

Regular exercise and subsequent loss of functional independence or death among Chinese older adults with multimorbidity: a longitudinal CLHLS study

Tianzheng Lu

Guilin University

Yongbin Li

liyongbin@glu.edu.cn

Guilin University

Minghao Chen

Zhejiang University of Finance and Economics Dongfang College

Research Article

Keywords: multimorbidity, multimorbidity management, functional independence, exercise, social participation, sleep, healthy aging, CLHLS, longitudinal study

Posted Date: October 5th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-10390119/v1>

License: © ⓘ This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Additional Declarations: No competing interests reported.

Abstract

Background

Multimorbidity is linked to disability and mortality in later life, but functional trajectories vary among older adults with similar disease burden. We examined whether regular exercise, social participation, good sleep, and a cumulative score were associated with later ADL/IADL limitation or death among Chinese older adults with multimorbidity.

Methods

Using the 2008–2018 Chinese Longitudinal Healthy Longevity Survey, we constructed rolling person-period observations for three intervals. Respondents were eligible if, at interval start, they were aged 65 years or older, had ≥ 2 chronic conditions, and reported no limitations in activities of daily living (ADL) or instrumental activities of daily living (IADL). The outcome was incident ADL/IADL limitation among survivors or death before the next wave. Modified Poisson GEE models estimated adjusted risk ratios (RRs). Sensitivity analyses adjusted for health indicators, applied inverse-probability weighting (IPW) for follow-up availability, used logistic regression, and excluded mobility items closely related to exercise.

Results

The analytic file included 1,241 person-intervals from 1,045 respondents; 696 adverse transitions occurred. Regular exercise was associated with lower risk of the composite adverse transition (RR 0.87, 95% CI 0.78–0.96; $P = 0.007$). Model-standardized risks were 52.5% with regular exercise and 60.5% without it (risk difference – 8.0 percentage points, 95% CI – 13.8 to – 2.2). The association remained after health-reserve adjustment (RR 0.89), IPW (RR 0.87), and exclusion of walking, carrying, and crouching/standing items (RR 0.84). Social participation, sleep, and the resource score were not independently associated with the outcome. Associations were concentrated in IADL and community-function transitions, and interval-specific estimates suggested possible temporal heterogeneity.

Conclusions

Among Chinese older adults with multimorbidity who were functionally independent at interval start, regular exercise was associated with a modestly lower risk of ADL/IADL limitation or death by the next survey wave. The association remained after measured health-reserve adjustment, IPW, and exclusion of mobility items closely related to exercise. These observational findings support further study of exercise as a potential component of functional-maintenance strategies in this population, while causal interpretation remains limited.

Background

Multimorbidity, usually defined as the coexistence of two or more chronic conditions, is a defining challenge of population aging. It complicates clinical decision-making, increases treatment burden, and is associated with disability, frailty, cognitive impairment, care dependence, and mortality [1–3]. Healthy-aging frameworks, however, emphasize that health in later life should not be judged by disease counts alone. Functional ability, the capacity to do what people have reason to value in their everyday environments, is central to quality of life and care need [4–6].

This distinction is especially important in very old populations, where eliminating disease is often unrealistic and preserving everyday function is a central care priority. Older adults with multimorbidity may need medication management, symptom control, rehabilitation, social support, and environmental adaptation at the same time. Disease counts identify burden, but they do not explain why some people remain able to bathe, dress, shop, cook, walk outside, and participate in community life while others with a similar burden lose independence. Functional transition is therefore directly relevant to geriatric research and practice.

Older adults with multimorbidity are not functionally homogeneous. Some maintain self-care, mobility, and instrumental independence despite multiple chronic conditions, whereas others experience rapid functional decline. This heterogeneity raises a practical question: which potentially modifiable behavioral and social factors are related to avoiding loss of daily independence after chronic disease has accumulated? ADL and IADL measures are useful for this question because they capture self-care, independent living, and community-function capacities that are directly relevant to older adults, families, clinicians, and community services [7–9].

In this study, functional maintenance is operationalized as an observed transition rather than as an unobserved resilience trait. Among older adults who already have multimorbidity and are functionally independent at the beginning of a survey interval, the key question is whether they remain free of ADL/IADL limitation and alive by the next wave. This approach is more conservative than a cross-sectional comparison because resources are measured before follow-up and the analysis distinguishes prevalent independence from subsequent transition.

Prior research suggests that physical activity, social participation, and sleep may each support later-life functioning. Physical activity can support strength, balance, mobility, cardiometabolic health, and chronic disease management [10–14]. Social participation may provide routine, identity, cognitive stimulation, emotional support, and opportunities to remain active outside the home [15–18]. Sleep is linked with recovery, symptom burden, emotional regulation, metabolic processes, and mortality risk [19–24]. These domains are attractive in public health because they are not simply biomarkers: they can potentially be supported through community programs, age-friendly environments, and chronic disease management.

These factors may also overlap. Social participation can involve walking, travel outside the home, role performance, and exposure to health information. Exercise may improve sleep through circadian,

metabolic, and mood pathways. Good sleep may make activity and participation more feasible by reducing fatigue and improving daytime function. Conversely, poor function may reduce all three factors, creating a downward cycle in which disability limits activity, social contact, and sleep quality. This interdependence makes it tempting to summarize them as a cumulative score, but it also creates a methodological challenge: cross-sectional accumulation may partly reflect underlying functional status rather than a prospective association with lower transition risk. Related longitudinal studies have examined multimorbidity resilience and trajectories of social participation or frailty in older-adult cohorts, supporting attention to these patterns over time [25, 26].

Recent CLHLS and related older-adult cohort studies have examined physical activity, lifestyle, frailty trajectories, frailty transitions, social isolation, healthy-aging scores, and mortality [27–34]. However, these studies have generally focused on mortality, frailty, healthy-aging trajectories, social isolation, or prevalent functional status rather than death-inclusive loss of ADL/IADL independence among older adults who are already multimorbid and functionally independent at interval start.

The present study was designed to address this gap by defining a prospective at-risk population. Its target population is deliberately restricted to older adults with multimorbidity who have not yet crossed the functional-limitation threshold at the start of each interval. This restriction creates an at-risk population for loss of independence and avoids mixing prevalent disability with incident decline. Incorporating death into the primary outcome is also important because mortality is a competing endpoint for functional maintenance. Treating deaths as missing observations would make the healthiest surviving subgroup appear more stable than the original at-risk population.

