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Assessment of Physical Resilience Using Residual Methods and Its Association With Adverse Outcomes in Older Adults

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Abstract

Background and Objectives: Physical resilience (PR) is recognized as the ability to recover from the adverse effects of a stressor. However, there is a lack of consensus on how to optimally measure PR in older adults in general. We aimed to measure PR using residuals from regression analyses and investigated its association with adverse outcomes in older adults.

Research Design and Methods: A total of 6 508 older adults were included from the National Health and Aging Trends Study, which was a population-based prospective cohort study. PR was assessed using residual methods from a linear model regressing the short physical performance battery on clinical diseases, age, sex, race/ethnicity, and health condition. Adverse outcomes included all-cause mortality, falls, and overnight hospitalization.

Results: The mean age was 77.48 (7.84) years. Increased PR was associated with a lower risk of all-cause mortality (hazard ratio [HR] = 0.85, 95% confidence interval [CI]: 0.83–0.87). Compared to participants with reduced PR, those with normal PR had a lower risk for mortality (HR = 0.51, 95% CI: 0.46–0.56). Specifically, restricted cubic spline regression revealed a dose–response relationship between PR and all-cause mortality (*p*-overall < .0001, *p*-nonlinear = .011). Additionally, we also found significant associations of increased PR with lower risks of falls (HR = 0.98, 95% CI: 0.96–0.99) and overnight hospitalization (HR = 0.98, 95% CI: 0.97–1.00).

Discussion and Implications: PR, measured by residual methods, was robustly and independently associated with all-cause mortality, falls, and overnight hospitalization. Our findings provide evidence that this approach may be a simple and feasible strategy to assess PR.

Translational Significance: Physical resilience (PR) is the ability to recover from the adverse effects of a stressor. However, there is a lack of consensus on how to optimally measure PR and its association with adverse outcomes in older adults in general. This study assessed PR by residual methods from regression analyses, which were based on statistical thinking. We found that PR was associated with all-cause mortality, falls, and overnight hospitalization. Our findings provide evidence that this approach may be a simple and feasible strategy to assess PR in clinical practice.

Keywords: All-cause mortality, Falls, Overnight hospitalization, Physical resilience

Background and Objective

Physical resilience (PR), the ability to resist decline or recover function after experiencing the adverse effects of a stressor (1–3), has attracted increasing attention and has been recognized as a fundamental determinant of clinical outcomes (4,5). PR was proposed as the ability to mobilize physiological reserves and is expected to decline in the aging process (6). A low level of PR was reported to be a risk factor for frailty, disability, hospitalization, and mortality (7–10). Hence, it is of great importance to assess PR in older adults to contribute to decision making in healthcare, such as therapeutic decision making, acute care management, rehabilitation therapy, and assessment of adverse medication effects (3).

However, due to its dynamic and multidimensional nature, the measurement of PR may be challenging (1,6). According to the concept of PR, measuring PR requires the identification

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of a stressor followed by multiple functional observations over time (1–3). Apparently, longitudinal data with rational stressors and repeated assessments of physical function were considered indispensable for assessing PR. Additionally, restricted to unified stressors (including type, intensity, frequency, etc.), disparate levels of PR may be observed for the same individual (1). Hence, measures of PR were not usable in individuals who did not encounter stressors or provide longitudinal data. Fortunately, Sanders et al. introduced a residual approach from a linear model regressing the level of frailty on demographic characteristics, disease burdens, and symptoms to measure PR (11). That approach has been proposed as a novel approach for quantifying and classifying PR (9,12) and has also been widely applied in measuring cognitive resilience (13–16). This approach could be used to measure PR before encountering a stressor and in a cross-sectional setting. Hence, the approach using residuals from regression analyses may be a feasible strategy to measure PR. Frailty is indicated by measures of gait speed, grip strength, physical activity, usual energy level, and weight change (9,11). It is a broad concept characterized by not only decreased endurance and strength but also reduced physiological function (17). Frailty in aging marks a state of decreased reserves resulting in increased vulnerability to adverse outcomes when exposed to stressors (18). It emerges when the dysregulation of multiple interconnected physiological and biological systems crosses a threshold to critical dysfunction, severely compromising homeostasis (18–20). Therefore, it can be viewed as "a syndrome of geriatric syndromes" rather than purely physical performance. The short physical performance battery (SPPB), constructed from balance assessment, gait speed, and extremity strength, reflects more objective and direct information on physical function (21). In summary, using the SPPB score to measure PR may purely identify levels of PR.

