

Joint Trajectories of Peak Expiratory Flow and Handgrip Strength and Subsequent Disability, Frailty, and Mortality Among Middle-Aged and Older Chinese Adults: A CHARLS Cohort Study

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Abstract

Background

Peak expiratory flow (PEF) and handgrip strength are inexpensive, repeatable measures of respiratory performance and peripheral muscle function, but the prognostic relevance of their joint longitudinal patterns is unclear.

Methods

We analyzed 11,630 participants aged 45 years or older from the China Health and Retirement Longitudinal Study who had paired PEF and handgrip measurements in at least two of the 2011, 2013, and 2015 waves. Group-based multi-trajectory modeling identified joint patterns of wave-specific standardized PEF and grip strength. Multivariable logistic regression examined associations with incident activities of daily living (ADL) disability, instrumental ADL (IADL) disability, any ADL/IADL disability, and frailty in 2018, and with all-cause mortality between 2015 and 2018.

Results

Five joint trajectories were identified: very high PEF–very high grip (8.76%), high PEF–high grip declining (24.00%), average PEF–average grip declining (33.32%), low PEF–moderate grip declining (6.38%), and low PEF–low grip declining (27.54%). Compared with the very high PEF–very high grip group, the low PEF–low grip declining group had higher adjusted odds of incident ADL disability (odds ratio [OR], 2.24; 95% confidence interval [CI], 1.44–3.50), IADL disability (OR, 1.86; 95% CI, 1.24–2.79), any ADL/IADL disability (OR, 1.85; 95% CI, 1.25–2.74), frailty (OR, 2.29; 95% CI, 1.49–3.52), and mortality (OR, 3.49; 95% CI, 1.71–7.11). Mortality odds were also higher in the low PEF–moderate grip declining group (OR, 3.14; 95% CI, 1.56–6.32) and the high PEF–high grip declining group (OR, 2.04; 95% CI, 1.07–3.87), although the latter association was less consistent in sensitivity analyses. No statistically significant interaction by sex was detected.

Conclusions

A trajectory characterized by persistently low standardized PEF and low, declining grip strength showed the most consistent associations with disability, frailty, and death. Repeated joint assessment of these two simple functional measures may improve risk stratification in middle-aged and older adults, although sex-appropriate standardization and external validation are needed before clinical application.

1. Introduction

Preserving independence is a central goal of healthy aging because activities of daily living (ADL) disability, instrumental activities of daily living (IADL) disability, frailty, and death are related but clinically distinct consequences of declining functional capacity. Frailty reflects reduced ability to withstand and recover from stressors rather than an inevitable effect of chronological age^{1–3}. Likewise, lower intrinsic capacity is associated with subsequent functional decline and mortality⁴. These findings underscore the need for simple, repeatable measures that can identify adverse functional aging before dependency develops.

Peak expiratory flow (PEF) provides a practical measure of maximal expiratory performance. Although PEF cannot replace spirometry for diagnosing airway disease, it is influenced by airway caliber, lung and chest-wall mechanics, expiratory muscle force, and the ability to perform a coordinated high-effort maneuver. In community-dwelling older adults, low PEF has predicted subsequent disability and death⁵, while recent longitudinal studies have linked adverse PEF or lung-function trajectories to frailty progression and incident sarcopenia^{6–8}. Repeated PEF measurement may therefore provide functional information not captured by a single value or a recorded respiratory diagnosis.

Handgrip strength complements PEF by indexing peripheral muscle function. Grip strength is simple to obtain and has established associations with disability and mortality^{9,10}. Respiratory and limb muscle function are also interconnected: the consensus concept of respiratory sarcopenia recognizes the coexistence of respiratory muscle weakness and systemic muscle loss¹¹, and genetic and prospective evidence links grip strength with pulmonary function and respiratory disease^{12,13}. Respiratory sarcopenia has also been associated with mortality¹⁴. Together, these findings support evaluating PEF and grip strength as a combined functional phenotype rather than as unrelated tests.

Current evidence remains limited in two respects. First, most studies have examined PEF or grip strength separately, often using a single baseline value or fixed cutoff. Such approaches cannot distinguish persistently low function from decline beginning at a higher level. Second, single-domain trajectory studies show that longitudinal patterns of PEF and grip strength carry prognostic information^{6,15}, but population-based evidence on their joint evolution and its relation to several aging outcomes remains sparse. A joint trajectory approach may therefore reveal combinations of respiratory performance and muscle strength that are not captured by separate analyses.

Using repeated measurements from the China Health and Retirement Longitudinal Study (CHARLS), we aimed to identify joint trajectories of PEF and handgrip strength from 2011 to 2015 and to examine their associations with incident ADL disability, incident IADL disability, incident frailty, and all-cause mortality. We hypothesized that trajectories characterized by lower joint functional levels, particularly low PEF accompanied by low and declining grip strength, would be associated with less favorable outcomes.

2. Methods

2.1 Study design, data source, and ethics

This longitudinal cohort study used data from CHARLS, a nationally representative survey of Chinese adults aged 45 years or older¹⁶. CHARLS used a multistage, stratified, probability-proportional-to-size sampling design and collected repeated information on sociodemographic characteristics, health behaviors, clinical conditions, physical measurements, functional status, and survival. The national baseline survey was conducted in 2011–2012, with follow-up waves in 2013, 2015, and 2018. PEF and handgrip strength measured from 2011 to 2015 were used to construct joint trajectories; incident disability and frailty were assessed in 2018, and all-cause mortality was assessed from 2015 to 2018. The CHARLS protocol was approved by the Institutional Review Board of Peking University (IRB00001052-11015). All participants provided written informed consent. The present study was a secondary analysis of deidentified public-use data. We accessed the publicly available dataset on June 25, 2026. All data were de-identified prior to release, and the authors did not have access to participant identifiers at any time during or after data collection.

2.2 Study population

Participants were eligible for trajectory modeling if they were aged 45 years or older, had nonmissing age and sex information, and had paired valid PEF and handgrip measurements in at least two of the 2011, 2013, and 2015 waves. Measurements that failed prespecified plausibility or data-quality checks were treated as missing, leaving 11,630 participants for joint trajectory modeling.

Outcome-specific analytic samples were constructed to preserve the temporal sequence between trajectory assessment and subsequent outcomes. Participants with the relevant disability or frailty in 2015 were excluded from the corresponding incidence analysis. Participants confirmed alive in 2015 were eligible for mortality follow-up through 2018. Complete-case samples were then defined according to the outcome and covariates required by each regression model (Fig. 1).