This study used CLHLS 2008–2018 data to examine whether regular exercise, social participation, good sleep, and their cumulative score were associated with incident functional limitation or death among older adults with multimorbidity who were functionally independent at the start of each follow-up interval.

Methods

Data Source

Data came from the Chinese Longitudinal Healthy Longevity Survey (CLHLS) 2008–2018 longitudinal release. The CLHLS is a population-based survey of health, longevity, family circumstances, socioeconomic status, health behaviors, chronic disease, and functional status among older adults in China [35–37]. The 2008–2018 file follows respondents interviewed in 2008 through the 2011/2012, 2014, and 2018 waves and includes information on survivors, deceased respondents, and loss to follow-up. The original CLHLS obtained informed consent and ethical approval through the survey team. The present study used de-identified secondary data and is reported in accordance with STROBE principles for observational studies [38].

The CLHLS supports this transition analysis in three ways. First, it includes repeated measures of chronic disease, functional status, health behaviors, sleep, and social activities, allowing exposure status and independence to be assessed before each follow-up interval. Second, the survey includes mortality information for deceased respondents, which is essential when studying maintenance of independence in an older population. Third, the long observation window from 2008 to 2018 permits a transition framework rather than a single baseline-to-endpoint contrast, allowing respondents who remained independent after one wave to contribute later risk intervals.

Study Design and Analytic Sample

We constructed a rolling person-period transition file for three intervals: 2008 to 2011/2012, 2011/2012 to 2014, and 2014 to 2018. At each interval start, respondents were eligible if they were aged 65 years or older, had multimorbidity, and reported no ADL or IADL limitation. Respondents could contribute more than one interval if they remained observed, alive, multimorbid, and functionally independent at the start of the next interval. Intervals were excluded when interval-start exposure or covariate information was missing, when respondents were lost to follow-up before the next wave, or when follow-up functional status was unavailable among survivors. The final analytic file therefore represents observed transitions from an independent multimorbid state to either maintained independence, incident limitation, or death. This design treats functional independence as a dynamic state that can be maintained or lost over successive survey intervals rather than as a single cross-sectional classification.

The rolling design differs from a conventional baseline cohort in which all eligible participants are defined once and followed until the end of the study. Here, eligibility was re-evaluated at the start of each interval. For example, a respondent who was multimorbid and independent in 2008 could contribute the 2008–2011/2012 interval; if still alive, observed, multimorbid, and independent in 2011/2012, the same respondent could contribute the next interval. This approach increases the use of available longitudinal information while preserving temporal ordering because exposures and covariates are measured at the start of each interval and outcomes are measured after that point.

This design was chosen because functional independence among older adults is not a permanent baseline characteristic. A person who is independent in 2008 but develops limitation by 2011/2012 is no longer at risk of incident limitation in the same way at the next interval start. Conversely, a person who remains independent can continue to be observed as being at risk for future transition. By conditioning interval entry on current independence, the analysis focuses on predictors of maintaining independence rather than predictors of having ever been independent at baseline.

Measures

Multimorbidity was defined as two or more chronic conditions at the interval start [1–3]. Chronic conditions were counted from self-reported disease items available across the relevant waves, including

hypertension, diabetes, heart disease, stroke or cerebrovascular disease, respiratory disease, cancer, gastric or duodenal ulcer, Parkinson disease, arthritis, dementia, and chronic nephritis. A stricter threshold of three or more chronic conditions was examined in sensitivity analysis.

A count-based definition was used because it is widely applied in multimorbidity research and is feasible in large population surveys. The threshold of two or more chronic conditions identifies the broad population with multimorbidity, while the stricter threshold of three or more conditions tests whether results are similar among respondents with heavier disease accumulation. The analysis did not weight individual diseases by severity because comparable severity information was not available across all waves. This means the chronic disease count should be interpreted as a measure of disease burden rather than a full clinical profile.

Functional independence was defined as reporting no limitation in ADL or IADL items at the interval start. ADL items included bathing, dressing, toileting, indoor transferring, continence, and feeding. IADL and mobility-related items included going outside to visit neighbors, shopping, cooking, washing clothes, walking one kilometer, carrying weight, crouching and standing, and taking public transportation. The primary outcome was a composite adverse transition by the next wave: incident ADL/IADL limitation among survivors or death before the next survey. This composite reflects the fact that death is incompatible with maintaining functional independence and should not be treated as ordinary missingness in this research question.

The ADL and IADL items represent complementary dimensions of independence. ADL limitations reflect difficulty with basic self-care, whereas IADL and mobility limitations often appear earlier and indicate difficulty maintaining daily life in the community. Combining both domains creates a sensitive definition of loss of functional independence. The composite outcome was intentionally defined as adverse transition rather than disability alone. In older cohorts, excluding deaths can introduce survivor bias because individuals who die before follow-up cannot be classified as maintaining independence. A survivor-only functional-limitation model was therefore used as a sensitivity analysis rather than as the primary outcome.

The main exposures were social participation, regular exercise, and good sleep measured at the interval start. Social participation was coded as current participation in social activities at any reported frequency. Regular exercise was coded from the current exercise item. Good sleep required acceptable sleep quality and usual sleep duration of 6–9 hours. A cumulative resource score summed these three binary indicators, ranging from 0 to 3. Covariates included age, sex, rural residence, education, current marital status, logged household income, chronic disease count, and survey interval.

The exposure definitions were intentionally simple and reproducible across waves. Social participation was treated as any current activity because the available measure was not detailed enough to reliably distinguish social role quality, frequency, or activity type across the analytic intervals. Regular exercise captured whether respondents reported exercising currently; it did not measure duration, intensity, or exercise modality. Good sleep combined subjective sleep quality with a usual sleep duration range of 6–

9 hours to avoid classifying very short or very long sleep as favorable. These broad measures are appropriate for population surveillance but cannot identify the specific dose or type of resource most relevant to lower transition risk.

