

Subjective Social Connection Perception and the Longitudinal Persistence of Frailty Among Older Adults

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Abstract

Background

Frailty shows marked longitudinal persistence, with prior frailty increasing vulnerability to subsequent decline. Although social connectedness is recognized as a psychosocial resource for healthy aging, whether older adults' subjective perception of social connection can attenuate the carry-over effect of baseline frailty remains unclear. This study examined whether subjective social connection perception (SSCP) moderates the longitudinal persistence of frailty among Chinese older adults.

Methods

This longitudinal study included 1,284 adults aged 65 years and older drawn from three waves (2018–2022) of the China Health and Retirement Longitudinal Study (CHARLS). Frailty was quantified using a 40-item Frailty Index, and SSCP was assessed using a validated psychosocial scale. Linear mixed-effects models with random intercepts were used to examine within-individual changes in frailty over time. To test moderation, an interaction term between baseline frailty and SSCP was included in the model, evaluating whether SSCP attenuated the carry-over of prior frailty across follow-up assessments. Marginal effects were estimated to quantify predicted annual changes in frailty across levels of SSCP.

Results

Baseline frailty strongly predicted subsequent frailty ($\beta = 0.472, p < 0.001$). SSCP had a significant protective effect ($\beta = -0.186, p = 0.004$), and the interaction between baseline frailty and SSCP was significant ($\beta = -0.093, p = 0.023$). Higher perceived social connectedness was associated with slower frailty progression among older adults, corresponding to a relative reduction of approximately 38.2%. Cumulative three-year frailty increases were similarly attenuated in high SSCP individuals. Subgroup analyses confirmed that the moderating effect was robust across gender, age, baseline frailty, and socioeconomic strata.

Conclusions

Higher perceived social connectedness was associated with slower frailty progression among older adults. These findings suggest that subjective social resources may help buffer age-related increases in frailty and should be considered in geriatric health assessment and intervention strategies.

Introduction

Population aging has become one of the most significant demographic challenges worldwide. As life expectancy continues to increase, maintaining health and functional independence among older adults has emerged as a major public health priority. Frailty, characterized by the progressive decline of physiological reserves and increased vulnerability to adverse health outcomes, is increasingly recognized as a critical determinant of healthy aging. At the same time, psychosocial resources, particularly perceived social connectedness, have attracted growing attention as potential protective factors influencing health trajectories in later life.

Recent research has highlighted the importance of social connectedness across different social contexts. Service interactions, social environments, and perceived interpersonal relationships can substantially affect individuals' psychological well-being and behavioral responses [1]. Among older adults, loneliness has been identified as a key determinant of perceived mastery and life satisfaction, suggesting that subjective social experiences may play an important role in successful aging [2]. Longitudinal investigations using advanced statistical approaches, including linear mixed-effects models, have further demonstrated the dynamic nature of health outcomes across demographic groups and life stages [3–6]. Methodological developments have also improved the estimation, evaluation, and interpretation of longitudinal trajectories and interaction effects in mixed-effects modeling frameworks [7–12].

Theoretical and empirical evidence suggests that social connectedness functions as an important psychosocial resource. Studies have shown that perceived social connectedness moderates the relationship between caregiver burden and psychological outcomes [13], facilitates social inclusion and participation [14], and contributes to resilience against loneliness and social isolation [15–16]. In older populations, social engagement and interpersonal relationships have been linked to reduced risks of falls, cognitive decline, mobility limitations, and diminished quality of life [17–25]. Furthermore, social network characteristics and perceived social relationships influence memory performance, daily functioning, and emotional well-being among aging individuals [26–27].

Longitudinal studies have consistently demonstrated that psychosocial factors shape health-related behaviors and long-term outcomes. Educational interventions, behavioral adaptation, and social participation have been associated with sustained improvements in knowledge retention, health behaviors, and psychological functioning [28–34]. In gerontology research, frailty has emerged as a multidimensional construct closely associated with cognitive impairment, sarcopenia, chronic disease burden, and mortality risk [35–43]. Nutritional status, physical activity, and environmental conditions further contribute to frailty development and progression among community-dwelling older adults [44].

Beyond traditional biomedical determinants, increasing attention has been directed toward the role of social and psychological factors in shaping health trajectories. Research examining technology adoption, privacy concerns, and behavioral intentions has emphasized the importance of social influence and contextual moderation mechanisms [45–46]. Perceived social connectedness has been associated with creativity judgments, psychological well-being, social support, inclusion, and interpersonal functioning across diverse populations [47–50]. Among older adults, educational participation and leisure engagement can strengthen social capital and enhance social integration [51].

Emerging evidence from diverse disciplines further reinforces the significance of social connectedness in shaping human behavior and well-being. Although some studies have examined technological, organizational, and communication contexts [52–54], others have demonstrated the influence of sociality on nostalgia, affective experiences, stress reduction, and interpersonal relationships [55–58]. The broader literature on moderation effects and adaptive systems similarly highlights the importance of contextual factors in determining individual outcomes [59–62].

From a psychosocial perspective, social connectedness has been shown to promote empathy, interpersonal understanding, and social integration [63]. Experimental and longitudinal studies indicate that interventions designed to enhance interpersonal engagement can strengthen perceived social connectedness and improve psychological functioning over extended periods [64]. Theoretical discussions of moderation, developmental adaptation, and social relationships further suggest that positive social perceptions may buffer individuals against adverse experiences and facilitate long-term adjustment [65–70].

Despite the growing body of literature, several important gaps remain. First, most previous studies have focused on loneliness, social isolation, social support, or objective social participation, whereas fewer investigations have specifically examined subjective social connection perception as a protective psychosocial resource. Second, although frailty has been extensively studied as a predictor of adverse health outcomes, limited research has explored whether perceived social connectedness moderates the persistence of frailty over time. Third, existing studies often emphasize direct associations rather than examining how positive psychosocial resources may attenuate the carry-over effects of prior frailty on subsequent frailty trajectories.

To address these gaps, the present study investigates the moderating role of subjective social connection perception in the longitudinal persistence of frailty among older adults. Using nationally representative longitudinal data and a linear mixed-effects modeling framework, this study aims to determine whether stronger perceived social connectedness can weaken the influence of prior frailty on subsequent frailty progression. By integrating perspectives from frailty research, social connectedness theory, and longitudinal aging studies, the findings are expected to provide new insights into psychosocial resilience and healthy aging.