2.3 Assessment of PEF and handgrip strength

PEF was measured with a handheld peak flow meter, and the highest valid reading within each wave was retained as an indicator of maximal expiratory performance. Handgrip strength was measured twice in each hand with a dynamometer; the highest valid value across the four measurements represented muscle strength for that wave.

Within each survey wave, PEF and handgrip strength were standardized separately across the full trajectory sample to produce wave-specific z scores. This placed the two measures on comparable scales for joint modeling. Because standardization was wave specific, the trajectories describe participants' relative positions within each wave rather than absolute population-level change in the original measurement units.

2.4 Identification of PEF–grip joint trajectory groups

Group-based multi-trajectory modeling was performed with the gbmt package to identify subgroups following similar concurrent patterns of standardized PEF and handgrip strength from 2011 to 2015¹⁷. Survey waves were coded as 0, 1, and 2. Linear models containing one to five trajectory groups were fitted. Quadratic specifications were explored but did not converge and were not retained.

Model selection considered statistical fit, parsimony, classification quality, minimum group size, and clinical interpretability. We examined the Akaike information criterion (AIC), Bayesian information criterion (BIC), consistent AIC (CAIC), sample-size-adjusted BIC (SSBIC), log likelihood, group-specific average posterior probabilities, and agreement between assigned and model-estimated group proportions. Each participant was assigned to the group with the highest posterior membership probability.

The selected model contained five groups with linear time terms. Labels summarized the observed relative levels and directions of change: very high PEF–very high grip, high PEF–high grip declining, average PEF–average grip declining, low PEF–moderate grip declining, and low PEF–low grip declining. Supplementary Table S1 presents the converged candidate models, and Supplementary Table S2 presents classification diagnostics for the selected solution.

2.5 Outcome assessment

2.5.1 Incident ADL and IADL disability

ADL disability was assessed using six basic self-care activities: dressing, bathing or showering, eating, getting into or out of bed, using the toilet, and controlling urination and defecation. Participants reporting difficulty with or inability to perform at least one activity were classified as having ADL disability.

IADL disability was assessed using five activities required for independent living: performing household chores, preparing hot meals, shopping for groceries, managing money, and taking medications. Participants reporting difficulty with or inability to perform at least one activity were classified as having IADL disability.

Any ADL/IADL disability was defined as the presence of either ADL or IADL disability. Incident disability was defined as absence of the corresponding disability in 2015 and presence of that disability in 2018.

2.5.2 Incident frailty

Frailty was assessed separately in 2015 and 2018 using a 32-deficit accumulation frailty index (FI) constructed according to established procedures^{18,19}. The FI comprised 10 chronic conditions, 2 sensory deficits, 5 ADL limitations, 5 IADL limitations, 7 mobility limitations, and one deficit each for self-rated health, depressive symptoms, and cognition. Binary deficits were scored 0 or 1, whereas the cognitive deficit was entered as a continuous score from 0 to 1. At each wave, the FI was calculated as the sum of observed deficit scores divided by the number of observed deficit units. FI values were calculated only when at least 26 of the 32 units were available (no more than 6 missing); otherwise, the FI was set to missing. The FI ranges from 0 to 1, with higher values indicating a greater deficit burden. An FI cutoff of 0.25 was used to define frailty, consistent with its established use in community-dwelling populations²⁰. Variables and scoring are detailed in Supplementary Table S7.

Incident frailty was defined as a transition from nonfrailty in 2015 ($FI < 0.25$) to frailty in 2018 ($FI \geq 0.25$). Participants who were already frail in 2015 were excluded from the incident-frailty analysis.

2.5.3 All-cause mortality

All-cause mortality was ascertained from harmonized CHARLS follow-up records. Participants confirmed alive in 2015 were classified according to vital status at the 2018 wave; records with unresolved status were excluded. Because exact dates of death were unavailable, mortality was analyzed as a binary outcome rather than as time-to-event data.

2.6 Covariates

Baseline covariates were measured in 2011 unless otherwise specified and were selected a priori as potential confounders of the associations between PEF–grip trajectories and subsequent outcomes. They included age, sex, education, marital status, residence, smoking, drinking, body mass index (BMI), hypertension, diabetes, cancer, lung disease, heart disease, stroke, arthritis, dyslipidemia, kidney disease, and depressive symptoms.

BMI was calculated as weight in kilograms divided by height in meters squared; values outside 10–60 kg/m² were treated as missing. Chronic conditions were based on self-reported physician diagnoses. Depressive symptoms were measured with the 10-item Center for Epidemiologic Studies Depression Scale (CES-D-10), with higher scores indicating more severe symptoms. Waist circumference, systolic and diastolic blood pressure, household income, and self-rated health were included in the descriptive analysis.

Household income and self-rated health were excluded from the primary models because of substantial missingness but were added in an extended-adjustment sensitivity analysis; household income was log transformed. Supplementary Table S3 summarizes missingness in baseline variables.

2.7 Statistical analysis

Baseline characteristics were summarized for the full trajectory sample and by trajectory group. Continuous variables are presented as mean $\pm$ standard deviation (SD), and categorical variables as number (percentage), using available observations as denominators. Because several continuous variables were skewed, group differences were assessed with Kruskal–Wallis tests; categorical variables and unadjusted outcome frequencies were compared with Pearson chi-square or Fisher exact tests, as appropriate.

Separate binary logistic regression models were fitted for each outcome, with the very high PEF–very high grip group as the reference. Associations are reported as odds ratios (ORs) with Wald 95% confidence intervals (CIs).

Covariate adjustment was introduced in prespecified tiers. Model 1 included age and sex. Model 2 additionally included education, marital status, residence, smoking, drinking, and BMI. Model 3 further included hypertension, diabetes, cancer, lung disease, heart disease, stroke, arthritis, dyslipidemia, kidney disease, and CES-D-10 score.

Analyses were based on participants with complete data for the relevant outcome and the covariates included in each model; sample sizes therefore varied by outcome and adjustment level.

Robustness was evaluated by additionally adjusting for log-transformed household income and self-rated health, repeating analyses after multiple imputation of missing covariates with 20 chained-equation datasets, and excluding participants with baseline lung disease. Outcomes and trajectory assignments were not imputed. Additional outcome-specific analyses examined alternative eligibility or outcome definitions described in the Supplementary Material.

Potential effect modification by sex was assessed by adding trajectory-group-by-sex interaction terms to Model 3 and comparing models with a likelihood-ratio test with 4 degrees of freedom, using the same outcome-specific analytic samples.