For reproducibility, social participation was coded as 1 when respondents reported taking part in social activities at any frequency and 0 when they reported never participating. Regular exercise was coded as 1 for respondents who reported currently exercising regularly and 0 otherwise. Sleep quality was treated as acceptable when respondents rated their sleep as good, very good, or fair/so-so, and usual sleep duration was treated as favorable when it was 6–9 hours per day. The good-sleep indicator required both acceptable subjective quality and favorable duration. These cut points were chosen before modeling and were kept constant across all survey intervals.

Covariates were selected a priori based on their likely associations with both resources and functional transition. Age and sex capture major demographic gradients in disability and mortality. Rural residence, education, marital status, and household income capture social and economic conditions that may influence activity opportunities, health care access, and support. Chronic disease count adjusts for disease burden within the multimorbid population. Interval indicators adjust for differences in calendar period, follow-up length, cohort aging, and survey wave conditions.

Statistical Analysis

Descriptive statistics summarized interval-start characteristics by subsequent event status. The primary model used modified Poisson generalized estimating equations (GEE) with a log link, independence working correlation, respondent-level clustering, and robust sandwich standard errors to estimate risk ratios (RRs) for adverse transition by the next observed wave [39, 40]. This approach was chosen because the composite outcome was common and odds ratios would overstate the relative risk. The primary model included social participation, regular exercise, and good sleep simultaneously and adjusted for age, sex, rural residence, education, marital status, logged household income, chronic disease count, and interval indicators. A separate secondary model replaced the three indicators with the cumulative resource score.

The estimand was a wave-to-wave adverse transition rather than a continuous-time hazard. Exact timing of functional limitation was unavailable, and exact death timing was not consistently available in the analytic release. The models therefore estimate whether an interval-start resource was associated with functional limitation or death by the next observed survey wave, not the instantaneous rate of transition.

Adjusted absolute risks were estimated by standardization. For regular exercise, the fitted modified Poisson model was used to predict the composite outcome twice for every analytic interval, first setting exercise to 0 and then setting exercise to 1 while leaving all other covariates at their observed values. Predicted risks were averaged over the analytic sample, and the adjusted risk difference was calculated as the standardized risk under exercise minus the standardized risk under no exercise. Confidence

intervals for standardized risks and risk differences were calculated using the delta method with the robust sandwich covariance matrix.

Targeted robustness analyses evaluated whether the exercise association was sensitive to measured health status, observed follow-up, model choice, outcome construction, follow-up interval, or multimorbidity threshold. The enhanced health-reserve model added self-rated health, interviewer-rated health, orientation score, verbal fluency, body mass index, current smoking, current drinking, visual function, interviewer-assessed hearing, and recent serious illness count. Quality of life, psychological items, retrospective health change, and hospitalization count were not included in this model because they either overlapped conceptually with well-being, could capture incipient decline, or had weaker availability across intervals.

IPW analyses assessed the influence of excluding complete at-risk intervals without observed follow-up outcomes. The probability of observed follow-up was modeled using interval-start demographic, socioeconomic, disease-burden, resource, and health-reserve variables. Missing predictor values were imputed to medians with missingness indicators. Because the attrition prediction model showed instability with a standard logistic specification, the final weights were generated using a lightly regularized binomial generalized linear model with a ridge penalty; this model was used only to predict observed-follow-up probability, not to interpret attrition predictors. Predictions were bounded away from 0 and 1, stabilized weights were calculated from the marginal observed-follow-up probability, and the main IPW sensitivity analysis trimmed weights at the 5th and 95th percentiles. IPW models used the same modified Poisson GEE structure, with trimmed stabilized weights entered as model weights. Logistic regression with respondent-clustered standard errors was retained as an odds-ratio sensitivity analysis for comparability with earlier models.

Outcome-boundary analyses examined whether the exercise association depended on functional items closest to the exposure. We redefined the composite outcome after excluding walking one kilometer, carrying 5 kg, and crouching/standing items; constructed a community/domestic IADL-or-death outcome using going outside to visit neighbors, shopping, cooking, washing clothes, public transportation, and death; and examined survivor-only community/domestic IADL, physical mobility, domestic IADL, basic ADL, and death-only outcomes. Leave-one-item-out analyses were used as a further diagnostic.

Temporal consistency was evaluated by estimating interval-specific RRs for the 2008–2011/2012, 2011/2012–2014, and 2014–2018 intervals and by testing exercise-by-interval interaction terms. Additional sensitivity analyses changed the multimorbidity threshold from at least two to at least three chronic conditions. No adjustment was made for multiple comparisons. Secondary, outcome-component, and leave-one-item-out analyses were interpreted as exploratory assessments of consistency and boundary conditions rather than independent confirmatory hypothesis tests. Complete-case models were used for the primary analysis because the exposure and transition definitions

depended on observed interval-start and follow-up survey responses. Analyses were conducted using Python with pandas and statsmodels.

Codex and ChatGPT (OpenAI; accessed in 2026) were used to assist with drafting and revising Python code, formatting checks, and language refinement. The authors executed the code, reviewed the analysis outputs, and verified the reported results and manuscript text.

Results

Sample Construction and Event Incidence

The rolling sample construction is shown in Fig. 1. Across the 2008, 2011/2012, and 2014 interval starts, 30,617 potential interval-start records were screened. After applying the age, chronic disease, multimorbidity, functional-independence, complete-data, and observed follow-up criteria, the final analytic file included 1,241 person-interval observations from 1,045 respondents.

Figure 1. Sample selection flow.

Legend: Selection of eligible rolling person-period observations from CLHLS 2008–2018. ADL, activities of daily living; IADL, instrumental activities of daily living. Eligibility was re-evaluated at each interval start.

Across the three follow-up intervals, 696 composite events occurred, including 527 incident functional limitations among survivors and 169 deaths before the next wave. Event counts were substantial in each interval, with 361 events from 2008 to 2011/2012, 198 from 2011/2012 to 2014, and 137 from 2014 to 2018 (Table 1).

A diagnostic comparison of complete at-risk intervals with and without observed follow-up outcomes is provided in Supplementary Table S6 in Additional file 1. Included and excluded intervals were similar in age, chronic disease count, good sleep, and resource score. Excluded intervals were somewhat more often female, less often rural, and had slightly higher education, underscoring that loss to follow-up may not be completely random.

