The bidirectional association between self-perceptions of aging and frailty: the mediating role of subjective cognitive decline

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Abstract

Objective With the global population aging rapidly, understanding the factors influencing health outcomes in older adults is crucial. This study explores the longitudinal causal relationship between self-perceptions of aging and frailty and examines whether subjective cognitive decline mediated the associations.

Methods The Brief-Aging Perceptions Questionnaire(B-APQ), the Frailty Phenotype Assessment Scale, and the Subjective Cognitive Decline Questionnaire were used to survey 619 community-dwelling older adults in Xinxiang, Henan, China, from March to October 2021 and from March to October 2023, respectively. A cross-lagged model was employed to analyze the potential mediating roles of subjective cognitive decline, controlling for confounders including age, gender, income, employment status, and education.

Results (1) The cross-lagged model analysis revealed a bidirectional causal relationship between self-perceptions of aging and frailty ($P < 0.001$), with the effect of T1 self-perceptions of aging on T2 frailty ($\beta = 0.109$, $SE = 0.038$, $P < 0.01$) and the reverse effect ($\beta = 0.129$, $SE = 0.041$, $P < 0.01$). Further comparisons of the path coefficients indicated that the effect sizes of the two paths showed no statistical difference ($\chi^2 = 0.119$, $P > 0.05$). (2) The longitudinal mediation analysis indicated that T1 self-perceptions of aging had an indirect effect on T2 frailty through subjective cognitive decline (indirect effect = 0.011). Concurrently, T1 frailty also indirectly influenced T2 self-perceptions of aging via subjective cognitive decline (indirect effect = 0.010), with all effects demonstrating statistical significance ($P < 0.05$).

Conclusion This study demonstrates a bidirectional causal relationship between self-perceptions of aging and frailty, with subjective cognitive decline identified as a mediating mechanism. These findings provide important guidance for future efforts aimed at reducing frailty rates among older adults in community settings.

Keywords Community, Mediation, Cross-lagged panel study

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Introduction

As population aging increases dramatically worldwide, health issues among older adults are increasingly attracting attention. China has the largest older adult population in the world, and studies suggest that by 2050, the population aged 65 and over in China will reach 395 million [1]. It is essential to focus on health issues such as

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frailty, disability, falls, and cognitive impairments among older adults [2, 3]. Frailty is a common and complex health problem in old age, which refers to the increased vulnerability of the individual and the weakening of the ability to maintain the inner balance of the self, mainly manifested by the decline of the body's reserves and resilience [4]. In a comprehensive global study spanning 62 countries, the frailty rate escalated with age, starting at 11% for those aged 50 to 59 years and peaking at 51% among nonagenarians and older. These findings align with a Chinese "expert consensus" definition, which estimates that approximately 10% of older adult individuals aged 60 and above, 15% of those aged 75 to 84, and nearly 25% of those aged 85 and above in community settings are affected by frailty [5, 6]. This indicates that the prevalence in the older adult population is high in the community. Additionally, studies suggest that frailty is a dynamic state, with the possibility of bidirectional transitions between frail and non-frail states [7, 8]. Therefore, exploring and reducing the influencing factors of frailty, especially modifiable factors, can help decrease the progression of frailty among older adults.

Based on the Cognitive Phenomenological Transactional theory [9], older adults often perceive multifaceted stress associated with aging. The perception can lead to negative cognitive evaluations towards aging. Negative self-perceptions of aging may in turn result in adverse health outcomes such as frailty. Self-perceptions of aging (SPA), as an important psycho-social factor, is proposed based on the self-regulation theory as the subjective perceptions and emotional responses generated by older adults when faced with threats related to psychological, and social aging. These subjective feelings and emotional responses can influence the behavioral tendencies of older adults during the aging process [10]. SPA is not only closely related to the physical health of older adults but also plays a vital role in various positive health outcomes for this population. For instance, a longitudinal study demonstrated that positive SPA not only enhances the psychological resilience of older adults following a fall but also further promotes their social engagement [11]. Older adults with positive self-perceptions of aging are more likely to participate in physical exercise [12]. Furthermore, previous studies have also indicated a relationship between self-perceptions of aging and adverse health outcomes [13]. For example, negative self-perceptions of aging are associated with slower walking speed in older adults [14]. Physical activity and walking speed are also components of frailty. The direct association between self-perceptions of aging and frailty comes from a longitudinal study that explored the bidirectional relationship between subjective age (a construct similar to self-perceptions of aging) and frailty. The results indicated that

subjective age predicts frailty (pre-frailty/frailty) regardless of whether covariates are controlled for, and the association between frailty and subjective age significantly decreases after controlling for variables [15]. This suggests that, when exploring the relationship between the two, more research evidence tends to support the notion that self-perceptions of aging act as the cause and frailty as the effect. In contrast to subjective age, self-perceptions of aging is a multidimensional concept that can more comprehensively describe older adults' perceptions of their aging status on both physical and psychological levels. Therefore, this study focuses on examining the strength of the causal relationship between multidimensional self-perceptions of aging and frailty, and further exploring their potential mechanisms.

