Low Grip Strength and Cognition Predict Functional Limitation in Older Europeans

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Impact Statement

We certify that this work is confirmatory of recent novel clinical research.

There is a list of references to the relevant research that the work confirms.


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Few previous studies have focused on the association of grip strength or cognitive function with longitudinal change in functional limitation. Therefore, our study uses a large, population-based sample of older Europeans to estimate the effects of baseline grip strength and cognition on the trajectory of functional limitation over time.

Abstract

Objective: To estimate the effects of baseline grip strength and cognition on the trajectory of functional limitation over time.

Design: Longitudinal study of older adults participating in the Survey of Health, Ageing and Retirement in Europe (SHARE)

Setting: Urban and rural households in 11 European countries and Israel.

Participants: A total of 14,073 participants (52.5% females) aged above 50 years from the SHARE (2004-2015) were included with the follow-up time ranging from 0.9 to 11.6 years.

Measurements: Outcome variables were five visits scores of functional limitation. Main exposure variables were grip strength and cognitive measures including memory, verbal fluency, and numeracy at baseline. Basic demographics, life habits, and health status were considered as potential confounders. Mixed-effect linear regression models were fitted.

Results: Functional limitation was significantly increased over time (β=0.051, P<0.001).
Mixed-effect linear regression models identified significant interactions of grip strength ($\beta=-0.001, P<0.001$), numeracy ($\beta=-0.012, P<0.001$), verbal fluency ($\beta=-0.003, P<0.001$) and word recall ($\beta=-0.006, P<0.001$) with time on functional limitation.

**Conclusions:** Higher baseline grip strength and cognition predicted the slower increasing rate of functional limitation over time among the older adults. Grip strength and cognitive function appeared to be useful indicators of the functional limitation process and attested to their value in monitoring functional change in European older adults.

**Keywords:** Functional limitation; Grip strength; Cognitive function; Ageing

**Introduction**

In Europe, the proportion of older adults has been increased from around 16.0 percent in 1980 to over 24.7 percent in 2017, to the point where about one in every four Europeans is above 60 years old \(^1\). With increasing age, it is more often that people suffer from functional limitation such as difficulties in walking, climbing, balance or fine motor \(^2\). As a substantial impairment in an individual’s ability to effectively perform major life activities \(^3\), the functional limitation has been believed to be the major factor contributing to several adverse health outcomes, including the loss of capacity of independent living \(^4\), the decreased quality of life \(^4,5\), depression \(^6\), dementia \(^7\) and even mortality \(^8,9\). It is generally viewed that functional limitation is the precursor to functional disability \(^10,11\) and is amenable to interventions \(^2\). Thus,
a better understanding of the underlying factors that influence physical function and its limitation is essential to ameliorate additional functional loss and prevent the subsequent disability.

Muscle strength has been found important to maintain physical function. Earlier cross-sectional studies showed a significant non-linear relationship between muscle strength and functional limitation \(^{12,13}\), and recent prospective studies identified that the higher baseline grip strength was associated with better follow-up physical function \(^{14,15}\). It suggests that minimum level of strength is prerequisite for physical function, and when strength is above the minimum required level, the greater muscle strength may serve as reserve capacity, which is beneficial to prevent functional limitation in the future. However, there were few studies focused on the role of muscle strength in the trajectory of functional limitation over time.

Studies on the association of cognitive function with functional limitation were also few and limited in scope. Although several observational studies have identified that low executive function was a risk factor of gait and balance \(^{16-18}\), the effects of other cognitive domains including memory and numeracy on the functional limitation have not been thoroughly investigated.

Here we conduct a prospective study by using a large, population-based sample derived from “The Survey of Health, Ageing and Retirement in Europe (SHARE)” (2004-2015) to
estimate the effect of baseline grip strength and cognition on the longitudinal change of functional limitation over a 10 years period.

Methods

Study sample

The SHARE is a biennial longitudinal survey of the ageing process in individuals aged 50 or older across most European Union countries and Israel. This survey collected information such as health, socio-economic status as well as social and family networks. Based on probability household sampling, respondents were surveyed by using standardized computer-assisted personal interviews. Details about the sampling procedure can be found in the previous article \(^{19}\). To date, SHARE has collected five panel waves (W1, 2, 4, 5 and 6) and a retrospective life history wave (W3). We analyzed data from the five panel waves in this study \(^{20-24}\). SHARE was reviewed and approved by the Ethics Committee of the University of Mannheim and the Ethics Council of the Max Planck Society.

