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Non-completion of handgrip strength testing and incident disability in older adults: a three-cohort longitudinal analysis

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Abstract

Background: Handgrip strength is widely used to assess vulnerability in older adults, but some people do not complete testing. The prognostic meaning of this result, particularly relative to low measured strength, is uncertain. We examined its association with incident disability across three ageing cohorts.

Methods: We analysed adults aged 60 years or older in the China Health and Retirement Longitudinal Study (CHARLS), Health and Retirement Study (HRS) and Survey of Health,

Ageing and Retirement in Europe (SHARE). The primary outcome was incident activities of daily living (ADL) disability. Participants were classified as completers with non-low handgrip strength, completers with low handgrip strength (at or below the cohort-, sex- and wave-specific 20th percentile), or non-completers. Cohort-specific Cox estimates were pooled using random effects. Analyses addressed competing death, missing covariates, repeated assessments, event timing, loss of observation and baseline stroke-related diagnoses. Secondary analyses examined instrumental activities of daily living (IADL) disability, mortality and sample-standardized absolute risks.

Results: The primary ADL analysis included 79,284 participants, 4,020 non-completers and 16,410 events. Relative to completers with non-low handgrip strength, pooled hazard ratios were 1.43 (95% confidence interval, 1.23–1.66) for low handgrip strength and 1.53 (1.11–2.10) for non-completion. After excluding positive or unknown baseline stroke-related records, the non-completion estimate was 1.52 (1.12–2.05). The direct comparison of non-completion with low handgrip strength gave a hazard ratio of 1.07 (0.87–1.32). For non-completion, estimates relative to non-low handgrip strength were 1.60 (1.39–1.83) in wave-updated first-event models and 1.62 (1.07–2.46) after observation weighting. Model-based five-year ADL risk differences were 12.0, 6.3 and 4.8 percentage points in CHARLS, HRS and SHARE, respectively. Estimates following later event-free visits were imprecise. Comparisons with low handgrip strength remained uncertain at alternative thresholds. IADL disability and mortality estimates were heterogeneous.

Conclusions: Non-completion of handgrip strength testing was associated with incident ADL disability relative to non-low handgrip strength, with uncertain risk relative to low handgrip strength. Recording non-completion and its reasons may inform functional assessment. Added predictive value and benefits of a targeted clinical response require evaluation.

Keywords: handgrip strength; test non-completion; activities of daily living; disability; ageing cohorts; longitudinal analysis

Background

Handgrip dynamometry is an inexpensive and portable assessment of muscle strength, a central component of sarcopenia and muscle health [1,2]. Longitudinal evidence links low handgrip strength to subsequent activities of daily living (ADL) and instrumental activities of daily living (IADL) dependency [3], disability and mortality [4,5,6]. Individual cohorts have linked low measured strength with incident ADL limitations [7,8], and repeated measurements suggest that changes in strength accompany the disabling process [9]. Recent China Health and Retirement Longitudinal Study (CHARLS) research also associated stronger measured handgrip strength with fewer reported falls, although the cross-sectional design left temporal ordering unresolved [10]. Together, these findings support the use of measured strength to inform assessment of an older person's functional vulnerability.

Evidence based on measured handgrip strength is conditional on test completion. A previous analysis of CHARLS, the Health and Retirement Study (HRS) and the Survey of Health, Ageing and Retirement in Europe (SHARE) linked measured handgrip strength with incident stroke but excluded participants without successful baseline handgrip measurements [11]. Non-completion has also been evaluated directly. Huang and colleagues compared inability to complete physical tests with both the poorest performers and other completers in CHARLS; ADL and mortality estimates for handgrip strength testing were imprecise [12]. Liao and colleagues subsequently associated explicitly health/safety-related non-completion of balance, gait-speed or chair-stand tests with ADL disability and mortality in CHARLS, with functional-outcome replication using balance, chair-stand and handgrip tests in the English Longitudinal Study of Ageing (ELSA)

[13]. These findings support considering the assessment process alongside measured performance.

When a handgrip strength test is not completed, its interpretation relative to a low measured result remains uncertain. A completion flag without comparable reason-specific information may identify a different population from documented health/safety-related non-completion. We analysed adults aged 60 years or older in CHARLS, HRS and SHARE. We compared recorded non-completion with both non-low and low measured handgrip strength for incident ADL disability and quantified cohort-specific five-year absolute risks. Repeated assessments and sensitivity analyses examined the temporal context and robustness of these associations. Secondary outcomes were incident IADL disability and all-cause mortality.

Methods

Study design and participants

We conducted a longitudinal analysis of three population-based ageing cohorts: HRS in the United States [14], SHARE in Europe and Israel [15], and CHARLS in China [16]. Analyses used harmonised cohort data [17–26]. The available interviews covered CHARLS Waves 1–5 (2011–2020), HRS Waves 5–15 (2000–2021), and SHARE Waves 1, 2 and 4–8 (2004–2020). Handgrip assessment status was available in CHARLS Waves 1–3, HRS Waves 7–14 and all seven included SHARE waves; subsequent outcome assessments contributed to follow-up (Figure 1). Survey participation and retention in SHARE have been described elsewhere [27]. Participants entered the study at their first interview at age 60 years or older with classifiable handgrip assessment status. The primary analysis included participants without ADL disability at baseline who had positive follow-up time to a subsequent ADL assessment or a known death and complete core covariate data. A known death could contribute follow-up even when no

subsequent ADL assessment was available. All eligible records were included; no prospective sample-size calculation was performed. The participant selection process is shown in Supplementary Figure 1.

Handgrip strength testing

Handgrip strength was the maximum valid measurement from either hand. Values greater than 0 and no greater than 100 kg were accepted. Participants with a valid measurement were classified as test completers. Among those without a valid measurement, a harmonised completion indicator of 0 defined test non-completion; participants in this category are termed non-completers. Other missing assessments remained unclassifiable. HRS proxy interviews were excluded from both classifications. Comparable proxy indicators were unavailable in CHARLS and SHARE, and structurally unavailable handgrip assessments were excluded from classification. The harmonised files lacked comparable reasons for non-completion, so recorded non-completion did not distinguish inability to complete the test from other reasons. Completers were classified as having low or non-low handgrip strength using the cohort-, sex- and wave-specific 20th percentile (P20). Low handgrip strength was defined as a value at or below P20, with ties retained. Baseline cutoffs were estimated among first-assessment completers; wave-updated cutoffs were estimated separately from all eligible repeated assessments. These categories represented relative handgrip strength within each cohort rather than clinical sarcopenia thresholds. Threshold estimation is described in Supplementary Methods (Additional file 1).