Cognitive function is considered one of the most pronounced health indicators in the aging process [16]. Subjective cognitive decline refers to the state in which individuals feel that their cognitive levels have declined compared to the previous state, despite objective neurological tests showing no pathological changes [17]. This condition represents an initial stage of cognitive decline and has a high prevalence among community-dwelling older adults, yet it is often overlooked. Cross-sectional studies have indicated that subjective cognitive decline is not only significantly associated with the occurrence of frailty [18], but it is also a significant predictor of frailty onset in older adults [19]. Additionally, longitudinal analyses have confirmed a temporal relationship between subjective cognitive decline and frailty [20]. Furthermore, a review of the evidence and causal mechanisms linking frailty and cognitive impairment suggests that frailty increases the likelihood of future cognitive decline. Conversely, cognitive impairment also heightens the risk of frailty, indicating an interactive relationship between the two within a cycle of decline [21]. Moreover, related research demonstrates that negative perceptions of aging contribute to a vicious cycle of subjective cognitive decline. Specifically, negative views of aging are associated with subjective cognitive decline [22], which in turn exacerbates negative perceptions of aging [23]. Based on these findings, there appears to be a complex interplay among these three factors. Previous studies have shown that cognitive function mediates the relationship between self-perceptions of aging and frailty [24], but this study is limited to a cross-sectional design, which overlooks the dynamic nature of the relationship between subjective cognitive decline and frailty. As a result, it cannot establish causal links or account for potential mechanisms that may change over time, thereby influencing the relationship between the two variables. Furthermore, this research employs subjective cognitive decline as a variable, which occurs in the preclinical

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stage of cognitive impairment and is subject to intervention and recovery [25]. In an aging society with limited healthcare resources, exploring these reversible factors' impact on frailty not only helps reduce medical costs but also allows for more time to prevent subsequent adverse health outcomes. To address these issues, this study utilizes a cross-lagged panel model, a form of path analysis that examines reciprocal and longitudinal relationships among a set of inter-correlated variables. We include two years of subjective cognitive decline as a mediating variable and hypothesize that declines in subjective cognitive abilities may mediator the relationship between self-perceptions of aging and frailty. The specific hypotheses are as follows:

(1) There is a bidirectional causal relationship between self-perceptions of aging and frailty, with the influence of self-perceptions of aging on frailty being significantly greater than the reverse effect;

(2) Subjective cognitive decline mediates the effect of self-perceptions of aging on frailty, and subjective cognitive decline also mediates the effect of frailty on self-perceptions of aging.

Materials and methods
Study participants
In the period from March to October 2021, a convenience sampling method was employed to select a total of 619 older adults from five communities in Xinxiang City, Henan, China, including Binhu Community, Chengcheng Community, Yangguang Community, Xinglong Community, and Luotuowan Community. A follow-up was conducted two years later, from March to October 2023. The inclusion criteria for this study were as follows: Age ≥ 65 years, and voluntarily willing to participate in this study. Participants diagnosed with dementia or mental disorders by a physician, as well as those unable to provide consent due to severe visual, auditory, or language impairments, were excluded. Additionally, participants who could not walk independently (or with the aid of a walker) on level surfaces indoors were also excluded from the study. All participants provided informed consent, and the study received approval from the Institutional Review Boards and Ethics Committee of Xinxiang Medical University (XYLL-2021004).

Self-perceptions of aging assessments
The Brief-Aging Perceptions Questionnaire (B-APQ) is used for assessment. It was developed by Irish researchers Sexton et al. in 2014 based on Leventhal's self-regulation model [26]. The questionnaire has been translated into Chinese by Hu Na [27, 28]. It consists of 17 items across five dimensions: negative consequences and

control, positive consequences, timeline chronicity, positive control, and emotional representations. The questionnaire uses a 5-point Likert scale, with a total score range of 17 to 85 points. Higher scores indicate a higher level of self-perceptions of aging, reflecting a more negative attitude towards aging among older adults. In this study, the Cronbach's alpha values at T1 (baseline) were 0.74, and the Cronbach's alpha values at T2 (2-year follow-up) were 0.82.

