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Proactive Health Behaviors and Frailty in Older Adults with Multimorbidity: A Cross-Sectional Study

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Highlights

What are the main findings?

- Frailty prevalence was 56.52% among community-dwelling older adults with multimorbidity in Shanghai. Proactive health behaviors are generally at a moderate level and show a significant negative bivariate association with frailty.
- Significant inverse associations between higher proactive health behaviors and lower frailty scores were observed in the 60–74 years, 75–89 years and two-chronic-disease subgroups in uncorrected exploratory analyses. The two-condition subgroup association remained significant after correction for multiple comparisons.

What are the implications of the main findings?

- These cross-sectional findings generate hypotheses for longitudinal research on proactive health behaviors and multidimensional frailty in older adults with multimorbidity.

Abstract

Background/Objectives: This study examined the association between proactive health behaviors and frailty among community-dwelling older adults with multimorbidity in Shanghai. Methods: A cross-sectional survey of 207 residents was conducted from July 2025 to January 2026 using the Chinese-adapted Health-Promoting Lifestyle Profile II (HPLP-II) and Tilburg Frailty Indicator (TFI). Analyses included Spearman correlation, Firth-penalized logistic regression, and exploratory subgroup comparisons with Bonferroni correction. Results: Frailty prevalence was 56.52%, and the median HPLP-II score was 136 (IQR 125–154). HPLP-II and TFI scores were inversely correlated ($r = -0.396$, $p < 0.01$). The primary adjusted model did not detect a statistically significant association between behavior level and frailty. In exploratory Model B, which additionally included care dependency, high versus low proactive health behavior was associated with lower frailty odds (OR = 0.253, 95% CI: 0.065–0.980, $p = 0.047$). In the primary model, widowhood was associated with higher frailty odds versus being married (OR = 3.174, 95%CI 1.355–7.434, $p = 0.008$). In unadjusted stratified analyses, TFI total scores differed across health-promoting lifestyle behavior levels among participants aged 60–74 years ($p = 0.014$), those aged 75–89 years ($p = 0.029$), and those with two chronic conditions ($p < 0.001$). After Bonferroni correction, only the two-disease subgroup remained significant. Conclusions: Frailty was highly prevalent among community-dwelling older adults with multimorbidity. Bivariate analyses showed an inverse association between proactive health behaviors and frailty. Future longitudinal and intervention studies are warranted to confirm these findings.

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1. Introduction

With the acceleration of population aging, more than 700 million people worldwide are aged 65 years and older [1]. As the world's most populous country, China faces a particularly severe challenge of population aging. According to the 2024 National Bulletin on the Development of Aging Undertakings, by the end of 2024, the number of people aged 60 years and above in China had reached 310.31 million, accounting for 22.0% of the total population; the number of people aged 65 years and above reached 220.23 million, making up 15.6% of the total population [2].

Chronic diseases are prevalent health concerns among older populations. Global data indicate that the prevalence of multimorbidity among adults aged 60 years and older is approximately 51% (95% CI: 44.1–58.0) [3], while the prevalence of multimorbidity among Chinese older adults is as high as 44.1% [4]. The coexistence of multiple chronic conditions has become a major public health issue threatening the health of older adults. Accumulating evidence shows that multimorbidity is closely associated with the high prevalence of frailty in older populations, reflecting the interaction between frailty and chronic disease burden [5,6].

Frailty refers to a clinical state in older adults characterized by reduced physiological reserve and markedly impaired homeostatic capacity in response to stressors, resulting in increased vulnerability and elevated risk of adverse health outcomes [7]. Conceptually, frailty research has evolved along two dominant paradigms: the physical phenotype model and the multidimensional deficit accumulation model [8,9]. The classic Fried Frailty Phenotype, proposed in 2001, operationalizes frailty as a purely physical syndrome comprising five somatic components (unintentional weight loss, exhaustion, weakness, slow walking speed, and low physical activity), focusing exclusively on physiological reserve decline [9]. In contrast, the multidimensional perspective—represented by Rockwood's deficit accumulation model and the Tilburg Frailty Indicator (TFI)—extends frailty beyond physical function to encompass psychological and social domains, recognizing that frailty is a biopsychosocial state rather than merely a physical impairment [8,10].

For older adults with multimorbidity, frailty is rarely limited to physical decline; chronic disease burden frequently co-occurs with depressive symptoms, social withdrawal, and impaired self-management capacity, all of which fall within the scope of multidimensional frailty [5,11]. Developed by Gobbens et al. based on an integral conceptual model, the TFI defines frailty as "a dynamic state affecting an individual who experiences losses in one or more domains of human functioning (physical, psychological, social) that are caused by the influence of a range of variables and which increases the risk of adverse outcomes" [12]. This definition explicitly excludes diseases and disability as constituent elements of frailty, and emphasizes that frailty is modifiable rather than an inevitable consequence of aging [12]. With 15 self-report items covering 8 physical, 4 psychological and 3 social components, the TFI is one of the few instruments that captures the biopsychosocial nature of frailty in an economical screening format, and has demonstrated good predictive validity for disability, healthcare utilization and quality of life [10,12]. Cross-cultural adaptations have confirmed its psychometric properties across multiple European and Asian populations, with internal consistency coefficients ranging from 0.67 to 0.71 and test–retest reliability of 0.87–0.88 [13,14]. Validation studies in Chinese community-dwelling older adults have further supported its reliability and construct validity, with a Cronbach's α of 0.71 [14] and moderate agreement with the Fried Frailty Phenotype (Kappa = 0.569) [15].

Epidemiological data show that the prevalence of multidimensional frailty among older adults in China is 42.6% [16]. Among older adults with multimorbidity, the prevalence rises to 40–50% and demonstrates a dose–response gradient with increasing number of chronic conditions [17]. A 2025 systematic review and meta-analysis of 37 studies further confirmed that multimorbidity significantly increases the risk of prevalent frailty (pooled OR = 2.18, 95% CI 1.87–2.54) [5]. Longitudinal trajectory research based on 10-year follow-up of community-dwelling young–old adults further revealed that frailty does not progress uniformly: three distinct trajectories (low-stable, moderate-increasing and high-rapidly rising) can be identified, and baseline prefrailty is the strongest predictor of adverse long-term trajectories, alongside modifiable factors such as smoking, obesity and low social engagement [18].