The baseline (W1) survey was conducted in the 11 European countries (Austria, Germany, Sweden, Netherlands, Spain, Italy, France, Denmark, Greece, Switzerland, and Belgium) in 2004 and Israel in 2005-2006. The average household response rate was 62%, and a total of 30,434 people have participated in this survey. Some participants were excluded from this study. The excluded participants are those who were younger than 50-year-old at baseline (n=1,192), didn’t participant in any of the following surveys (n=4,983), or had
related diseases including cancer (n=2,485), Parkinson (n=458), stroke (n=2,072), fracture (hip or femoral, n=1,210) as well as Alzheimer’s disease (n=1,115) at any wave. Meanwhile, 4,174 people who shared the same household with primary respondents were also excluded so that all the observations in the sample were independent. After filtering, 14,073 individuals were included in this study (Figure 1).

**Functional limitation**

Functional limitation was assessed by answers from a list of 10 physical function related questions, including walking 100 meters; sitting for approximately 2 hours; getting up from a chair after sitting for long periods; climbing several flights of stairs without resting; climbing one flight of stairs without resting, stooping, kneeling or crouching; reaching or extending the arms above shoulder level; pulling or pushing large objects such as a living room chair; lifting or carrying weights over 10 pounds/5 kilos and picking up a small coin from a table\(^{25}\). For each item, the participant got 1 score when he/she reported being affected by function problem and 0 otherwise. Scores of all items were aggregated into one functional limitation score that ranges from 0 to 10, with a higher score for an individual representing more severe functional limitation he/she experienced. We calculated the scores for W1, W2, W4, W5 and W6 to track the status and changes of functional limitation for 10 years.

**Grip strength**

Baseline grip strengths of the interviewers were measured using a handheld
dynamometer (Smedley, S Dynamometer, TTM, Tokyo, 100 kilograms)\textsuperscript{26,27}. Respondents were instructed to stand (preferably) or sit to keep the upper arms tight against the trunk with their elbows at a 90° angle, and then squeeze the handles as hard as possible. Two values were recorded for each hand, expressed as kilogram. Measurements were defined valid when the values of two measurements in one hand that differed by less than 20 kilograms, and invalid if values were 0 or above 100 kilograms. The maximum value of four measurements was used in this study and will be referred as grip strength from this point\textsuperscript{26}. Based on the age- and sex-specific median for grip strength, participants were grouped as ‘low grip strength’ and ‘high grip strength’ (Supplementary Table S1).

**Cognitive function**

Baseline cognitive function was measured in 3 domains: memory, verbal fluency, and numeracy. Memory performance was assessed using the ten-word-list-learning test from a modified version of Rey’s Auditory Verbal Learning Test—RAVLT\textsuperscript{28}. In the test, participants were presented with ten common words and asked to recall the words immediately (immediate recall) and again five minutes later (delayed recall). The memory score was defined as the number of correct immediate and delayed recalls with a range from 0 to 20. Verbal fluency was measured by asking respondents to correctly name as many animals as possible, without repetitions or proper nouns during a one-minute period. It is a test for executive functioning and language ability\textsuperscript{29,30}. The participants got 1 point every time they
successfully name an animal. In the examination of numeracy ability, the respondent had to solve mathematical questions from daily life, varying from estimating simple mathematical relations to calculations of compound interest. The score ranged from 1 to 5. For each domain, the higher score indicates the better cognition. The global cognitive function was measured as the summation of memory, verbal fluency and numeracy scores. According to the official report of SHARE, we re-coded each of the cognitive measures to a binary variable with as close as possible to age- and sex-specific 7% lowest scoring as impaired (this approximates to 1.5 fold of standard deviations below the mean, a generally agreed criterion for relative cognitive impairment) (Supplementary Table S2) 27.