Frailty assessments
The Fried Frailty Phenotype Scale was used for assessment [29]. The scale includes five aspects: unexplained weight loss, self-reported fatigue, decreased grip strength, reduced walking speed, and decreased physical activity levels. Unexplained weight loss, defined as an unintentional decrease of 4.5 kg or 5% of baseline body weight within the past year, was assessed through self-reported measures. Fatigue levels were evaluated using two items from the CES-D questionnaire: "I felt that doing anything was an effort in the past week" and "I felt unable to carry on with my daily activities in the past week." Grip strength thresholds were established based on gender and BMI. For men, low grip strength was defined by the following criteria: ≤ 29 kg for BMI ≤ 24; ≤ 30 kg for BMI 24.1–26; ≤ 30 kg for BMI 26.1–28; ≤ 32 kg for BMI > 28. For women, the criteria for low grip strength were as follows: ≤ 17 kg for BMI ≤ 23; ≤ 17.3 kg for BMI 23.1–26; ≤ 18 kg for BMI 26.1–29; ≤ 21 kg for BMI > 29. The decline in walking speed was measured by timing how long it took participants to walk 4.57 m. According to established height and gender criteria, a walking speed was classified as slow if, for men, those with a height of ≤ 173 cm and speed ≥ 7 s or those > 173 cm and speed ≥ 6 s; for women, a height of ≤ 159 cm and speed ≥ 7 s or a height > 159 cm and speed ≥ 6 s. Grip strength was measured using a dynamometer (Electronic hand grip dynamometer EH101; Guangdong Xiangshan Weighing Apparatus Group Co., Ltd.), with three trials conducted and the maximum value recorded. Furthermore, decreased physical activity levels were evaluated using the International Physical Activity Questionnaire short version [30]. Each dimension was scored as 1, resulting in total scores ranging from 0 to 5, with higher scores indicating greater frailty. Participants' frailty status was classified as robust (score 0), pre-frail (scores 1–2), or frail (scores 3–5).

Subjective cognitive decline assessments-9
The Chinese version of SCD-Q-9 [31] consists of 2 dimensions and 9 items, including overall memory function and time comparison (4 items) and daily activity ability(5 items). It adopts a 2 or 3-point rating scale, ranging

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from "yes" to "no" or from "often" to "never", with scores running from 1 to 0 sequentially, all items using positive scoring. A higher score indicates a higher likelihood of cognitive impairment. In this study, the Cronbach's alpha values at T1 (baseline) were 0.74, and the Cronbach's alpha values at T2 (2-year follow-up) were 0.77.

Covariates

Sociodemographic characteristics collected at baseline included gender, age, marital status (married/widowed or divorced/single), Education (elementary school and below/junior high school/high school and technical secondary school/university and above), Employment status (farmer/civil servant /worker/others), Living arrangements (with spouse and children/with spouse/with children/others), Income (<1000 yuan/month, 1000–2999 yuan/month, 3000–4999 yuan/month, ≥5000 yuan/month), Dietary habit (balanced diet/predominantly meat diet/predominantly vegetarian diet) and BMI (<18 .5/18.5~24.9/25~29.9/≥30). We evaluated dietary habits by asking the question: "Does your diet consist of a balanced mix of vegetables and meat, is it predominantly meat-based, or is it primarily vegetarian?" Living arrangement was evaluated using the question: "What is your typical living situation?" The response options included "with spouse and children," "with spouse," "with children," or "with others." Income was assessed by inquiring about participants' earnings after retirement, which may include pensions or compensation for employment undertaken post-retirement. Height and weight were measured by community doctors using a Stature and Weight Instrument (IPR-scale 02; Zhengzhou Iprtech Co., Ltd.) on fasting older adult individuals in the morning. BMI was determined by dividing weight in kilograms by the square of height in meters. The remaining variables were collected in a self-reported form.

Statistical analysis

Using SPSS 25.0 for descriptive statistics, continuous variables with normal distribution are presented as Mean ± SD and categorical variables are counted as frequencies (%). The relationships between different demographic characteristics and the three variables were explored using t-tests and analysis of variance (ANOVA). We assessed the distributions of items related to self-perceptions of aging, subjective cognitive decline, and frailty. Pearson and Spearman correlation analyses were conducted to examine the associations between self-perceptions of aging, subjective cognitive decline, and frailty at two distinct time points. Methodological literature indicates that cross-lagged model mediation analysis can effectively analyze the temporal influences of variables and determine causal relationships between them

[32]. In this study, Mplus 8.3 software was used to conduct cross-lagged analyses of the data. Two cross-lagged models were constructed, the first model assessed the relationship between self-perceptions of aging and frailty. In addition, we conducted three additional alternative model tests based on the first model. The second model included subjective cognitive decline as a mediator based on the first model (Fig. 1). To assess the mediation effect, we utilized the bootstrap test method with 5000 replications. We also adjusted for several covariates (age, gender, income, employment status, education) that might confound the relationship between self-perceptions of aging, subjective cognitive decline, and frailty. To evaluate the model fit, chi-square tests and fit indices such as the Comparative Fit Index (CFI), Root Mean Square Error of Approximation (RMSEA), and Standardized Root Mean Square Residual (SRMR) were conducted. Generally, a model fit is considered acceptable when CFI > 0.80, TLI > 0.80, and RMSEA < 0.08 [33, 34]. There were no missing data, and as such, no specific methods for handling missing data were applied.