As China's medical and health model gradually shifts to a proactive health paradigm oriented toward the whole life cycle and the entire health continuum, with proactive health interventions adopted as a core strategy for chronic disease control and population aging response [19,20], new opportunities have emerged for the early prevention and modification of frailty. Proactive health is a person-centered health paradigm that emphasizes activating individuals' willingness, knowledge, competence, and health beliefs to engage in active disease self-management and voluntary adoption of healthy lifestyles, rather than passively receiving medical services [20]. At the behavioral level, proactive health behaviors manifest as a comprehensive set of health-promoting lifestyle practices covering multiple domains: physical activity, nutritional management, health responsibility, interpersonal support, stress regulation, and spiritual growth [21,22]. These domains overlap with the health-promoting lifestyle practices measured by the HPLP-II. Chen et al. [23] developed a 20-item proactive health behavior scale in 334 Chinese patients with chronic diseases, encompassing individual health responsibility, psychological stress coping, exercise, nutrition, and interpersonal support. Their study provides a chronic-disease-specific framework for proactive health behavior assessment. This study used the 52-item Chinese-adapted HPLP-II to operationalize health-promoting lifestyle practices as an indicator of proactive health behaviors. Evidence concerning its reliability and factor structure in Chinese community residents is reported by Wang et al. [22]. The 52-item Chinese HPLP-II has also been used to assess health-promoting lifestyles among community residents in China [24]. This approach aligns with previous Chinese studies that have used the HPLP-II to assess health-promoting lifestyle behavior levels in chronic disease populations [19,25].

Accumulating longitudinal evidence has reported inverse associations between healthy lifestyles and frailty risk. A 2024 umbrella review of 44 systematic reviews encompassing 1150 primary studies confirmed that regular physical activity, high-quality diet, adequate social participation and better psychological health were each independently associated with lower odds of frailty, with greater adherence to a Mediterranean diet the only lifestyle factor supported by high-certainty evidence (OR = 0.44, 95% CI 0.31–0.64), whereas those for depression and loneliness were of moderate certainty [26]. A 2025 meta-analysis further verified that multimorbidity significantly increases frailty risk, while evidence regarding whether health behaviors can buffer this risk among multimorbid older adults remains inconsistent and insufficient [5].

Evidence from Chinese community populations further clarifies the shape of this relationship. Using restricted cubic spline modelling, Li et al. [27] demonstrated a non-linear inverse association between physical activity volume and frailty risk: each 1 MET-h/day increase in physical activity was associated with a 7.2% lower prevalence of frailty, but the marginal benefit diminished beyond 5 MET-h/day. In contrast, sedentary time exhibited a linear positive association: each additional hour of daily sitting increased frailty risk by 11.4%, and sitting time ≥ 8 h/day was associated with 3.14-fold higher odds of frailty after

adjustment [27]. Critically, the two behaviours interact: excessive sedentary time attenuates and may even reverse the inverse association with physical activity, with the combination of low physical activity and prolonged sitting carrying an 8-fold higher frailty risk relative to high activity and low sitting time [27].

Specifically, most existing evidence comes from general older populations or single-disease cohorts, with limited focus on multimorbid populations [26,28]. A 2024 scoping review of 144 studies by Young et al. [29] found that existing physical activity interventions for people living with both frailty and multiple long-term conditions predominantly focused on structured multicomponent exercise, with very few addressing comprehensive lifestyle behaviors or social and psychological dimensions. Furthermore, most available studies have used a physical frailty phenotype rather than a multidimensional frailty measure, meaning that the association between comprehensive health behaviors and biopsychosocial frailty in multimorbid populations remains understudied [11]. Evidence from Chinese community populations is particularly scarce: existing studies have examined the association between single behaviors (such as physical activity or sedentary time) and frailty in general older adults [27], but no study has yet investigated the association between multidimensional proactive health behaviors and multidimensional frailty among Chinese community-dwelling older adults with multimorbidity.

Notably, the relationship between health behaviors and frailty is likely bidirectional. On one hand, engaging in proactive health behaviors may slow physiological decline, maintain social connection, and reduce psychological distress, thereby lowering frailty risk. On the other hand, the onset and progression of frailty can reduce physical capacity, motivation, and social participation, leading to decreased engagement in health-promoting behaviors—a well-recognized reverse causation pathway in frailty research [30,31]. Longitudinal studies have confirmed that baseline frailty status predicts subsequent declines in physical activity and social engagement, independent of baseline behavior levels [30,32]. Given the cross-sectional design of the present study, we cannot establish temporal order or disentangle the direction of the association; instead, this study aims to describe the cross-sectional association and generate hypotheses for future longitudinal and intervention research.

This study makes three incremental contributions to the existing literature. First, it focuses specifically on community-dwelling older adults with multimorbidity—a high-risk group for frailty that has been understudied in previous health behavior research—providing empirical data from a Chinese urban community setting. Second, it adopts a multidimensional framework for both the exposure (10-dimensional proactive health behaviors) and the outcome (3-domain biopsychosocial frailty), allowing for a more comprehensive examination of domain-specific associations beyond single behaviors and physical frailty alone. Third, it conducts exploratory subgroup analyses by age and disease burden, and formally tests for interaction effects, providing preliminary evidence for population-specific effect patterns. We hypothesized that (1) higher levels of proactive health behaviors would be inversely associated with frailty, and (2) the strength of this association would vary by age group and number of chronic conditions.

2. Materials and Methods

2.1. Design

A cross-sectional study of older adults in Shanghai, China, between 2025 and 2026. This study was reported in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines [33].

2.2. Setting, Sampling, and Eligibility Criteria

The study was conducted across eight research sites in five districts of Shanghai (Pudong New District, Songjiang District, Xuhui District, Baoshan District, and Huangpu District) between July 2025 and January 2026. The specific research sites and their respective recruitment periods were as follows: (1) Lingqiao Fifth Community Committee, Pudong New District (September 2025); (2) Xinqiao Community Committee, Xinbang Town, Songjiang District (August 2025); (3) Xujia Village Committee, Xinbang Town, Songjiang District (September 2025); (4) Pingjiang Community Committee, Fenglin Street, Xuhui District (July 2025); (5) Youyi Street Community Health Service Center, Baoshan District (July 2025); (6) Dapuqiao Community Health Service Center, Huangpu District (July to September 2025); (7) Fuhui Canteen, Huangpu District (July to September 2025); and (8) Rihui Liu Village Community (September to October 2025). The selected sites covered both urban and rural communities, encompassing older adults with multimorbidity across different living environments and lifestyle patterns, while providing convenient settings for recruitment and data collection.

Participants were recruited using a non-probability convenience sampling strategy. Two trained researchers identified potential participants through referrals from community workers and on-site screening, and proactively approached and invited eligible older adults who were present at the community sites during scheduled data collection sessions. After obtaining informed consent, questionnaires were completed. Participants who declined to participate did not provide informed consent, and therefore no data were collected on declined individuals.

Eligibility criteria required participants to be aged 60 years or older, diagnosed with two or more chronic diseases (as defined below), residing in Shanghai communities for at least 3 months, and willing to participate in the study with written informed consent. The diagnosis of each chronic disease was based on self-report, i.e., participants reported that a licensed physician had previously diagnosed the condition. Exclusion criteria included severe cognitive impairment, severe hearing or visual impairment, and severe mental illness or other critical medical conditions.