Although previous methodological literature discussed the novel measure of PR (22), few studies evaluated the utility of the PR concept in the general population (9), and evidence for whether the approach of using residuals from regression analyses was valuable for the identification of PR among older adults in the general population was still insufficient at the time of this study. Therefore, we aimed to evaluate the applicability of assessing PR using residual methods from regressing the SPPB score on demographic characteristics, disease burdens, and symptoms and investigated its association with adverse outcomes in older adults. We first hypothesized that PR measured by residuals was a novel approach to purely measure PR and then validated its applicability by examining the associations of PR assessed by residuals with several geriatric outcomes (including mortality, falls, and overnight hospitalization) in older adults.

Research Design and Methods

Study Population

Data for this study were obtained from the National Health and Aging Trends Study (NHATS), which is a longitudinal, nationally representative survey of Medicare beneficiaries aged 65 years residing in the United States (23). We used data from 2011 Round 1 (R1) to 2018 Round 8 (R8). A total of 8 245 participants were recruited (Supplementary Figure S1). Of them, 1 737 participants without physical and/or clinical information were excluded. Finally, 6 508 participants with complete data were included. For the primary outcome, during the 8-year follow-up, 1 664 participants died. For secondary outcomes, a total of 6 180 and 6 508 participants had fall and hospitalization information and were analyzed, respectively. Among 6 180 participants who had fall information, 4 885 participants without falls in Round 1 were followed up. During the 8-year follow-up, 2 143 participants were defined as incident falls. Additionally, among 6 508 participants who had hospitalization information, 5 034 participants without hospitalization at Round 1 were followed up, and 2 143 participants were ultimately defined as having incident hospitalization. Our analysis of publicly available, deidentified data was considered exempt from institutional review board review.

Measures

Demographic variables

In NHATS, participants self-reported demographic variables. In detail, participants or proxies were asked to report birthday, race/ethnicity (White non-Hispanic, Black non-Hispanic, Hispanic, or Other), marital status (married, living with a partner, separated, divorced, widowed, or never married), sex (male or female), body mass index (BMI), and residential care status (community or other). Smoking status was also reported (current, former, or never). Specifically, we categorized marital status into married/partnered (including married and living with a partner) and single/widowed (including separated, divorced, widowed, and never married) in our analyses. BMI was divided into underweight ($BMI < 18.5$), normal ($18.5 \le BMI < 25$), overweight ($25 \le BMI < 30$), and obese ($BMI \ge 30$).

Clinical information

In this study, participants or proxies were asked to report any clinical diagnosis received, including myocardial infarction, heart disease, hypertension, arthritis, osteoporosis, diabetes, lung disease, stroke, and cancer. Additionally, self-rated health was also collected by asking "Would you say that in general, your health is excellent, very good, good, fair, or poor?"

Physical resilience

PR was measured based on a residual approach that was proposed previously, in which capturing PR is derived from the theory that persons who are resilient have the intrinsic ability to adapt to and mitigate the consequences of cumulative damage in organ systems (9,11,12). In detail, we first assessed physical function by SPPB, which is widely used in geriatric assessments and has been proven to be associated with disability, falls, cardiovascular disease, and mortality in older adults (24–27). The SPPB was scored from 0 (lowest) to 12 (highest) and included a series of 3 tests to assess objective physical function: balance assessment, gait speed, and extremity strength (21). Second, linear regression was used to regress the SPPB score (0–12) on clinical diseases (including myocardial infarction, heart disease, hypertension, arthritis, osteoporosis, diabetes, lung disease, stroke, and cancer), age, age^2, age^3, sex, race/ethnicity, and self-rated health. Finally, residuals from the regression were calculated as the difference between the predicted and actual outcome for an individual relative to the population estimate (Supplementary Figure S2). The calculated residuals were defined as PR. Individuals with better actual outcomes than predicted (higher residuals) were considered to have better PR (Supplementary Figure S3).

Outcomes

The primary outcome was all-cause mortality during the follow-up. The month and year of death were obtained from follow-up interviews. When a sample person was confirmed as deceased, typically by a family member, the last month of life portion of the sample person interview was administered (23). Person-time was calculated from the study baseline (Round 1) to the year of death, loss to follow-up, or study endpoint (Round 8).