Overall, 56.1% of person-intervals ended in the composite adverse transition. Functional limitation accounted for most events, and deaths represented nearly one quarter of the composite outcome.

The number of at-risk intervals declined over time, from 645 in 2008–2011/2012 to 374 in 2011/2012–2014 and 222 in 2014–2018. This decline is expected in an older multimorbid cohort because respondents may die, develop functional limitations, be lost to follow-up, or no longer meet all interval-start eligibility criteria. The proportion experiencing an adverse transition before the next observed wave was 56.0% in 2008–2011/2012, 52.9% in 2011/2012–2014, and 61.7% in 2014–2018, suggesting that adverse transitions remained common throughout the study window rather than being concentrated in a single wave.

Table 1
Events by follow-up interval

From wave	To wave	At-risk intervals	Composite events	Deaths	Functional limitation
2008	2011/2012	645	361	93	268
2011/2012	2014	374	198	45	153
2014	2018	222	137	31	106

Interval-Start Characteristics

Intervals ending in functional limitation or death began at older ages and were more often rural, less educated, and unmarried. Regular exercise was reported in 61.5% of intervals without a subsequent event compared with 51.1% of intervals with an event. Differences for social participation and good sleep were smaller (Table 2).

Event intervals began at a mean age of 78.5 years, compared with 73.6 years for intervals without an event. They also had lower mean education and a lower proportion of currently married respondents. Chronic disease count was similar between groups.

The descriptive resource pattern was strongest for regular exercise. Social participation was slightly less common in event intervals than non-event intervals, but the difference was modest. Good sleep was also similar between groups. The mean cumulative resource score differed only slightly between event and non-event intervals.

Table 2
Interval-start characteristics by subsequent event status

Characteristic	Overall	No event	Event
Age, years	76.3 (7.5)	73.6 (6.0)	78.5 (7.9)
Female	552 (44.5%)	221 (40.6%)	331 (47.6%)
Rural residence	551 (44.4%)	219 (40.2%)	332 (47.7%)
Education, years	4.0 (4.3)	4.8 (4.3)	3.4 (4.1)
Currently married	765 (61.6%)	381 (69.9%)	384 (55.2%)
Chronic disease count	2.4 (0.7)	2.4 (0.7)	2.4 (0.7)
Social participation	349 (28.1%)	164 (30.1%)	185 (26.6%)
Regular exercise	691 (55.7%)	335 (61.5%)	356 (51.1%)
Good sleep	773 (62.3%)	347 (63.7%)	426 (61.2%)
Resource score	1.5 (0.9)	1.6 (0.9)	1.4 (0.9)
Note: Values are mean (SD) for continuous variables and n (%) for categorical variables.			

Primary Modified Poisson/GEE Associations

Regular exercise was the only individual resource independently associated with the composite outcome in the primary modified Poisson GEE model. Intervals with regular exercise had a lower risk of subsequent ADL/IADL limitation or death than intervals without regular exercise (RR 0.87, 95% CI 0.78–0.96; $P = 0.007$). Social participation (RR 1.02, 95% CI 0.91–1.14) and good sleep (RR 1.00, 95% CI 0.91–1.10) were not independently associated with the composite outcome. The resource score estimate was below 1.00 but did not reach statistical significance (RR per additional resource 0.96, 95% CI 0.91–1.01; $P = 0.125$) (Table 3).

Table 3
Adjusted associations between resources and subsequent functional limitation or death

Exposure/model	Adjusted RR (95% CI)	P value
Social participation	1.02 (0.91–1.14)	0.792
Regular exercise	0.87 (0.78–0.96)	0.007
Good sleep	1.00 (0.91–1.10)	0.961
Resource score, per additional resource	0.96 (0.91–1.01)	0.125

Note: Modified Poisson generalized estimating equation models with respondent clustering. Models adjusted for age, sex, rural residence, education, marital status, logged household income, chronic disease count, and interval. Individual resources were mutually adjusted. The score model used the three-item resource score.

Standardized Risks, Robustness Checks, and Outcome Boundaries

Standardized risks provided an absolute scale for the primary exercise association. In the primary model, the adjusted risk of ADL/IADL limitation or death was 60.5% when intervals were standardized to no regular exercise and 52.5% when standardized to regular exercise. This corresponded to an adjusted risk difference of – 8.0 percentage points (95% CI – 13.8 to – 2.2). In the health-reserve model, the corresponding adjusted risks were 59.4% and 52.8%, with a risk difference of – 6.6 percentage points (95% CI – 12.7 to – 0.4) (Table 4).

Key robustness checks supported the exercise association. After adjustment for measured health-reserve indicators, the exercise RR was 0.89 (95% CI 0.80–0.99). In IPW analysis for observed follow-up, the RR was 0.87 (95% CI 0.78–0.96), and in the model combining IPW with health-reserve adjustment, the RR was 0.89 (95% CI 0.80–0.99). The logistic regression sensitivity analysis gave an OR of 0.68 (95% CI 0.51–0.89) (Table 5).

Outcome-boundary analyses addressed whether the association merely reflected overlap between self-reported regular exercise and mobility-related functional items. After excluding walking one kilometer, carrying 5 kg, and crouching/standing from the composite outcome, regular exercise remained associated with lower transition risk (RR 0.84, 95% CI 0.73–0.97). When the outcome was limited to community/domestic IADL or death, the RR was 0.83 (95% CI 0.72–0.96). Among survivors, the association was evident for community/domestic IADL limitation (RR 0.81, 95% CI 0.67–0.98), but not for domestic IADL alone.

Table 4
Standardized adjusted risks for regular exercise

Model and scenario	Adjusted risk (95% CI)	Risk difference (95% CI)	N intervals
Primary model: no regular exercise	60.5% (56.3–64.6%)	Reference	1241
Primary model: regular exercise	52.5% (48.9–56.1%)	–8.0 pp (– 13.8 to – 2.2)	1241
Health-reserve model: no regular exercise	59.4% (55.1–63.7%)	Reference	1184
Health-reserve model: regular exercise	52.8% (49.1–56.6%)	–6.6 pp (– 12.7 to – 0.4)	1184
Note: Standardized risks were estimated from modified Poisson models by setting regular exercise to 0 or 1 for all analytic intervals and averaging predictions over the observed covariate distribution. Risk differences are exercise minus no exercise.			