All tests were two sided, with $P < 0.05$ considered statistically significant. Interpretation emphasized effect estimates and their precision rather than isolated P values. Analyses were unweighted and did not incorporate the complex survey design. All analyses were performed in R version 4.4.3 (R Foundation for Statistical Computing, Vienna, Austria).

3. Results

3.1 Study population and identification of joint trajectories

Of 25,586 CHARLS participants assessed for trajectory eligibility, 8,655 were excluded because they were younger than 45 years or lacked age or sex information, 5,301 had fewer than two waves with paired valid PEF and handgrip measurements. The final trajectory sample included 11,630 participants (Fig. 1). Among converged candidate solutions, the five-group linear model provided the most favorable combination of fit, subgroup size, and classification quality (log likelihood, $-68,733$; AIC, 137,542; BIC, 137,857). The smallest group comprised 6.38% of participants, and group-specific average posterior probabilities ranged from 0.793 to 0.883 (Supplementary Tables S1 and S2).

3.2 Trajectory patterns

Five joint trajectories were identified: very high PEF–very high grip ($n = 1,019$; 8.76%), high PEF–high grip declining ($n = 2,791$; 24.00%), average PEF–average grip declining ($n = 3,875$; 33.32%), low PEF–moderate grip declining ($n = 742$; 6.38%), and low PEF–low grip declining ($n = 3,203$; 27.54%). The groups remained separated across all three waves. Standardized PEF was comparatively stable within groups, whereas standardized grip strength declined to varying degrees in four groups (Fig. 2). Because both measures were standardized within wave, the plotted curves represent relative positions in the study population rather than changes in the original PEF or kilogram scales.

3.3 Baseline characteristics

The mean age of the trajectory sample was 58.60 years (SD, 8.94), and 52.38% were women. Baseline characteristics differed across trajectory groups (Table 1). Participants in the low PEF–low grip declining group were older, had lower mean household income, lower educational attainment, poorer self-rated health, and higher CES-D-10 scores than those in the higher-function groups. The low PEF–moderate grip declining group had the highest prevalence of baseline lung disease (31.56%). Sex distributions were markedly uneven: men comprised 99.31% of the very high PEF–very high grip group, whereas women comprised 88.23% of the low PEF–low grip declining group.

Table 1
Baseline characteristics according to PEF–grip joint trajectory groups.

Variable	Overall N = 11,630	Very high PEF–very high grip N = 1,019	High PEF–high grip declining N = 2,791	Average PEF– average grip declining N = 3,875	Low PEF– moderate grip declining N = 742	Low PEF–low grip declining N = 3,203	P value
Age, years	58.60 ± 8.94	52.50 ± 5.77	56.53 ± 7.31	57.26 ± 8.30	61.54 ± 8.95	63.30 ± 9.45	< 0.001
Income	23968.07 ± 53155.28	35190.50 ± 68617.62	27112.24 ± 64187.94	26327.04 ± 57211.28	21326.83 ± 59012.72	17070.29 ± 26586.18	< 0.001
BMI, kg/m ²	23.51 ± 3.84	24.59 ± 3.46	23.48 ± 3.61	23.82 ± 3.72	22.77 ± 3.82	22.99 ± 4.18	< 0.001
Waist, cm	84.39 ± 12.39	88.35 ± 12.02	84.52 ± 11.98	84.29 ± 12.23	84.04 ± 11.70	83.23 ± 12.95	< 0.001
SBP, mmHg	129.18 ± 21.18	128.23 ± 18.43	127.86 ± 19.08	127.16 ± 20.66	131.05 ± 21.53	132.64 ± 23.67	< 0.001
DBP, mmHg	75.34 ± 12.20	77.96 ± 12.26	75.91 ± 12.25	74.81 ± 11.92	75.72 ± 12.28	74.56 ± 12.32	< 0.001
Depression score	8.40 ± 6.26	5.64 ± 4.93	6.93 ± 5.56	8.26 ± 5.97	8.82 ± 6.29	10.62 ± 6.80	< 0.001
Sex							< 0.001
Female	6,092 (52.38)	7 (0.69)	324 (11.61)	2,727 (70.37)	208 (28.03)	2,826 (88.23)	
Male	5,538 (47.62)	1,012 (99.31)	2,467 (88.39)	1,148 (29.63)	534 (71.97)	377 (11.77)	
Education							< 0.001
College or above	145 (1.25)	41 (4.02)	56 (2.01)	38 (0.98)	6 (0.81)	4 (0.12)	
Middle/high school	3,431 (29.50)	615 (60.35)	1,192 (42.71)	1,083 (27.95)	164 (22.10)	377 (11.77)	
Primary school or below	8,054 (69.25)	363 (35.62)	1,543 (55.28)	2,754 (71.07)	572 (77.09)	2,822 (88.10)	
Marital status							< 0.001
Married	10,277 (88.40)	986 (96.76)	2,614 (93.66)	3,506 (90.50)	651 (87.85)	2,520 (78.75)	
Unmarried/separated/divorced/widowed	1,348 (11.60)	33 (3.24)	177 (6.34)	368 (9.50)	90 (12.15)	680 (21.25)	
Residence							< 0.001
Rural	7,587 (65.24)	597 (58.59)	1,773 (63.53)	2,500 (64.52)	504 (67.92)	2,213 (69.09)	

Notes: Continuous variables are presented as mean ± SD, and categorical variables are presented as n (%). Percentages were calculated among participants with nonmissing data. P values were calculated using Kruskal–Wallis tests for continuous variables and Pearson chi-square or Fisher exact tests for categorical variables, as appropriate. PEF, peak expiratory flow; BMI, body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure.