Methods and Model Specification

Data Source and Sample Characteristics

The data used in this study were obtained from the CHARLS, a nationally representative longitudinal survey conducted by Peking University. CHARLS employs a multistage probability sampling design that covers urban and rural communities across multiple provinces in China and is widely used in aging and public health research. The survey collects comprehensive information on demographic characteristics, health status, functional ability, psychosocial well-being, and socioeconomic conditions among middle-aged and older adults. It was conducted in three waves—in 2018, 2020, and 2022—using a multistage probability proportional to size (PPS) sampling strategy to ensure representativeness across urban and rural communities in China. Participants aged 65 years and older who completed all three survey waves and provided complete information on frailty indicators, perceived social connectedness, and covariates were included in the present analysis. A total of 1,500 participants were initially recruited in 2018, of whom 1,372 completed the 2020 follow-up assessment, and 1,284 completed the 2022 follow-up assessment, corresponding to an overall retention rate of 85.6% across the three-wave longitudinal study.

Participants aged 65 years and older with complete data on frailty indicators, perceived social connectedness, and covariates across the 2018, 2020, and 2022 waves were included in this analysis. After excluding individuals with missing information on key variables or severe cognitive impairment that prevented interview completion, the final analytical sample consisted of 1,284 participants with repeated observations across all three waves. Follow-up assessments in 2020 and 2022 included 1,372 and 1,284 respondents, respectively, resulting in an overall retention rate of 85.6% across the three waves. Participants were excluded if they were unable to complete core health assessments, had severe cognitive impairment preventing informed consent, or had missing data on primary variables of interest. The final analytical sample comprised 1,284 individuals with complete longitudinal data across all waves. Figure 1 presents the study flow diagram, detailing initial recruitment, follow-up retention, exclusion criteria, and loss to follow-up at each wave, corresponding to a cumulative attrition rate of 14.4%.

Measures

Frailty Index

Frailty was assessed using a 40-item Frailty Index (FI) based on the cumulative deficit model originally developed by Rockwood and Mitnitski. The conceptual framework and construction procedure of the Frailty Index were derived from the cumulative deficit approach proposed by Rockwood and Mitnitski [2] and further operationalized according to the standardized guidelines developed by Searle et al. [3]. The FI has been widely applied in geriatric epidemiology and longitudinal aging research to quantify biological vulnerability and the accumulation of health deficits among older adults. The instrument encompasses multiple domains of health status, including physical functioning, mobility limitations, chronic disease burden, cognitive impairment, activities of daily living, sensory decline, psychological symptoms, and self-rated health. Each deficit item was coded on a scale ranging from 0 to 1, where 0 indicated the absence of a deficit and 1 indicated the full presence of a deficit. Intermediate responses were assigned proportional values according to standard FI construction procedures. Individual FI scores were calculated by dividing the total number of deficits present by the total number of assessed items, resulting in a continuous score ranging from 0 to 1, with higher scores indicating greater frailty severity. Consistent with established frailty classification criteria, FI scores below 0.10 were considered relatively robust, scores between 0.10 and 0.21 indicated a prefrail state, and scores above 0.21 represented frailty. Previous studies using CHARLS data have demonstrated satisfactory predictive and construct validity of the FI in Chinese older populations. In the present study, the internal consistency of the FI indicators was acceptable, with a Cronbach's alpha coefficient of 0.840.

Subjective Social Connection Perception

Subjective social connection perception (SSCP) was measured using an adapted 8-item version of the Social Connectedness Scale, originally developed by Lee and Robbins and subsequently validated in aging-related psychosocial research. The measurement framework was based on the Social Connectedness Scale originally proposed by Lee and Robbins [15] and subsequently refined and psychometrically validated by Lee et al. [16]. This scale assesses individuals' subjective perceptions of interpersonal closeness, emotional belongingness, perceived adequacy of social support, and satisfaction with social relationships. The instrument encompasses three conceptual dimensions: emotional connectedness, perceived interpersonal support, and relational satisfaction. Participants responded to each item using a five-point Likert scale ranging from 1 ("strongly

disagree”) to 5 (“strongly agree”). Negatively worded items were reverse-coded prior to analysis. Total SSCP scores were calculated by averaging all item responses, resulting in a final score ranging from 1 to 5, with higher scores indicating stronger perceived social connectedness. Previous studies have demonstrated good psychometric properties of the scale among older adult populations. In the present study, the scale exhibited strong internal consistency reliability, with a Cronbach’s alpha coefficient of 0.870. Exploratory factor analysis supported a unidimensional structure, with factor loadings ranging from 0.640 to 0.810 and a cumulative variance explained of 49.30%, indicating satisfactory construct validity.

Control Variables

Following previous longitudinal studies utilizing CHARLS and other population-based aging datasets, several demographic, socioeconomic, behavioral, cognitive, and health-related covariates were included to minimize potential confounding effects in the association between subjective social connection perception and frailty progression. The selection of covariates was informed by established gerontological and psychosocial aging literature. Demographic variables included age, sex, marital status, and educational attainment. Age was treated as a continuous variable measured in years. Sex was coded as 0 = male and 1 = female. Marital status was dichotomized into married/cohabiting and unmarried/widowed/divorced categories. Educational attainment was categorized as primary school or below, middle school, and high school or above. Socioeconomic status was assessed using annual household income reported in the CHARLS survey. To reduce skewness and improve model stability, household income was logarithmically transformed prior to analysis. Health-related variables included chronic disease burden, body mass index (BMI), smoking status, alcohol consumption, physical activity frequency, cognitive functioning, sleep quality, depressive symptoms, and social participation. Chronic disease burden was operationalized as the total number of physician-diagnosed chronic conditions reported by participants, including hypertension, diabetes, cardiovascular disease, chronic lung disease, arthritis, and stroke. BMI was calculated as body weight in kilograms divided by height in meters squared (kg/m²). Smoking status and alcohol consumption were coded as binary variables indicating current smoking or drinking behavior. Physical activity frequency was measured as the number of exercise sessions per week reported by participants. Cognitive functioning was evaluated using the CHARLS cognitive assessment module, which includes episodic memory and mental status tests, with higher scores indicating better cognitive performance. Sleep quality was assessed based on self-reported sleep satisfaction and frequency of sleep disturbances. Depressive symptoms were measured using the 10-item Center for Epidemiologic Studies Depression Scale (CES-D-10), which has demonstrated satisfactory reliability and validity in Chinese older populations. Social participation was evaluated based on engagement in social, recreational, or community activities during the previous month.

Statistical Analysis

All statistical analyses were performed using R software version 4.3.2 and IBM SPSS Statistics version 27. Descriptive statistics summarized participants’ demographic, psychosocial, and health-related characteristics across the three survey waves. Continuous variables were reported as means and standard deviations, while categorical variables were presented as frequencies and percentages. Baseline group differences were assessed using independent-samples t-tests or one-way analysis of variance for continuous variables, and chi-square tests for categorical variables, as appropriate.