Assessment of disability and mortality

The primary outcome was first recorded ADL disability after baseline. ADL disability was defined as difficulty with at least one of five activities: dressing, bathing, eating, getting in or out

of bed, and toileting. Secondary outcomes were incident IADL disability and all-cause mortality. IADL disability was defined using four activities: money management, medication use, shopping and meal preparation. Each disability measure required valid binary responses to all component items; otherwise, outcome status was missing. Incident disability analyses included participants free of the corresponding disability at baseline. Outcome interviews were not otherwise restricted by proxy status.

Disability follow-up began at baseline and ended at the first positive assessment, death or the last valid outcome assessment. Disability recorded at or before death was counted as an event; death preceding recorded disability was a competing event. In mortality analyses, participants without a recorded death were censored at their last contact. Death dates were obtained from harmonised year and month fields. Follow-up and event-time sensitivity analyses are described in Supplementary Methods. Because disability was assessed at intermittent interviews, the endpoint represented the first observed post-baseline episode rather than its exact onset or a confirmed lifetime first episode.

Covariates

Covariates were selected to account for demographic, socioeconomic, behavioural and baseline health differences related to both handgrip assessment and disability. Core models included age, sex, education in three categories, ever smoking and the number of reported diagnoses of hypertension, diabetes, cancer, chronic lung disease, heart disease, stroke and arthritis. The diagnosis count required valid responses for at least five of the seven conditions; missing items were not treated as negative responses. ADL models additionally included baseline IADL status, IADL models included baseline ADL status, and mortality models included both. Extended models added body mass index (BMI), memory and orientation. Age and BMI were modelled

using natural cubic splines with 3 degrees of freedom. Covariate definitions and measurement availability are described in Supplementary Methods.

Statistical analysis

We estimated hazard ratios (HRs) and 95% confidence intervals (CIs) using cohort-specific cause-specific Cox models. Core-adjusted complete-case models were the primary analyses, with non-low handgrip strength as the reference and a direct comparison of non-completion with low handgrip strength. Models were stratified by assessment wave and, in SHARE, jointly by wave and country. We assessed the proportional hazards (PH) assumption using Schoenfeld-residual tests for the overall handgrip group term. Cohort-specific log HRs were pooled using restricted maximum likelihood (REML) random-effects meta-analysis with modified Hartung–Knapp intervals [28]. Cohort estimates and I^2 accompany pooled estimates because only three cohorts were available.

We examined competing mortality using Fine–Gray models and an ADL-or-death composite endpoint [29]. Missing covariates were addressed in extended sensitivity models using multiple imputation by chained equations (MICE; 20 datasets and 20 iterations per cohort) [30,31,32]. Imputation models included exposure, covariates, design factors, event indicators and cumulative hazards for ADL and death. Only covariates were imputed, and estimates were combined using Rubin's rules before meta-analysis. Specifications and diagnostics are provided in Supplementary Methods and Supplementary Results (Additional file 1).

Wave-updated start–stop Cox models used attained age as the time scale and participant-clustered standard errors. Each eligible ADL-free handgrip assessment initiated an interval ending at the next ADL assessment or an earlier death. All available ADL observations identified the first event, irrespective of handgrip data availability; participants could not re-enter after

disability. Handgrip assessment status and covariates were updated at interval entry, and SHARE models were stratified by country. Completion-history analyses used prior assessments only to distinguish first non-completion, repeated non-completion and completion after non-completion, relative to completion with no prior recorded non-completion.

We assessed event-time uncertainty using midpoint dating between the last negative and first positive interview, Weibull interval-censored models, and exclusion of records with ambiguous ADL/death ordering. The interval-censored models treated death as censoring at death or at the last ADL-negative visit. Separate Cox models estimated associations during 0–2, 2–5 and more than 5 years under first-positive and midpoint dating.

Landmark analyses began at the first observed ADL-negative visit at or after one or two years, among participants with no earlier event and subsequent follow-up. Baseline handgrip assessment status and covariates were retained, age was advanced and follow-up reset. These analyses concerned observed event-free survivors. We also restricted the primary analysis to five years of follow-up.

We estimated five-year ADL risk accounting for competing death using separate piecewise-exponential models for ADL and death over 0–2 and 2–5 years [33]. Models included interactions between handgrip group and follow-up period. Predicted risks were standardized to the same complete-case covariate distribution within each cohort. Delta-method CIs incorporated joint participant-clustered covariance across causes, conditional on that sample. Observed-group predictions were compared with Aalen–Johansen cumulative incidence estimates [34]. Model specifications, calculations and support diagnostics are provided in Additional file 1.

We assessed sensitivity to loss of observation using inverse probability of censoring weighting (IPCW) [35]. Follow-up stopped at the first missed eligible ADL assessment; later returns were

185 excluded and earlier known deaths remained competing events. Pooled logistic models estimated
186 stabilized observation weights. Weighted Cox models using untruncated weights or truncation at
187 the 1st/99th or 5th/95th percentiles were compared with an unweighted model on the same
188 retained intervals. Standard errors were conditional on the fitted weights.
189 Alternative exposure analyses used the cohort-, sex- and wave-specific 10th, 20th and 30th
190 percentiles while holding participants and outcomes fixed. A two-part model combined a natural
191 cubic spline for measured handgrip strength, standardized within cohort and sex, with a separate
192 non-completion indicator. No handgrip value was imputed for non-completers. These
193 exploratory analyses assessed sensitivity to the exposure definition; they did not identify an
194 optimal clinical threshold.
195 We evaluated sensitivity to baseline stroke-related diagnoses using the recorded stroke indicator
196 from each participant's handgrip baseline wave. Among participants with a valid yes/no
197 indicator, we compared the core model with a model additionally adjusting for that indicator. We
198 also repeated the core model among participants with a negative baseline record, excluding
199 positive and unknown records. Original handgrip categories and P20 thresholds, follow-up
200 definitions and the chronic-condition count were retained. Cohort-specific diagnostic definitions
201 and measurement limitations are described in Supplementary Methods.
202 Descriptive summaries and primary models were unweighted and did not incorporate the survey
203 sampling strata or sampling-unit corrections. IPCW addressed observation loss only; estimates
204 apply to the analysed samples. We report two-sided 95% CIs and P values without adjustment
205 for multiple comparisons. No formal subgroup or contrast-by-time interaction tests were
206 performed; interactions between handgrip group and follow-up period were included only in the
207 absolute-risk models. Analyses used R 4.5.2 and Python; package versions and computational

details are provided in Supplementary Methods. Reporting followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement [36].

OpenAI Codex (OpenAI) was used to assist with literature retrieval, checking of analysis code and numerical consistency, and drafting and revision of the manuscript. Its outputs were checked against source publications and saved analysis results. The authors retain responsibility for the analyses and interpretation.