Variable	Overall N = 11,630	Very high PEF—very high grip N = 1,019	High PEF—high grip declining N = 2,791	Average PEF— average grip declining N = 3,875	Low PEF— moderate grip declining N = 742	Low PEF—low grip declining N = 3,203	P value
Urban	4,043 (34.76)	422 (41.41)	1,018 (36.47)	1,375 (35.48)	238 (32.08)	990 (30.91)	
Smoking status							< 0.001
Current smoker	3,508 (30.63)	578 (57.80)	1,431 (52.73)	752 (19.60)	336 (46.15)	411 (12.95)	
Former smoker	937 (8.18)	164 (16.40)	342 (12.60)	197 (5.14)	105 (14.42)	129 (4.07)	
Never smoker	7,006 (61.18)	258 (25.80)	941 (34.67)	2,887 (75.26)	287 (39.42)	2,633 (82.98)	
Drinking status							< 0.001
Less than once a month	920 (8.42)	131 (14.22)	322 (12.59)	253 (6.86)	61 (8.76)	153 (4.99)	
Never	7,743 (70.84)	350 (38.00)	1,295 (50.63)	2,979 (80.73)	441 (63.36)	2,678 (87.35)	
Once a month or more	2,268 (20.75)	440 (47.77)	941 (36.79)	458 (12.41)	194 (27.87)	235 (7.66)	
Hypertension							< 0.001
No	8,608 (74.60)	796 (78.73)	2,167 (77.98)	2,903 (75.58)	554 (75.17)	2,188 (69.00)	
Yes	2,931 (25.40)	215 (21.27)	612 (22.02)	938 (24.42)	183 (24.83)	983 (31.00)	
Diabetes							0.013
No	10,797 (93.98)	949 (94.71)	2,620 (94.96)	3,580 (93.35)	701 (95.24)	2,947 (93.35)	
Yes	692 (6.02)	53 (5.29)	139 (5.04)	255 (6.65)	35 (4.76)	210 (6.65)	
Cancer							0.839
No	11,456 (99.25)	1,010 (99.51)	2,753 (99.28)	3,816 (99.22)	730 (99.05)	3,147 (99.21)	
Yes	87 (0.75)	5 (0.49)	20 (0.72)	30 (0.78)	7 (0.95)	25 (0.79)	
Lung disease							< 0.001
No	10,482 (90.74)	972 (95.58)	2,576 (92.90)	3,634 (94.37)	503 (68.44)	2,797 (88.07)	
Yes	1,070 (9.26)	45 (4.42)	197 (7.10)	217 (5.63)	232 (31.56)	379 (11.93)	

Notes: Continuous variables are presented as mean $\pm$ SD, and categorical variables are presented as n (%). Percentages were calculated among participants with nonmissing data. P values were calculated using Kruskal–Wallis tests for continuous variables and Pearson chi-square or Fisher exact tests for categorical variables, as appropriate. PEF, peak expiratory flow; BMI, body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure.

Variable	Overall N = 11,630	Very high PEF—very high grip N = 1,019	High PEF—high grip declining N = 2,791	Average PEF— average grip declining N = 3,875	Low PEF— moderate grip declining N = 742	Low PEF—low grip declining N = 3,203	P value
Heart disease							< 0.001
No	10,197 (88.41)	940 (92.43)	2,516 (90.83)	3,418 (88.96)	636 (86.65)	2,687 (84.74)	
Yes	1,337 (11.59)	77 (7.57)	254 (9.17)	424 (11.04)	98 (13.35)	484 (15.26)	
Stroke							0.003
No	11,312 (97.80)	1,002 (98.62)	2,729 (98.24)	3,778 (98.00)	718 (97.29)	3,085 (97.01)	
Yes	255 (2.20)	14 (1.38)	49 (1.76)	77 (2.00)	20 (2.71)	95 (2.99)	
Arthritis							< 0.001
No	7,645 (66.05)	801 (78.76)	1,998 (71.84)	2,467 (63.96)	498 (67.39)	1,881 (59.13)	
Yes	3,930 (33.95)	216 (21.24)	783 (28.16)	1,390 (36.04)	241 (32.61)	1,300 (40.87)	
Dyslipidemia							< 0.001
No	10,260 (90.21)	871 (87.19)	2,475 (90.30)	3,398 (89.61)	687 (94.50)	2,829 (90.85)	
Yes	1,113 (9.79)	128 (12.81)	266 (9.70)	394 (10.39)	40 (5.50)	285 (9.15)	
Kidney disease							0.143
No	10,865 (94.31)	964 (94.88)	2,624 (94.59)	3,633 (94.76)	685 (93.45)	2,959 (93.55)	
Yes	655 (5.69)	52 (5.12)	150 (5.41)	201 (5.24)	48 (6.55)	204 (6.45)	
Self-rated health							< 0.001
Excellent	64 (0.77)	12 (1.36)	23 (1.02)	19 (0.75)	3 (0.53)	7 (0.35)	
Very good	706 (8.54)	133 (15.03)	234 (10.34)	211 (8.32)	23 (4.10)	105 (5.19)	
Good	1,472 (17.81)	213 (24.07)	483 (21.35)	424 (16.71)	91 (16.22)	261 (12.91)	
Fair	4,026 (48.70)	434 (49.04)	1,138 (50.31)	1,276 (50.30)	280 (49.91)	898 (44.41)	
Poor	1,999 (24.18)	93 (10.51)	384 (16.98)	607 (23.93)	164 (29.23)	751 (37.14)	
Notes: Continuous variables are presented as mean ± SD, and categorical variables are presented as n (%). Percentages were calculated among participants with nonmissing data. P values were calculated using Kruskal–Wallis tests for continuous variables and Pearson chi-square or Fisher exact tests for categorical variables, as appropriate. PEF, peak expiratory flow; BMI, body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure.							

3.4 Distribution of adverse outcomes

Among outcome-eligible participants, incident ADL disability occurred in 1,067 of 7,874 (13.55%), incident IADL disability in 1,333 of 7,445 (17.90%), any incident ADL/IADL disability in 1,402 of 6,532 (21.46%), and incident frailty in 1,209 of 8,024 (15.07%). Among 11,469 participants confirmed alive in 2015, 513 (4.47%) had died by the 2018 wave (Table 2). Unadjusted event proportions were highest or near highest in the two low-PEF groups.

Table 2
Distribution of incident disability, incident frailty, and all-cause mortality by PEF–grip joint trajectory group.

Outcome	Overall	Very high PEF–very high grip	High PEF–high grip declining	Average PEF–average grip declining	Low PEF–moderate grip declining	Low PEF–low grip declining	P value
Incident ADL disability in 2018	1,067/7,874 (13.55)	42/838 (5.01)	173/2,093 (8.27)	364/2,681 (13.58)	73/468 (15.60)	415/1,794 (23.13)	< 0.001
Incident IADL disability in 2018	1,333/7,445 (17.90)	55/834 (6.59)	270/2,090 (12.92)	453/2,570 (17.63)	100/447 (22.37)	455/1,504 (30.25)	< 0.001
Any incident ADL/IADL disability in 2018	1,402/6,532 (21.46)	70/789 (8.87)	305/1,901 (16.04)	487/2,221 (21.93)	104/381 (27.30)	436/1,240 (35.16)	< 0.001
Incident frailty in 2018	1,209/8,024 (15.07)	48/858 (5.59)	221/2,205 (10.02)	389/2,759 (14.10)	89/467 (19.06)	462/1,735 (26.63)	< 0.001
All-cause mortality	513/11,469 (4.47)	18/1,012 (1.78)	112/2,767 (4.05)	111/3,842 (2.89)	69/720 (9.58)	203/3,128 (6.49)	< 0.001
Notes: Participants with the relevant disability or frailty in 2015 were excluded from incidence analyses; frailty was defined as FI ≥ 0.25. Mortality analyses included participants confirmed alive in 2015 and followed through 2018. P values were calculated using Pearson chi-square tests. PEF, peak expiratory flow; ADL, activities of daily living; IADL, instrumental activities of daily living; FI, frailty index.							