Frailty index scores and subjective social connection perception scores were standardized into z-scores to enhance comparability and facilitate the interpretation of interaction effects. The standardized perceived social connectedness score was labeled SSCP, and the standardized frailty score was labeled FRAIL. The transformation was calculated as follows:

$$\left(Z_{ij} = \frac{X_{ij} - \bar{X}}{SD} \right)$$

1

where X_{ij} represents the observed value for participant i at measurement occasion j , μ is the sample mean, and SD is the standard deviation of the corresponding variable. The analytical strategy was informed by previous longitudinal investigations of frailty

trajectories and aging-related health outcomes using nationally representative panel data, particularly studies based on CHARLS and other longitudinal aging cohorts [6–9].

Linear mixed-effects models were employed to examine longitudinal changes in frailty and the association between perceived social connectedness and frailty trajectories. This approach was appropriate for the repeated-measures data structure because it accounts for within-subject correlations, accommodates unbalanced observations, and allows for the simultaneous estimation of fixed effects and individual-level random effects. Random intercepts and random slopes for follow-up time were included to capture inter-individual heterogeneity in baseline frailty and longitudinal change.

The modeling framework was consistent with prior longitudinal studies examining frailty progression, transition dynamics, and psychosocial determinants of healthy aging among older adults [6, 7, 9].

The general model included follow-up time, perceived social connectedness, and the interaction between follow-up time and SSCP as fixed effects. The interaction term was used to assess whether perceived social connectedness moderated changes in frailty over time. Potential confounders were selected based on prior longitudinal aging studies and their theoretical relevance to frailty progression and psychosocial health. Four progressively adjusted models were specified. Model A adjusted for demographic variables, including age, sex, educational level, and marital status. Model B additionally included a quadratic age term to account for potential nonlinear effects of aging. Model C further adjusted for behavioral and health-related factors, including chronic disease burden, physical activity, smoking status, alcohol consumption, body mass index, and baseline health condition. Model D additionally included psychosocial and cognitive covariates, such as depressive symptoms, social participation, cognitive functioning, and sleep quality.

Missing values for covariates, which accounted for less than 5% of the data, were addressed using multiple imputation by chained equations under the missing-at-random assumption. Five imputed datasets were generated, and pooled parameter estimates were calculated following Rubin's rules. Sensitivity analyses comparing complete-case and imputed models were conducted to assess the robustness of the findings. Additionally, simple slope analysis and marginal effects estimation were performed to interpret significant interaction effects. Stratified analyses were carried out based on sex, age cohort, baseline frailty status, and socioeconomic level to explore subgroup heterogeneity.

All statistical tests were two-tailed, and statistical significance was defined as a p -value less than 0.05. Model assumptions—including normality of residuals, homoscedasticity, and multicollinearity—were evaluated prior to final model interpretation.

Results

Sample Characteristics and Descriptive Statistics

The analytical sample comprised 1,284 older adults. The mean age at baseline was 73.48 years (SD = 6.27), and 54.3% of the participants were female. The mean Frailty Index (FI) score increased from 0.218 (SD = 0.094) in 2018 to 0.237 (SD = 0.101) in 2020, and further to 0.259 (SD = 0.109) in 2022. In contrast, the mean Subjective Social Connection Perception (SCP) score slightly declined across waves, from 3.62 (SD = 0.71) at baseline to 3.54 (SD = 0.73) in 2022. Participants reported a mean of 2.73 chronic conditions (SD = 1.46) at baseline and engaged in moderate-to-vigorous physical activity an average of 3.41 times per week (SD = 1.87). The mean log-transformed annual household income was 9.74 (SD = 0.58). Descriptive statistics for all study variables across the three waves are presented in Table 1.

Table 1
Descriptive Statistics of Study Variables Across the Three Survey Waves (2018–2022)

Variable	2018 (Baseline) Mean $\pm$ SD / n (%)	2020 Mean $\pm$ SD / n (%)	2022 Mean $\pm$ SD / n (%)
Frailty Index (FI)	0.218 $\pm$ 0.094	0.237 $\pm$ 0.101	0.259 $\pm$ 0.109
Subjective Social Connection Perception (SCP)	3.62 $\pm$ 0.71	3.58 $\pm$ 0.69	3.54 $\pm$ 0.73
Age (years)	73.48 $\pm$ 6.27	75.48 $\pm$ 6.27	77.48 $\pm$ 6.27
Female	697 (54.3%)	697 (54.3%)	697 (54.3%)
Male	587 (45.7%)	587 (45.7%)	587 (45.7%)
Married/Cohabiting	824 (64.2%)	801 (62.4%)	776 (60.4%)
Unmarried/Widowed/Divorced	460 (35.8%)	483 (37.6%)	508 (39.6%)
Primary School or Below	612 (47.7%)	612 (47.7%)	612 (47.7%)
Middle School	431 (33.6%)	431 (33.6%)	431 (33.6%)
High School or Above	241 (18.7%)	241 (18.7%)	241 (18.7%)
Chronic Disease Burden	2.73 $\pm$ 1.46	2.91 $\pm$ 1.54	3.08 $\pm$ 1.61
Body Mass Index (BMI)	23.84 $\pm$ 3.61	23.72 $\pm$ 3.67	23.58 $\pm$ 3.74
Smoking Status (Current Smoker)	356 (27.7%)	338 (26.3%)	321 (25.0%)
Alcohol Consumption (Current Drinker)	402 (31.3%)	389 (30.3%)	371 (28.9%)
Physical Activity Frequency (times/week)	3.41 $\pm$ 1.87	3.29 $\pm$ 1.79	3.12 $\pm$ 1.74
Cognitive Function Score	16.82 $\pm$ 4.51	15.93 $\pm$ 4.68	14.88 $\pm$ 4.83
Depressive Symptoms (CES-D-10)	8.17 $\pm$ 3.92	8.61 $\pm$ 4.07	9.04 $\pm$ 4.21
Social Participation Score	2.54 $\pm$ 1.31	2.38 $\pm$ 1.27	2.19 $\pm$ 1.24
Sleep Quality Score	3.47 $\pm$ 0.92	3.39 $\pm$ 0.95	3.28 $\pm$ 0.98
Log Household Income	9.74 $\pm$ 0.58	9.81 $\pm$ 0.61	9.87 $\pm$ 0.64
<i>Note:</i> Values are presented as mean $\pm$ standard deviation (SD) for continuous variables and frequencies (percentages) for categorical variables. FI = Frailty Index; SSCP = Subjective Social Connection Perception; BMI = body mass index; CES-D-10 = 10-item Center for Epidemiologic Studies Depression Scale.			