Results

Correlation analysis and descriptive statistics results

The descriptive statistics results at baseline are shown in Table 1. The average chronological age of older adults
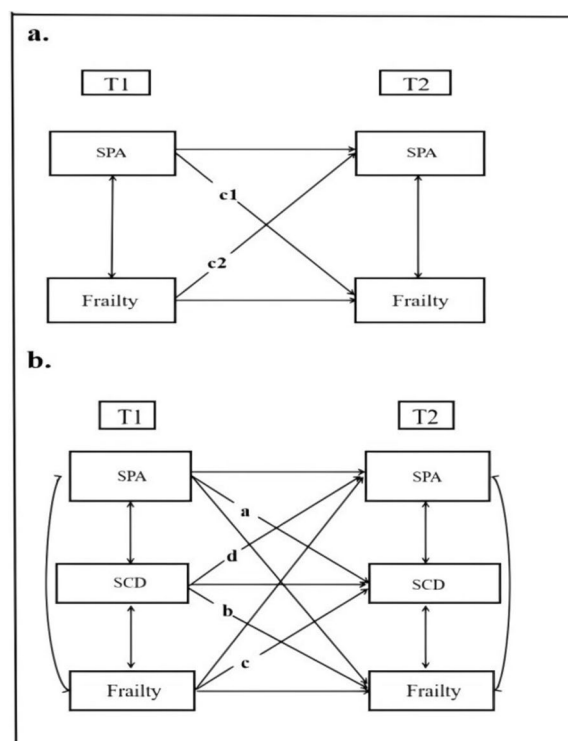
Fig. 1 Cross-lagged (**a**) and longitudinal mediation (**b**) theoretical framework model diagram

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Table 1 Baseline characteristics of the participants

Variables (619)		*n*(%)
Age(years)	65–69	277(44.74)
	70–79	293(47.34)
	≥80	49(7.92)
Sex	men	245(39.57)
	women	374(60.43)
Marital status	married	527(85.14)
	widowed or divorced	92(14.86)
	single	0(0)
Education	elementary school and below	104(16.80)
	junior high school	173(27.94)
	high school and technical secondary school	104(16.81)
	university and above	238(38.45)
Employment status	farmer	44 (7.10)
	civil servant	158(25.53)
	worker	193(31.18)
	others	224(36.19)
Living arrangements	with spouse and children	162(26.16)
	with spouse	339(54.77)
	with children	82(13.25)
	others	36(5.82)
Income(yuan/month)	<1000	38(6.14)
	1000–2999	181(29.24)
	3000–4999	270(43.62)
	≥5000	130(21.00)
Dietary habit	balanced diet	323(52.18)
	predominantly meat diet	27(4.36)
	predominantly vegetarian diet	269(43.46)
BMI	<18.5	9(1.45)
	18.5–24.9	348(56.22)
	25–29.9	236(38.13)
	≥30	26(4.20)

was 71.3 ± 4.9 years old at baseline. More than 50% were female. 7.1% were farmers, 25.5% were civil servants, 31.2% were workers, and 36.2% belonged to other professional categories. In terms of income, the number of participants with incomes of 3000–4999 yuan/month accounts for the largest proportion, and those with incomes less than 1000 yuan/month account for the least. Additionally, in terms of education, 16.8% were in primary school and below, 27.9% were in junior high school, 16.8 were in high school and technical secondary school, and 38.5% were in university and above.

The means, standard deviations, and correlation analysis results of each variable in this study are presented in Table 2. The results indicate a significant positive correlation between self-perceptions of aging and frailty as well as subjective cognitive decline, with consistent findings at T1 and T2, suggesting a stable relationship between the variables, which allows for cross-lagged analysis. Based on the results of the ANOVA, and previous research [35–39], we finally included age, gender, education, employment status, and income as covariates (refer to Table 3). Therefore, these covariates, age (categorized as $1 = 60$–69 years, $2 = 70$–79 years, $3 = 80$ years and above), gender (male $= 1$, female $= 2$), employment status (farmer $= 1$, civil servant $= 2$, worker $= 3$, others $= 4$), education (Elementary school and below $= 1$, junior high school $= 2$, High school and technical secondary school $= 3$, University and above $= 4$) and income (categorized as $1 = $ <1000 yuan/month, $2 = 1000 \sim 2999$ yuan/month, $3 = 3000 \sim 4999$ yuan/month, $4 = \geq 5000$ yuan/month) were included as control variables in the subsequent analyses.