3.5 Joint trajectories and incident disability

After full adjustment, associations with incident disability were concentrated in the average and low-function trajectory groups (Table 3 and Fig. 3). Compared with the very high PEF–very high grip group, the average PEF–average grip declining group had higher odds of incident ADL disability (OR, 1.63; 95% CI, 1.09–2.44), IADL disability (OR, 1.45; 95% CI, 1.00–2.10), and any ADL/IADL disability (OR, 1.44; 95% CI, 1.02–2.04). Corresponding ORs for the low PEF–moderate grip declining group were 1.63 (95% CI, 1.03–2.60), 1.70 (95% CI, 1.11–2.58), and 1.76 (95% CI, 1.18–2.63). The low PEF–low grip declining group had the largest estimates: 2.24 (95% CI, 1.44–3.50), 1.86 (95% CI, 1.24–2.79), and 1.85 (95% CI, 1.25–2.74), respectively. The high PEF–high grip declining group was not associated with disability after full adjustment.

Table 3
Associations of PEF–grip trajectories with incident disability, frailty, and all-cause mortality.

Outcome	Trajectory group	Model 1	Model 2	Model 3
Incident ADL disability in 2018	High PEF–high grip declining	1.43 (1.00, 2.03); P = 0.047	1.35 (0.93, 1.97); P = 0.114	1.18 (0.80, 1.72); P = 0.402
	Average PEF–average grip declining	2.32 (1.61, 3.34); P < 0.001	2.05 (1.38, 3.05); P < 0.001	1.63 (1.09, 2.44); P = 0.018
	Low PEF–moderate grip declining	2.41 (1.59, 3.63); P < 0.001	2.32 (1.49, 3.62); P < 0.001	1.63 (1.03, 2.60); P = 0.038
	Low PEF–low grip declining	3.51 (2.37, 5.21); P < 0.001	3.31 (2.15, 5.10); P < 0.001	2.24 (1.44, 3.50); P < 0.001
Incident IADL disability in 2018	High PEF–high grip declining	1.67 (1.23, 2.27); P = 0.001	1.52 (1.09, 2.13); P = 0.014	1.34 (0.95, 1.88); P = 0.092
	Average PEF–average grip declining	2.01 (1.45, 2.78); P < 0.001	1.73 (1.20, 2.48); P = 0.003	1.45 (1.00, 2.10); P = 0.047
	Low PEF–moderate grip declining	2.50 (1.73, 3.61); P < 0.001	2.12 (1.41, 3.17); P < 0.001	1.70 (1.11, 2.58); P = 0.014
	Low PEF–low grip declining	3.04 (2.13, 4.35); P < 0.001	2.41 (1.62, 3.59); P < 0.001	1.86 (1.24, 2.79); P = 0.003
Any incident ADL/IADL disability in 2018	High PEF–high grip declining	1.60 (1.21, 2.11); P < 0.001	1.46 (1.08, 1.99); P = 0.014	1.28 (0.94, 1.75); P = 0.117
	Average PEF–average grip declining	2.05 (1.52, 2.78); P < 0.001	1.74 (1.24, 2.44); P = 0.001	1.44 (1.02, 2.04); P = 0.039
	Low PEF–moderate grip declining	2.52 (1.78, 3.57); P < 0.001	2.25 (1.53, 3.30); P < 0.001	1.76 (1.18, 2.63); P = 0.006
	Low PEF–low grip declining	3.04 (2.17, 4.26); P < 0.001	2.50 (1.72, 3.65); P < 0.001	1.85 (1.25, 2.74); P = 0.002
Incident frailty in 2018	High PEF–high grip declining	1.56 (1.12, 2.16); P = 0.008	1.56 (1.10, 2.22); P = 0.013	1.33 (0.92, 1.91); P = 0.126
	Average PEF–average grip declining	2.03 (1.44, 2.86); P < 0.001	2.01 (1.37, 2.93); P < 0.001	1.54 (1.04, 2.28); P = 0.031
	Low PEF–moderate grip declining	2.68 (1.82, 3.95); P < 0.001	2.59 (1.70, 3.95); P < 0.001	1.75 (1.12, 2.74); P = 0.013
	Low PEF–low grip declining	3.52 (2.42, 5.11); P < 0.001	3.47 (2.30, 5.26); P < 0.001	2.29 (1.49, 3.52); P < 0.001
All-cause mortality	High PEF–high grip declining	1.68 (1.01, 2.80); P = 0.045	1.96 (1.06, 3.63); P = 0.032	2.04 (1.07, 3.87); P = 0.030
	Average PEF–average grip declining	1.57 (0.93, 2.66); P = 0.094	1.94 (1.02, 3.68); P = 0.042	1.91 (0.98, 3.73); P = 0.057
	Low PEF–moderate grip declining	3.03 (1.75, 5.25); P < 0.001	3.28 (1.69, 6.38); P < 0.001	3.14 (1.56, 6.32); P = 0.001
	Low PEF–low grip declining	3.11 (1.77, 5.45); P < 0.001	3.68 (1.87, 7.26); P < 0.001	3.49 (1.71, 7.11); P < 0.001

Values are ORs (95% CIs); P values follow semicolons. The very high PEF–very high grip group was the reference. Model 1 adjusted for age and sex; Model 2 additionally adjusted for education, marital status, residence, smoking, drinking, and BMI; and Model 3 further adjusted for hypertension, diabetes, cancer, lung disease, heart disease, stroke, arthritis, dyslipidemia, kidney disease, and CES-D-10 score. Outcome eligibility is described in Methods. PEF, peak expiratory flow; ADL, activities of daily living; IADL, instrumental activities of daily living; BMI, body mass index; CES-D-10, 10-item Center for Epidemiologic Studies Depression Scale; CI, confidence interval; FI, frailty index; OR, odds ratio.

3.6 Joint trajectories and incident frailty

Incident frailty showed a similar pattern. Relative to the reference group, the fully adjusted OR was 1.54 (95% CI, 1.04–2.28) for the average PEF–average grip declining group, 1.75 (95% CI, 1.12–2.74) for the low PEF–moderate grip declining group, and 2.29 (95% CI, 1.49–3.52) for the low PEF–low grip declining group. The estimate for the high PEF–high grip declining group was 1.33 (95% CI, 0.92–1.91).