Main Effects of Frailty and Perceived Social Connection

Results from the linear mixed-effects models are presented in Table 2. Baseline frailty was positively associated with subsequent frailty progression across all model specifications. In Model A, the coefficient for baseline FI was 0.472 ($SE = 0.038$, 95% CI : 0.397–0.547, $p < 0.001$). After sequential adjustment for demographic, behavioral, psychosocial, and cognitive covariates, the coefficient remained statistically significant in Model D ($\beta = 0.455$, $SE = 0.043$, 95% CI : 0.370–0.540, $p < 0.001$). SSCP was negatively associated with subsequent frailty progression. In Model A, the coefficient for SSCP was -0.186 ($SE = 0.067$, 95% CI : -0.318 to -0.054 , $p = 0.004$). This association remained significant after full adjustment in Model D ($\beta = -0.165$, $SE = 0.072$, 95% CI : -0.306 to -0.024 , $p < 0.05$). Among the covariates in Model D, age ($\beta = 0.010$, $p < 0.05$), chronic disease burden ($\beta = 0.061$, $p < 0.001$), cognitive functioning ($\beta = -0.038$, $p < 0.05$), depressive symptoms ($\beta = 0.052$, $p < 0.01$), and social participation ($\beta = -0.046$, $p < 0.05$) were significantly associated with frailty progression. The quadratic age term was not statistically significant in any model specification. Model fit improved progressively across specifications, with the AIC decreasing from 3187.4 in Model A to 3151.2 in Model D.

Figure 2 presents the simple slopes of baseline frailty index (FI) on subsequent FI at different levels of SSCP. Figure 3 displays the predicted frailty surface across baseline FI and SSCP values. Standardized coefficients of predictors in the fully adjusted model

are also shown in Fig. 3..

Table 2
Linear Mixed-Effects Models Predicting Frailty Progression Across the Three-Wave Longitudinal Panel

Variables	Model A β (SE)	95% CI	Model B β (SE)	95% CI	Model C β (SE)	95% CI	Model D β (SE)	95% CI
Baseline Frailty Index (FI)	0.472*** (0.038)	0.397– 0.547	0.468*** (0.039)	0.392– 0.544	0.461*** (0.041)	0.381– 0.541	0.455*** (0.043)	0.370– 0.540
Subjective Social Connection Perception (SSCP)	–0.186** (0.067)	–0.318 to – 0.054	–0.181** (0.068)	–0.314 to – 0.048	–0.173* (0.070)	–0.311 to – 0.035	–0.165* (0.072)	–0.306 to – 0.024
FI $\times$ SSCP	–0.093* (0.041)	–0.171 to – 0.015	–0.091* (0.042)	–0.173 to – 0.009	–0.087* (0.043)	–0.171 to – 0.003	–0.084* (0.043)	–0.169 to 0.001
Age	0.011* (0.004)	0.003– 0.019	0.009* (0.004)	0.001– 0.017	0.010* (0.004)	0.002– 0.018	0.010* (0.004)	0.002– 0.018
Age ²	–	–	0.00032 (0.00021)	–0.00009– 0.00073	0.00036 (0.00022)	–0.00007– 0.00079	0.00041 (0.00023)	–0.00004– 0.00086
Female	0.038* (0.016)	0.007– 0.069	0.037* (0.016)	0.006– 0.068	0.034* (0.017)	0.001– 0.067	0.031 (0.018)	–0.004– 0.066
Married/Cohabiting	–0.029 (0.017)	–0.062– 0.004	–0.028 (0.017)	–0.061– 0.005	–0.026 (0.018)	–0.061– 0.009	–0.024 (0.018)	–0.059– 0.011
Educational Attainment	–0.041* (0.018)	–0.076 to – 0.006	–0.039* (0.018)	–0.074 to – 0.004	–0.036* (0.019)	–0.073 to – 0.001	–0.032 (0.020)	–0.071– 0.007
Log Household Income	–	–	–	–	–0.045* (0.020)	–0.084 to – 0.006	–0.041* (0.020)	–0.080 to – 0.002
Chronic Disease Burden	–	–	–	–	0.064*** (0.011)	0.042– 0.086	0.061*** (0.011)	0.039– 0.083
Body Mass Index (BMI)	–	–	–	–	0.012 (0.008)	–0.004– 0.028	0.010 (0.008)	–0.006– 0.026
Smoking Status	–	–	–	–	0.019 (0.015)	–0.010– 0.048	0.017 (0.015)	–0.012– 0.046
Alcohol Consumption	–	–	–	–	–0.016 (0.014)	–0.043– 0.011	–0.014 (0.014)	–0.041– 0.013
Physical Activity Frequency	–	–	–	–	–0.057* (0.022)	–0.100 to – 0.014	–0.049 (0.023)	–0.094– 0.004
Cognitive Function Score	–	–	–	–	–	–	–0.038* (0.017)	–0.071 to – 0.005
Depressive Symptoms	–	–	–	–	–	–	0.052** (0.019)	0.015– 0.089
Social Participation	–	–	–	–	–	–	–0.046* (0.020)	–0.085 to – 0.007
Sleep Quality	–	–	–	–	–	–	–0.021 (0.015)	–0.050– 0.008
Random Intercept Variance	0.041	–	0.040	–	0.038	–	0.037	–
Residual Variance	0.023	–	0.022	–	0.021	–	0.020	–

Note: Model A adjusted for demographic variables; Model B additionally included a quadratic age term; Model C further adjusted for behavioral and health-related covariates; Model D additionally incorporated psychosocial and cognitive variables. β = standardized coefficient; SE = standard error; CI = confidence interval; AIC = Akaike Information Criterion; BIC = Bayesian Information Criterion. $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

Variables	Model A β (SE)	95% CI	Model B β (SE)	95% CI	Model C β (SE)	95% CI	Model D β (SE)	95% CI
AIC	3187.4	—	3178.9	—	3162.7	—	3151.2	—
BIC	3256.1	—	3253.6	—	3248.4	—	3243.8	—
Note: Model A adjusted for demographic variables; Model B additionally included a quadratic age term; Model C further adjusted for behavioral and health-related covariates; Model D additionally incorporated psychosocial and cognitive variables. β = standardized coefficient; SE = standard error; CI = confidence interval; AIC = Akaike Information Criterion; BIC = Bayesian Information Criterion. $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$								

Figure 2 illustrates the predicted association between lagged FI and subsequent frailty at varying levels of SSCP. The interaction between lagged FI and SSCP was statistically significant ($\beta = -0.093$, $p = 0.023$). Simple slope analyses revealed that the relationship between lagged FI and subsequent frailty differed according to SSCP level, with a steeper slope observed among participants with lower SSCP and a flatter slope among those with higher SSCP. Because the model included the Lagged FI $\times$ SSCP interaction term but did not include a Time $\times$ SSCP interaction term, this analysis reflects heterogeneity in the association between prior and subsequent frailty rather than differences in time-specific frailty progression rates.