2.3. Data Collection

Data were collected on-site by two researchers who were trained to use a standardized questionnaire administration guide before data collection, ensuring a consistent script and procedure for introducing the study and completing each questionnaire. To minimize potential information bias, they used standardized instructions to introduce the study's objectives and completion requirements to the participating older adults. For participants who were illiterate or had visual impairments, the researchers assisted by asking the questions and recording their responses. Once completed, each questionnaire was verified against standardized written and oral instructions. All procedures were conducted in private, quiet rooms within the participating institutions to protect confidentiality and reduce social desirability bias. The researchers supervised the entire process to ensure consistency across all participants.

2.4. Instruments and Measures

A structured, study-specific sociodemographic questionnaire was used to collect gender, age, education level, marital status, number of children, source of income, type of medical insurance, living arrangements, pre-retirement occupation, chronic disease presence and count, and medication count. Care-dependency status was assessed with a single self-reported item asking about current daily self-care ability, with three response options: basically independent, needing assistance, and completely dependent on others. To as-

sess proactive health behaviors, the Health-Promoting Lifestyle Profile II (HPLP-II) scale was used. The original HPLP-II, developed by Walker et al., comprises six dimensions: physical activity, nutrition, health responsibility, interpersonal relations, stress management, and spiritual growth, with 52 items in total. The 52-item Chinese version has been applied in community-based health management research [24]. Wang et al. [22] conducted a psychometric evaluation of the HPLP-II Chinese version among community residents and, through exploratory factor analysis, extracted 10 factors with a cumulative variance contribution rate of 55.54%. The confirmatory factor analysis yielded $\chi^2/df = 3.62$, GFI = 0.88, AGFI = 0.85, and RMSEA = 0.05. In this study, the 52 items were scored across the following 10 dimensions: (1) healthy eating, (2) regular exercise, (3) interpersonal relations, (4) stress management, (5) health responsibility, (6) spiritual growth, (7) health awareness, (8) health habits, (9) stress coping, and (10) psychological status. Each item is rated on a 4-point Likert scale (1 = never, 2 = sometimes, 3 = usually, 4 = always), yielding a total score range of 52–208. Based on the total score range, health-promoting lifestyle behavior levels are categorized into three groups: low (52–104), moderate (105–156), and high (157–208), representing approximately equal thirds of the possible score range and corresponding to cutoffs used in previous Chinese community research [24]. The Chinese version demonstrated good internal consistency with a Cronbach's α coefficient of 0.93 [22]. In the present sample, the Cronbach's α coefficient was 0.926. Throughout this article, the Chinese-adapted HPLP-II total score is interpreted as a measure of proactive health behaviors.

To evaluate frailty status, the Tilburg Frailty Indicator (TFI) was adopted. The TFI assesses frailty across three dimensions—physical, psychological, and social—comprising 15 items [10]. All items are scored dichotomously (0 = absent, 1 = present). Total scores range from 0 to 15; participants are classified as frail (total score ≥ 5) or non-frail (0–4) [10]. In the present study, the TFI demonstrated a Cronbach's α coefficient of 0.766, indicating acceptable internal consistency. When applied to community-dwelling older adults [15], using the TFI with a cut-off score of ≥5, the scale demonstrated a Cronbach's α coefficient of 0.71 and a Kappa value of 0.569 for agreement with the Fried Frailty Phenotype.

2.5. Statistical Analysis

Descriptive and categorical analyses were performed in SPSS 27.0. Firth-penalized logistic models and interaction tests were reproduced in Python 3.12 using SciPy and statsmodels. Categorical data were described using frequencies and percentages, while continuous data were presented as medians and interquartile ranges [M (Q1, Q3)]. Categorical distributions were compared using Pearson's chi-square test without continuity correction; the test statistic, degrees of freedom, and asymptotic *p*-value are reported in the Results section. Because the data did not meet the assumption of normal distribution, the Kruskal–Wallis H test was used for comparisons among groups. When statistically significant differences were found in multiple-group comparisons, pairwise comparisons were further conducted with Bonferroni correction. Spearman's rank correlation analysis was employed to examine the correlations between the total score and each dimension of the HPLP-II and the TFI scores. The 95% confidence interval for the frailty prevalence was calculated using the Wilson score interval. A p-value < 0.05 was considered statistically significant.

Exploratory subgroup analyses were conducted by age group (60–74 years, 75–89 years, and ≥90 years) and recorded number of chronic conditions (2, 3, and >3 conditions) to examine whether the association between proactive health behaviors and frailty varied across population strata. Between-group differences in TFI total scores across lifestyle behavior levels were tested using the Kruskal–Wallis H test within each stratum. To limit

the risk of Type I error from multiple subgroup comparisons, Bonferroni correction was applied across the six strata. The adjusted significance threshold was $\alpha' = 0.05/6 \approx 0.008$.

Formal interaction tests were performed using likelihood-ratio tests, comparing nested logistic regression models with and without product terms between health-promoting lifestyle behavior levels and each stratification variable. A statistically significant interaction was defined as $p < 0.05$.

Covariates were selected a priori from a conceptual causal framework and prior literature. Sex, age, residence, education, marital status, and pre-retirement occupation were considered potential common causes of lifestyle behavior and frailty. Chronic disease count and medication burden were included as markers of clinical health burden. Care dependency was excluded from the primary model because it may lie downstream of lifestyle behavior and overlap with the physical domain of the TFI. Variables were included irrespective of univariable p values because selection on statistical significance can introduce bias. The number of chronic diseases was categorized as 2, 3, or ≥4, with 2 conditions as the reference category. All models used forced entry. Model fit was assessed using the Hosmer–Lemeshow test, discrimination using the C-statistic, and multicollinearity using variance inflation factors. Firth-penalized logistic regression was used for Models A and B to reduce small-sample bias and address separation associated with the absence of non-frail participants in the ≥90-year age group. Participants in this age group were retained as a separate category in both models, with those aged 60–74 years as the reference group.

2.6. Variable Definitions

The primary exposure variable was proactive health behaviors, measured by the Chinese-adapted Health-Promoting Lifestyle Profile II (HPLP-II) total score [22]. Based on the total score, proactive health behavior levels were categorized into three groups: low (52–104), moderate (105–156), and high (157–208).

The outcome variable was frailty, defined as TFI score ≥ 5 (frail) versus 0–4 (non-frail). Covariates pre-specified as baseline confounders were: sex, age (three categories: young-old 60–74, old-old 75–89, oldest old ≥ 90 years [34]), residence, educational level, marital status, pre-retirement occupation type, number of chronic diseases, and number of medications taken. These were entered simultaneously using the forced-entry method. Self-reported care dependency was treated as a potential mediating variable and examined separately in an exploratory model (Model B). Reference categories were the lowest code of each variable (male, young-old, urban, primary school, married, mental labor, 2 chronic diseases, no medications, low behavior level).

Multimorbidity was defined as the coexistence of two or more chronic diseases lasting ≥3 months. Chronic diseases were classified according to WHO categories [35], including cardiovascular diseases, chronic respiratory diseases, diabetes, cancer, and other chronic conditions. The number of chronic conditions for each participant was determined by summing the total number of self-reported chronic diseases.

