with nonsuper movers. These findings align with results from clinicopathologic studies, such as the Alzheimer’s Disease Neuroimaging Initiative (age 60–89 years) and the 90+ Study (90–101 years), that found no significant differences in A β or tau pathology between older adults with superior cognitive performance and their age-matched counterparts.^{36,37} This convergence of evidence suggests that the cognitive benefits in super movers (and other exceptional aging phenotypes) may not necessarily stem from resistance to developing ADRD pathology but rather arise from cognitive resilience mechanisms (brain’s capacity to maintain cognition) that allow coping with the effects of accumulating ADRD pathology.^{17,38}

Supporting this speculation, our brain imaging analyses in the LonGenity study showed that super movers had higher hippocampal volume, particularly in ventral hippocampal subfields (i.e., CA1, presubiculum), that are important for memory processing and locomotor functions.³⁹ In animal and human studies, ventral hippocampal fields play important roles in spatiotemporal context retrieval, spatial navigation, and establishing cognitive strategies required for movement execution.^{40,41} These structural advantages in super movers align with previous findings that showed lower hippocampal volume was associated with poorer gait (i.e., slow speed, greater variability^{42–44}) and especially lower presubiculum volume was associated with slow speed in another Bronx-based cohort (Einstein Aging Study⁴⁵). In contrast, cortical thickness analyses revealed no significant differences between super movers and nonsuper movers, although super movers showed slower decline in nonmemory cognitive tests (e.g., TMT A/B, DSST). This may reflect insufficient statistical power in the MRI subsample to detect widespread

associations in brain regions important for nonmemory cognitive domains. Overall, our results support an exceptional aging phenotype in which superior gait performance in late life may serve as a marker of broader neurocognitive resilience.

Although super movers had lower risk of incident cognitive impairment, these associations remain observational (despite adjustments for previous global cognitive performance) and may reflect either parallel expressions of an underlying healthy aging phenotype, or healthy brain aging contributing to both preserved gait and cognitive resilience. Thus, future research is needed to determine whether being a super mover is itself neuroprotective.

It is important considering that life expectancies and survival rates vary across countries. Living to the ninth decade is uncommon with most countries having lower median survival ages. Our goal was to identify a novel exceptional aging phenotype, yet, we acknowledge that the chronological age threshold of 80 years to define super movers is relatively arbitrary and recommend other metrics to be explored in the future such as biological aging to define this exceptional phenotype or use comparable age cut-scores across countries.

Our findings have important implications for globally relevant public health strategies and targeted interventions aimed at promoting cognitive resilience. By studying what factors contribute to this unique group of older adults, we may be able to identify actionable targets. Our earlier analyses revealed that super movers have better lifestyle profiles.¹ To translate these into effective prevention strategies, further research is needed to identify specific lifestyle factors—such as diet, physical activity, and sleep—in super movers and

understand how such factors are shaped by broader social and environmental determinants. Structural factors such as neighborhood environment, access to safe spaces for physical activity, availability of leisure opportunities, social capital, and policies may either facilitate or hinder the conditions needed for exceptional aging.⁴⁶⁻⁴⁸ For example, in HRS-INS, CHARLS, and MHAS—representing older adults in middle-income countries—revealed notably lower physical activity levels compared with high-income settings, highlighting the need for context-sensitive interventions.

A major strength of our study is the use of nationally representative, multicountry datasets with uniform gait assessments, including cohorts from understudied middle-income countries, and application of super mover gait speed definition individualized to each cohort to minimize population variations. This enhances the generalizability of our findings and provides a unique opportunity to examine the cognitive health profiles of super movers across diverse populations. By integrating structural brain measures and ADRD pathology markers, we offer a multifaceted view of brain health in this exceptional group. However, a few limitations are worth noting. Our definition of super movers was based on gait speed—a pragmatic choice aimed at ensuring simplicity, scalability, and applicability across diverse settings. Although we have shown that other measures such as step-to-step variability may offer additional insights into gait-cognitive associations,^{15,16} their assessment requires sophisticated instruments that may limit feasibility in large-scale studies or resource-limited settings. Further, because both high and low variability reflect impairment, this may complicate establishing a clear definition.⁴⁹ The prevalence of super movers was high in RUSH MAP, which may affect the comparability of findings across datasets. This higher prevalence is likely attributable to the volunteer-based nature of RUSH-MAP where older adults who are highly educated, more health conscious, and generally high-functioning, hence introducing potential selection biases. Despite the high prevalence of super movers, there were no statistically significant differences in cognitive performance or rates of ADRD diagnosis at the last visit, which could be due to potential confounding factors such as overall health, comorbidities, and survival bias. Other limitations include the relatively small subsamples of individuals aged ≥ 80 with neuroimaging data, limited examination of functional brain networks, more nuanced markers of resilience, genetic markers (i.e., APOE4), and the possibility of unmeasured or residual confounding factors, which should be the focus of future studies.

Super movers show lower risk for developing cognitive impairment and self-reported diagnosis of Alzheimer and dementia and slower declines in both memory and non-memory-related cognitive functions. They display higher hippocampal volumes but had levels of ADRD pathology and cortical thickness similar to those of nonsuper movers. Identifying the behavioral, biological, and environmental factors that characterize super movers may assist

developing targeted interventions to promote cognitive resilience.

Author Contributions

O. Jayakody: drafting/revision of the manuscript for content, including medical writing for content; major role in the acquisition of data; study concept or design; analysis or interpretation of data. S. Milman: drafting/revision of the manuscript for content, including medical writing for content. N. Barzilai: drafting/revision of the manuscript for content, including medical writing for content. E.F. Weiss: drafting/revision of the manuscript for content, including medical writing for content. C. Wang: drafting/revision of the manuscript for content, including medical writing for content; analysis or interpretation of data. Y. Jin: drafting/revision of the manuscript for content, including medical writing for content; analysis or interpretation of data. H. Blumen: drafting/revision of the manuscript for content, including medical writing for content; study concept or design. J. Verghese: drafting/revision of the manuscript for content, including medical writing for content; study concept or design; analysis or interpretation of data.

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Disclosure

Go to [Neurology.org/N](https://www.neurology.org/N) for full disclosures.

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