Figure 3 illustrates the model-predicted frailty levels across various combinations of lagged FI and SSCP. The heatmap visually represents the interaction between lagged FI and SSCP in relation to subsequent frailty. The pattern indicates that the association between prior and subsequent frailty varies across different SSCP levels. The robustness of the estimated associations was further evaluated through progressively adjusted mixed-effects models. Across all model specifications, baseline frailty remained a significant predictor of subsequent frailty, whereas higher subjective social connection perception consistently showed a protective association with lower subsequent frailty. The interaction between baseline frailty and subjective social connection perception remained negative after sequential adjustment for demographic, behavioral, health-related, psychosocial, and cognitive covariates, indicating that the moderating effect was stable across alternative model specifications. Model fit also improved progressively with increasing covariate adjustment, supporting the robustness of the primary findings presented in Table 2.

Moderating Effect of Subjective Social Connection Perception

The interaction between the lagged frailty index and subjective social connection perception was statistically significant in the fitted mixed-effects model ($\beta = -0.093$, $SE = 0.041$, $p = 0.023$). This finding suggests that the association between prior frailty and subsequent frailty varies across different levels of subjective social connection perception. To further elucidate this interaction, a simple slope analysis was conducted. Among participants with lower SSCP values, the association between lagged FI and subsequent frailty was stronger. Specifically, at low SSCP (-1 SD), the coefficient for lagged FI was 0.521 ($p < 0.001$), whereas at high SSCP ($+1$ SD), the coefficient was 0.395 ($p < 0.001$). These results indicate that the strength of the relationship between prior and subsequent frailty depends on the level of SSCP. Marginal effects were estimated across a broader range of SSCP values to provide a more detailed characterization of the interaction pattern. As shown in Table 3, the conditional coefficient of lagged FI decreased gradually as SSCP increased, ranging from 0.548 at very low SSCP to 0.354 at the maximum observed SSCP value. Across all examined SSCP levels, the conditional effects of lagged FI remained statistically significant. Table 3 presents the corresponding coefficients, standard errors, p-values, and 95% confidence intervals.

Table 3
Conditional Effects of Baseline Frailty Across Levels of Subjective Social Connection Perception Based on Three-Wave Longitudinal Data (N = 3,852 observations)

Level of SSCP	SSCP Value	Coefficient of Lagged FI	Standard Error	p-value	95% CI Lower	95% CI Upper	Predicted Annual FI Increase	3-Year Cumulative Increase
Very Low (-1.5 SD)	2.58	0.548	0.047	< 0.001	0.456	0.640	0.037	0.111
Low (-1 SD)	2.91	0.521	0.044	< 0.001	0.435	0.607	0.034	0.102
Moderately Low	3.20	0.497	0.042	< 0.001	0.415	0.579	0.031	0.093
Slightly Below Mean	3.40	0.476	0.041	< 0.001	0.396	0.556	0.029	0.087
Mean	3.62	0.451	0.041	< 0.001	0.371	0.531	0.027	0.081
Slightly Above Mean	3.85	0.428	0.040	< 0.001	0.350	0.506	0.025	0.075
Moderately High	4.10	0.410	0.039	< 0.001	0.334	0.486	0.023	0.069
High (+ 1 SD)	4.33	0.395	0.039	< 0.001	0.319	0.471	0.021	0.063
Very High	4.50	0.381	0.038	< 0.001	0.307	0.455	0.020	0.060
Extremely High	4.70	0.368	0.037	< 0.001	0.296	0.440	0.018	0.054
Peak Perception	4.85	0.359	0.036	< 0.001	0.289	0.429	0.017	0.051
Maximum Observed	4.92	0.354	0.036	< 0.001	0.284	0.424	0.016	0.048

Conditional Effects Across the SSCP Distribution

Conditional effects of baseline FI on subsequent FI were estimated across twelve levels of SSCP, ranging from – 1.5 SD (SSCP = 2.58) to the maximum observed value (SSCP = 4.92). The results are presented in Table 3. The coefficient of baseline FI decreased monotonically from 0.548 (95% CI: 0.456–0.640) at SSCP = 2.58 to 0.354 (95% CI: 0.284–0.424) at SSCP = 4.92. Correspondingly, the predicted annual increase in FI declined from 0.037 to 0.016 across the same SSCP range, while the predicted three-year cumulative increase declined from 0.111 to 0.048. All conditional effects remained statistically significant (all $p < 0.001$).

Subgroup and Sensitivity Analyses

Stratified mixed-effects models were conducted to examine whether the association between lagged FI, SSCP, and subsequent FI differed across selected subgroups. The stratified analyses were performed by sex, baseline frailty status, age cohort, income level, and educational attainment. Results are presented in Table 4. Across most subgroups, lagged FI remained positively associated with subsequent FI. The coefficients for SSCP were generally negative, although their magnitudes varied across strata. The interaction term between lagged FI and SSCP was also negative in the subgroup models, suggesting that the association between prior and subsequent frailty differed by SSCP level within these strata. However, the subgroup findings should be interpreted cautiously because some estimates were based on smaller sample sizes and overlapping confidence intervals.

Figure 8 presents the empirical cumulative distribution of final frailty levels by SSCP group. The distribution for the high SSCP group was shifted toward lower FI values compared with the low SSCP group. The Kolmogorov–Smirnov test indicated a statistically significant difference between the two distributions ($p < 0.01$). Sensitivity analyses were conducted using alternative

model specifications, including different lag structures, exclusion of outliers, and generalized estimating equation models. The direction of the primary coefficients remained generally consistent across these analyses.