Ethics

The original cohort studies obtained ethical approval and informed consent. This study analysed de-identified data under the respective cohort data-use agreements, without new participant recruitment, contact or data collection. Approval details are provided in the Declarations.

Results

Participant characteristics

Of 199,245 source participants, 131,178 had a classifiable first handgrip assessment at age 60 years or older: 10,614 in CHARLS, 18,780 in HRS and 101,784 in SHARE. The primary ADL analysis included 79,284 participants, comprising 7,590 in CHARLS, 14,197 in HRS and 57,497 in SHARE. Of the 10,307 non-completers in the initial exposure cohort, 4,020 entered the primary analysis: 106, 545 and 3,369 in the respective cohorts. Compared with completers with non-low handgrip strength, non-completers were older, were more often women and had more baseline IADL difficulty (Table 1). Participant selection, cohort-specific characteristics and handgrip strength thresholds are presented in Supplementary Figure 1 and Supplementary Tables S1–S2. The handgrip group distribution in the larger exposure cohort is shown in Supplementary Figure 2.

Table 1. Characteristics of the primary ADL complete-case population at baseline.

Characteristic	Non-low handgrip strength	Low handgrip strength	Non-completers
Participants	61193	14071	4020
Age, years	66.8 (6.5)	73.1 (8.6)	70.9 (8.6)
Women	32547/61193 (53.2%)	7598/14071 (54.0%)	2475/4020 (61.6%)
Education			
Lower category	25528/61193 (41.7%)	8276/14071 (58.8%)	2143/4020 (53.3%)
Middle category	23131/61193 (37.8%)	4001/14071 (28.4%)	1320/4020 (32.8%)
Upper category	12534/61193 (20.5%)	1794/14071 (12.7%)	557/4020 (13.9%)
Ever smoked	29833/61193 (48.8%)	5846/14071 (41.5%)	1535/4020 (38.2%)
Reported chronic diagnoses	1.2 (1.1)	1.5 (1.2)	1.4 (1.2)
Baseline IADL difficulty	2411/61193 (3.9%)	1672/14071 (11.9%)	543/4020 (13.5%)
Maximum handgrip strength, kg	35.4 (10.3)	21.6 (7.0)	Not measured
Observed follow-up, years	6.33 (3.83–8.83)	4.50 (2.33–7.50)	4.50 (2.25–8.17)
Cohort			
CHARLS	6167/61193 (10.1%)	1317/14071 (9.4%)	106/4020 (2.6%)
HRS	11374/61193 (18.6%)	2278/14071 (16.2%)	545/4020 (13.6%)
SHARE	43652/61193 (71.3%)	10476/14071 (74.5%)	3369/4020 (83.8%)

Values are unweighted mean (standard deviation [SD]), median (interquartile range [IQR]), or n/N (%). All participants were ADL-free at baseline and complete for core covariates. Handgrip strength values describe test completers only. Follow-up is observed time to first ADL, death or censoring, not reverse Kaplan–Meier follow-up. Non-completion was defined from the harmonised completion indicator when no valid handgrip measurement was available; reason-specific fields were unavailable. Low handgrip strength means ≤P20, including ties. Education categories are defined in Supplementary Methods.

Handgrip assessment groups and incident ADL disability

Among the 79,284 participants in the primary analysis, 16,410 developed ADL disability. Non-completion was associated with a higher hazard of ADL disability than non-low handgrip strength in CHARLS (HR 1.49, 95% CI 1.14–1.94), HRS (1.37, 1.19–1.57) and SHARE (1.68, 1.56–1.81). The pooled HR was 1.53 (1.11–2.10; I^2=70.5%). Low handgrip strength was also

associated with ADL disability relative to non-low handgrip strength (1.43, 1.23–1.66; I^2=60.5%). In the direct comparison between non-completers and completers with low handgrip strength, the pooled HR was 1.07 (0.87–1.32; I^2=13.4%), providing no clear evidence of a difference (Tables 2–3; Figure 2). Unadjusted, design-stratified and extended ADL models are reported in Supplementary Table S3; secondary-outcome models are reported in Supplementary Table S4.

Table 2. Handgrip group and incident ADL disability in the core complete-case analysis.

Cohort	N / events	Low vs non-low	Non-completion vs non-low	Non-completion vs low	Overall PH P
CHARLS	7590 / 2808	1.35 (1.23-1.48)	1.49 (1.14-1.94)	1.10 (0.84-1.45)	0.242
HRS	14197 / 4065	1.40 (1.29-1.52)	1.37 (1.19-1.57)	0.98 (0.84-1.14)	0.001
SHARE	57497 / 9537	1.51 (1.43-1.58)	1.68 (1.56-1.81)	1.12 (1.03-1.21)	0.029

HRs with 95% CIs. Models adjust for age, sex, education, ever smoking, chronic-condition count and baseline IADL, with wave strata and country strata in SHARE. Cohort estimates are shown here; pooled estimates are reported in Table 3. Group counts are in Supplementary Table S1. The final column gives the overall handgrip group proportional-hazards (PH) test, with contrast-specific time interactions outside its scope.

IADL disability and mortality

For incident IADL disability, the pooled HR was 1.51 (95% CI 1.27–1.80) for low versus non-low handgrip strength, 1.43 (0.80–2.54) for non-completion versus non-low handgrip strength, and 0.96 (0.63–1.47) for non-completion versus low handgrip strength. The corresponding mortality HRs were 1.47 (1.19–1.81), 1.62 (0.82–3.22) and 1.09 (0.65–1.85). Associations of non-completion with IADL disability and mortality varied across cohorts, and the pooled CIs included 1.0 (Table 3; Figure 2).

Table 3. Pooled associations with ADL disability, IADL disability and all-cause mortality.

Outcome	N / events	Low vs non-low	Non-completion vs non-low	Non-completion vs low
Incident ADL disability	79284 / 16410	1.43 (1.23-1.66) I^2=60.5%; P=0.009	1.53 (1.11-2.10) I^2=70.5%; P=0.030	1.07 (0.87-1.32) I^2=13.4%; P=0.284
Incident IADL disability	80868 / 15231	1.51 (1.27-1.80) I^2=72.8%; P=0.009	1.43 (0.80-2.54) I^2=91.2%; P=0.116	0.96 (0.63-1.47) I^2=80.1%; P=0.720
All-cause mortality	92609 / 25937	1.47 (1.19-1.81) I^2=73.6%; P=0.015	1.62 (0.82-3.22) I^2=95.4%; P=0.094	1.09 (0.65-1.85) I^2=93.8%; P=0.535

Pooled hazard ratios use REML random effects with modified Hartung-Knapp 95% confidence intervals. Covariate adjustment is outcome-specific: incident ADL models include baseline IADL, incident IADL models include baseline ADL, and mortality models include both baseline ADL and IADL. I^2 denotes between-cohort heterogeneity. N and events refer to the complete-case population for each outcome; these populations are not interchangeable. P values are two-sided and refer to the pooled contrast; they are not adjusted for multiple comparisons.