2.7. Data Completeness

For each dimension of the HPLP-II and TFI scales, if the proportion of missing items within the dimension was less than 10%, missing data were handled using multiple imputation by chained equations (MICE); if the missing proportion exceeded 10%, the entire questionnaire was judged invalid and excluded from the analysis. In the raw dataset for the 207 included participants, 14 of 10,764 HPLP-II item responses (0.13%) were missing across nine participants (4.3%), and 17 of 3105 TFI item responses (0.55%) were missing across nine participants (4.3%). The final analytical sample comprised 207 participants.

2.8. Sample Size and Power Analysis

The study planned to analyze 29 variables in total, including 16 sociodemographic characteristics, 10 dimensions of the HPLP-II, and 3 dimensions of the TFI. Using the rule of thumb of five to ten observations per variable [36], the estimated planning range was 145–290 participants. For the adjusted logistic regression, an EPV criterion of 10 and an expected frailty prevalence of approximately 50% [16,17] suggested that a sample of about 300 would be desirable. Given the practical constraints of community recruitment, the feasible target was more than 200 participants. Of 227 completed questionnaires, 207 were retained after exclusions, including 117 frail and 90 non-frail participants. The primary Model A included 14 non-intercept regression terms, corresponding to 8.36 frailty events per term (117/14). The exploratory Model B included 16 non-intercept terms, corresponding to 7.31 frailty events per term (117/16).

Post hoc power was evaluated for the primary categorical exposure comparisons at a two-sided $\alpha = 0.05$ using the refitted Model A coefficients and standard errors. The adjusted odds ratios were 0.364 for moderate versus low behavior and 0.284 for high versus low behavior. In a conditional Monte Carlo sensitivity analysis, 10,000 outcome datasets were generated from the fitted Model A while keeping the observed covariates fixed; refitting the Firth model and applying the same two-sided Wald tests yielded power estimates of 36.1% and 45.2%, respectively. For the overall Spearman correlation between total HPLP-II and TFI scores ($r = -0.396$, $n = 207$), power estimated using the Fisher z approximation, with variance $1.06/(n - 3)$ for rank correlation [37], exceeded 99%.

3. Results

3.1. Participant Characteristics

Between July 2025 and January 2026, 227 community-dwelling older adults were screened across eight sites in five Shanghai districts, and all completed questionnaires. Twenty questionnaires (8.8%) were excluded: 14 participants had fewer than two chronic conditions, two had excessive missing scale data (>10%), two had other serious medical conditions, one had severe cognitive impairment, and one had severe hearing impairment. 207 valid questionnaires remained for analysis, with a valid questionnaire rate of 91.2%.

Among the 207 included participants, 121 (58.5%) were women and 86 (41.5%) were men; the mean age was 74.2 years (SD 10.4). Participants aged 60–74, 75–89, and ≥90 years numbered 109 (52.7%), 87 (42.0%), and 11 (5.3%), respectively. Of the sample, 127 (61.4%) lived in urban areas, 164 (79.2%) received a pension, and 123 (59.4%) had predominantly manual occupations before retirement. Most participants reported two chronic conditions ($n = 155$, 74.9%); 46 (22.2%) reported three and six (2.9%) reported more than three. Proactive health behavior levels were low in 23 participants (11.1%), moderate in 141 (68.1%), and high in 43 (20.8%).

3.2. Status of Chronic Conditions

The most common chronic-disease pair was hypertension plus diabetes (33.8%), followed by hypertension plus coronary heart disease (21.3%) and hypertension plus cognitive impairment (13.5%). Overall, 119 participants (57.5%) had at least one of these three disease pairs, with each participant counted once in this combined proportion. Other common pairs were hypertension plus hyperlipidemia (8.7%) and hypertension plus stroke (7.7%). The top seven pairs are shown in Table 1.

Table 1. Most common chronic-disease pairs.

Chronic Disease Pair	Participants, n	Participants (%)
Hypertension + diabetes	70	33.8
Hypertension + coronary heart disease	44	21.3
Hypertension + cognitive impairment	28	13.5
Hypertension + hyperlipidemia	18	8.7
Hypertension + stroke	16	7.7
Diabetes + cognitive impairment	14	6.8
Diabetes + coronary heart disease	12	5.8

Note. Each participant was counted once per disease pair. Participants with three or more chronic conditions could contribute to multiple rows. Percentages were calculated using all 207 participants as the denominator.

3.3. Frailty Status

The overall prevalence of frailty was 56.52% (117/207; 95% CI: 49.71–63.10). The median TFI total score was 6.00 (Q1–Q3: 3.00–9.00). Median scores were 3.00 (1.00–5.00) for the physical domain, 2.00 (1.00–3.00) for the psychological domain, and 1.00 (1.00–2.00) for the social domain. (Table 2).

Table 2. TFI total and domain score distributions (n = 207).

TFI score	Possible Range	Median (Q1–Q3)	Mean (SD)	≥1 Scored Item, n (%)
Total	0–15	6.00 (3.00–9.00)	5.66 (3.25)	—
Physical	0–8	3.00 (1.00–5.00)	2.71 (2.23)	159 (76.8)
Psychological	0–4	2.00 (1.00–3.00)	1.63 (1.20)	157 (75.8)
Social	0–3	1.00 (1.00–2.00)	1.32 (0.66)	191 (92.3)

Note. Q1 and Q3 denote the first and third quartiles; SD denotes standard deviation.

The overall prevalence of frailty was 56.52% (95% CI: 49.71–63.10). Univariate analysis showed statistically significant differences in the prevalence of frailty among older adults stratified by age, residence, educational level, marital status, pre-retirement occupation type, self-reported level of care dependency status, and level of proactive health behaviors ($p < 0.05$) (Table 3).

Table 3. Comparison of frailty status among older adults with different characteristics [n (%)].