Other variables

Our covariates recorded in the baseline survey include country, age, gender, educational level, body mass index (BMI), physical activity, depression, cigarette smoking, alcohol drinking, heart attack, arthritis, hypertension, hypercholesterolemia, diabetes and osteoporosis 31. Based on the International Standard Classification of Education (ISCED 97) 32, educational level was categorized as: ‘primary level’ (ISCED 0–1), ‘lower secondary level’ (ISCED 2), ‘upper secondary level’ (ISCED 3–4) and ‘tertiary level’ (ISCED 5–6) 33. Physical activity was measured by asking how often the participant engages in the moderate and vigorous intensity of physical activity in their daily life and was classified as ‘inactive level’, ‘low active level’, ‘intermediate active level’ and ‘high active level’ 34. The depressive
symptom was estimated by the Euro-depression (EURO-D) scale with greater score denoting a higher level of depression. Cigarette smoking was categorized as ‘never’, ‘current’ or ‘former’. Alcohol drinking was grouped as ‘frequency more than the recommended level’ and ‘frequency no more than the recommended level’. Heart attack, arthritis, hypertension, hypercholesterolemia, diabetes, and osteoporosis were dichotomized as ‘no’ or ‘yes’ based on the answers for the questions of ‘Have you been diagnosed with these problems by a doctor?’.

**Statistical analysis**

Baseline characteristics of mean ± standard deviation and percentages were calculated. Variation of functional limitation score over time was assessed in univariate mixed-effect linear regression model. Mixed-effect linear regression models were conducted to explore the possible impacts of different baseline grip strength and cognition level on variations of functional limitation score. The time variable interacted with each of the main exposure variables, namely baseline grip strength, memory, verbal fluency, and numeracy. These main exposure variables were firstly introduced as quantitative variables in the models and then were entered as binary variables to visualize in the figures. When one of the main exposures was tested, variables such as age, gender, country, education, BMI, physical activity, smoking, alcohol drinking, EURO-D score, heart attack, arthritis, hypertension, hypercholesterolemia, diabetes, osteoporosis and the other main exposures were adjusted as covariates. To reduce
the possibility of reverse causation, we conducted the sensitivity analysis by excluding data from participants with myocardial infarction or coronary thrombosis or any other heart problem at baseline.

All the data were analyzed using STATA version 15 (Stata Corp LP, College Station, Texas, USA).

Results

As shown in Figure 1, a total of 14,073 participants were eligible for this study after filtering. The follow-up time ranged from 0.9 to 11.6 years. Table 1 summarized the baseline characteristics and five functional limitation scores of the sample. A univariate mixed-effect linear regression model with $\beta=0.051$ ($P<0.001$) for an annual increase of functional limitation demonstrated the trend of increments in functional limitation over time.

Table 2 displayed associations between baseline exposures and longitudinal functional limitation change, based on mixed-effect linear regression analyses with each exposure as a quantitative variable. Each exposure was identified to negatively interact with time, suggesting that higher grip strength ($\beta=-0.001$, $P<0.001$), numeracy ($\beta=-0.012$, $P<0.001$), verbal fluency ($\beta=-0.003$, $P<0.001$) or word recall ($\beta=-0.006$, $P<0.001$) at baseline was associated with a significantly slower increase over time in the functional limitation.

Figure 2 depicted predictive margins of functional limitation from the mixed-effect linear regression models with exposure variables as the pre-set binary values, which focused on
differences in the predicted slopes. Supplementary Table S3 listed the interaction terms between each wave and time for each exposure. Functional limitation score increased significantly faster in participants with low grip strength than those with high grip strength during the follow-up period. Compared to the participants with normal cognitive measures, including memory, verbal fluency, and numeracy, participants with cognitive impairment had faster increasing rates of functional limitation. Sensitivity analysis excluding participants who reported cardiovascular diseases at baseline yielded similar results to the primary analyses (Supplementary Table S4).

**Discussion**

The main finding of this study is that low baseline grip strength and cognitive measures have longitudinal associations with the risk of functional limitation among the European older adults.