Bidirectional association between self-perceptions of aging and frailty

Table 4 shows the reciprocal relationship between self-perceptions of aging and frailty, and the standardized results after adjustment for potential confounders are presented. The model, being saturated, showed

Table 2 Correlation analysis of self-perceptions of aging, subjective cognitive decline, and frailty

Variables	1	2	3	4	5	6
T1 SPA[a]	-					
T2 SPA[a]	0.346[**]	-				
T1 SCD[a]	0.223[**]	0.193[**]	-			
T2 SCD[a]	0.240[**]	0.289[**]	0.371[**]	-		
T1 frailty[b]	0.380[**]	0.246[**]	0.249[**]	0.232[**]	-	
T2 frailty[b]	0.252[**]	0.287[**]	0.184[**]	0.281[**]	0.321[**]	-
Mean ± SD/*M*(*IQR*)	39.97 ± 5.93[c]	41.43 ± 9.06[c]	4.69 ± 2.14[c]	4.47 ± 2.12[c]	1(0, 1)[d]	1(0, 2)[d]

SPA Self-perceptions of aging, *SCD* Subjective cognitive decline, *SD* Standard deviation

[a] = Pearson correlation, [b]= Spearman correlation, [c]= Mean ± SD, [d]= Median(interquartile range)

[**] *P* < 0.01

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Table 3 Demographic factors associated with self-perceptions of aging, subjective cognitive decline, and frailty

Variables	gender	age	income	employment status	education
	χ^2	F	F	F	F
T1 SPA	36.474	1.683[*]	2.824[*]	1.803	2.289[*]
T2 SPA	50.206	4.320[***]	1.379	1.235	1.340
T1 SCD	27.285	1.541	2.376[*]	1.782	1.015
T2 SCD	33.265[*]	1.217	3.443[**]	2.543[*]	6.901[***]
T1 frailty	1.062	2.210[**]	1.122	0.942	0.689
T2 frailty	11.218[*]	1.896[**]	3.252[**]	1.291	3.002[**]

SPA Self-perceptions of aging, *SCD* Subjective cognitive decline

[***] $P < 0.001$, [**] $P < 0.01$, [*] $P < 0.05$

Table 4 Standardized estimates of the cross-lagged relationship between self-perceptions of aging and frailty

Path	Standardized coefficient β(SE)
Correlation	
T1 SPA ↔ T1 frailty	0.381(0.035)[***]
T2 SPA ↔ T2 frailty	0.203(0.044)[***]
Autoregressive	
T1 SPA →T2 SPA	0.238(0.038)[***]
T1 frailty → T2 frailty	0.306(0.042)[***]
Cross-lagged	
T1 SPA → T2 frailty	0.109(0.038)[**]
T1 frailty → T2 SPA	0.129(0.041)[**]

SPA Self-perceptions of aging, *SCD* Subjective cognitive decline

[***] $P < 0.001$, [**] $P < 0.01$, [*] $P < 0.05$

excellent fit with CFI = 1, TLI = 1, RMSEA = 0, and SRMR = 0 (It indicates that the number of free parameters in the model is equal to the degrees of freedom in the variance-covariance matrix of the observed variables, suggesting that the established model imposes no residual constraints and can fully fit the data). After controlling for all covariates (age, gender, education, employment status, income), self-perceptions of aging still had a significant bidirectional negative association with frailty. T1 self-perceptions of aging predicted T2 frailty significantly ($\beta = 0.109$, $SE = 0.038$, $P < 0.01$), and vice versa ($\beta = 0.129$, $SE = 0.041$, $P < 0.01$) (Fig. 2). We subsequently conducted tests for three alternative models based on the saturated model. First, we fixed the paths from T1 self-perceptions of aging to T2 frailty (c1) and from T1 frailty to T2 self-perceptions of aging (c2) to zero. Next, we tested a model estimating the path from T1 self-perceptions of aging to T2 frailty while fixing the cross-lagged path from T1 frailty to T2 self-perceptions of aging (c2) at zero. Finally, we assessed a model that estimated the path from T1 frailty to T2 self-perceptions of aging, with the cross-lagged path from T1 self-perceptions of aging to T2 frailty (c1) fixed at zero. Then we conducted a chi-square difference test to compare these three alternative models with the full model. The results are presented in Table 5, which includes fit statistics for each model, as well as comparisons between the full model and each alternative model. The results indicated a deterioration in fit indices for the three alternative models, and the chi-square tests for these three models compared to the full model yielded statistically significant results($P < 0.05$). In other words, the elimination of any single path led to a significant reduction in model fit. This finding suggests that all paths must be considered collectively within the model, further confirming the bidirectional causal relationship. Additionally, we conducted a comparison of the path coefficients in the full model, which revealed no statistically significant difference between the effect sizes of the two paths ($\chi^2 = 0.119$, $P > 0.05$).