Characteristic	Non-Frailty Group (n = 90)	Frailty Group (n = 117)	χ^2	df	*p*
Sex			3.535	1	0.060
Male	44 (48.9)	42 (35.9)			
Female	46 (51.1)	75 (64.1)			
Age			9.012	2	0.011
60–74 years old	51 (56.7)	58 (49.6)			
75~89 years old	39 (43.3)	48 (41.0)			
90 years old and above	0 (0)	11 (9.4)			
Residence			13.547	1	<0.001
Urban	68 (75.6)	59 (50.4)			
Rural	22 (24.4)	58 (49.6)			
Educational level			13.788	2	0.001
Primary school and below	16 (17.8)	43 (36.8)			
Junior/Senior Secondary Education and Vocational Upper Secondary Education	52 (57.8)	63 (53.8)			
College or above	22 (24.4)	11 (9.4)			

Table 3. *Cont.*

Characteristic	Non-Frailty Group (n = 90)	Frailty Group (n = 117)	χ^2	df	*p*
Marital status			16.295	2	<0.001
Married	72 (80.0)	65 (55.6)			
Widowed	12 (13.3)	45 (38.5)			
Other	6 (6.7)	7 (6.0)			
Number of children			5.403	2	0.067
None	2 (2.2)	5 (4.3)			
One	56 (62.2)	54 (46.2)			
Two or more	32 (35.6)	58 (49.6)			
Economic source			4.564	2	0.102
Pension	77 (85.6)	87 (74.4)			
Relatives	5 (5.6)	16 (13.7)			
Other	8 (8.9)	14 (12.0)			
Nature of occupation before retirement			4.559	1	0.033
Mainly mental work	44 (48.9)	40 (34.2)			
Mainly manual labor	46 (51.1)	77 (65.8)			
Types of medical insurance			1.231	2	0.540
Self-paying	2 (2.2)	6 (5.1)			
Resident medical insurance	54 (60.0)	66 (56.4)			
Employee medical insurance	34 (37.8)	45 (38.5)			
Number of chronic diseases			3.109	2	0.211
Two	72 (80.0)	83 (70.9)			
Three	17 (18.9)	29 (24.8)			
More than three	1 (1.1)	5 (4.3)			
Number of drugs taken			1.158	2	0.560
None	9 (10.0)	7 (6.0)			
1~2 kinds	41 (45.6)	55 (47.0)			
3 kinds or more	40 (44.4)	55 (47.0)			
Level of care dependency			32.691	2	<0.001
Basic self-care	81 (90.0)	62 (53.0)			
Need help	6 (6.7)	33 (28.2)			
Total dependence on others' care	3 (3.3)	22 (18.8)			
Living status			0.806	1	0.369
With household member	71 (78.9)	98 (83.8)			
Alone	19 (21.1)	19 (16.2)			
Health-promoting lifestyle behavior level			7.088	2	0.029
Low level	5 (5.6)	18 (15.4)			
Moderate level	61 (67.8)	80 (68.4)			
High level	24 (26.7)	19 (16.2)			

Note. Values are n (%), with percentages calculated within columns. χ^2 denotes Pearson's chi-square statistic; df denotes degrees of freedom.

3.4. Health-Promoting Lifestyle Behavior Levels

The results showed that 68.1% of older adults with multimorbidity had a moderate level of proactive health behaviors. Statistically significant differences in the distribution of health-promoting lifestyle behavior levels were observed among participants with different sex, residence, educational level, marital status, number of children, source of income, and number of chronic conditions ($p < 0.05$) (Table 4).

Table 4. Comparison of health-promoting lifestyle behavior levels among older adults with different characteristics [n (%)].

Characteristic	Low Level (n = 23)	Moderate Level (n = 141)	High Level (n = 43)	χ^2	df	*p*
Sex				6.534	2	0.038
Male	7 (30.4)	67 (47.5)	12 (27.9)			
Female	16 (69.6)	74 (52.5)	31 (72.1)			

Table 4. *Cont.*

Characteristic	Low Level (n = 23)	Moderate Level (n = 141)	High Level (n = 43)	χ^2	df	*p*
Age				7.623	4	0.106
60~74 years old	14 (60.9)	66 (46.8)	29 (67.4)			
75~89 years old	7 (30.4)	68 (48.2)	12 (27.9)			
90 years old and above	2 (8.7)	7 (5.0)	2 (4.7)			
Residence				17.763	2	<0.001
Urban	6 (26.1)	87 (61.7)	34 (79.1)			
Rural	17 (73.9)	54 (38.3)	9 (20.9)			
Educational level				31.444	4	<0.001
Primary school and below	17 (73.9)	38 (27.0)	4 (9.3)			
Junior/Senior Secondary Education and Vocational Upper Secondary Education	4 (17.4)	81 (57.4)	30 (69.8)			
College or above	2 (8.7)	22 (15.6)	9 (20.9)			
Marital status				9.882	4	0.042
Married	16 (69.6)	85 (60.3)	36 (83.7)			
Widowed	6 (26.1)	47 (33.3)	4 (9.3)			
Other	1 (4.3)	9 (6.4)	3 (7.0)			
Number of children				9.839	4	0.043
None	0 (0.0)	5 (3.5)	2 (4.7)			
One	11 (47.8)	68 (48.2)	31 (72.1)			
Two or more	12 (52.2)	68 (48.2)	10 (23.2)			
Economic source				12.690	4	0.013
Pension	22 (95.7)	103 (73.0)	39 (90.7)			
Relatives	1 (4.3)	20 (14.2)	0 (0.0)			
Other	0 (0.0)	18 (12.8)	4 (9.3)			
Nature of occupation before retirement				4.620	2	0.099
Mainly mental work	5 (21.7)	58 (41.1)	21 (48.8)			
Mainly manual labor	18 (78.3)	83 (58.9)	22 (51.2)			
Types of medical insurance				4.104	4	0.392
Self-paying	1 (4.3)	6 (4.3)	1 (2.3)			
Resident medical insurance	17 (73.9)	81 (57.4)	22 (51.2)			
Employee medical insurance	5 (21.7)	54 (38.3)	20 (46.5)			
Number of chronic diseases				13.007	4	0.011
Two	23 (100.0)	96 (68.1)	36 (83.7)			
Three	0 (0.0)	40 (28.4)	6 (14.0)			
More than three	0 (0.0)	5 (3.5)	1 (2.3)			
Number of drugs taken				9.014	4	0.061
None	2 (8.7)	10 (7.1)	4 (9.3)			
1~2 kinds	5 (21.7)	66 (46.8)	25 (58.1)			
3 kinds or more	16 (69.6)	65 (46.1)	14 (32.6)			
Level of care dependency				5.005	4	0.287
Basic self-care	17 (73.9)	91 (64.5)	35 (81.4)			
Need help	4 (17.4)	31 (22.0)	4 (9.3)			
Total dependence on others' care	2 (8.7)	19 (13.5)	4 (9.3)			
Living status				0.624	2	0.732
With household member	20 (87.0)	115 (81.6)	34 (79.1)			
Alone	3 (13.0)	26 (18.4)	9 (20.9)			

Note. Values are n (%) with percentages calculated within columns. χ^2 denotes Pearson's chi-square statistic; df denotes degrees of freedom.

3.5. Analysis of Differences in TFI Score Among Older Adults with Different Characteristics

Since the TFI score did not follow a normal distribution, the Kruskal–Wallis H test was applied to examine differences in the TFI score among older adults with different characteristics. The overall analysis showed statistically significant differences in the TFI score across age groups ($H = 14.218$, $p < 0.001$) and across levels of proactive health behaviors ($H = 17.756$, $p < 0.001$), whereas no significant between-group difference was observed for the number of chronic conditions ($H = 3.510$, $p = 0.173$).