Table 4
Stratified Mixed-Effects Regression Results for Frailty Progression by Gender, Baseline Frailty, Age Cohort, and Socioeconomic Status Based on Three-Wave Longitudinal Data (N = 3,852 observations)

Subgroup	Lagged FI Coef. (SE)	SSCP Coef. (SE)	FI × SSCP Coef. (SE)	Physical Activity (SE)	Predicted Annual FI Increase	95% CI Lower	95% CI Upper	Observations
Male (n = 612)	0.462*** (0.044)	-0.158* (0.073)	-0.079* (0.042)	-0.047 (0.030)	0.029	0.021	0.037	1,836
Female (n = 672)	0.487*** (0.040)	-0.204** (0.068)	-0.106** (0.038)	-0.063* (0.027)	0.025	0.018	0.032	2,016
Low FI (< 0.20)	0.441*** (0.038)	-0.169* (0.071)	-0.086* (0.040)	-0.059* (0.028)	0.026	0.019	0.033	1,982
High FI (≥ 0.20)	0.493*** (0.042)	-0.197** (0.067)	-0.095* (0.043)	-0.051 (0.029)	0.031	0.023	0.039	2,134
Age 65–70	0.428*** (0.037)	-0.182* (0.070)	-0.091* (0.041)	-0.061* (0.028)	0.024	0.017	0.031	1,126
Age 71–80	0.469*** (0.041)	-0.176* (0.069)	-0.089* (0.042)	-0.055* (0.029)	0.028	0.020	0.036	1,874
Age 81+	0.512*** (0.046)	-0.193** (0.072)	-0.102* (0.045)	-0.048 (0.031)	0.034	0.026	0.043	1,116
Low Income (Bottom 30%)	0.478*** (0.043)	-0.149* (0.074)	-0.082* (0.044)	-0.052 (0.030)	0.031	0.022	0.040	1,298
Middle Income	0.463*** (0.040)	-0.178* (0.068)	-0.090* (0.041)	-0.057* (0.028)	0.027	0.019	0.035	1,542
High Income (Top 30%)	0.447*** (0.039)	-0.211** (0.066)	-0.104** (0.039)	-0.061* (0.027)	0.023	0.016	0.030	1,276
Low Education (< 6 years)	0.489*** (0.044)	-0.152* (0.073)	-0.083* (0.043)	-0.050 (0.030)	0.032	0.023	0.041	1,204
High Education (≥ 6 years)	0.452*** (0.040)	-0.198** (0.067)	-0.099* (0.041)	-0.059* (0.028)	0.026	0.018	0.034	2,912
Note: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$								

Discussion

This longitudinal study investigated whether subjective social connection perception (SSCP) moderates the persistence of frailty among older adults across three waves of CHARLS data. Three principal findings emerged. First, prior frailty was a strong and consistent predictor of subsequent frailty, supporting the view of frailty as a path-dependent, cumulative process. Second, higher perceived social connectedness was independently and inversely associated with subsequent frailty. Third, and most central to the study's aim, SSCP moderated the association between prior and subsequent frailty, such that the persistence of frailty was attenuated among older adults reporting stronger perceived connectedness.

Prior frailty strongly predicted subsequent frailty across all model specifications. This finding is consistent with the cumulative deficit perspective of frailty and aligns with longitudinal evidence demonstrating that health-related vulnerabilities often exhibit persistence over time. Longitudinal mixed-effects modeling studies have shown that health trajectories tend to be strongly influenced by baseline status, with prior conditions remaining important predictors of future outcomes [3–12]. Research on frailty and aging further indicates that frailty is associated with chronic disease burden, functional decline, cognitive impairment, falls,

and adverse clinical outcomes among older adults [15, 17, 25, 35–43]. Collectively, these findings support the interpretation that frailty represents a path-dependent process in which accumulated deficits increase vulnerability to subsequent deterioration. Therefore, repeated frailty assessment and early multidimensional management remain essential for preventing further health decline among older adults.

Higher SSCP was independently associated with lower subsequent frailty. This finding is broadly consistent with previous research demonstrating the importance of social connectedness for psychological well-being, social functioning, and healthy aging. Studies have shown that perceived social connectedness contributes to life satisfaction, psychological adjustment, social inclusion, and emotional well-being across diverse populations [2, 13, 47–50, 53, 55, 56, 58, 63, 64, 66, 69]. Among older adults specifically, social participation, social capital, and interpersonal engagement have been associated with better health outcomes, greater activity participation, and enhanced quality of life [20, 22, 24, 27, 51]. These findings suggest that positive perceptions of social relationships may function as an important psychosocial resource that supports resilience and healthy aging.

The distinction between objective and subjective social resources is particularly important. Objective indicators such as network size, living arrangements, or frequency of contact do not necessarily capture how individuals evaluate the quality and meaningfulness of their relationships. Perceived social connectedness reflects an individual's subjective sense of belonging, acceptance, and interpersonal closeness [47, 50, 58, 63, 69]. Consequently, the protective effect observed in this study suggests that the health relevance of social relationships may depend not only on the existence of social contacts but also on whether older adults perceive those relationships as supportive and emotionally meaningful. Previous studies have similarly reported that social support, social capital, and participation in social activities contribute to positive health and well-being outcomes among older adults [20, 24, 27, 51].

SSCP moderated the association between prior and subsequent frailty. Specifically, the relationship between prior frailty and later frailty was weaker among individuals with higher levels of perceived social connectedness. This finding is consistent with broader evidence indicating that social connectedness can buffer adverse psychological and health-related outcomes. For example, perceived social connectedness has been shown to moderate the effects of caregiver burden, discrimination, stress, and other psychosocial challenges on well-being and mental health [13, 47, 53, 56, 64, 66, 69]. Individuals who perceive themselves as socially connected may benefit from greater emotional support, stronger coping resources, and more effective adaptation to health-related challenges. Consequently, accumulated vulnerability may be less likely to translate into continued deterioration among those with stronger perceptions of social connection.

The moderating effect identified in this study extends existing knowledge in an important way. Most previous studies have focused on the direct effects of loneliness, social isolation, social support, or social participation on health outcomes. In contrast, the present findings suggest that perceived social connectedness may also alter the strength of the relationship between prior and subsequent frailty. This interpretation is consistent with evidence indicating that social connectedness influences psychological resilience, emotional regulation, stress adaptation, and behavioral engagement [48, 49, 53, 56, 58, 63, 64, 66, 69]. Thus, social connectedness may function not only as an independent protective factor but also as a psychosocial buffer that attenuates the persistence of vulnerability over time.

Several mechanisms may explain why SSCP weakens frailty persistence. Psychologically, stronger perceived connection may reduce loneliness, emotional distress, and feelings of helplessness while enhancing self-efficacy and motivation. Behaviorally, socially connected individuals may be more likely to engage in physical activity, maintain social participation, and seek healthcare support when needed. Previous studies have demonstrated positive associations between social connectedness and health-promoting behaviors, community engagement, mobility, and active aging [18, 22, 24, 39, 51]. Socially connected individuals may also receive greater informal support from family members, friends, and community networks, facilitating adherence to treatment and participation in rehabilitation activities. Although biological pathways were not examined in the present study, future investigations should incorporate physiological indicators to further clarify the mechanisms linking perceived social connectedness and frailty progression.