Our finding on grip strength as a predictor of functional limitation draws a similar conclusion with previous studies from different populations.\(^{15,37}\). A 2-year follow-up investigation reported that participants with low grip strength had higher risk (adjusted OR: 2.05, 95% CI: 1.08 to 3.91) of functional limitation compared with those individuals with high grip strength among Japanese older women.\(^{37}\). Another large-scale prospective occupational cohort study, with individuals from the Honolulu Heart Program and the Honolulu-Asia Aging Study among 8,006 initially healthy men whose age ranges from 45 to
68 years, showed that baseline grip strength predicted functional limitation and disability 25 years later after correcting for cofounders\textsuperscript{15}. This study provides evidence to demonstrate that the longitudinal association between grip strength and functional limitation also exists in Europeans. Grip strength can approximately represent total body muscle strength because of correlation with the strength of other muscle groups\textsuperscript{38}. It also can be an overall indication of the integrity of the central nervous system\textsuperscript{39}. Low grip strength may indicate sarcopenia or central nervous system damage, which accelerates the functional limitation.

We also found the benefits of good baseline cognitive measures on the trajectory of functional limitation over time. There were only few studies focused on cognitive function and functional limitation. However, several analogous observations supported our findings. For example, a 2-year cohort study among older Japanese identified a significant correlation between lower Mini-Mental State Examination (MMSE) scores and an increased OR for functional decline\textsuperscript{40}. Another longitudinal study involving 977 community-dwelling people aged 65 and older reported that the rate of change in disability scores was affected by cognitive function\textsuperscript{41}. A randomized controlled trial (single-blind) with 5-year follow-up showed the evidence that reasoning training (one of the cognitive training) could slow down the functional decline in self-reported instrumental activities of daily life\textsuperscript{42}. A latest meta-analysis showed cognitive training interventions could improve function-related outcomes, especially physical function requiring higher-order executive functions\textsuperscript{43}. The
mechanisms underlying the relationship between cognitive function and functional limitation are not clear. At the simplest level, the execution of the physical task involves the sensorimotor nervous system and requires information processing and attention. A study using functional magnetic resonance imaging found an increased cognitive monitoring for movement in old than in young people\textsuperscript{44}, which indicates that cognitive function plays a vital role in functional limitation with ageing.

Our research provided evidence that maintaining the grip strength and optimizing mental capacity might forestall functional decline. Previous studies showed that functional decline is one of the prerequisites for several adverse health outcomes such as dementia\textsuperscript{7,45}. Thus, it is suggestive that using physical and cognitive training in older adults can potentially slow down functional decline and further prevent the incidence of adverse health outcomes.

A major strength of this study was a large number of participants from a long-term prospective study, which gave our statistical analysis sufficient power to conclude. Grip strength was objectively assessed by using validated methods, trained staff, and standard operating procedures. Functional limitation was comprehensively evaluated including gait, balance, arm function and fine motor. There were also some limitations to be considered. First, longitudinal data are often incomplete or unbalanced because of loss to follow-up. Previous studies reported that attrition in the longitudinal survey was more complicated than often assumed and it may not inevitably indicate bias and limit the generalizability of
longitudinal comparisons. In our research, we applied mixed-effect linear regression models which provided appropriate techniques for managing such a challenge. Mixed-effect linear regression models can deal with unbalanced or incomplete data under the assumption that observations are “missing at random”. The estimation based on either maximum likelihood or restricted maximum likelihood techniques use all available data. Thus, one neither must throw away a subject that has a missing observation nor to impute the missing observations. Second, walking speed, a measure of functional limitation, was not included in our models since it is unavailable in the questionnaire.

In conclusion, the present findings corroborated the notion that higher baseline grip strength and cognition predicted slower increase of functional limitation over time among older adults. Grip strength and cognitive function appeared to be a useful indicator of the functional limitation process and attested to their value in monitoring functional change over time. The current study could be beneficial in ways of both identifying individuals with a high risk of suffering from functional limitation and improving their life quality.

Acknowledgments:

Financial Disclosure:

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Conflict of Interest:

The authors declared no conflicts of interest with respect to the authorship or publication of this article.

Author Contributions:

Y.W., Q.T, D.Z. and T.W. conceptualized and designed this work. T.W., Y.W., W.L. and S.L. acquired, analyzed and interpreted the data. Y.W., T.W., W.L., S.L., Y.S., S.L., D.Z., Q.T. prepared manuscript and figures.

Sponsor’s Role: None.

Reference


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33. d'Uva TB, O'Donnell O, van Doorslaer E. Differential health reporting by education level and its impact on the measurement of health inequalities among older Europeans.