The secondary outcomes were falls and overnight hospitalization since the Round 1 interview. In the NHATS, participants were asked whether they sustained a fall, defined as "any fall, slip or trip in which you lose your balance and land on the floor or ground or at a lower level," in the last 12 months since the last interview. Participants were defined as having experienced "any fall" if they reported a fall since the Round 1 interview. Participants were asked whether they had an overnight hospital stay within the last 12 months, that is, since the last interview. Participants were defined as having experienced "Overnight hospitalization" if they responded "Yes" to the question after the Round 1 interview.

Statistical Analysis

Continuous and categorical variables are presented as the means with standard deviation (*SD*) or frequency (%), respectively. Group differences were analyzed by chi-square or analysis of variance. We used Cox proportional hazard regressions to evaluate the association of PR with the risk of all-cause mortality, falls, and overnight hospitalization using 2 models: Model 1 was unadjusted; and Model 2 was adjusted for age, sex, BMI, smoking status, marital status, race, and care status. We divided PR into 4 categories according to quartiles (Q1: PR ≤ −1.66, Q2: −1.66 < PR ≤ 0.10, Q3: 0.10 < PR ≤ 1.85, Q4: PR > 1.85). Additionally, we also defined worse (<0) and better (≥0) PR.

For the primary outcome, we first utilized the Cox proportional hazard model to estimate the hazard ratio (HR) of all-cause mortality associated with the continuous categories and status of PR. Specifically, we describe survival curves by Kaplan–Meier survival analysis. Second, we applied restricted cubic spline regressions, with 4 knots located at the 5th, 35th, 65th, and 95th percentiles of PR, to estimate the possible nonlinear relationship between PR and all-cause mortality by adjusting for potential confounding factors (28). The test of potential nonlinearity was assessed by the chi-square test, comparing the model with only the linear term to the model that included the cubic spline terms (29,30). In these analyses, PR was analyzed as a continuous variable, and HRs and 95% confidence intervals (CIs) were calculated using the median value of PR as a reference value (0). Finally, for sensitivity analysis, we excluded participants who died within 1 year after baseline (Round 1) and then conducted Cox proportional hazard regressions, Kaplan–Meier survival analysis and restricted cubic spline regression with adjustment for confounding factors to estimate the association between PR and all-cause mortality. For secondary outcomes, we also conducted a Cox proportional hazard model to estimate the HRs of falls and overnight hospitalization associated with the continuous variables, categories, and status of PR. All test results were considered significant when associated with a p value <.05 (2-tailed). All analyses were conducted using R statistical software (version 4.1.3; www.r-project.org).

Results

Characteristics of Study Participants

In this study, we included 6 508 participants aged ≥65 years (41.87% males and 58.13% females) from the NHATS. The mean age and SPPB score were 77.48 (7.84) years and 5.99 (3.47), respectively. Of these participants, 3 925 (60.31%) participants were aged less than 80 years. During the 8-year follow-up period, 1 664 (25.57%) participants died. The more basic characteristics of the participants at baseline are presented in Table 1 and Supplementary Tables S1 and S2.

Association of PR With Risk of All-Cause Mortality

Table 2 shows the results of Cox proportional hazard analyses between PR and the risk of all-cause mortality. When examining PR as a continuous variable, we found that increased levels of PR were associated with a lower risk of all-cause mortality in the unadjusted model (HR = 0.87, 95% CI = 0.86–0.89), and the significant association persisted after adjusting for age, sex, smoking status, marital status, race/ethnicity, BMI, and care status (HR = 0.85, 95% CI = 0.83–0.87).