The association was not evident for basic ADL limitation or death considered separately. The RR was 1.19 (95% CI 0.80–1.75) for incident basic ADL limitation among survivors, 0.95 (95% CI 0.77–1.19) for basic ADL limitation or death, and 0.82 (95% CI 0.61–1.10) for death only.

Interval-specific models showed that the pooled association was not fully temporally uniform. The exercise RR was 0.80 (95% CI 0.69–0.92) in the 2008–2011/2012 interval, 0.98 (95% CI 0.80–1.20) in the 2011/2012–2014 interval, and 0.87 (95% CI 0.69–1.09) in the 2014–2018 interval. Interaction tests provided borderline evidence of interval heterogeneity, with P values ranging from approximately 0.043 to 0.072 across base, IPW, and health-reserve models.

The stricter multimorbidity sensitivity analysis using at least three chronic conditions produced an exercise estimate below 1.00 but with a wide confidence interval, reflecting the smaller analytic sample. Exact follow-up dates were complete among survivors but were not consistently available for deaths; therefore, the death-inclusive primary analysis remained a wave-to-wave transition model rather than a continuous-time survival model.

Table 5
Key robustness and boundary analyses for regular exercise

Analysis	Metric	Estimate (95% CI)	P value	N intervals	Events
Primary composite model	RR	0.87 (0.78–0.96)	0.007	1241	696
Health-reserve adjusted model	RR	0.89 (0.80–0.99)	0.033	1184	662
IPW model	RR	0.87 (0.78–0.96)	0.007	1241	696
IPW + health-reserve model	RR	0.89 (0.80–0.99)	0.031	1184	662
Excluding walking/carrying/crouching	RR	0.84 (0.73–0.97)	0.015	1241	513
Community/domestic IADL or death	RR	0.83 (0.72–0.96)	0.010	1241	490
Community/domestic IADL among survivors	RR	0.81 (0.67–0.98)	0.027	1072	321
Basic ADL among survivors	RR	1.19 (0.80–1.75)	0.387	1072	116
Basic ADL or death	RR	0.95 (0.77–1.19)	0.679	1241	285
Death only	RR	0.82 (0.61–1.10)	0.189	1241	169

Figure 2. Regular exercise and adverse transitions.

Legend: Adjusted risk ratios for regular exercise from primary, robustness, outcome-boundary, and interval-specific modified Poisson/GEE models. Risk ratios are plotted on a logarithmic scale with 95% confidence intervals. Composite event was defined as incident ADL/IADL limitation among survivors or death before the next wave. ADL, activities of daily living; GEE, generalized estimating equation; IADL, instrumental activities of daily living; IPW, inverse-probability weighting; RR, risk ratio.

Discussion

This longitudinal CLHLS study examined wave-to-wave functional transitions among Chinese older adults with multimorbidity who were functionally independent at interval start. The main finding was that regular exercise was associated with a modestly lower risk of subsequent ADL/IADL limitation or death. The association was retained after adjustment for measured health reserve, inverse-probability weighting for observed follow-up, and exclusion of the walking, carrying, and crouching/standing items

most closely related to exercise. Social participation, good sleep, and the cumulative resource score were not independently associated with the composite outcome.

The magnitude of the association was more modest than the odds-ratio scale suggested. In the primary modified Poisson/GEE model, regular exercise was associated with an approximately 13% lower relative risk of the broad adverse transition. On the standardized absolute scale, the adjusted transition risk was 52.5% under regular exercise versus 60.5% under no regular exercise. After health-reserve adjustment, the corresponding risk difference was – 6.6 percentage points. These estimates are easier to interpret than odds ratios because the outcome was common.

Outcome-boundary analyses gave similar estimates after removing functional items most similar to exercise. The association persisted after excluding walking one kilometer, carrying 5 kg, and crouching/standing from the composite outcome. Similar patterns were observed for community/domestic IADL or death and for community/domestic IADL limitation among survivors. These findings suggest that the result was not limited to later reporting of difficulty with physical-performance items.

Outcome decomposition also narrowed the interpretation. Estimates were not clearly lower for basic ADL limitation among survivors, basic ADL limitation or death, death alone, or domestic IADL alone. The association was concentrated in IADL and community-function transitions rather than across all functional or mortality outcomes.

Interval-specific estimates were heterogeneous. The pooled association represented an average across follow-up intervals and was not fully temporally uniform. The association was strongest in the 2008-start interval, whereas estimates for later intervals were less precise and the 2011/2012-start estimate was close to the null. Interaction tests provided borderline evidence of interval heterogeneity. This pattern could reflect differences in sample composition, calendar period, follow-up conditions, measurement, or random variation as the risk set became smaller in later intervals.

This study adds to the CLHLS and physical-activity literature by focusing on a specific transition state rather than on prevalent limitation, mortality, frailty change, or broad activity-health associations across older populations with mixed baseline function [27–35]. By requiring multimorbidity and full ADL/IADL independence at each interval start, and by treating death as part of the adverse transition, this analysis asked which simple factors were associated with preserving independence before disability emerged. The contribution is an estimate of death-inclusive functional transition in a clinically vulnerable at-risk population.

The exercise finding is biologically plausible but remains observational. Physical activity can support muscle strength, balance, walking capacity, cardiometabolic regulation, and chronic disease management [10–14]. The CLHLS exercise item, however, did not measure duration, intensity, frequency, exercise type, supervision, or safety adaptation. Reporting regular exercise may also indicate better unmeasured physical reserve, less pain, better symptom control, safer environments, or greater access

to activity opportunities. Even after health-reserve adjustment, residual confounding and reverse selection remain possible.

The non-significant findings for social participation, good sleep, and resource accumulation should also be interpreted carefully. They do not show that social connection or sleep are irrelevant to healthy aging. Rather, the available CLHLS indicators were broad binary measures. Social participation may differ by frequency, role meaning, physical demands, accessibility, and whether activities involve movement outside the home. Sleep may differ by insomnia symptoms, fragmentation, pain, nocturia, medication use, and disease-related disruption. A simple unweighted resource score may dilute a stronger exercise signal by combining indicators with different meanings.