Sensitivity analyses

The association between non-completion and ADL disability relative to non-low handgrip strength persisted in the extended multiple-imputation analysis (HR 1.48, 95% CI 1.22–1.80) and the Fine–Gray analysis (subdistribution HR 1.41, 1.09–1.81). The pooled HR was 1.45 (1.04–2.02) for ADL disability or death and 1.73 (1.44–2.07) when follow-up was restricted to five years. Direct comparisons with completers with low handgrip strength remained inconclusive (Table 4; Figure 3; Supplementary Tables S5–S8).

The wave-updated analysis included 79,862 participants, 162,627 intervals and 13,786 first ADL events. The pooled HR for non-completion was 1.60 (95% CI 1.39–1.83) relative to non-low handgrip strength and 1.25 (0.87–1.81) relative to low handgrip strength. Compared with completion without prior recorded non-completion, the HRs were 1.50 (1.13–1.98) for first non-

completion, 1.23 (0.88–1.72) for repeated non-completion, and 0.98 (0.80–1.20) for completion after non-completion (Supplementary Table S9; Supplementary Figure 3).

The overall handgrip group PH tests indicated departures from proportional hazards in HRS and SHARE. With events dated at the first positive interview, pooled HRs for non-completion versus non-low handgrip strength were 1.98 (95% CI 1.30–3.02) during 0–2 years, 1.59 (1.27–2.00) during 2–5 years and 1.29 (0.69–2.41) after five years. Midpoint dating gave corresponding HRs of 1.80 (1.44–2.25), 1.43 (0.89–2.31) and 1.32 (0.89–1.95). Both approaches showed an elevated hazard during the first two years; later estimates were less precise. Differences between periods were not formally tested (Supplementary Table S10; Supplementary Figure 4).

Covariate missingness by analysis population is reported in Supplementary Table S11. Imputation stability and the implications of structurally unavailable cognition are described in the Supplementary Results.

The median interval between the last ADL-negative and first ADL-positive interview was 2.00 years in CHARLS, 2.08 years in HRS and 2.42 years in SHARE. The pooled HR for non-completion versus non-low handgrip strength was 1.51 (95% CI 1.14–2.01) with midpoint dating and 1.50 (1.15–1.95) in the Weibull interval-censored model. Exclusion of records with ambiguous ADL/death ordering had little effect on the estimates (Supplementary Table S6). Sensitivity analyses for incomplete diagnosis items and missing death months are reported in Supplementary Table S12.

In landmark analyses, pooled HRs for non-completion versus non-low handgrip strength were 1.32 (95% CI 0.84–2.07) after the one-year threshold and 1.31 (0.78–2.18) after the two-year threshold. Median qualifying visits occurred 2.00–2.17 and 2.08–2.67 years after baseline,

respectively. Estimates in these selected event-free populations were imprecise (Supplementary Table S5).

Table 4. Sensitivity analyses for incident ADL disability.

Analysis	Non-completion vs non-low	Non-completion vs low
Extended MICE	1.48 (1.22–1.80); I^2=11.2%	1.04 (0.89–1.21); I^2=0.0%
Fine-Gray	1.41 (1.09-1.81); I^2=39.4%	1.08 (0.92-1.26); I^2=0.0%
ADL or death composite	1.45 (1.04-2.02); I^2=84.2%	1.02 (0.79-1.31); I^2=65.1%
Five-year horizon	1.73 (1.44-2.07); I^2=0.0%	1.13 (0.93-1.36); I^2=0.0%
Wave-updated first-ADL model	1.60 (1.39-1.83); I^2=0.0%	1.25 (0.87-1.81); I^2=71.5%
Interval-midpoint event date	1.51 (1.14-2.01); I^2=60.2%	1.08 (0.91-1.27); I^2=5.9%
Observed-visit landmark after 1 year	1.32 (0.84-2.07); I^2=70.9%	0.95 (0.61-1.47); I^2=63.9%
Observed-visit landmark after 2 years	1.31 (0.78-2.18); I^2=74.3%	0.96 (0.54-1.73); I^2=77.3%
Observation-process sample, unweighted	1.60 (1.07-2.40); I^2=78.9%	1.12 (0.87-1.45); I^2=26.0%
IPCW, 1st/99th truncation	1.62 (1.07-2.46); I^2=80.3%	1.13 (0.87-1.46); I^2=28.0%

Pooled estimates with 95% CIs and I^2. Fine-Gray estimates are subdistribution HRs; the composite includes death. Wave-updated models stop at first ADL. Observed-visit landmarks begin at an actual ADL-negative visit after the nominal threshold. IPCW and its unweighted comparator use the same monotone observation-process sample; they do not share the primary model denominator.

Five-year risk of ADL disability

Standardized five-year ADL risks for completers with non-low handgrip strength and non-completers were 22.8% and 34.8% in CHARLS, 15.6% and 22.0% in HRS, and 8.5% and 13.3% in SHARE, respectively. Risk differences per 1,000 participants were 119.6 (95% CI 41.9–197.3), 63.2 (29.1–97.3) and 48.2 (36.9–59.6). The CIs for risk differences between non-completers and completers with low handgrip strength included zero in all cohorts (Table 5; Figure 4). Comparisons with observed-group cumulative incidence are reported in Supplementary Table S13. These model-based estimates had limited support in some strata, particularly in CHARLS, with 106 non-completers, and in SHARE, where 811 of 57,497

standardization records had no non-completer in the same country-wave-sex stratum (Supplementary Results).

Table 5. Standardized five-year ADL risk accounting for competing death.

Cohort	Non-low risk, %	Low risk, %	Non-completion risk, %	Difference vs non-low, per 1000	Difference vs low, per 1000
CHARLS	22.8 (21.8-23.8)	29.6 (27.3-32.0)	34.8 (27.5-42.8)	119.6 (41.9-197.3)	51.3 (-28.3–130.9)
HRS	15.6 (14.9-16.4)	19.7 (18.1-21.4)	22.0 (18.8-25.5)	63.2 (29.1-97.3)	22.2 (-14.5–59.0)
SHARE	8.5 (8.2-8.8)	12.5 (11.9-13.2)	13.3 (12.2-14.4)	48.2 (36.9-59.6)	7.4 (-4.6–19.4)

Values are estimates with 95% CIs. Risks average predictions over the same complete-case covariate distribution within each cohort. The two cause-specific piecewise-exponential models include 0-2 and 2-5-year bands and interactions between handgrip group and follow-up period. Confidence intervals use joint participant-clustered covariance and the delta method, conditional on the empirical standardization population. The estimates describe adjusted risks within the analysis samples; population rates and causal effects require separate estimation. Differences were calculated from unrounded predictions and may differ slightly from subtraction of displayed rounded risks. Sparse support and model extrapolation are described in Supplementary Results.