3.7 Joint trajectories and all-cause mortality

The mortality pattern differed from the nonfatal outcomes. Adjusted mortality odds were higher in the low PEF–low grip declining group (OR, 3.49; 95% CI, 1.71–7.11) and the low PEF–moderate grip declining group (OR, 3.14; 95% CI, 1.56–6.32). The high PEF–high grip declining group also had higher mortality odds in the primary complete-case model (OR, 2.04; 95% CI, 1.07–3.87), whereas the estimate for the average PEF–average grip declining group was imprecise (OR, 1.91; 95% CI, 0.98–3.73).

3.8 Sensitivity and interaction analyses

Sensitivity analyses supported the main pattern while showing that some associations were more dependent on analytic assumptions (Supplementary Tables S4 and S6). Disability and frailty estimates were generally similar after multiple imputation and exclusion of baseline lung disease. For mortality, associations in both low-PEF groups remained evident in these analyses, whereas the estimate for the high PEF–high grip declining group was attenuated after multiple imputation. Extended adjustment for income and self-rated health reduced sample size and precision. No statistically significant trajectory-by-sex interaction was detected for any outcome (all *P* for interaction ≥ 0.100 ; Supplementary Table S5).

4. Discussion

This study identified five joint PEF–grip trajectories with distinct outcome profiles. The low PEF–low grip declining group had the most consistent associations with incident disability, frailty, and mortality, and the low PEF–moderate grip declining group also showed elevated odds across these outcomes. The average PEF–average grip declining group was associated mainly with disability and frailty. The mortality association observed for the high PEF–high grip declining group was not accompanied by higher odds of nonfatal outcomes and was less consistent in sensitivity analyses. The strongest and most reproducible signal was therefore the combination of persistently low standardized PEF with lower or declining grip strength.

These findings extend earlier work by treating respiratory performance and peripheral muscle strength as a joint longitudinal phenotype. Prior studies have shown that low PEF predicts disability and death⁵, adverse PEF or lung-function trajectories predict frailty and sarcopenia^{21,22}, and low grip strength predicts disability and mortality^{9,23}. The present analysis adds that the prognostic pattern is not confined to either domain alone: participants with concurrently unfavorable PEF and grip profiles had the broadest range of adverse outcomes. This joint perspective is clinically relevant because PEF and grip strength are both effort-dependent performance measures influenced by neuromuscular function, body composition, health status, and the capacity to generate force^{12,13,24}.

The disability and frailty findings are consistent with a limited functional-margin explanation. Daily self-care and instrumental tasks require both peripheral strength and sufficient ventilatory support. When respiratory performance and muscle strength are jointly lower, ordinary activities may consume a larger proportion of available capacity, leaving less room to compensate during illness or other stressors. Longitudinal associations between grip strength and ADL disability, as well as evidence linking weakness, grip asymmetry, and lower cumulative grip exposure with poorer daily functioning, support this interpretation^{25,26}. The association of the average PEF–average grip declining group with disability and frailty also suggests that vulnerability may become detectable before both measures occupy the lowest relative range.

Mortality was most strongly associated with the two low-PEF trajectories, including the group with moderately preserved grip strength. This pattern suggests that low respiratory performance may add prognostic information beyond peripheral strength alone, consistent with evidence linking PEF, lung-function decline, and respiratory sarcopenia with death²⁷. By contrast, the mortality estimate for the high PEF–high grip declining group was sensitive to missing-data handling and extended adjustment. It should

therefore be viewed as a secondary signal that requires replication rather than as evidence that relative decline is more important than attained functional level.

The marked sex composition of the trajectory groups requires careful interpretation. Men predominated in the very high PEF–very high grip group and women in the low PEF–low grip group, reflecting well-established sex and body-size differences in both measures^{28,29}. Wave-specific standardization across the full sample therefore captured a mixture of relative functional status and expected sex-related physiology. Adjustment for sex and the absence of statistically significant interactions reduce concern about differential associations, but they do not establish that the same trajectory structure applies within each sex. Replication using sex-specific standardization, percent-predicted PEF, or sex-stratified trajectory models is an important next step.

Sensitivity analyses strengthened the central interpretation. The low PEF–low grip declining group remained the most consistent high-odds phenotype after multiple imputation and exclusion of baseline lung disease, and mortality associations in both low-PEF groups were comparatively stable. The attenuation seen after adding income and self-rated health should be interpreted in light of substantial missingness and reduced precision; self-rated health may also capture symptoms and functional consequences closely related to the exposure phenotype. These analyses support a focused conclusion about the low-PEF trajectories while arguing against placing equal emphasis on the less stable high-function declining trajectory.

The practical value of the joint phenotype lies in risk recognition rather than diagnosis. PEF and grip strength are inexpensive, portable, and repeatable, making them feasible for longitudinal assessment in community and primary-care settings. Persistently low or jointly unfavorable measurements could prompt confirmatory spirometry and broader evaluation of physical function, nutrition, activity, mood, and multimorbidity. PEF cannot replace diagnostic pulmonary testing, and grip strength alone does not diagnose sarcopenia. Nevertheless, trials showing benefits of multicomponent exercise, inspiratory muscle training, and resistance training indicate that respiratory and peripheral muscle function are potentially modifiable domains^{30–33}. Whether changing a PEF–grip trajectory improves disability or survival remains to be tested.

This study has several strengths. It used repeated paired measurements of two complementary functional indicators in a large national cohort, allowing joint patterns to be characterized rather than inferred from single baseline values. Applying the same trajectory phenotype to several prespecified outcomes, together with extensive adjustment and sensitivity analyses, made it possible to distinguish a broadly vulnerable pattern from associations that were less stable or more outcome specific.

Several limitations should be considered. The observational design does not establish causality, and early or undiagnosed disease may have influenced both trajectories and outcomes. Three measurements over four years provide limited temporal resolution, and latent trajectory groups are statistical approximations rather than fixed biological entities. PEF and grip strength depend on participant effort and technique. Full-sample wave-specific standardization contributed to marked sex separation between trajectory groups. Physical activity, nutrition, inflammation, medication use, and environmental exposures were not comprehensively measured, leaving potential residual confounding. Complete-case analysis may have introduced selection bias, and multiple imputation depends on the missing-at-random assumption. Because the 32-deficit FI incorporated ADL, IADL, and mobility limitations, frailty and disability were related rather than fully independent outcomes; their concordant associations should therefore be interpreted as convergent evidence across related functional domains. For nonfatal outcomes with appreciable incidence, ORs may exceed the corresponding risk ratios. Exact dates of death were unavailable, precluding time-to-event analysis, and the unweighted analyses should not be used to estimate national prevalence or incidence.