The mediation effect of subjective cognitive decline

Following the guidelines of Cole and Maxwell [40], the mediating effect (ab) of T1 self-perceptions of aging on

Table 5 Chi-squares and Fit indices of all models, Controlling for Age, gender, income, employment status, and Education

	Parameter constraints[a]	χ^2	df	χ^2diff [b]	CFI	TLI	RMSEA	SRMR
Saturated		0	0		1	1	0	0
Stability	c1=c2=0	19.207	2	19.207[*]	0.962	0.502	0.118	0.028
SPA-to-frailty	c1=0	7.317	1	7.317[*]	0.986	0.635	0.101	0.016
Frailty-to-SPA	c2=0	10.442	1	10.442[*]	0.979	0.454	0.124	0.019

SPA Self-perceptions of aging, *CFI* Comparative fit index, *TLI* Tucker-lewis index, *RMSEA* Root-mean-square error of approximation, *SRMR* Standardized root mean square residual

[a] The letters c1 and c2 denote cross-lagged parameters

[b] Comparison with the saturated. model

[*] $P < 0.05$

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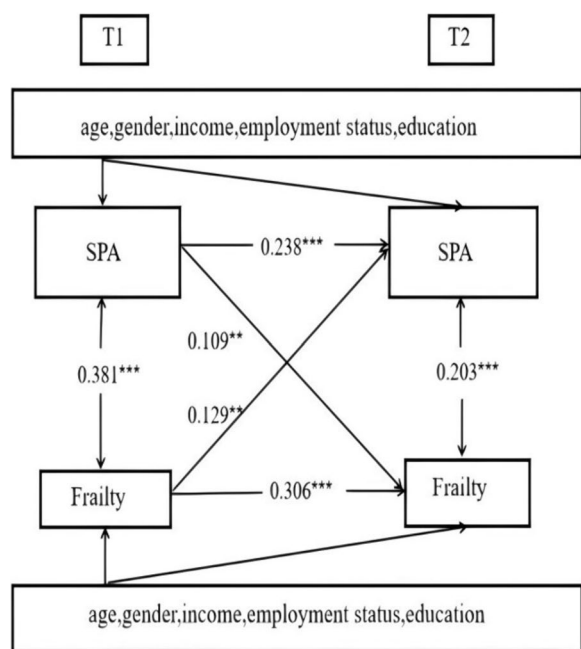
Fig. 2 Cross-lagged panel model for self-perceptions of aging and frailty. Note: All path coefficients were standardized, and all models were controlled for age[*], gender[*], income[*], employment status[*], and education[*]. Single-headed arrows represented regression paths. Double-headed arrows represented correlations. The solid lines indicated paths statistically significant at $P < 0.05$. [*]$P < 0.05$, [**]$P < 0.01$, [***]$P < 0.001$

T2 frailty through subjective cognitive decline is defined as the product of path a (the effect of T1 self-perceptions of aging on T2 subjective cognitive decline) and path b (the effect of T1 subjective cognitive decline on T2 frailty). Similarly, the mediating effect (cd) of T1 frailty on T2 self-perceptions of aging through subjective cognitive decline is defined as the product of path c (the effect of T1 frailty on T2 subjective cognitive decline) and path d (the effect of T1 subjective cognitive decline on T2 self-perceptions of aging). The Bootstrap method (bootstrap = 5000) was used to test the mediating effect of the model, and the results are shown in Fig. 3. The results of the study showed a good model fit (CFI = 0.959, TLI = 0.834, RMSEA = 0.068, and SRMR = 0.045). Table 6 presents the standardized path coefficients for the cross-lagged mediation model. The direct and indirect effects of T1 self-perceptions of aging on T2 frailty were both significant ($P < 0.05$), and the direct and indirect effects of T1 frailty on T2 self-perceptions of aging were also significant ($P < 0.05$). The indirect effect of subjective cognitive decline as a mediator between T1 self-perceptions of aging and T2 frailty was 0.011, while the indirect effect of subjective cognitive decline as a mediator between T1 frailty and T2 self-perceptions of aging was 0.010.

Therefore, the results of this study support the validity of Hypothesis 2.

Discussion

This study examined the relationship between self-perceptions of aging and frailty among community-dwelling older adults, as well as the mediating role of subjective cognitive decline. The results showed that self-perceptions of aging and frailty not only directly influence each other across time points but also indirectly affect each other through the mediating effect of subjective cognitive decline.