Loss to follow-up and alternative handgrip definitions

Within the sample followed until the first missed ADL assessment, the pooled HR for non-completion versus non-low handgrip strength was 1.60 (95% CI 1.07–2.40) without weighting and 1.62 (1.07–2.46) after IPCW with 1st/99th percentile truncation. Estimates using untruncated weights and 5th/95th percentile truncation were 1.62 (1.07–2.47) and 1.62 (1.07–2.44), respectively. Thus, weighting for the measured predictors of observation produced little change in this sample. Population construction, associations and weight diagnostics are presented in Supplementary Figure 5, Supplementary Tables S14–S15 and Supplementary Figure 6.

Using the 10th, 20th or 30th percentile to define low handgrip strength yielded pooled HRs of 1.00 (95% CI 0.85–1.18), 1.07 (0.87–1.32) and 1.12 (0.89–1.40) for non-completion versus low handgrip strength. Each CI included 1.0. Non-completion remained associated with a higher hazard than non-low handgrip strength at all three thresholds (Supplementary Table S16; Supplementary Figure 7). The analyses of continuous handgrip strength showed a higher hazard of ADL disability at lower measured handgrip strength, with wider uncertainty at the extremes (Supplementary Figure 8).

Baseline stroke-related diagnoses

Baseline stroke-related records were positive for 3,292 participants and unknown for 8. Among the 79,276 participants with known status, the pooled HR for non-completion versus non-low handgrip strength was 1.53 (95% CI 1.11–2.10) both before and after adding the stroke indicator to the core model. Restriction to participants with negative baseline records retained 75,984 participants and 15,347 ADL events. The pooled HRs were 1.42 (1.21–1.65) for low versus non-low handgrip strength, 1.52 (1.12–2.05) for non-completion versus non-low handgrip strength, and 1.08 (0.91–1.28) for non-completion versus low handgrip strength (Supplementary Table S17).

Discussion

In three longitudinal cohorts of adults aged 60 years or older, non-completion of handgrip strength testing was associated with incident ADL disability relative to non-low measured strength (pooled HR 1.53). This finding extends the interpretation of physical assessment to participants without a recorded strength value. Stringa and colleagues linked higher measured handgrip strength to fewer functional limitations over long-term follow-up in the Longitudinal Ageing Study Amsterdam [37]. Evidence on non-completion addresses a complementary

question: Huang and colleagues examined inability to complete physical tests, with imprecise estimates for handgrip testing [12], whereas Liao and colleagues studied documented health/safety-related non-completion and included handgrip testing in their ELSA replication [13]. Our analysis adds a common comparison across CHARLS, HRS and SHARE, directly contrasts non-completion with low measured strength, and examines timing and absolute ADL risk. The distinction in exposure definition is consequential: our harmonised flag combines reasons that may carry different prognostic meanings. Some CHARLS participants may overlap with earlier studies, while HRS and SHARE provide evidence from additional populations. The association with non-low strength was evident, but the risk contrast with low strength remained uncertain.

Non-completion may capture vulnerability extending beyond muscle force. Weakness is one component of frailty [38], while obtaining a valid measurement also depends on the testing protocol and the participant's ability to engage with it [39]. Associations of measured handgrip strength with cognition, dementia and neuroimaging outcomes in UK Biobank further suggest that muscle and neurological health are closely related [40]. Potential contributors to non-completion include pain, neurological impairment, transient illness, refusal and procedural barriers, although their individual roles were not measured. Baseline stroke adjustment and restriction to participants with negative baseline records changed the association little, suggesting that recorded cerebrovascular disease alone did not account for the finding. The non-completion-versus-low-strength HR of 1.07 (95% CI 0.87–1.32), however, allowed differences in either direction. Similar uncertainty across the 10th-, 20th- and 30th-percentile definitions, alongside the continuous gradient among completers, suggests possible overlap in vulnerability without establishing equivalence between groups. Relative percentiles accommodate variation in

population strength distributions [41]; they serve a different purpose from clinical definitions such as those of the Sarcopenia Definition and Outcomes Consortium, which link measured weakness and slow gait to adverse outcomes [42]. Non-completion leaves strength magnitude and sarcopenia status unresolved.

The temporal findings place non-completion within a potentially changing course of functional health. Associations were elevated during the first two years under both first-positive and midpoint dating, and updated assessment status remained associated with subsequent ADL disability. First non-completion was associated with higher incidence, whereas intervals for repeated non-completion and return to completion included the null. In a cohort assessed monthly, Gill and colleagues linked hospitalisation and restricted activity to disability transitions and impaired recovery [43], providing a plausible context for temporary interruptions to testing. Our data did not measure these intervening events or formally compare periods and completion states; return to completion therefore leaves the possibility of recovery unresolved. The estimated five-year ADL risks among non-completers were 34.8%, 22.0% and 13.3% in CHARLS, HRS and SHARE, with excesses of 12.0, 6.3 and 4.8 percentage points over non-low strength. Each estimate was standardized within its own cohort. Differences in background health, environmental demands and assistance may influence the transition from impairment to reported disability [44], while measurement and selection may also contribute to variation across cohorts. These absolute risks describe the magnitude of the association in the analysed populations, rather than a common risk level for all non-completers.

The heterogeneous IADL and mortality findings, with pooled intervals including the null, leave generalisation beyond ADL uncertain. Deeg and colleagues found differing long-term trajectories of measured performance and self-reported disability in the Longitudinal Ageing

Study Amsterdam [45]. Kim and colleagues associated low measured handgrip strength with earlier IADL-onset patterns in the Korean Longitudinal Study of Ageing (KLoSA), although class assignment varied by model [46]. Differences in physical capacity, task demands and outcome measurement may help explain these functional patterns; our estimates do not establish specificity to ADL disability. Clinically, recorded non-completion could prompt clarification of its reason and review of current daily function, followed by assessment of relevant physical, cognitive and support needs, consistent with the World Health Organization (WHO) Integrated Care for Older People (ICOPE) approach [47]. Bernabei and colleagues showed that physical activity and nutritional counselling reduced mobility disability in ambulatory older adults with physical frailty, sarcopenia and Short Physical Performance Battery scores of 3–7 [48]. That trial supports the potential value of addressing functional vulnerability, but involved a different population and outcome. Whether non-completion adds useful information to existing functional assessments, and whether a response tailored to its cause improves ADL outcomes, require prospective evaluation.