5. Conclusions

In conclusion, joint trajectories of PEF and handgrip strength differentiated patterns of subsequent functional vulnerability. Persistently low standardized PEF accompanied by low and declining grip strength identified the group with the most consistent elevations in disability, frailty, and mortality, while low PEF with moderately preserved grip strength also marked increased risk. These findings support repeated joint assessment as a pragmatic approach to risk stratification, with the strongest evidence centered on the low-PEF trajectories. Sex-appropriate standardization, objective pulmonary testing, longer follow-up, and external validation are required before clinical implementation.

Abbreviations

ADL
activities of daily living
AIC
Akaike information criterion
BIC
Bayesian information criterion
BMI
body mass index
CAIC
consistent Akaike information criterion
CES-D-10
10-item Center for Epidemiologic Studies Depression Scale
CHARLS
China Health and Retirement Longitudinal Study
CI
confidence interval
DBP
diastolic blood pressure
FI
frailty index
IADL
instrumental activities of daily living
OR
odds ratio
PEF
peak expiratory flow
SBP
systolic blood pressure
SD
standard deviation
SSBIC
sample-size-adjusted Bayesian information criterion.

Declarations

Ethics approval and consent to participate

The CHARLS protocol was approved by the Institutional Review Board of Peking University (IRB00001052-11015). All participants provided written informed consent. The present study was a secondary analysis of deidentified public-use data, and the authors did not have access to participant identifiers at any time during or after data collection.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Author Contribution

YH contributed to the conceptualization and design of the study, conducted the data analysis, and drafted the manuscript. YZ and YR contributed to data collection and curation. HQ performed the statistical modeling analyses. HL contributed to the interpretation of the findings and revision of the Discussion. HZ supervised the study and critically revised the manuscript for important intellectual content. All authors reviewed and approved the final version of the manuscript and agree to be accountable for all aspects of the work.

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Data Availability

This longitudinal cohort study used data from CHARLS, a nationally representative survey of Chinese adults aged 45 years or older 16. CHARLS used a multistage, stratified, probability-proportional-to-size sampling design and collected repeated information on sociodemographic characteristics, health behaviors, clinical conditions, physical measurements, functional status, and survival. The national baseline survey was conducted in 2011–2012, with follow-up waves in 2013, 2015, and 2018. PEF and handgrip strength measured from 2011 to 2015 were used to construct joint trajectories; incident disability and frailty were assessed in 2018, and all-cause mortality was assessed from 2015 to 2018. The CHARLS protocol was approved by the Institutional Review Board of Peking University (IRB00001052-11015). All participants provided written informed consent. The present study was a secondary analysis of deidentified public-use data. We accessed the publicly available dataset on June 25, 2026. All data were de-identified prior to release, and the authors did not have access to participant identifiers at any time during or after data collection.

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Figures

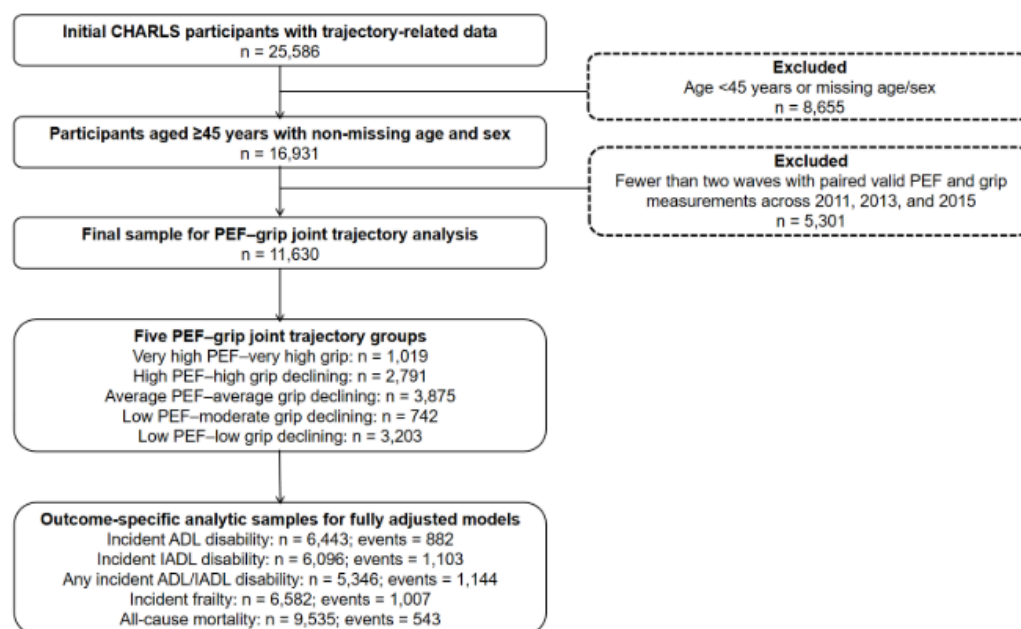


Figure 1

Study flow and outcome-specific analytic samples.

Notes: Outcome-specific analytic samples correspond to complete-case samples used in the fully adjusted models. Participants with the relevant disability or frailty in 2015 were excluded from incidence analyses; participants confirmed alive in 2015 were followed for mortality through 2018. PEF, peak expiratory flow; ADL, activities of daily living; IADL, instrumental activities of daily living.