The bidirectional relationship between self-perceptions of aging and frailty

The results of this study partially support research hypothesis 1, which states that negative self-perceptions of aging is associated with higher levels of frailty. In comparison, higher levels of frailty are associated with more negative self-perceptions of aging. The path coefficients indicate that the influence of self-perceptions of aging on frailty ($\beta = 0.109$) is slightly smaller than the reverse pathway ($\beta = 0.129$), but further comparisons of the path coefficients indicated that the effect sizes of the two paths showed no statistical difference ($P > 0.05$). This differs from previous studies, and this result further provides new insights into the relationship between the two, indicating that self-perceptions of aging and frailty consistently impact each other in terms of their dynamic changes over time. Firstly, self-perceptions of aging are positively correlated with the incidence of frailty two years later, which is consistent with previous research findings [41]. This may be because older adults who hold negative self-perceptions of aging tend to reduce their activity levels [11] and experience impaired mental health [42]. Additionally, studies indicate that older adults with positive self-perceptions of aging tend to have better physical performance [43], all of which are factors influencing the occurrence of frailty. On the other hand, the occurrence of frailty is also positively correlated with self-perceptions of aging two years later. This aligns with research indicating that older adults with poor physical health (such as those who are frail) hold more negative age stereotypes compared to healthier individuals [15]. Furthermore, diminished grip strength has been associated with a higher subjective age [44]. This finding underscores the bidirectional relationship between self-perceptions of aging and frailty, consistent with the concept of the interrelationship between physical and mental health.

The theoretical model of self-perceptions of aging is based on self-regulation, emphasizing how individual beliefs influence coping strategies in the face of

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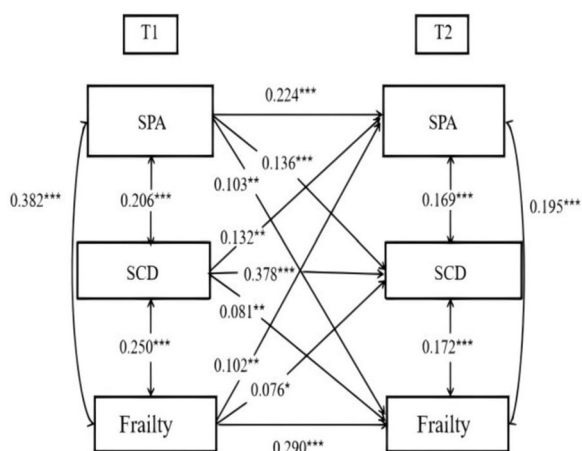
Fig. 3 Cross-lagged panel model for self-perceptions of aging, subjective cognitive decline, and frailty. Note: All path coefficients were standardized, and all models controlled for age[*], gender[*], income[*], employment status[*], and education[*]. Single-headed arrows represented regression paths. Double-headed arrows represented correlations. Solid lines indicated statistically significant paths at $P <$ 0.05. [*]$P < 0.05$, [**]$P < 0.01$, [***]$P < 0.001$

Table 6 Standardized estimates of the mediating role of subjective cognitive decline

Path	Standardized coefficient β(SE)
Correlation	
T1 SPA ↔ T1 SCD	0.206(0.038)[***]
T1 SCD ↔ T1 frailty	0.250(0.034)[***]
T1 SPA ↔ T1 frailty	0.382(0.035)[***]
T2 SPA ↔ T2 SCD	0.169(0.041)[***]
T2 SCD ↔ T2 frailty	0.172(0.038)[***]
T2 SPA ↔ T2 frailty	0.195(0.044)[***]
Autoregressive	
T1 SPA → T2 SPA	0.224(0.037)[***]
T1 SCD → T2 SCD	0.378(0.038)[***]
T1 frailty → T2 frailty	0.290(0.043)[***]
Cross-lagged	
T1 SCD → T2 frailty	0.081(0.040)[**]
T1 SCD → T2 SPA	0.132(0.037)[***]
T1 frailty → T2 SCD	0.076(0.038)[*]
T1 frailty → T2 SPA	0.102(0.041)[**]
T1 SPA → T2 frailty	0.103(0.038)[**]
T1 SPA → T2 SCD	0.136(0.039)[***]

SPA Self-perceptions of aging, *SCD* Subjective cognitive decline

[***] $P < 0.001$, [**] $P < 0.01$, [*] $P < 0.05$

health-related threats or stressors. Individuals evaluate the effectiveness of their coping behaviors and adjust their perceptions of health and coping strategies based on these evaluations [45]. Therefore, positive self-perceptions of aging can reduce the incidence of frailty among older adults, while a reduction in frailty can foster a more positive self-identity, promoting a virtuous cycle.

The mediating role of subjective cognitive decline in the relationship between self-perceptions of aging and frailty

Self-perceptions of aging and frailty not only have a direct causal relationship but are also indirectly influenced by the mediating factor of subjective cognitive decline. This result supports research hypothesis 2. This finding provides a valuable perspective for a deeper understanding of the relationship between self-perceptions of aging and frailty.

Self-perceptions of aging influence frailty through subjective cognitive decline, which also validates the perspective in positive psychology regarding "the effects of autonomy and self-regulation, and how optimism and hope affect health" [46]. At the same time, consistent with previous cross-sectional research findings, this study also adds that frailty can indirectly influence self-perceptions of aging through subjective cognitive decline [24]. The main mechanism may be related to the variability in brain structures associated with negative self-perceptions of aging and key cognitive functions, such as lower hippocampal volume and reduced gray matter volume in the

inferior frontal gyrus and superior temporal gyrus [47]. Compared to older adults with normal cognitive abilities, those experiencing subjective cognitive decline are also more likely to become frail [48]. On the other hand, frail older adults are more prone to cognitive decline, and those with subjective cognitive decline may perceive themselves as older [49], which could lead to a greater tendency toward negative self-perceptions of aging.