Several limitations affect interpretation. Residual confounding and functional decline preceding baseline limit causal inference. The completion flag lacked comparable reason-specific information, and unclassifiable assessments could include further non-completers; explicit proxy exclusions were available only in HRS. Stroke indicators were self-reported, variably defined and potentially retrospectively corrected, without independent adjudication. Complete-case, imputed and observation-weighted analyses address selection under different assumptions. Imputation was approximate, with uncertain compatibility with nonlinear Cox terms and extrapolation for structurally unmeasured cognition; IPCW depends on measured predictors and correct response models, with uncertainty conditional on fitted weights. Intermittent interviews

and approximated dates limit onset resolution, death may conceal preceding disability, and repeated-testing and landmark analyses condition on survival and continued observation. Requiring complete chronic-condition items yielded similar estimates (Supplementary Tables S11–S12). Sparse covariate support, including only 106 CHARLS non-completers and SHARE strata without observed five-year ADL events, may make absolute-risk intervals overprecise. SHARE dominated the sample, and three cohorts provide limited information about heterogeneity. Estimates apply to the unweighted analysis samples and retain cohort-specific case mix; they do not represent national rates.

Conclusions

Non-completion of handgrip strength testing was associated with incident ADL disability relative to non-low handgrip strength in older adults from three longitudinal cohorts. Its risk relative to low handgrip strength remained uncertain. Recording non-completion, clarifying its reasons and assessing current daily function may help interpret an otherwise unavailable strength measurement. The incremental predictive value and benefits of a targeted clinical response remain to be established.

List of abbreviations

ADL: activities of daily living; BMI: body mass index; CHARLS: China Health and Retirement Longitudinal Study; CI: confidence interval; ELSA: English Longitudinal Study of Ageing; HR: hazard ratio; HRS: Health and Retirement Study; IADL: instrumental activities of daily living; ICOPE: Integrated Care for Older People; IPCW: inverse probability of censoring weighting; IQR: interquartile range; KLoSA: Korean Longitudinal Study of Ageing; MICE: multiple imputation by chained equations; P20: 20th percentile; PH: proportional hazards; REML: restricted maximum likelihood; SD: standard deviation; SHARE: Survey of Health, Ageing and

Retirement in Europe; STROBE: Strengthening the Reporting of Observational Studies in Epidemiology; WHO: World Health Organization.

Additional files

Additional file 1

File name: Additional_file_1.docx. File format: .docx. Title: Supplementary methods and results. Description: Supplementary Methods and Supplementary Results, 17 individually numbered Supplementary Tables S1–S17 and Supplementary Figures 1–8, including participant-selection and observation-process flow diagrams.

Declarations

Ethics approval and consent to participate

This study used de-identified data from CHARLS, HRS and SHARE under the respective cohort data-use agreements and involved no new participant recruitment, contact or data collection. The original cohorts obtained ethical approval and informed consent. CHARLS was approved by the Biomedical Ethics Review Committee of Peking University (IRB00001052-11015). HRS was approved by the University of Michigan Health Sciences and Behavioral Sciences Institutional Review Board (HUM00061128). SHARE Waves 1–4 were reviewed and approved by the Ethics Committee of the University of Mannheim; Wave 4 and the continuation of SHARE were reviewed and approved by the Ethics Council of the Max Planck Society, with additional national ethics review where required. The secondary analysis was conducted in accordance with the ethical principles of the Declaration of Helsinki.

Consent for publication

Not applicable.

Availability of data and materials

HRS public-use data are available to registered users through the HRS data portal [49]. SHARE Release 9.0.0 data for Waves 1, 2 and 4–8 [20–26] are available free of charge for scientific use to individually registered users through the SHARE Research Data Center [50], subject to the SHARE Conditions of Use. CHARLS data are available to registered users through the official CHARLS website [51]. No new primary data were generated. Source-cohort data cannot be redistributed by the authors. Harmonisation specifications and analysis code are available from the corresponding authors on reasonable request; access to any derived analytic dataset remains subject to the applicable source-cohort data-use agreements.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

ZY performed the data analyses and drafted the manuscript. YL, TL, LP and WR audited the data. SJ and ZW provided overall oversight and critically reviewed the manuscript. All authors read and approved the final manuscript and agreed to be accountable for all aspects of the work.

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Figure legends

Figure 1. Temporal structure of handgrip assessment and incident ADL follow-up.

Black nodes mark survey waves; coloured circles and squares indicate functional assessments with and without handgrip data, respectively. The diamond marks SHARE death records. Spacing is schematic. Baseline was the first classifiable handgrip assessment at age ≥60 years, without ADL disability. ADL, activities of daily living; IADL, instrumental activities of daily living.

Figure 2. Non-completion of handgrip strength testing, low handgrip strength and subsequent outcomes.