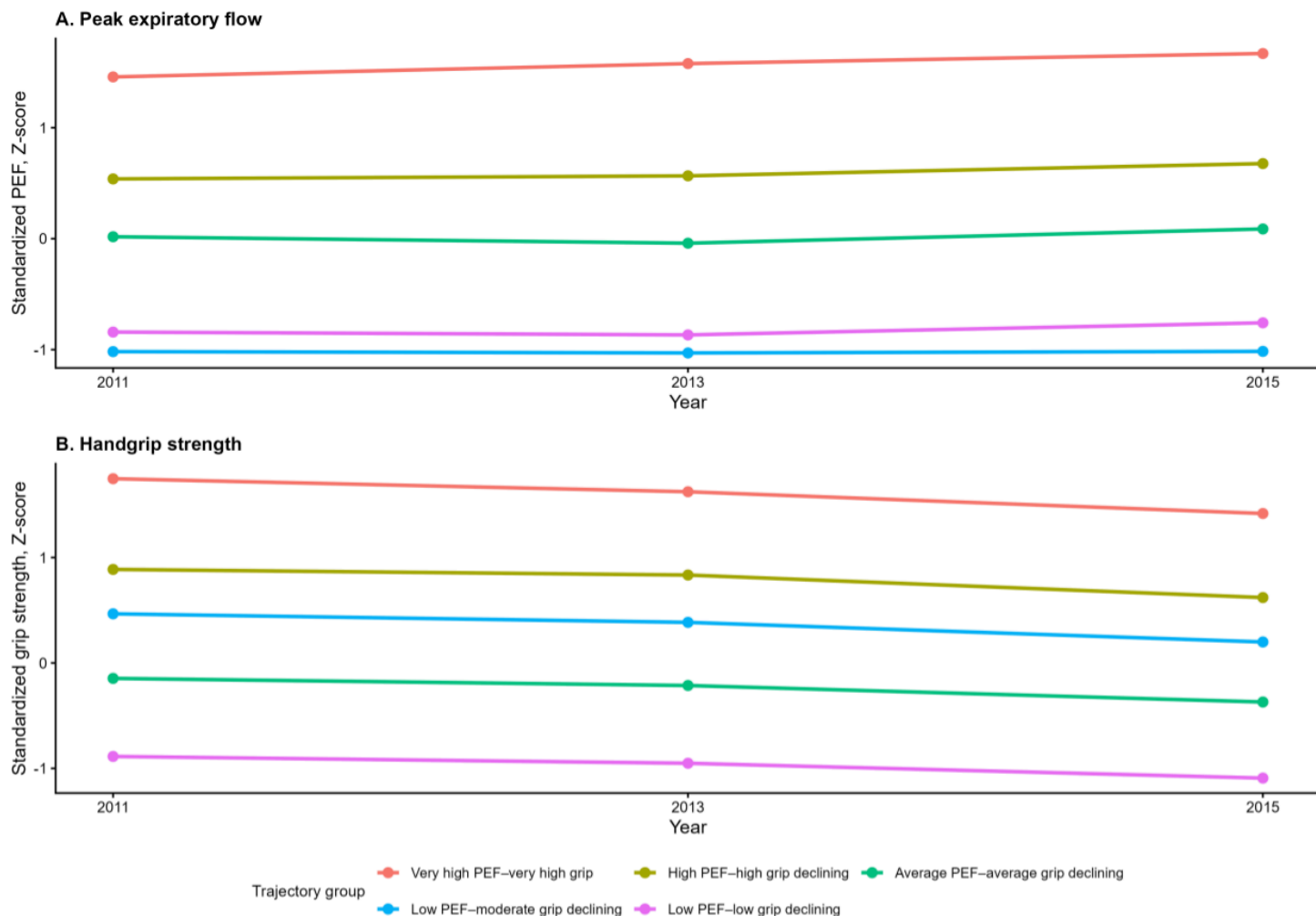


Figure 2

Joint trajectories of peak expiratory flow and handgrip strength, 2011–2015.

Notes: Panel A shows PEF and panel B handgrip strength. Lines and points are observed mean wave-specific z scores within each trajectory group. Because each measure was standardized separately within wave, the trajectories show relative positions in the analytic sample. PEF, peak expiratory flow.

Associations of PEF-grip joint trajectory groups with adverse outcomes

Reference group: very high PEF-very high grip

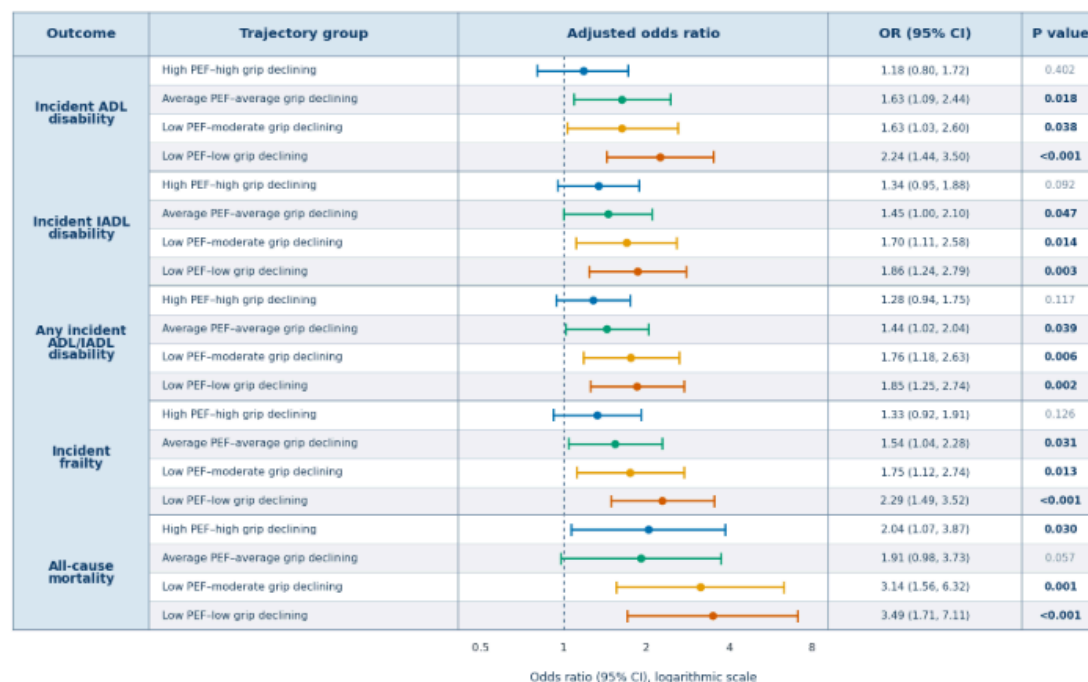


Figure 3

Associations of PEF-grip trajectories with adverse outcomes.

Notes: Points and horizontal lines show ORs and Wald 95% CIs from fully adjusted logistic regression models. Models included age, sex, education, marital status, residence, smoking, drinking, BMI, hypertension, diabetes, cancer, lung disease, heart disease, stroke, arthritis, dyslipidemia, kidney disease, and CES-D-10 score. The very high PEF-very high grip group was the reference; the dashed line indicates OR = 1.0. The horizontal axis is logarithmic. PEF, peak expiratory flow; ADL, activities of daily living; IADL, instrumental activities of daily living; BMI, body mass index; CES-D-10, 10-item Center for Epidemiologic Studies Depression Scale; CI, confidence interval; OR, odds ratio.

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