In further analyses, for the categorical variable of PR (Table 2), compared with the Q1 group, the Q2, Q3, and Q4 groups were associated with lower risks of all-cause mortality both in unadjusted (for Q2: HR = 0.65, 95% CI = 0.58–0.73; for Q3: HR = 0.45, 95% CI = 0.39–0.51; for Q4: HR = 0.34, 95% CI = 0.29–0.39) and adjusted models (for Q2: HR = 0.62, 95% CI = 0.55–0.72; for Q3: HR = 0.46, 95% CI = 0.40–0.53; for Q4: HR = 0.33, 95% CI = 0.29–0.39). For PR status, compared to participants with worse PR, those with normal PR had a lower risk of all-cause mortality (HR = 0.48, 95% CI = 0.44–0.53). After controlling for confounding factors, the association was still significant (HR = 0.50, 95% CI = 0.45–0.56). Figure 1 presents Kaplan–Meier curves indicating the change in the proportion of participants, stratified by the groups of PRs at baseline and followed over the study period. Additionally, to visualize the potential dose–response relationship, multivariable restricted cubic spline regression was performed to predict the HRs for all-cause mortality between the 5th and 95th percentiles of the PR (Figure 2). Interestingly, a dose–response association of PR with the risk of all-cause mortality was found (p-overall < .0001, p-nonlinear = .0113).

In the sensitivity analysis, we excluded participants who died within 1 year after baseline (Round 1) and reanalyzed the association of PR with all-cause mortality. Similar findings were observed in Cox proportional hazard regression (Supplementary Table S3), Kaplan–Meier survival analysis (Supplementary Figures S4 and S5) and restricted cubic spline regression (Supplementary Figure S6) after adjusting for confounding factors.

Association of PR With Risks of Falls and Overnight Hospitalization

We also examined the associations of continuous categories and PR status with risks of falls and overnight hospitalization (Supplementary Table S4). We found that increased levels of PR were associated with a lower risk of falls (HR = 0.98, 95% CI = 0.96–0.99) and overnight hospitalization (HR = 0.91, 95% CI = 0.97–1.00) after controlling for confounding factors. Additionally, for the categorical variable PR, the Q3 and Q4 groups were associated with lower risks of falls (for Q3: HR = 0.87, 95% CI = 0.77–0.98; for Q4: HR = 0.87,

Table 1. Characteristics of the Study Population Grouped by PR Status at Baseline

Characteristic	Overall (*N* = 6 508)	Worse PR (*n* = 3 144)	Normal PR (*n* = 3 364)	*p* Value
Age, years, *M* (*SD*)	77.48 (7.84)	77.99 (7.93)	77.01 (7.73)	<.0001
<80, years, *N* (%)	3 925 (60.31)	1 827 (58.11)	2 098 (62.37)	<.001
≥80, years, *N* (%)	2 583 (39.69)	1 317 (41.89)	1 266 (37.63)	
Gender, *N* (%)				.01
Male	2 725 (41.87)	1 262 (40.14)	1 463 (43.49)	
Female	3 783 (58.13)	1 882 (59.86)	1 901 (56.51)	
Care status, *N* (%)				<.0001
Community	6 179 (94.94)	2 934 (93.32)	3 245 (96.46)	
Others	329 (5.06)	210 (6.68)	119 (3.54)	
BMI, *N* (%)				<.0001
Underweight	215 (3.30)	125 (3.98)	90 (2.68)	
Normal	2 380 (36.57)	1 058 (33.65)	1 322 (39.30)	
Overweight	2 438 (37.46)	1 159 (36.86)	1 279 (38.02)	
Obese	1 475 (22.66)	802 (25.51)	673 (20.00)	
Race/ethnicity, *N* (%)				<.0001
White non-Hispanic	4 530 (69.61)	2 111 (67.14)	2 419 (71.91)	
Black non-Hispanic	1 368 (21.02)	760 (24.17)	608 (18.07)	
Hispanic	394 (6.05)	195 (6.20)	199 (5.92)	
Others	216 (2.32)	78 (2.48)	138 (4.10)	
Marital status,* *N* (%)				<.0001
Married/partnered	3 357 (51.58)	1 445 (45.96)	1 912 (56.84)	
Single/widowed	3 145 (48.32)	1 694 (53.88)	1 451 (43.13)	
Smoking status,* *N* (%)				.010
Never smokers	3 246 (49.88)	1 589 (50.54)	1 657 (49.26)	
Former smokers	2 766 (42.50)	1 288 (40.97)	1 478 (43.94)	
Current smokers	490 (7.53)	262 (8.33)	228 (6.78)	
Clinical disease, *N* (%)				
Myocardial infarction	977 (15.02)	480 (15.27)	497 (14.77)	.58
Heart disease	1 184 (18.19)	584 (18.58)	600 (17.84)	.44
Hypertension	4 352 (66.87)	2 127 (67.65)	2 225 (66.14)	.19
Arthritis	3 583 (55.06)	1 778 (56.55)	1 805 (53.66)	.04
Osteoporosis	1 303 (20.02)	647 (20.58)	656 (19.50)	.28
Diabetes	1 594 (24.49)	790 (25.13)	804 (23.90)	.30
Lung disease	968 (14.87)	478 (15.20)	490 (14.57)	.47
Stroke	373 (5.73)	371 (11.80)	366 (10.88)	.24
Cancer	1 674 (25.72)	812 (25.83)	862 (25.62)	.62
Fall, *N* (%)	1 295 (19.90)	681 (21.66)	614 (18.25)	<.0001
Hospitalization, *N* (%)	1 474 (22.65)	863 (27.45)	611 (16.16)	<.0001
Self-rated health, *N* (%)				<.0001
Excellent	830 (12.75)	393 (12.50)	437 (12.99)	
Very good	1 804 (27.72)	841 (26.75)	963 (28.63)	
Good	2 073 (31.85)	937 (29.80)	1 136 (33.77)	
Fair	1 328 (20.41)	698 (22.20)	630 (18.73)	
Poor	473 (7.27)	275 (8.75)	198 (5.89)	
SPPB, *M* (*SD*)	5.99 (3.47)	3.64 (2.72)	8.19 (2.53)	<.0001
PR, *M* (*SD*)	0	-2.16 (1.74)	2.02 (1.43)	<.0001