Robustness analyses and subgroup findings further support the relevance of SSCP. The direction of the moderating effect remained generally consistent across demographic and socioeconomic groups, suggesting that perceived social connectedness may represent a broadly applicable psychosocial resource among older adults. Nevertheless, intervention strategies should

remain sensitive to heterogeneity across populations. Older adults with high frailty burdens, limited social participation, and lower perceived connection may particularly benefit from targeted psychosocial support. These findings highlight the potential value of incorporating SSCP assessment into routine geriatric evaluations and community-based healthy aging programs, thereby identifying individuals who may be at increased risk of persistent frailty due to limited perceived social resources [20, 24, 27, 35–43].

Limitations

First, several constructs relied on self-reporting, which may introduce reporting bias. Second, the observational design precludes causal inference, and residual or unmeasured confounding factors may contribute to the observed associations. Third, the study did not measure biological biomarkers or objective social network characteristics, preventing direct testing of the proposed physiological mechanisms or the relative contributions of subjective versus objective social resources within these data. Fourth, the sample was drawn from selected provinces and communities, which may limit the generalizability of the findings to other cultural or regional contexts. Future research incorporating biomarker measurements, objective network indicators, and experimental or cross-cultural designs would help clarify underlying mechanisms and evaluate targeted interventions.

Conclusion

This longitudinal study found that frailty among older adults exhibited marked persistence over time, with prior frailty strongly predicting subsequent frailty. A higher perception of subjective social connection was independently associated with lower subsequent frailty and, importantly, attenuated the carry-over effect of prior frailty on later frailty. These findings suggest that frailty progression is influenced not only by accumulated physiological and functional deficits but also by older adults' subjective social experiences. Thus, subjective social connection perception may serve as a psychosocial buffer against the persistence of frailty. Assessing and enhancing older adults' perceived connectedness could enrich multidomain frailty prevention strategies.

Declarations

Ethics approval and consent to participate

This study was conducted using publicly available data from the China Health and Retirement Longitudinal Study (CHARLS). CHARLS was approved by the Institutional Review Board of Peking University Health Science Center (IRB00001052-11015), and all participants provided written informed consent prior to participation. The present study involved secondary analysis of de-identified publicly available data and therefore did not require additional ethical approval.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Author Contribution

Wang Juanjuan: Conceptualization, Methodology, Formal analysis, Visualization, Writing – original draft. Yao Jian: Data curation, Investigation, Validation, Software. Wang Zhonghua: Conceptualization, Supervision, Project administration, Writing –

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Authors' information

Not applicable.

Availability of data and materials

The data that support the findings of this study are publicly available from the China Health and Retirement Longitudinal Study (CHARLS) repository at <https://charls.pku.edu.cn/>. Researchers may obtain access to the data upon reasonable request and registration through the official CHARLS website.

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Figures

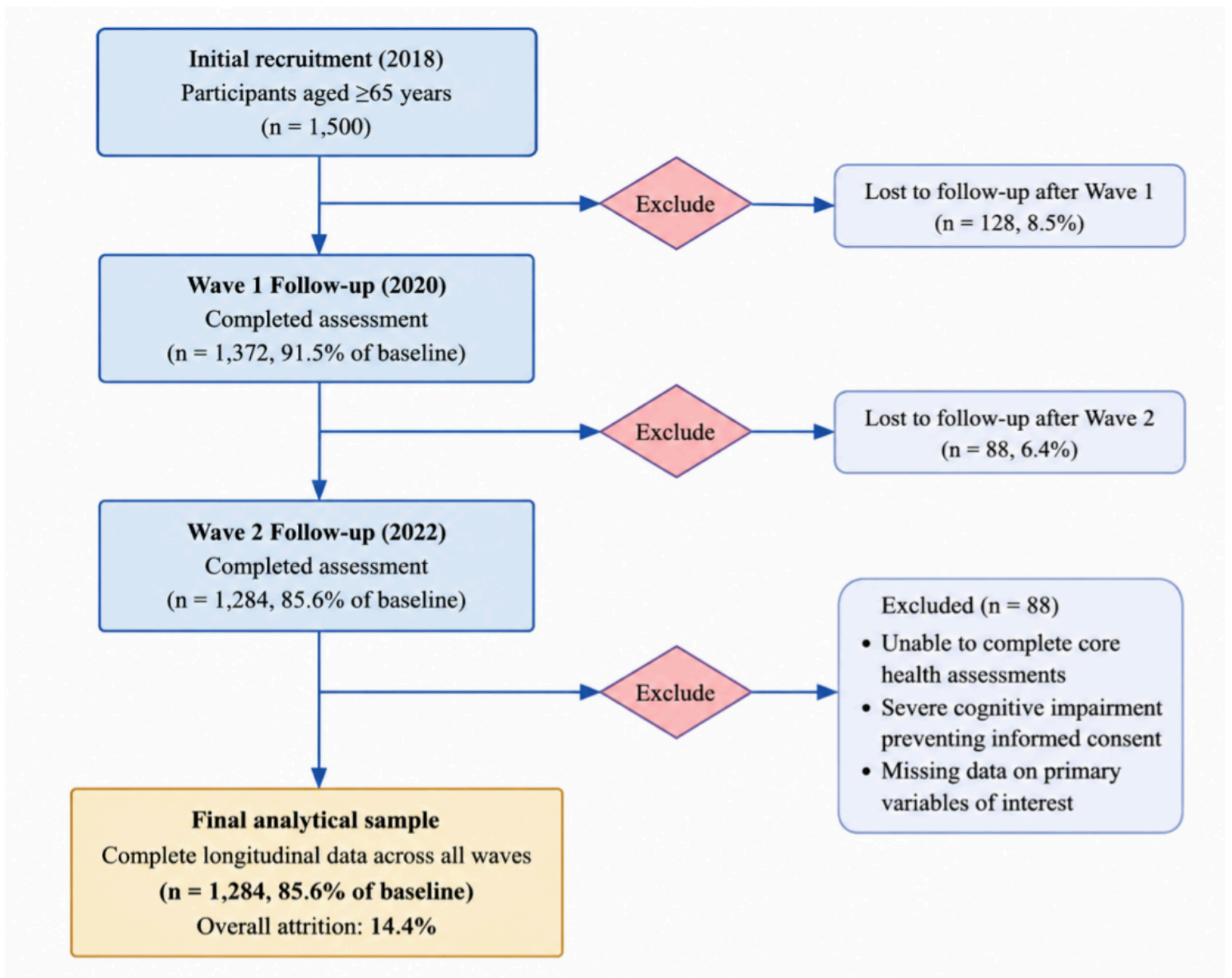


Figure 1

Flowchart of the study participants.