Post hoc pairwise comparisons with Bonferroni correction revealed that the TFI score of oldest old adults (≥90 years) was significantly higher than that of young-old adults ($p < 0.001$) and old-old adults ($p = 0.007$). With regard to proactive health behaviors, the high-level group had a significantly lower TFI score than both the moderate-level group ($p = 0.010$) and the low-level group ($p < 0.001$); the moderate-level group also exhibited

a significantly lower TFI score than the low-level group ($p = 0.038$), showing a graded unadjusted pattern across behavior levels.

To further explore the population-specific effects of proactive health behaviors on frailty, subgroup analyses were conducted stratified by age and number of chronic conditions. Nonparametric tests were used to compare differences in the TFI score across levels of proactive health behaviors within each stratum. The results are summarized in Table 5.

Table 5. TFI scores across lifestyle behavior levels within age and disease-count strata.

Stratum	Subgroup	n	Low: Median (IQR)	Moderate: Median (IQR)	High: Median (IQR)	H	*p*
Age	60–74 years	109	6.50 (4.25–11.50)	5.00 (3.00–8.00)	3.00 (1.00–6.00)	8.476	0.014
	75–89 years	87	7.00 (6.50–10.50)	6.00 (3.00–9.00)	3.00 (1.00–4.75)	7.065	0.029
	≥90 years	11	12.00 (12.00–12.00)	9.00 (7.50–9.00)	8.50 (7.75–9.25)	4.922	0.085
Disease count	2	155	7.00 (5.00–12.00)	5.50 (3.00–9.00)	3.00 (1.00–6.00)	18.417	<0.001
	3	46	— (n = 0)	6.00 (4.00–9.00)	5.50 (4.25–6.75)	0.033	0.855
	>3	6	— (n = 0)	8.00 (6.00–10.00)	5.00 (5.00–5.00)	0.771	0.380

Note. Values are median (P25–P75). H = Kruskal–Wallis statistic. For the 3-condition and >3-condition strata, no participant was in the low lifestyle behavior group, so the tests compared moderate and high levels.

In exploratory stratified analyses, nominally significant between-group differences in TFI total scores across lifestyle behavior levels were observed in the 60–74 years age group ($H = 8.476$, $df = 2$, $p = 0.014$), the 75–89 years age group ($H = 7.065$, $df = 2$, $p = 0.029$), and the group with 2 chronic conditions ($H = 18.417$, $df = 2$, $p < 0.001$; Table 5). No significant differences were observed in the ≥90 years group ($H = 4.922$, $p = 0.085$), the 3-condition group ($H = 0.033$, $p = 0.855$), or the >3-condition group ($H = 0.771$, $p = 0.380$).

After Bonferroni correction for multiple comparisons (adjusted $\alpha = 0.008$), only the association in the 2-condition stratum remained below the corrected significance threshold. The 60–74 and 75–89 years age-group findings were nominal and did not remain significant after correction.

Formal interaction tests showed no statistically significant age × behavior-level (likelihood-ratio $\chi^2(4) = 0.71$, $p = 0.950$) or disease-count × behavior-level (likelihood-ratio $\chi^2(4) = 0.54$, $p = 0.970$) interactions, providing no evidence of effect modification. These interaction tests were conducted using multivariable logistic regression models with product terms (age or disease count × behavior level), adjusted for the same covariates as Model A.

3.6. Correlation Analysis of Proactive Health Behaviors and Frailty

Spearman rank correlation analysis was further performed to examine the association between proactive health behaviors and frailty. The results showed that the total HPLP-II score was significantly and negatively correlated with the total TFI score ($r = -0.396$, $p < 0.01$), indicating that higher levels of proactive health behaviors corresponded to less severe frailty. At the dimensional level, the regular exercise dimension showed the numerically largest negative correlation with physical frailty ($r = -0.491$, $p < 0.01$) among the dimension-level correlations examined. The psychological status dimension was negatively correlated with social frailty ($r = -0.340$, $p < 0.01$). In addition, dimensions including stress management, health responsibility, and healthy eating were also negatively correlated with the total TFI score or its subdimensions to varying degrees (Table 6).

Table 6. Spearman Rank Correlations Between HPLP-II Scores and TFI Scores (n = 207).

HPLP-II Scale/Dimension	TFI Total Score	Physical Domain	Psychological Domain	Social Domain
HPLP-II Total Score	−0.396 **	−0.341 **	−0.313 **	−0.190 **
Healthy eating	−0.321 **	−0.265 **	−0.269 **	−0.110
Regular exercise	−0.498 **	−0.491 **	−0.315 **	−0.226 **
Interpersonal relations	−0.091	−0.032	−0.190 **	0.011
Psychological status	−0.317 **	−0.244 **	−0.237 **	−0.340 **
Spiritual growth	−0.065	−0.055	−0.026	−0.048
Stress management	−0.292 **	−0.233 **	−0.263 **	−0.177 *
Stress coping	−0.393 **	−0.351 **	−0.312 **	−0.140 *
Health responsibility	−0.275 **	−0.197 **	−0.274 **	−0.203 **
Health awareness	−0.299 **	−0.293 *	−0.176 *	−0.248 **
Health habits	−0.058	0.019	−0.172 *	0.078

Note. * $p < 0.05$; ** $p < 0.01$ (two-tailed).

3.7. Multivariable Logistic Regression Analysis of Factors Associated with Frailty

The multivariable analysis presented in this section is the primary, confounder-adjusted analysis used to evaluate the association between proactive health behaviors and frailty and to identify other independently associated factors.

The pre-specified confounder set (sex, age, residence, educational level, marital status, pre-retirement occupation type, number of chronic diseases, and number of medications taken), together with the exposure variable (level of proactive health behaviors), was entered into a forced-entry binary logistic regression model (Model A; see Section 2.6). The variable coding scheme is presented in Table 7. Care dependency was entered only in the exploratory Model B because it may lie downstream of lifestyle behavior and overlap with the physical domain of the TFI.

Table 7. Assignment table.