With the rapid advancement of population aging, the World Health Organization has proposed the Global Strategy and Action Plan on Ageing and Health, which provides a direction for promoting the health of older adults, and early identification and intervention of factors leading to frailty at the psychological level by health managers not only helps to reduce the burden on the healthcare system but also facilitates the development of targeted intervention measures. Based on the self-regulation model, self-perception of aging, which is potentially modifiable, can be positively influenced by organizing older adults' group activities and community volunteer work for seniors [50–52]. Such initiatives can enhance the sense of self-worth in older adults, mitigate their negative attitudes toward aging, and decrease frailty rates. For those already experiencing frailty, exercises such as mind-body practices [53] can improve their frail condition. Additionally,

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programs like gratitude [54] and group music therapy [55] can increase positive emotional experiences in aging, preventing the exacerbation of self-perceptions of aging due to frailty, which could lead to a vicious cycle of increased frailty. Concurrently, computer-based multidomain cognitive training [56], which targets various aspects of cognitive function, can reduce the role of subjective cognitive decline in the interplay between self-perceptions of aging and frailty. Active participation in exercise and activities can help older adults develop more positive self-perceptions of aging. This underscores the importance of promptly addressing negative aging-related emotions among older individuals. Implementing timely intervention measures for those experiencing such negative feelings can reduce the risk of adverse health outcomes. Ultimately, these efforts contribute to the promotion of a healthier aging society.

It is worth noting that gender, age, education, employment status, and income were included in the covariates in this study. These all affect the level of self-perceptions of aging and frailty. As reported by the World Health Organization, gender disparities intensify the vulnerabilities faced by older women [34]. And there are gender differences in the incidence of frailty [36]. A longitudinal study tracking self-perceptions of aging over 21 years reveals that adults' self-perceptions of aging exhibit different trends at various age points, such as 55, 65, and 70 [57]. Simultaneously, differences in employment, income levels, and educational attainment are all associated with self-perceptions of aging, and frailty [38, 39]. These factors may further influence the health outcomes of older adults, suggesting that future research should focus on further subgroup differentiation among diverse populations to validate our findings. This approach would enhance the accuracy of the research results and facilitate the development of more targeted intervention measures for different groups. Additionally, over half of the participants in this study had a high school education or higher. Research suggests that older adults with higher educational attainment are better equipped to seek a high quality of life and healthy lifestyles as they navigate the physical and psychological challenges of aging [38]. This capability may offer some protection against negative perceptions of aging. Consequently, this can further reduce the incidence of frailty through subjective cognitive decline. Despite controlling for education in our analysis, it is important to acknowledge that this variable may still introduce bias into our results.

Limitations

The limitations of this study include a relatively short duration of follow-up, indicating that future research needs to extend the tracking period. Although the SCD-9 scale employed in this study is widely regarded as a reliable tool for assessing subjective cognitive decline [58], the evaluation of variables primarily relies on self-reported measures, which may introduce a degree of recall bias. Therefore, future research should consider integrating both self-assessments and informant comparison assessments to mitigate the inherent limitations of self-reporting, thereby enhancing the credibility of the findings [59]. Furthermore, the covariates included in this study are limited, and we did not consider psychological and other factors that may influence our results. Additionally, our inclusion criteria were based solely on prior cognitive status and clinical diagnoses of mental health, without considering current conditions, which may introduce generalizability bias into the findings. Lastly, as our study only focused on community-dwelling older adults from a central plain city in China, future research should include a broader range of participants such as nursing home residents, clinical older adults, and rural older adult populations, to enhance the generalizability of the findings.

Conclusion

The results of this longitudinal study suggest the temporal changes and characteristics in the relationships among self-perceptions of aging, subjective cognitive decline, and frailty. This research contributes to the field by highlighting subjective cognitive decline as a temporal mediator in the relationship between self-perceptions of aging and frailty. It may offer new perspectives into the mechanisms by which self-perceptions of aging influence frailty outcomes and provides a new theoretical basis for the development of future frailty intervention strategies.

Abbreviations
SPA   Self-perceptions of aging
SCD   Subjective cognitive decline

Authors' contributions
Y.GY. and F.XY. contributed to the concept and the design of the study. F.XY. and D.MH. analyzed the data and wrote the original draft. Y.GY. and L.YY. revised the article critically for important intellectual content. Y.GY., X.PK., WLY, W.HJ., Z.WJ., D.MH., and L.YY. participated in the interpretation of data. All authors contributed to the article and approved the submitted version.

Data availability
The data that support the findings of this study are available from the corresponding author upon reasonable request.

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Declarations

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