Notes: BMI = body mass index; *M* = mean; PR = physical resilience; *SD* = standard deviation; SPPB = short physical performance battery.
*Missing: married status 6 (0.09%), smoking status 6 (0.09%).

95% CI = 0.77–0.99) and overnight hospitalization (for Q3: HR = 0.86, 95% CI = 0.76–0.98; for Q4: HR = 0.85, 95% CI = 0.75–0.97) after adjusting for confounding factors compared to the Q1 group. Meanwhile, compared with the worse PR groups, the normal PR groups also had lower risks for falls (HR = 0.91, 95% CI = 0.83–0.99) and overnight hospitalization (HR = 0.90, 95% CI = 0.82–0.98) after adjusting for confounding factors.

Table 2 The Relationship Between PR and All-Cause Mortality

Variable		Model 1		Model 2	
	Events/*N* (%)	HR (95% CI)	*p* Value	HR (95% CI)	*p* Value
Continuous PR	1 664/6 508 (25.57%)	0.87 (0.86, 0.89)	<.0001	0.85 (0.83, 0.87)	<.0001
PR categories					
Q1 (PR ≤ −1.66)	603/1627 (37.06%)	1 (Ref)	1 (Ref)	1 (Ref)	1 (Ref)
Q2 (−1.66 < PR ≤ 0.10)	459/1625 (28.25%)	0.65 (0.58, 0.73)	<.0001	0.62 (0.55, 0.72)	<.0001
Q3 (0.10 < PR ≤ 1.85)	341/1629 (20.93%)	0.45 (0.39, 0.51)	<.0001	0.46 (0.40, 0.53)	<.0001
Q4 (PR > 1.85)	261/1627 (16.04%)	0.34 (0.29, 0.39)	<.0001	0.33 (0.29, 0.39)	<.0001
p-Trend			<.0001		<.0001
PR status					
Worse	1037/3144 (32.98%)	1 (Ref)	1 (Ref)	1 (Ref)	1 (Ref)
Normal	627/3364 (18.64%)	0.48 (0.44, 0.53)	<.0001	0.50 (0.45, 0.56)	<.0001

Notes: CI = confidence interval; HR = hazard ratio; PR = physical resilience. Model 1, unadjusted model; Model 2, adjusted for age, gender, smoking status, marital status, race/ethnicity, body mass index, and care status.