Legends:

Figure 1 Participants’ flow in the study

Figure 2 (a) Mixed-effect linear regression examining the association of baseline grip strength with five visits scores of functional limitation; (b) Mixed-effect linear regression examining the association of baseline numeracy with five visits scores of functional limitation; (c) Mixed-effect linear regression examining the association of baseline verbal fluency with five visits scores of functional limitation; (d) Mixed-effect linear regression examining the association of baseline word recall with five visits scores of functional limitation

Supporting Information

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

Table S1. Cut-off points for age and sex-specific binary grip strength

Table S2. Cut-off points for age and sex-specific binary cognitive function

Table S3. Fully Adjusted, Mixed-Effect Linear Regression Examining the Associations of Baseline Binary Cognitive Variables and Grip Strength with Five Visits Scores of Functional limitation
Table S4. The Associations of Baseline Grip Strength and Cognitive Function with Five Visits Scores of Functional limitation: Comparing Primary Analysis and Sensitivity Analysis
<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, mean ± SD (n=14,073)</td>
<td>63.5±9.9</td>
</tr>
<tr>
<td>Female, % (n=14,073)</td>
<td>52.5</td>
</tr>
<tr>
<td>Country, %(n=14,073)</td>
<td></td>
</tr>
<tr>
<td>Austria</td>
<td>5.5</td>
</tr>
<tr>
<td>Germany</td>
<td>7.3</td>
</tr>
<tr>
<td>Sweden</td>
<td>10.5</td>
</tr>
<tr>
<td>Netherlands</td>
<td>9.2</td>
</tr>
<tr>
<td>Spain</td>
<td>8.3</td>
</tr>
<tr>
<td>Italy</td>
<td>8.2</td>
</tr>
<tr>
<td>France</td>
<td>10.1</td>
</tr>
<tr>
<td>Denmark</td>
<td>5.9</td>
</tr>
<tr>
<td>Greece</td>
<td>11.6</td>
</tr>
<tr>
<td>Switzerland</td>
<td>3.4</td>
</tr>
<tr>
<td>Belgium</td>
<td>12.0</td>
</tr>
<tr>
<td>Israel</td>
<td>8.0</td>
</tr>
<tr>
<td>Education, % (n=13,940)</td>
<td></td>
</tr>
<tr>
<td>Primary</td>
<td>33.4</td>
</tr>
<tr>
<td>Lower secondary</td>
<td>17.1</td>
</tr>
<tr>
<td>Upper secondary</td>
<td>29.5</td>
</tr>
<tr>
<td>Tertiary</td>
<td>20.0</td>
</tr>
<tr>
<td>Smoking, % (n=14,035)</td>
<td></td>
</tr>
<tr>
<td>Never</td>
<td>51.4</td>
</tr>
<tr>
<td>Former</td>
<td>28.8</td>
</tr>
<tr>
<td>Current</td>
<td>19.8</td>
</tr>
<tr>
<td>Alcohol drinking, % (n=14,019)</td>
<td></td>
</tr>
<tr>
<td>Frequency more than recommended level</td>
<td>13.1</td>
</tr>
<tr>
<td>BMI, mean ± SD (n=13,818)</td>
<td>26.5±4.3</td>
</tr>
<tr>
<td>Physical activity, % (n=14,030)</td>
<td></td>
</tr>
<tr>
<td>Inactive</td>
<td>8.3</td>
</tr>
<tr>
<td>Low active</td>
<td>40.9</td>
</tr>
<tr>
<td>Intermediate active</td>
<td>16.4</td>
</tr>
<tr>
<td>High active</td>
<td>34.4</td>
</tr>
<tr>
<td>EURO-D Score, mean ± SD (n=13,840)</td>
<td>2.2±2.2</td>
</tr>
<tr>
<td>Heart attack, % (n=14,030)</td>
<td>11.1</td>
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<tr>
<td>Arthritis, % (n=14,030)</td>
<td>18.6</td>
</tr>
<tr>
<td>Hypertension, % (n=14,030)</td>
<td>30.8</td>
</tr>
<tr>
<td>Hypercholesterolemia, % (n=14,030)</td>
<td>20.6</td>
</tr>
<tr>
<td>Diabetes, % (n=14,030)</td>
<td>9.3</td>
</tr>
<tr>
<td>Osteoporosis, % (n=14,030)</td>
<td>7.0</td>
</tr>
<tr>
<td>Grip strength, mean ± SD (n=13,265)</td>
<td>35.0±12.5</td>
</tr>
<tr>
<td>Cognitive function, mean ± SD</td>
<td></td>
</tr>
<tr>
<td>Numeracy (n=14,007)</td>
<td>3.4±1.1</td>
</tr>
<tr>
<td>Verbal Fluency (n=13,875)</td>
<td>19.1±7.2</td>
</tr>
<tr>
<td>Word Recall (n=13,926)</td>
<td>8.3±3.4</td>
</tr>
<tr>
<td>Cognitive impairment, %</td>
<td>Impaired Numeracy</td>
</tr>
<tr>
<td>Functional limitation, %</td>
<td>Wave1 (n=14,033)</td>
</tr>
<tr>
<td>--------------------------</td>
<td>------------------</td>
</tr>
<tr>
<td>Impaired Verbal Fluency</td>
<td>7.7</td>
</tr>
<tr>
<td>Impaired Word Recall</td>
<td>7.3</td>
</tr>
</tbody>
</table>