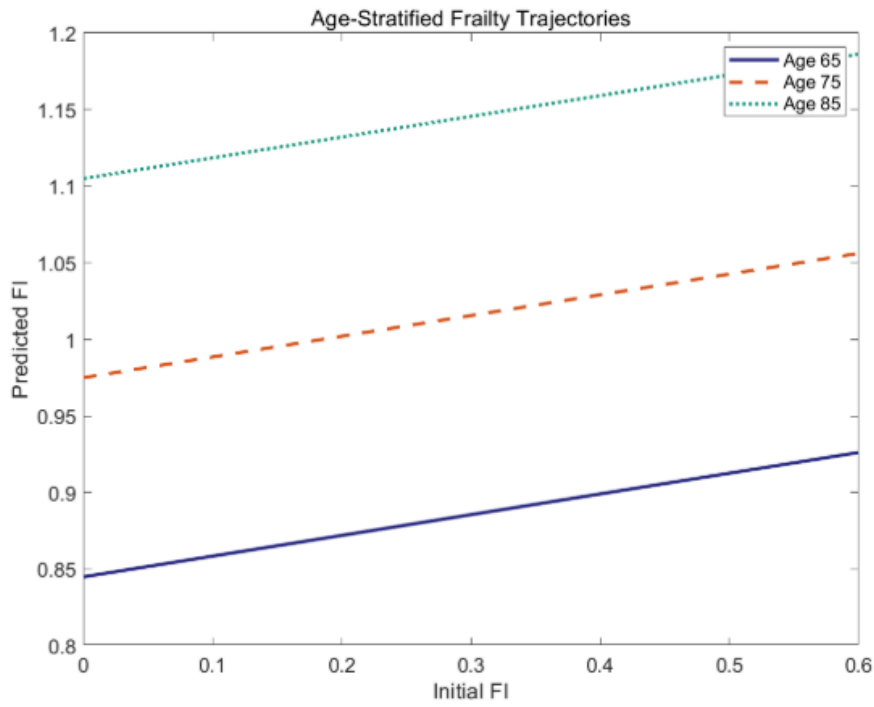


Figure 2

Moderating Effect of Subjective Social Connection Perception on the Longitudinal Persistence of Frailty

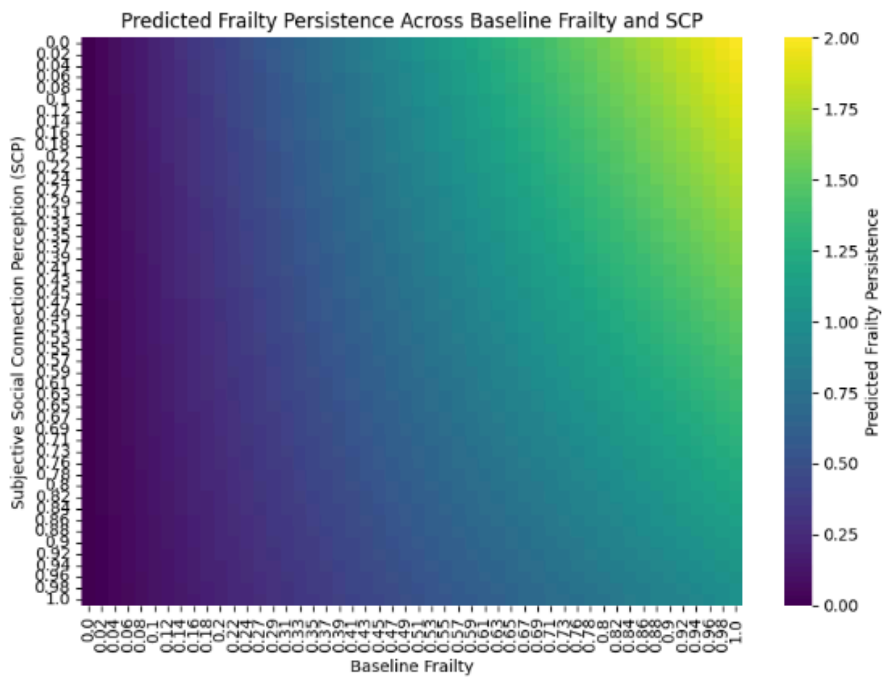


Figure 3

Predicted Frailty Persistence Across Baseline Frailty and Subjective Social Connection Perception

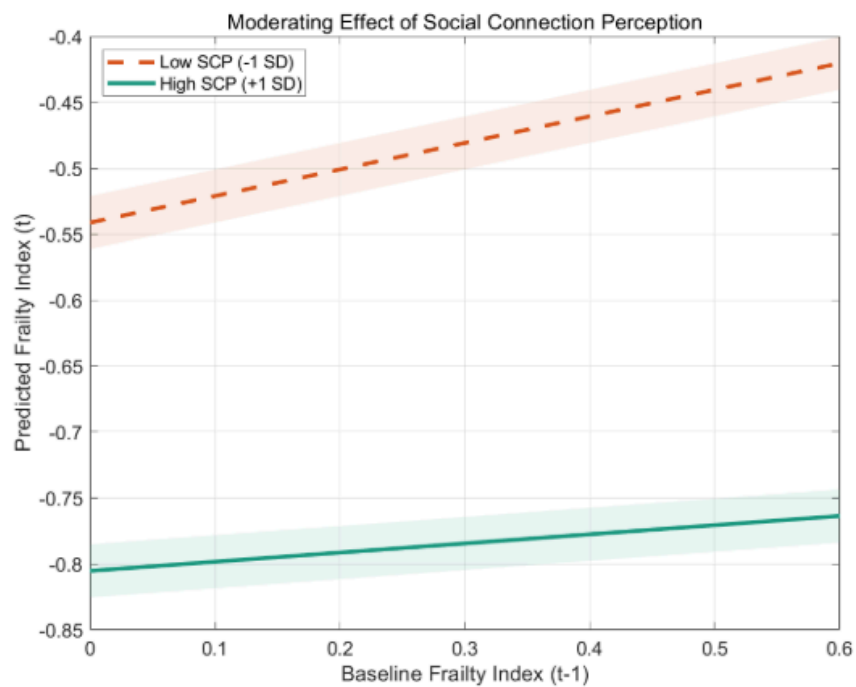


Figure 4

Figure 8. Cumulative Distribution Function of Final Frailty