The findings are relevant to multimorbidity management because they point to functional maintenance as a care priority alongside disease control. Regular exercise should be interpreted as a marker of lower transition risk and as a topic for further intervention research, rather than as a uniform prescription. For older adults with multimorbidity, future activity-support strategies may need to consider symptom control, fall-risk assessment, rehabilitation referral, supervised or home-based exercise, assistive devices, and safer community environments.

Strengths of the study include the rolling risk-set design, restriction to functionally independent participants at each interval start, inclusion of death in the primary outcome, reporting of risk ratios and standardized risks, and targeted sensitivity analyses for measured health reserve, observed follow-up, outcome construction, and interval heterogeneity. These features make the analysis a temporally ordered test of functional transition rather than a description of prevalent independence.

This study also has several limitations. Chronic diseases, behaviors, sleep, and functional limitations were self-reported. Disease severity, pain, medication burden, depressive symptoms, physical performance, neighborhood environment, rehabilitation access, and family caregiving were not fully measured. Exact dates of functional limitation were unavailable, and exact death timing was not consistently available in the analytic release, so the analysis estimated wave-to-wave transitions rather than continuous-time hazards. Complete-case analysis and loss to follow-up may still introduce bias, although IPW did not materially change the exercise estimate. Finally, the exercise measure was broad and could not identify dose, type, intensity, or safety.

Taken together, the results indicate that, among functionally independent older adults with multimorbidity, regular exercise was the most consistent measured prospective marker of lower broad adverse transition risk. The evidence was concentrated in IADL and community-function domains and varied across follow-up intervals. Future work should test more detailed activity measures and interventions that account for multimorbidity severity, safety, environment, and functional goals.

Conclusions

Among Chinese older adults with multimorbidity who were functionally independent at interval start, regular exercise was associated with a modestly lower risk of ADL/IADL limitation or death by the next observed survey wave. The association remained after adjustment for measured health reserve, inverse-probability weighting for observed follow-up, and exclusion of mobility items closely related to exercise. Associations were evident mainly for IADL and community-function transitions, not for basic ADL limitation or death alone, and interval-specific analyses suggested possible temporal heterogeneity. These observational findings support further study of exercise-sensitive functional maintenance in multimorbid older adults, while causal interpretation remains limited.

Abbreviations

ADL

activities of daily living

CI

confidence interval

CLHLS

Chinese Longitudinal Healthy Longevity Survey

GEE

generalized estimating equation

IADL

instrumental activities of daily living

IPW

inverse-probability weighting

OR

odds ratio

RR

risk ratio

STROBE

Strengthening the Reporting of Observational Studies in Epidemiology.

Declarations

Clinical trial number: not applicable.

Ethics approval and consent to participate

The CLHLS was approved by the Biomedical Ethics Committee of Peking University (IRB00001052–13074), and informed consent was obtained from participants or their proxy respondents by the original survey team. The present analysis used de-identified secondary data and did not involve new contact with human participants.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

Funding

Author Contribution

TL: conceptualization, methodology, software, formal analysis, data curation, visualization, writing-original draft, writing-review and editing, and project administration. YL: supervision, conceptualization, validation, interpretation of findings, writing-review and editing, critical revision of the manuscript, and correspondence. MC: validation, interpretation of findings, writing-review and editing, and critical revision of the manuscript. All authors approved the submitted version and agree to be accountable for the content of the work.

Acknowledgement

The authors thank the CLHLS research team and all participants for making this study possible. During manuscript preparation, Codex was used to assist with drafting and debugging Python code for author-specified data processing and statistical analyses, and ChatGPT was used for language and formatting review. The authors executed and verified all code and outputs, determined all data-processing decisions, model specifications, interpretations, and conclusions, and take full responsibility for the manuscript.

Data Availability

The datasets analyzed during the current study are available from the Peking University Open Research Data Platform in the Chinese Longitudinal Healthy Longevity Survey (CLHLS)-Longitudinal Data (1998–2018), <https://doi.org/10.18170/DVN/WB07LK>, subject to registration and applicable data-use requirements. Analysis code and derived non-identifiable tables are available from the corresponding author upon reasonable request, where permitted by the data-use agreement.

References

1. Barnett K, Mercer SW, Norbury M, Watt G, Wyke S, Guthrie B. Epidemiology of multimorbidity and implications for health care, research, and medical education: a cross-sectional study. *Lancet*.

- 2012;380:37–43. 10.1016/S0140-6736(12)60240-2.
2. Skou ST, Mair FS, Fortin M, Guthrie B, Nunes BP, Miranda JJ, et al. Multimorbidity Nat Rev Dis Primers. 2022;8:48. 10.1038/s41572-022-00376-4.
 3. Marengoni A, Angleman S, Melis R, Mangialasche F, Karp A, Garmen A, et al. Aging with multimorbidity: a systematic review of the literature. Ageing Res Rev. 2011;10:430–9. 10.1016/j.arr.2011.03.003.
 4. World Health Organization. World report on ageing and health. Geneva: World Health Organization. 2015. Available from: <https://www.who.int/publications/i/item/9789241565042>. Accessed 4 July 2026.
 5. World Health Organization. Decade of Healthy Ageing: baseline report. Geneva: World Health Organization. 2020. Available from: <https://www.who.int/publications/i/item/9789240017900>. Accessed 4 July 2026.
 6. Beard JR, Officer A, de Carvalho IA, Sadana R, Pot AM, Michel JP, et al. The World report on ageing and health: a policy framework for healthy ageing. Lancet. 2016;387:2145–54. 10.1016/S0140-6736(15)00516-4.
 7. Katz S, Ford AB, Moskowitz RW, Jackson BA, Jaffe MW. Studies of illness in the aged. The index of ADL: a standardized measure of biological and psychosocial function. JAMA. 1963;185:914–9. 10.1001/jama.1963.03060120024016.
 8. Lawton MP, Brody EM. Assessment of older people: self-maintaining and instrumental activities of daily living. Gerontologist. 1969;9:179–86. 10.1093/geront/9.3_Part_1.179.
 9. Verbrugge LM, Jette AM. The disablement process. Soc Sci Med. 1994;38:1–14. 10.1016/0277-9536(94)90294-1.
 10. Bull FC, Al-Ansari SS, Biddle S, Borodulin K, Buman MP, Cardon G, et al. World Health Organization 2020 guidelines on physical activity and sedentary behaviour. Br J Sports Med. 2020;54:1451–62. 10.1136/bjsports-2020-102955.
 11. Cunningham C, O'Sullivan R, Caserotti P, Tully MA. Consequences of physical inactivity in older adults: a systematic review of reviews and meta-analyses. Scand J Med Sci Sports. 2020;30:816–27. 10.1111/sms.13616.
 12. McPhee JS, French DP, Jackson D, Nazroo J, Pendleton N, Degens H. Physical activity in older age: perspectives for healthy ageing and frailty. Biogerontology. 2016;17:567–80. 10.1007/s10522-016-9641-0.
 13. Chodzko-Zajko WJ, Proctor DN, Fiatarone Singh MA, Minson CT, Nigg CR, Salem GJ, et al. Exercise and physical activity for older adults. Med Sci Sports Exerc. 2009;41:1510–30. 10.1249/MSS.0b013e3181a0c95c.
 14. Lee IM, Shiroma EJ, Lobelo F, Puska P, Blair SN, Katzmarzyk PT. Effect of physical inactivity on major non-communicable diseases worldwide. Lancet. 2012;380:219–29. 10.1016/S0140-6736(12)61031-9.