BMI, body mass index; SD, standard deviation
Table 2 Fully Adjusted, Mixed-Effect Linear Regression Examining the Associations of Baseline Cognitive Function and Grip Strength with Five Visits Scores of Functional limitation

<table>
<thead>
<tr>
<th>Variables</th>
<th>Functional limitation&lt;sup&gt;a&lt;/sup&gt;</th>
<th>( \beta \pm SE(\beta) )</th>
<th>( P )</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Grip strength</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grip strength</td>
<td>-0.022 ± 0.002</td>
<td>(&lt;0.001)</td>
<td></td>
</tr>
<tr>
<td>Time</td>
<td>0.097 ± 0.006</td>
<td>(&lt;0.001)</td>
<td></td>
</tr>
<tr>
<td>Time x Grip strength</td>
<td>-0.001 ± 0.000</td>
<td>(&lt;0.001)</td>
<td></td>
</tr>
<tr>
<td><strong>Cognitive function</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Numeracy</td>
<td>-0.006 ± 0.013</td>
<td>0.621</td>
<td></td>
</tr>
<tr>
<td>Time</td>
<td>0.098 ± 0.007</td>
<td>(&lt;0.001)</td>
<td></td>
</tr>
<tr>
<td>Time x Numeracy</td>
<td>-0.012 ± 0.002</td>
<td>(&lt;0.001)</td>
<td></td>
</tr>
<tr>
<td>Verbal Fluency</td>
<td>-0.002 ± 0.002</td>
<td>0.244</td>
<td></td>
</tr>
<tr>
<td>Time</td>
<td>0.113 ± 0.006</td>
<td>(&lt;0.001)</td>
<td></td>
</tr>
<tr>
<td>Time x Verbal Fluency</td>
<td>-0.003 ± 0.000</td>
<td>(&lt;0.001)</td>
<td></td>
</tr>
<tr>
<td>Word Recall</td>
<td>0.008 ± 0.004</td>
<td>0.075</td>
<td></td>
</tr>
<tr>
<td>Time</td>
<td>0.107 ± 0.006</td>
<td>(&lt;0.001)</td>
<td></td>
</tr>
<tr>
<td>Time x Word Recall</td>
<td>-0.006 ± 0.001</td>
<td>(&lt;0.001)</td>
<td></td>
</tr>
</tbody>
</table>

Bold for \( P<0.05 \).

\( \beta \) beta coefficient, \( SE \) standard error,

<sup>a</sup> Models were adjusted for age, gender, country, education, BMI, physical activity, smoking, alcohol drinking, EURO-D score, grip strength, heart attack, arthritis, hypertension, hypercholesterolemia, diabetes, osteoporosis and other main exposures.
Participants of SHARE Wave 1
N = 30,434

N = 1,192 excluded
Younger than 50-year-old at baseline

N = 4,983 excluded
Did not participate in any of the following surveys

N = 24,259

Excluded – had disease of interest at any wave
Cancer: N = 2,485
Parkinson disease: N = 458
Stroke: N = 2,072
Fracture (hip or femoral): N = 1,210
Alzheimer's disease: N = 1,115

N = 18,247

N = 4,174 excluded
Share same household as primary respondents

Final sample
N = 14,073
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