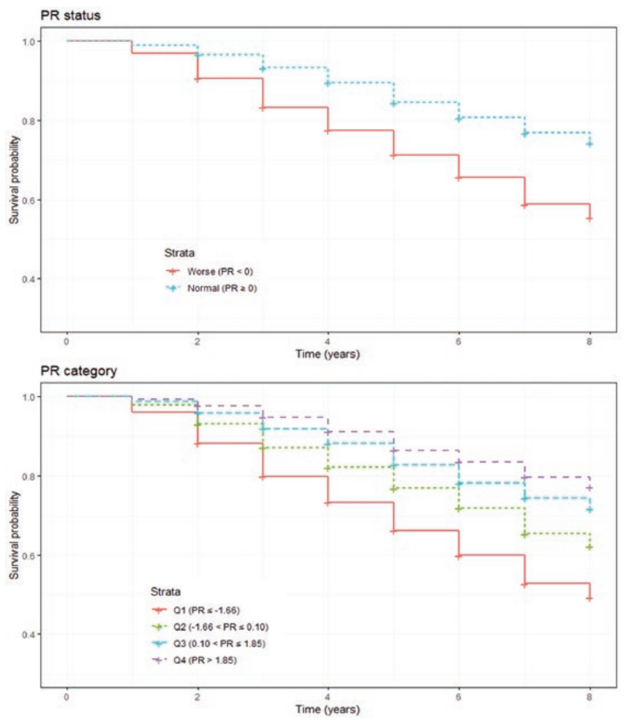

Figure 1. Kaplan–Meier curves for the relationship between physical resilience (PR) and all-cause mortality by different categorized methods.

Discussion and Implications

In this population-based, longitudinal study, we measured PR by the residual method and validated its applicability by examining the association of PR with geriatric assessments over 8-year follow-up periods. We found that a high PR was robustly and independently associated with all-cause mortality, falls, and overnight hospitalization in older adults. Specifically, the association between PR and mortality was nearly nonlinear in this study. In summary, our findings suggested that the novel method was a potentially feasible strategy to measure PR in older adults in general.

PR was defined as the ability to resist decline or recover function after experiencing the adverse effects of a stressor (1–3). At present, 2 approaches have been proposed to classify and measure PR (22). The first was grounded in clinical thinking. The approach required the identification of a stressor followed by multiple functional observations over time (1–3). According to the concept of PR, longitudinal data with repeated assessments of physical function are essential to capture PR. More importantly, a rational stressor was also indispensable in this approach, such as fall, hip fracture, surgery, chemotherapy, and infection (5,8). Spontaneously, the approach was widely used to measure PR in populations with specific stressors, such as acutely hospitalized older adults (31), patients with incident dialysis (32), hip fracture (33,34), advanced lung cancer (35), and total knee arthroplasty and replacement (36,37). Apparently, this method might be restricted to unified stressors, and disparate PR measures may be observed for the same individual (1). Therefore, while that approach may be appropriate for assessing prognosis in clinical practice and identifying high- and low-risk groups in health services research (22), it is not suitable for healthy individuals without encountering stressors or providing longitudinal data. Nevertheless, residuals from regression analyses, which were based on statistical thinking, had been developed as an alternative operational approach (9,11,22). This method was based on observed differences between the actual outcome and that predicted by several variables of interest (such as demographic characteristics, disease burdens, and symptoms). More importantly, this approach could measure PR before encountering a stressor and be developed using cross-sectional data. Therefore, the method using residuals from regression analyses may be a potentially simple and feasible strategy to measure PR.

Wu et al. used linear regression to regress the level of frailty (score: 0–10) on clinical diseases, disease burdens, and demographic characteristics. Residuals from the regression were used to measure PR in the Health, Aging, and Body Composition Study (9). They found that individuals with high PR levels had a longer healthy lifespan and lower rates of adverse outcomes (26). PR can be described as the ability to mobilize the physiological reserve and is a continuous spectrum that applies across the lifespan (2); theoretically, the levels of PR can be quantified at every point in the lifetime of an individual (38). In contrast, frailty is a state of declining physiological reserve that increases vulnerability to adverse outcomes (39); it often evolves near the end of life and represents