15. Holt-Lunstad J, Smith TB, Layton JB. Social relationships and mortality risk: a meta-analytic review. *PLoS Med.* 2010;7:e1000316. 10.1371/journal.pmed.1000316.
16. Holt-Lunstad J, Smith TB, Baker M, Harris T, Stephenson D. Loneliness and social isolation as risk factors for mortality. *Perspect Psychol Sci.* 2015;10:227–37. 10.1177/1745691614568352.
17. Douglas H, Georgiou A, Westbrook J. Social participation as an indicator of successful aging: an overview of concepts and their associations with health. *Aust Health Rev.* 2017;41:455–62. 10.1071/AH16038.
18. Tomioka K, Kurumatani N, Hosoi H. Social participation and the prevention of decline in effectiveness among community-dwelling elderly. *PLoS ONE.* 2015;10:e0139065. 10.1371/journal.pone.0139065.
19. Luyster FS, Strollo PJ, Zee PC, Walsh JK. Sleep: a health imperative. *Sleep.* 2012;35:727–34. 10.5665/sleep.1846.
20. Itani O, Jike M, Watanabe N, Kaneita Y. Short sleep duration and health outcomes: a systematic review, meta-analysis, and meta-regression. *Sleep Med.* 2017;32:246–56. 10.1016/j.sleep.2016.08.006.
21. Jike M, Itani O, Watanabe N, Buysse DJ, Kaneita Y. Long sleep duration and health outcomes: a systematic review, meta-analysis and meta-regression. *Sleep Med Rev.* 2018;39:25–36. 10.1016/j.smrv.2017.06.011.
22. Cappuccio FP, D'Elia L, Strazzullo P, Miller MA. Sleep duration and all-cause mortality: a systematic review and meta-analysis. *Sleep.* 2010;33:585–92. 10.1093/sleep/33.5.585.
23. Watson NF, Badr MS, Belenky G, Bliwise DL, Buxton OM, Buysse D, et al. Recommended amount of sleep for a healthy adult: a joint consensus statement. *Sleep.* 2015;38:843–4. 10.5665/sleep.4716.
24. Grandner MA. Sleep, health, and society. *Sleep Med Clin.* 2017;12:1–22. 10.1016/j.jsmc.2016.10.012.
25. Wister A, Li L, Whitmore C, Ferris J, Klasa K, Linkov I. Multimorbidity resilience and health behaviors among older adults: a longitudinal study using the Canadian Longitudinal Study on Aging. *Front Public Health.* 2022;10:896312. 10.3389/fpubh.2022.896312.
26. Bi Y, Hu J, Ma Y, Yin P, Wang P. Dual trajectories of social participation and frailty in Chinese older adults: a longitudinal study based on CLHLS from 2008 to 2018. *Front Public Health.* 2024;12:1401145. 10.3389/fpubh.2024.1401145.
27. Ojijieme NG, Feng T, Chui CM, Qi X, Liu Y. Physical activity dynamically moderates the impact of multimorbidity on the trajectory of healthy aging over sixteen years. *BMC Geriatr.* 2024;24:565. 10.1186/s12877-024-05067-1.
28. Tang S, Mao X, Xu J, Jiao H. Healthy lifestyle, multimorbidity and all-cause mortality among older people: a retrospective cohort study based on CLHLS 2005–2018. *BMC Geriatr.* 2025;25:644. 10.1186/s12877-025-06246-4.
29. Yang X, Wang W, Zhou W, Zhang H. Effect of leisure activity on frailty trajectories among Chinese older adults: a 16-year longitudinal study. *BMC Geriatr.* 2024;24:771. 10.1186/s12877-024-05370-x.