Variables	Coding
Frailty	Non-frailty = 0, Frailty = 1
Sex	Male = 1, Female = 2
Age	60~74 years old (young-old) = 1, 75~89 years old (old-old) = 2, 90 years old and above (oldest old) = 3
Place of residence	Urban = 1, Rural = 2
Educational level	Primary school or below = 1, Junior high school, senior high school and technical secondary school = 2, Junior college or above = 3
Marital status	Married = 1, Widowed = 2, Others = 3
Occupational nature before retirement	Predominantly mental labor = 1, Predominantly physical labor = 2
Self-reported level of care dependency	Basic self-care = 1, Need assistance = 2, Complete dependence on others for care = 3
Level of proactive health behaviors	Low level = 1, Moderate level = 2, High level = 3
Number of chronic diseases	2 conditions = 1, 3 conditions = 2, ≥4 conditions = 3
Medications taken	None = 1, 1–2 medications = 2, ≥3 medications = 3 (ordinal term)

In the pre-specified confounder model (Model A; forced-entry Firth penalized logistic regression), widowhood was significantly associated with increased frailty risk (OR = 3.174, 95% CI: 1.355–7.434, $p = 0.008$) relative to being married. Proactive health behaviors showed an inverse direction: high-level behavior was not statistically significant (OR = 0.284, 95% CI: 0.077–1.041, $p = 0.058$), and moderate-level behavior showed a similar direction (OR = 0.364,

95% CI: 0.115–1.149, $p = 0.085$). Other covariates showed no independent association with frailty (all $p > 0.05$). Model A demonstrated adequate calibration (Hosmer–Lemeshow $\chi^2 = 4.02$, df = 8, $p = 0.855$), acceptable discrimination (C-statistic = 0.748), and no serious multicollinearity (all VIFs < 3). Full results are presented in Table 8. In exploratory Model B, which additionally included care dependency, high versus low behavior was associated with lower odds of frailty (OR = 0.253, 95% CI: 0.065–0.980, $p = 0.047$), whereas moderate versus low behavior was not statistically significant (OR = 0.317, 95% CI: 0.096–1.053, $p = 0.061$).

Table 8. Firth-penalized logistic regression: Model A and Model B.

Variable	Category (Reference)	Model A OR	Model A 95% CI	Model A *p*	Model B OR (95% CI)	Model B *p*
Health-promoting lifestyle behavior level	Moderate vs. low	0.364	0.115–1.149	0.085	0.317 (0.096–1.053)	0.061
	High vs. low	0.284	0.077–1.041	0.058	0.253 (0.065–0.980)	0.047 *
Marital status	Widowed vs. married	3.174	1.355–7.434	0.008 *	2.039 (0.809–5.140)	0.131
	Other vs. married	1.512	0.452–5.065	0.502	1.408 (0.392–5.057)	0.599
Age group	75–89 vs. 60–74 y	0.660	0.326–1.333	0.246	0.511 (0.242–1.080)	0.079
	≥90 vs. 60–74 y	7.567	0.354–161.835	0.195	5.462 (0.173–172.318)	0.335
Chronic diseases	3 vs. 2	1.822	0.793–4.184	0.157	1.756 (0.719–4.291)	0.217
	≥4 vs. 2	3.758	0.458–30.841	0.218	2.557 (0.269–24.283)	0.414
Educational level	Secondary vs. primary	1.382	0.543–3.519	0.498	1.452 (0.537–3.928)	0.463
	College vs. primary	0.707	0.189–2.641	0.606	0.940 (0.231–3.832)	0.931
Sex	Female vs. male	1.108	0.570–2.153	0.763	1.205 (0.599–2.423)	0.601
Residence	Rural vs. urban	1.704	0.731–3.971	0.217	1.767 (0.734–4.253)	0.204
Occupation	Manual vs. mental	1.028	0.480–2.200	0.943	1.007 (0.454–2.235)	0.987
Medications	Per category (ordinal)	0.924	0.553–1.543	0.762	1.063 (0.620–1.822)	0.824
Care dependency (Model B only)	Needs help vs. independent	—	—	—	4.391 (1.610–11.980)	0.004 *
	Fully dependent vs. independent	—	—	—	6.182 (1.733–22.057)	0.005 *

Note. OR = odds ratio; CI = confidence interval; TFI = Tilburg Frailty Indicator. * $p < 0.05$.

All 11 participants aged ≥90 years were classified as frail. The adjusted estimates for this age group had wide confidence intervals in both models, indicating substantial uncertainty (Table 8).

In a sensitivity analysis, disease-count group was entered as an ordinal variable (2, 3, and >3 conditions) with the same covariates as Model A. Each one-category increase was not significantly associated with frailty (OR = 1.926, 95% CI 0.959–3.867, $p = 0.065$), consistent with the primary categorical analysis.

4. Discussion

4.1. Frailty Status Among Older Adults with Multimorbidity

Frailty was present in 56.52% of participants (95% CI: 49.71–63.10), with a median TFI total score of 6.00. This estimate is higher than the 43.7% reported by Qiu et al. in 933 Chinese community-dwelling older adults assessed using the same instrument [38].

The median physical-domain score was 3.00, and 76.8% of participants had at least one scored physical item. The TFI captures difficulties involving mobility, balance, sensory function, strength and tiredness, as well as perceived physical health and weight loss [10]. In a Dutch study of 47,768 older adults, Gobbens et al. found that chronic diseases were more strongly associated with physical frailty than with psychological or social frailty [39]. The

physical difficulties observed in our sample may therefore reflect the cumulative functional burden of multimorbidity. Durán-Gómez et al. [40] likewise reported that frailty and a greater number of chronic conditions were associated with poorer physical health-related quality of life among institutionalised older adults in Spain. Together, these findings support attention to physical functioning when evaluating the health needs of older adults with multimorbidity.

Psychological vulnerability was also frequent, with a median score of 2.00 and at least one scored item in 75.8% of participants. This domain covers memory problems, feeling down, anxiety and difficulty coping [10]. Qiu et al. identified feeling down, together with walking and balance difficulties, as central symptoms in a Chinese TFI symptom network [38]. A longitudinal study by Gobbens and van Assen further found that feeling down predicted subsequent quality of life after adjustment for background characteristics and diseases [41]. These findings support considering emotional and coping difficulties alongside physical functioning when describing frailty.

The social domain had a median score of 1.00, and 92.3% of participants had at least one scored item. The three items address living alone, missing other people and insufficient support [10]. Although 81.6% of participants lived with others, co-residence alone does not establish adequate companionship or support. Longitudinal evidence from Mehrabi et al. links earlier frailty to later social isolation and loneliness, with loneliness also predicting later frailty at some time points [32].

4.2. The Association Between Proactive Health Behaviors and Frailty

Most participants reported moderate proactive health behaviors (68.1%). Higher HPLP-II scores were correlated with lower TFI scores ($r = -0.396$), but the primary adjusted model did not establish a statistically significant association. Chen et al. reported a comparable pattern in 10,388 Chinese older adults: the overall health-promotion score was not associated with frailty after adjustment, although nutritional behaviors and physical activity showed inverse associations [28]. This suggests that a composite score may conceal differences across behavioral domains. In the exploratory model additionally adjusted for care dependency, high versus low behavior was associated with lower frailty odds (OR = 0.253, 95% CI: 0.065–0.980, $p = 0.047$). This association was not statistically significant in the primary Model A (OR = 0.284, 95% CI: 0.077–1.041, $p = 0.058$). Care dependency may be downstream of health behavior and overlaps with aspects of physical frailty, so including it can change the estimand and introduce overadjustment or selection bias. This finding should therefore be treated as hypothesis-generating.

Regular exercise had the numerically strongest correlation with physical frailty ($r = -0.491$), consistent with Chinese community evidence concerning physical activity, sedentary behavior and frailty [27]. In a randomized trial, Ng et al. found that physical training improved frailty status, with improvements in knee strength and gait speed [42]. Maintaining strength and mobility is therefore a plausible pathway linking exercise to lower physical vulnerability.