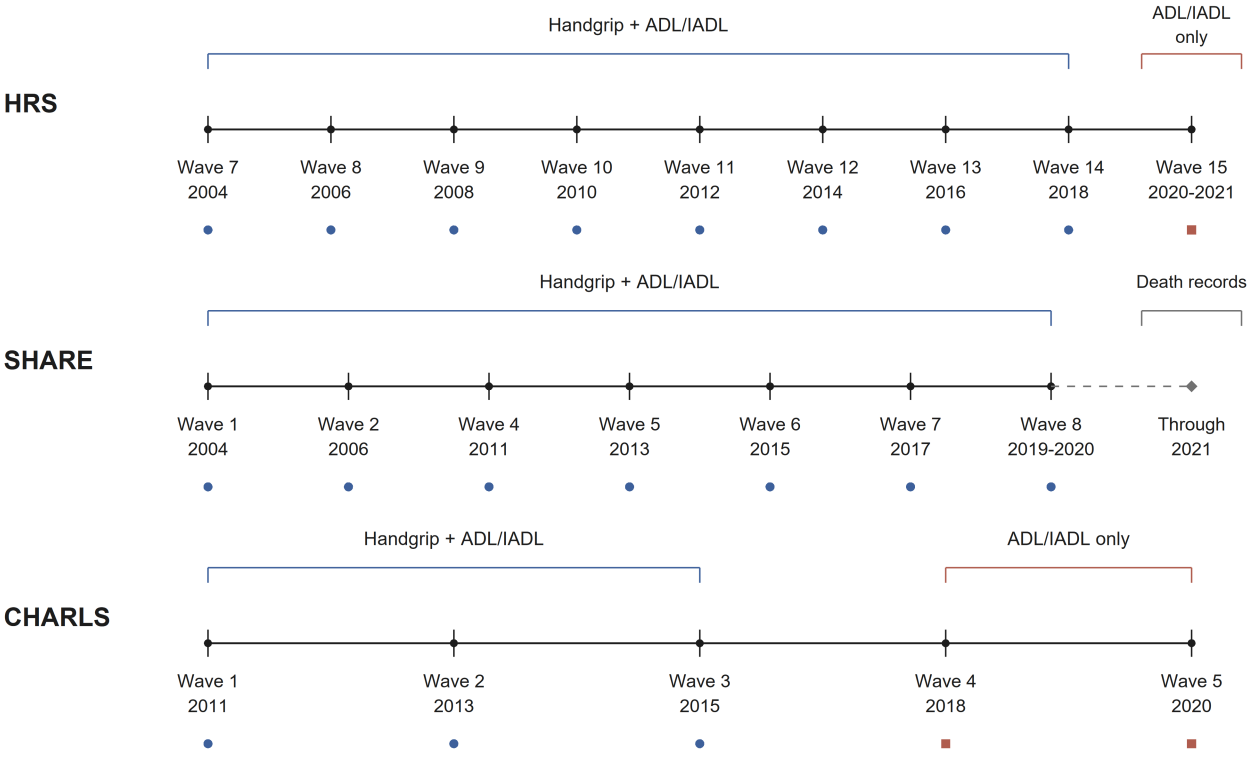
Circles and diamonds show cohort-specific and pooled hazard ratios, respectively; bars indicate 95% confidence intervals. Low strength denotes ≤20th percentile among cohort-, sex- and wave-specific completers. Axes are logarithmic. ADL, activities of daily living; IADL, instrumental activities of daily living.

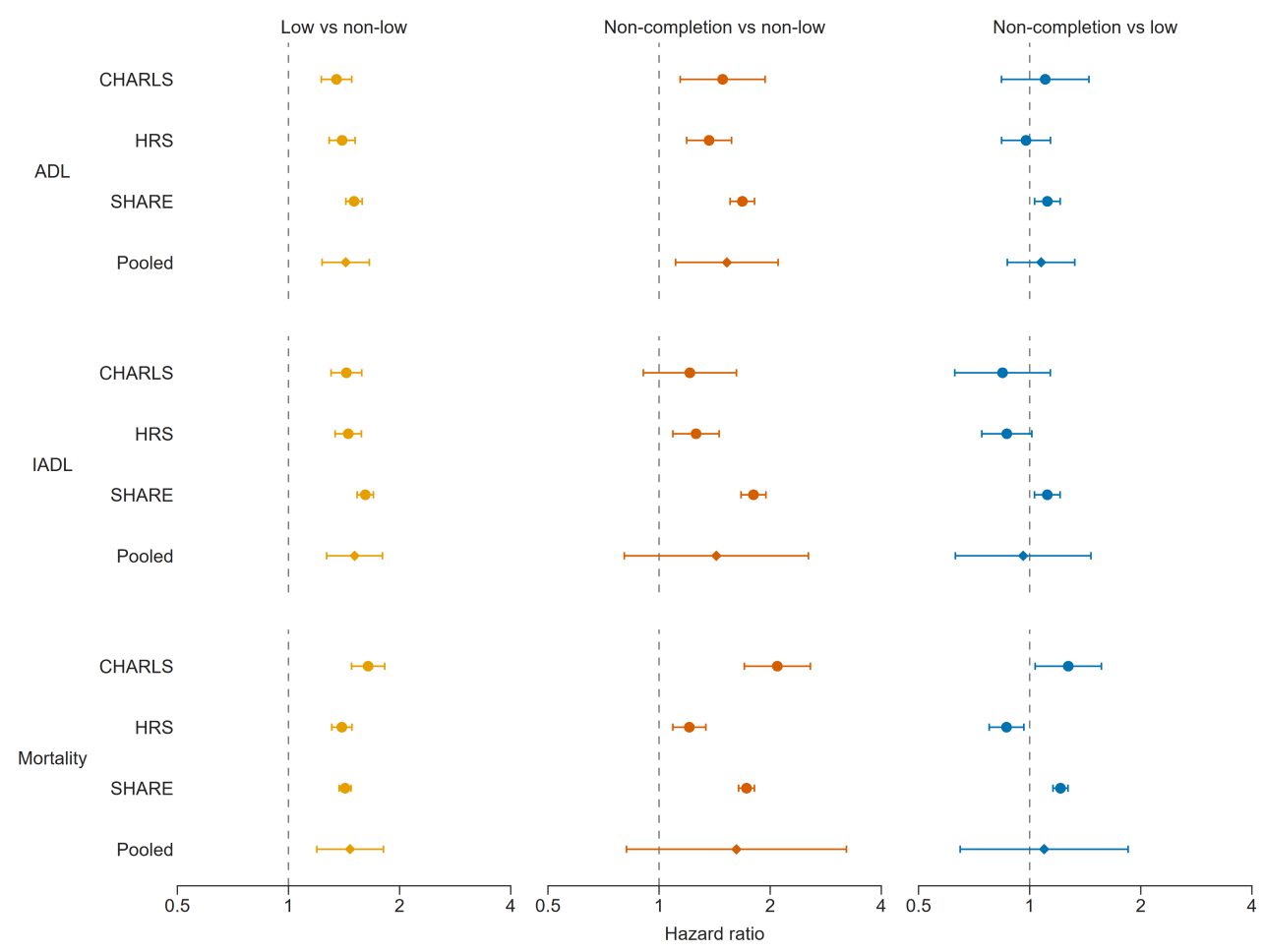
Figure 3. Sensitivity analyses for non-completion versus non-low handgrip strength.