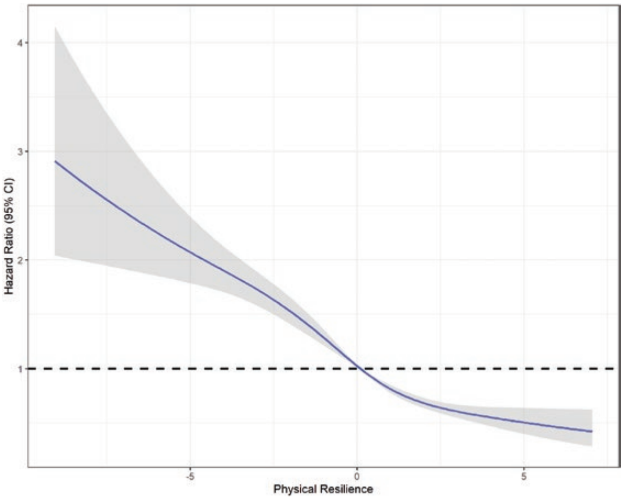

Figure 2. Restricted cubic splines for the association between physical resilience and all-cause mortality in primary analyses. *P* overall < .0001, *p*-nonlinear = .0113. The hazard ratio was calculated based on the per unit increase in physical resilience. Odds ratios (blue solid line) and confidence intervals (CI; shaded area) were estimated using the median level of physical resilience as the reference value (0). The horizontal dashed line represents the reference hazard ratio of 1.0. The models were adjusted for age, gender, smoking status, marital status, race/ethnicity, body mass index, and care status.

an extreme stage in the healthspan (38). Whereas Wu et al. calculated the residuals (PR) from the regression that was based on frailty, the PR in healthier individuals would be restricted (9). In our study, we used linear regression to regress the SPPB score on clinical diseases, age, sex, race/ethnicity, and health condition. Residuals from the regression were used to capture PR. We found that worse PR was significantly associated with an increased risk of mortality, falls, and overnight hospitalization. Although this study was the first to develop a measure of PR using residuals from linear regression with SPPB as the dependent variable, Wu et al. and Sanders et al. quantified PR using linear regression to regress the level of frailty (9,11). The SPPB involves more objective and direct information on physical function, such as balance assessment, gait speed, and extremity strength (21). The SPPB was not only applied to assess physical function in the general population (40–43) but also in other low physical-function populations, including patients with chronic obstructive pulmonary disease (44), heart failure (45), and chronic kidney disease (46). Compared with the SPPB, frailty can be viewed as "a syndrome of geriatric syndromes," rather than one based solely on physical performance. In summary, using the SPPB score to measure PR may have enabled the pure identification of PR in this study.

Our study has several strengths. First, the study was a population-based, longitudinal, and prospective cohort study. It included a long follow-up period and detailed information on clinical disease and all-cause mortality. Therefore, the findings in our study are more valid and generalizable. Second, the measure of PR was based on wide characteristics of the study population, including clinical diseases, age, sex, race/ethnicity, and health condition. Thus, the measured PR in our study was multidimensional and reflected synthetic and holistic levels of PR. Last, the PR using residual methods could be measured before encountering a stressor and developed in a cross-sectional setting. Additionally, the PR could be measured at any point, and then trajectories of PR across the life course could be captured. Simple methods would be accessible in clinical practice. Nevertheless, several limitations should be noted in the interpretation of our findings. On the one hand, NHATS was subject to survey errors and missing data. For example, the clinical information was obtained based on self- or proxy-reported diagnosis, which might be subject to recall bias and misclassification. On the other hand, the NHATS was an observational study, and causal associations of PR with all-cause mortality, falls, and overnight hospitalization were not investigated. Additionally, we merely validated the associations of PR with all-cause mortality, falls and overnight hospitalization, and it would be interesting for future research to obtain more insight into the role of PR in other geriatric assessments (such as disability, cognitive impairment, depression, etc.) to validate our findings.

Conclusions and Implications

In this population-based and longitudinal study, we developed and validated the measure of PR using residuals from linear regression and demonstrated that lower PR was a robust and independent predictor of falls, overnight hospitalization, and all-cause mortality. Our findings provided evidence that this residual-based approach could be a potentially feasible strategy to measure PR in older adults in general. More importantly, this simple approach could be applied in cross-sectional data and constantly capture levels of PR before individuals encounter a stressor. Additionally, the predictive effect of PR for falls, overnight hospitalization, and all-cause mortality reminds us to conduct early interventions to improve quality of life and reduce medical burdens. This simple and feasible approach may help further research to better understand the characteristics and mechanisms of PR in clinical practice, which in turn contribute to decision making in health care.

Supplementary Material

Supplementary data are available at *Innovation in Aging* online.

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Conflict of Interest

None.

Data Availability

The data sets analyzed in the study are publicly available after registration at https://www.nhats.org/researcher. The data sets generated and analyzed during the current study are available from the corresponding author on reasonable request.

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