30. Wang Z, Ruan H, Li L, Song N, He S. Association of changes in frailty status with the risk of all-cause mortality and cardiovascular death in older people: results from the Chinese Longitudinal Healthy Longevity Survey (CLHLS). *BMC Geriatr.* 2024;24:96. 10.1186/s12877-024-04682-2.
31. Liu D, Ma Q, Zuo M, Niu Y, Wang J, Yan G. Association of 3-year change in frailty index with risk of all-cause mortality among older Chinese population: a national cohort study. *BMC Geriatr.* 2024;24:1045. 10.1186/s12877-024-05639-1.
32. Dai L, Tang Y, Guo Y, Lai X, Wang X, Li B. The association between exercise, activities, and frailty in older Chinese adults: a cross-sectional study based on the Chinese Longitudinal Healthy Longevity Survey (CLHLS) data. *BMC Geriatr.* 2025;25:131. 10.1186/s12877-025-05802-2.
33. Li Y, Jigeer G, Lv Y, Wang K, Peng Y, Sun L, et al. Social isolation and likelihood of becoming centenarians: evidence from the Chinese longitudinal healthy longevity survey. *BMC Geriatr.* 2024;24:839. 10.1186/s12877-024-05417-z.
34. Zhu C, Lian Z, Sun J, Huang Y, Li S, Zhang H, et al. Combined lifestyle habits, subjective well-being, and all-cause mortality among older adults in China. *BMC Geriatr.* 2025;25:675. 10.1186/s12877-025-06345-2.
35. Zeng Y, Feng Q, Hesketh T, Christensen K, Vaupel JW. Survival, disabilities in activities of daily living, and physical and cognitive functioning among the oldest-old in China: a cohort study. *Lancet.* 2017;389:1619–29. 10.1016/S0140-6736(17)30548-2.
36. Zeng Y. Introduction to the Chinese Longitudinal Healthy Longevity Survey (CLHLS). In: Zeng Y, Poston DL, Vlosky DA, Gu D, editors. *Healthy longevity in China*. Dordrecht: Springer; 2008. pp. 23–38. 10.1007/978-1-4020-6752-5_2.
37. Gu D. General data quality assessment of the CLHLS. In: Zeng Y, Poston DL, Vlosky DA, Gu D, editors. *Healthy longevity in China*. Dordrecht: Springer; 2008. pp. 39–60. 10.1007/978-1-4020-6752-5_3.
38. von Elm E, Altman DG, Egger M, Pocock SJ, Gøtzsche PC, Vandenbroucke JP. The STROBE statement: guidelines for reporting observational studies. *PLoS Med.* 2007;4:e296. 10.1371/journal.pmed.0040296.
39. Zou G. A modified poisson regression approach to prospective studies with binary data. *Am J Epidemiol.* 2004;159:702–6. 10.1093/aje/kwh090.
40. Liang KY, Zeger SL. Longitudinal data analysis using generalized linear models. *Biometrika.* 1986;73:13–22. 10.1093/biomet/73.1.13.

Figures



Figure 1

Sample selection flow.

Legend: Selection of eligible rolling person-period observations from CLHLS 2008–2018. ADL, activities of daily living; IADL, instrumental activities of daily living. Eligibility was re-evaluated at each interval start.

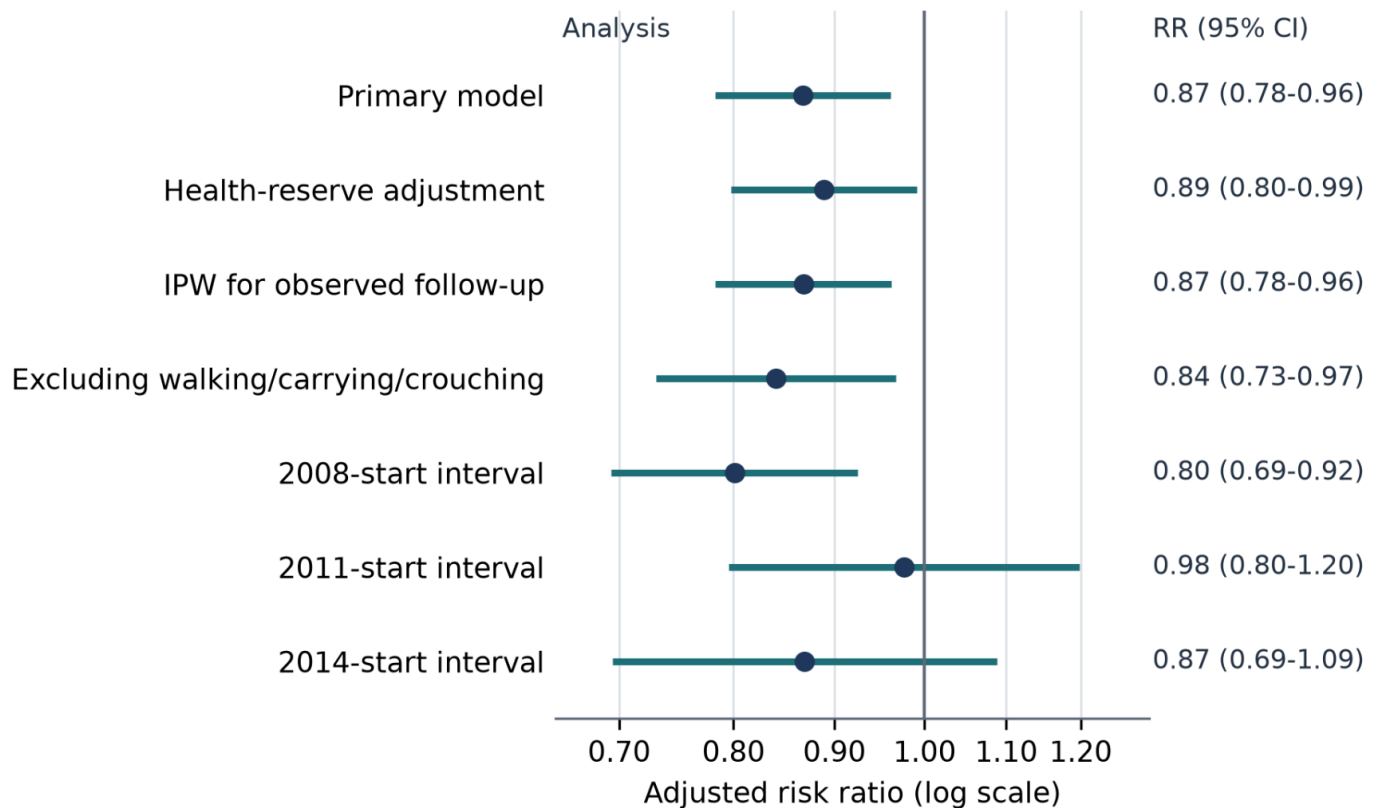


Figure 2

Regular exercise and adverse transitions.

Legend: Adjusted risk ratios for regular exercise from primary, robustness, outcome-boundary, and interval-specific modified Poisson/GEE models. Risk ratios are plotted on a logarithmic scale with 95% confidence intervals. Composite event was defined as incident ADL/IADL limitation among survivors or death before the next wave. ADL, activities of daily living; GEE, generalized estimating equation; IADL, instrumental activities of daily living; IPW, inverse-probability weighting; RR, risk ratio.

Supplementary Files

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

- [Additionalfile1.docx](#)