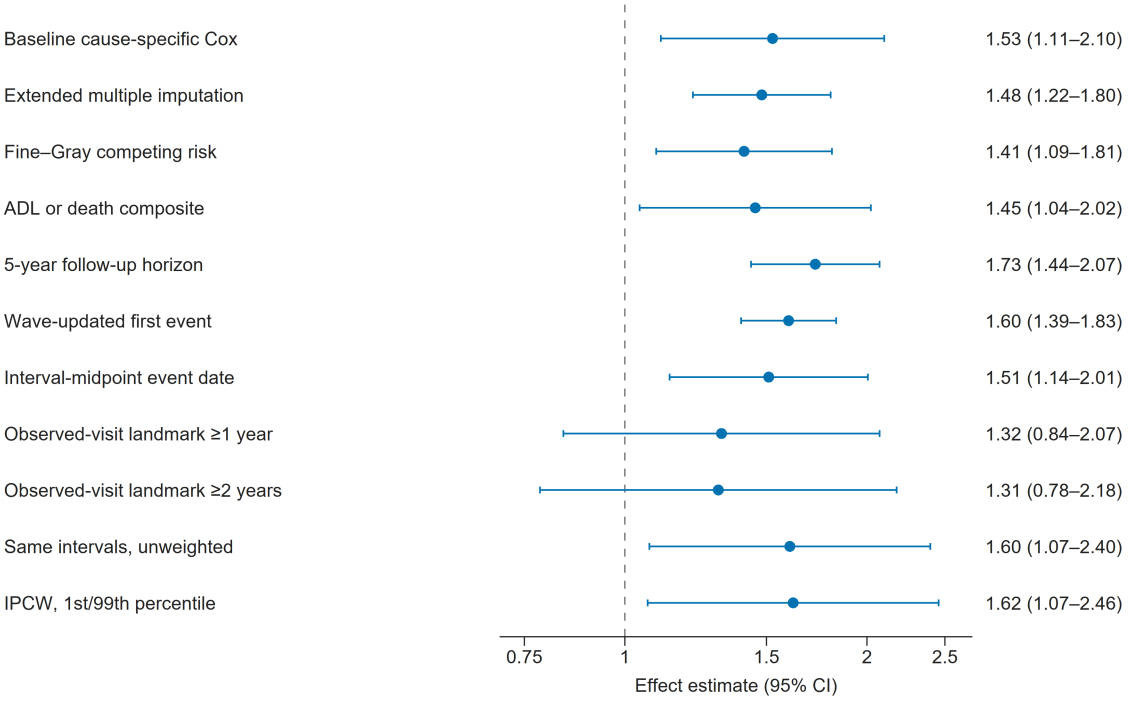
Points and bars show pooled hazard ratios and 95% confidence intervals (CIs); Fine–Gray estimates are subdistribution hazard ratios. IPCW and its unweighted comparator use identical follow-up intervals. ADL, activities of daily living; IPCW, inverse probability of censoring weighting.

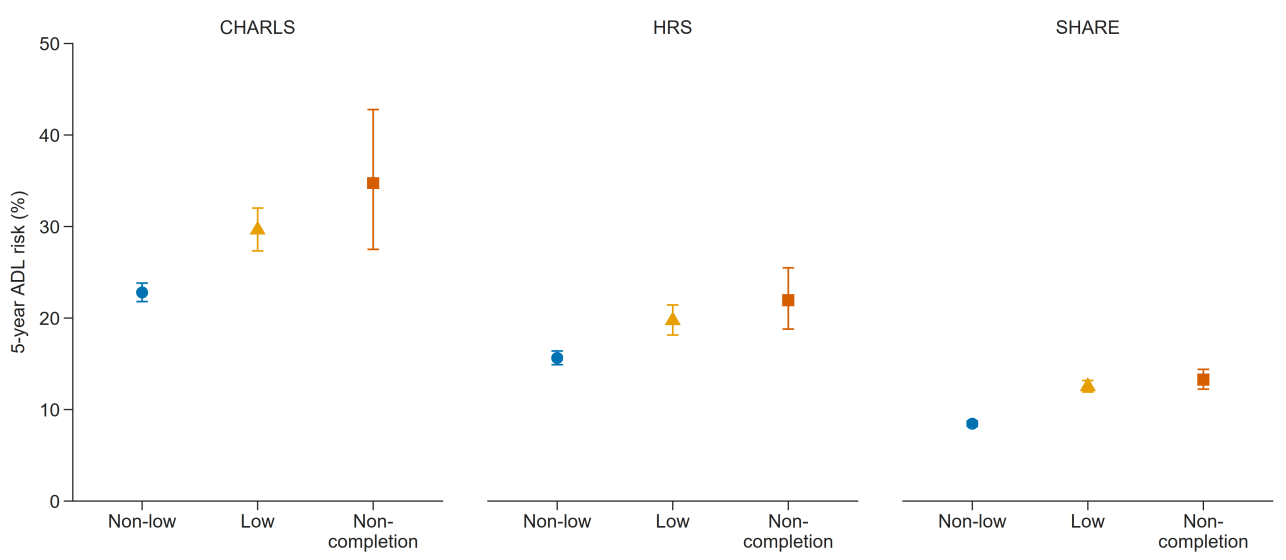
Figure 4. Standardized five-year ADL risk accounting for competing death.

Points and bars show standardized five-year risks and 95% confidence intervals, accounting for competing death. All groups are standardized to the same complete-case population within each cohort. Low strength denotes ≤20th percentile among cohort-, sex- and wave-specific completers. ADL, activities of daily living.


HRS
Handgrip + ADL/IADL
ADL/IADL only
Wave 7 2004
Wave 8 2006
Wave 9 2008
Wave 10 2010
Wave 11 2012
Wave 12 2014
Wave 13 2016
Wave 14 2018
Wave 15 2020-2021
SHARE
Handgrip + ADL/IADL
Death records
Wave 1 2004
Wave 2 2006
Wave 4 2011
Wave 5 2013
Wave 6 2015
Wave 7 2017
Wave 8 2019-2020
Through 2021
CHARLS
Handgrip + ADL/IADL
ADL/IADL only
Wave 1 2011
Wave 2 2013
Wave 3 2015
Wave 4 2018
Wave 5 2020


Low vs non-low
Non-completion vs non-low
Non-completion vs low
ADL
IADL
Mortality
CHARLS
HRS
SHARE
Pooled
0.5
1
2
4
Hazard ratio


Baseline cause-specific Cox
1.53 (1.11–2.10)
Extended multiple imputation
1.48 (1.22–1.80)
Fine–Gray competing risk
1.41 (1.09–1.81)
ADL or death composite
1.45 (1.04–2.02)
5-year follow-up horizon
1.73 (1.44–2.07)
Wave-updated first event
1.60 (1.39–1.83)
Interval-midpoint event date
1.51 (1.14–2.01)
Observed-visit landmark ≥1 year
1.32 (0.84–2.07)
Observed-visit landmark ≥2 years
1.31 (0.78–2.18)
Same intervals, unweighted
1.60 (1.07–2.40)
IPCW, 1st/99th percentile
1.62 (1.07–2.46)
0.75
1
1.5
2
2.5
Effect estimate (95% CI)


CHARLS
HRS
SHARE
5-year ADL risk (%)
50
40
30
20
10
0
Non-low
Low
Non-completion
Non-low
Low
Non-completion
Non-low
Low
Non-completion

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Additionalfile1.docx