Healthy eating was inversely correlated with total frailty ($r = -0.321$). In a nationwide cohort of 12,457 Chinese older adults, Wang et al. found that persistently low dietary diversity and marked declines in diversity were associated with subsequent frailty [43]. Together with the nutrition-related findings of Chen et al. [28], these findings support examining sustained dietary quality alongside physical activity. For people following several disease-specific diets, nutritional adequacy and variety deserve assessment, but the present HPLP-II data cannot identify specific nutrient deficiencies or establish the benefits of a particular diet.

The inverse correlations of stress coping with total frailty ($r = -0.393$) and psychological status with social frailty ($r = -0.340$) suggest that the behavioral association also involves psychosocial functioning. Emotional well-being and coping may help maintain participation, while declining function may restrict opportunities for activity and social connection. The longitudinal findings of Mehrabi et al. [32] reinforce the possibility of reciprocal relationships.

Among participants with two chronic conditions, median TFI scores were 7.00 in the low-behavior group and 3.00 in the high-behavior group, and the overall comparison remained significant after Bonferroni correction. The age-group findings did not survive correction. The findings justify further longitudinal and intervention research on feasible behavioral support. Such studies should address limitations in community resources, health literacy and social connection, and accommodate symptoms and functional capacity. Ou et al. [44] found that proactive health behavior ability among 325 care-dependent older adults in 15 nursing homes was associated with disability level, caregiver responsiveness and participation in health-related institutional activities, among other factors. Their care-specific instrument and institutional sample differ from ours, but the findings suggest that opportunities and support for behavior may matter alongside individual motivation. They also reinforce the need for caution when care dependency is entered into exploratory explanatory models.

4.3. Other Factors Associated with Frailty

Widowhood was associated with higher odds of frailty in Model A (OR = 3.174, 95% CI: 1.355–7.434, $p = 0.008$). Loss of companionship and practical support may make daily activities and disease management more difficult, while bereavement-related distress may affect psychological well-being. In a longitudinal study of 1931 older adults, Pollak et al. found that loneliness predicted faster frailty progression in married and widowed participants [45]. Lyu et al. [46] also examined marital status in relation to frailty progression among middle-aged and older adults in China. These studies place our finding within a broader literature on partnership and social relationships, but neither the present cross-sectional association nor marital status alone establishes the mechanisms linking bereavement and frailty. Moreover, the widowhood estimate was smaller and non-significant in Model B (OR = 2.039, 95% CI: 0.809–5.140), indicating sensitivity to model specification.

The number of chronic conditions was not significantly associated with frailty in the primary adjusted model, despite evidence from larger population-based studies relating multimorbidity burden to frailty [47]. Disease composition may provide a more informative context than count alone. In a population-based cohort, Tazzeo et al. [48] identified distinct multimorbidity patterns with different risks of incident physical frailty, particularly patterns involving cardiovascular or neuropsychiatric conditions. Hypertension combined with diabetes, coronary heart disease, or cognitive impairment was common in our sample. The two-condition finding therefore motivates further examination of specific disease combinations and functional limitations, rather than defining a disease-count threshold for behavioral benefit.

4.4. Limitations

The cross-sectional design precludes causal inference and cannot exclude reverse causation. Convenience sampling in Shanghai and exclusion of people with severe impairments limit generalizability and may underestimate frailty burden. Self-reported and researcher-assisted assessments are susceptible to recall and social desirability biases, and shared self-report methods may contribute to correlated measurement error [49]. The Chinese-adapted HPLP-II operationalizes proactive health behaviors but does not indepen-

dently validate that broader construct. In addition, cognitive eligibility screening was not standardized and reported cognitive impairment was not verified against clinical records, allowing possible misclassification of cognitive status and differences in response reliability.

The modest sample and sparse subgroups limited precision despite Firth penalization; participants with three or more conditions had no representation in the low-behavior category. Subgroup analyses were not pre-specified, and domain-level correlations involved multiple comparisons; these findings remain exploratory despite post hoc correction of subgroup tests. Unmeasured disease severity, socioeconomic circumstances, nutritional status, depressive symptoms, social support, and healthcare access may confound the associations. Longitudinal studies with objective behavioral and functional measures and pre-specified analyses are needed.

Finally, data collection began in July 2025 before formal ethics approval on 09 March 2026. This delayed approval is acknowledged as an ethical and methodological limitation.

5. Conclusions

This cross-sectional study found a high prevalence of frailty (56.52%) among community-dwelling older adults with multimorbidity in Shanghai. Proactive health behaviors were at a moderate level and were significantly negatively correlated with TFI scores in unadjusted analysis (Spearman r = −0.396, $p < 0.01$). The primary adjusted model did not detect a statistically significant association between behavior level and frailty. High versus low behavior was associated with lower frailty odds in exploratory Model B after inclusion of care dependency (OR = 0.253, 95% CI: 0.065–0.980, $p = 0.047$). Unadjusted subgroup analyses showed differences in TFI total scores across health-promoting lifestyle behavior levels in the 60–74-year, 75–89-year, and two-disease subgroups; after Bonferroni correction, only the two-disease subgroup remained significant. Interaction tests found no evidence of effect modification by age or disease count. These findings highlight the high burden of frailty in this population and provide preliminary cross-sectional evidence consistent with a potential inverse association between proactive health behaviors and frailty. Future longitudinal and intervention studies with larger samples, objective outcome measures, and pre-specified analytic plans are warranted to further elucidate the temporal relationship and to examine whether targeted behavioral interventions are associated with favorable frailty outcomes in this vulnerable population.

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Institutional Review Board Statement: This observational study involved questionnaire-based data collection. Data collection began in July 2025, and the study protocol was approved by the Ethics Committee of the School of Nursing, Fudan University on 9 March 2026 (approval number: H2026044). The delayed approval is disclosed in the Limitations section.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available on request from the corresponding authors. The reason for the restricted data availability is stated as follows: The dataset

of this study contains sensitive personal health information of community-dwelling older adults with multimorbidity, including their demographic characteristics, chronic disease profiles, functional status assessment results, and individual health behavior records. Given the vulnerability of the older adult population and the high privacy sensitivity of health-related personal data, full public disclosure of the raw dataset would pose potential risks to the confidentiality and privacy of study participants. To balance academic data sharing and participant privacy protection, de-identified data will be made available upon reasonable request from the corresponding authors. All data requests will be reviewed by the research team and the relevant ethics authority to ensure the data is only used for non-commercial academic research purposes, and that participant confidentiality is fully maintained.

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Abbreviations

The following abbreviations are used in this manuscript:

HPLP-II	Health-Promoting Lifestyle Profile-II
TFI	Tilburg Frailty Indicator
STROBE	Strengthening the Reporting of Observational Studies in Epidemiology
EPV	Events per variable

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