AGING AND HEALTH IN CHINA

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AGING AND HEALTH IN CHINA

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Editorial: Aging and health in China

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KEYWORDS

healthy aging, population aging, China, older adults, COVID-19

Editorial on the Research Topic
Aging and health in China

Population aging is sweeping the globe. In the foreseeable future, though being replaced soon by India as the most populous nation, China is and will be holding the largest older population in the world. According to the most recent census of China in 2020, the proportion of Chinese older individuals aged 65 years old and above has approached nearly 14 percent, suggesting China is becoming an aged society. This is a huge challenge for China nowadays, especially regarding how to meet the health needs of the large size of older Chinese. Research is thus called for, including but not limited to investigations on the prevalence and trend of chronic diseases and their related risk factors, the transformation of eldercare and healthcare, and evaluations of the policies and interventions of population aging. This Research Topic on *Aging and health in China* has collected cutting-edge studies on these critical topics from an interdisciplinary perspective, representing the current research progress in this vital field.

This Research Topic chose three papers under the theme of health trends in China's older population. In "*Trends of healthy life expectancy of the elderly in China in 1994 to 2015: Revisiting from the perspective of morbidity transition*," Zhang, Dong et al. applied the classic Sullivan method to examine the change in Healthy Life Expectancy (HLE) for the recent two decades, which was measured by activities of daily living (ADL). Interestingly, it was observed that the 1994–2004 period witnessed a trend of morbidity expansion, whereas the 2005–2010 period experienced a scenario of morbidity compression. Yu et al. further explored the trend of hypertension among Chinese older persons in the article "*Hypertension prevalence rates among urban and rural older adults of China, 1991 to 2015: A standardization and decomposition analysis.*" Using nine waves of data from the China Health and Nutrition Survey, the study reported the crude and standardized prevalence of hypertension in both rural and urban China and further examined the temporal changes of the rural-urban gap, which narrowed in the 1993–1997 period, enlarged in the 1997–2011 period, and narrowed again in the 2011–2015 period. Last, Hu, Gu et al. examined the cognitive function trend of Chinese older people in the

article "*Trends in cognitive function among Chinese elderly from 1998 to 2018: An age-period-cohort analysis*." Using eight waves of data from the Chinese Longitudinal Healthy Longevity Survey, the authors found that cognitive function deteriorated with age at an increasing rate, whereas the period effect and cohort effect were relatively small compared to the age effect.

The Research Topic further included four papers to discuss the risk factors for survival, health, and wellbeing of older Chinese. In the article "*Association between functional limitations and incident cardiovascular diseases and all-cause mortality among the middle-aged and older adults in China: A population-based prospective cohort study*," Hu, Zheng et al. conducted a 7-year longitudinal analysis and found that functional limitations of the middle-aged and older Chinese adults were significantly associated with subsequent cardiovascular diseases and mortality. Along this line of research, Cao et al. further investigated the effect of the sensory impairment on the mortality of older persons in the article "*Is olfactory impairment associated with 10-year mortality mediating by neurodegenerative diseases in older adults? The four-way decomposition analysis*." Based on the 10-year longitudinal data analysis, they reported that olfactory impairment (OI) was associated with a higher mortality risk amongst older adults, and such an association was stronger with the presence of neurodegenerative diseases (NDDs). Next, Zhang, Xiao et al. examined the patterns and correlates of multimorbidity in later life in the article "*Urban-rural differences in patterns and associated factors of multimorbidity among older adults in China: A cross-sectional study based on apriori algorithm and multinomial logistic regression*." According to this study, rural older adults had a higher prevalence of multimorbidity than their urban counterparts. It was also found that age, family health history, education, smoking and drinking, and anxiety were significant factors of multimorbidity among older Chinese persons. The last article under this theme, "*Association between self-perceived stigma and quality of life among urban Chinese older adults: The moderating role of attitude toward own aging and traditionality*," focused on the quality of life. In this article, Sun et al. found that self-perceived stigma contributed to the decreased quality of life among Chinese urban older adults. This association was found to be moderated by the attitude toward own aging and traditionality, the term of which refers to the degree of adherence to traditional values. The study called for more attention to the cultural and ideational factors in understanding the health and wellbeing of older Chinese people.

Negative life events such as widowhood, accident, and disaster have been long documented in the literature to affect health and health behaviors of old ages. Under this theme, this Research Topic had four studies. In "*Negative life events, social ties, and depressive symptoms for older adults in China*," with the two waves of the Chinese Longitudinal Aging Social Survey, Ruan et al. found a significant association between negative life events and depressive symptoms among Chinese older persons. They further revealed that friendship ties could play a moderating role here, the effect of which was more prominent for male, rural, and less educated individuals. Similarly, in the article "*Stressful life events and Chinese older people depression: Moderating role of social support*," Yu and Liu confirmed that stressful life events were detrimental to older individuals' psychological health, and this negative association could be buffered by social support. Another two papers under this theme are related to the ongoing COVID-19. In the article "*Lifestyle behaviors and quality of life among older adults after the first wave of the COVID-19 pandemic in Hubei China*," Duan et al. used the survey data from Hubei province to examine the correlates of the quality of life during the pandemic. They proposed that lifestyle behavior such as physical activity, fruit and vegetable intake, and preventative behaviors such as frequent hand washing, facemask wearing, and social distancing all had significant associations with the quality of life during the pandemic. Chai further examined how the COVID-19 outbreak affected older adults' health literacy and health behavior in the article "*How has the nationwide public health emergency of the COVID-19 pandemic affected older Chinese adults' health literacy, health behaviors and practices, and social connectedness? Qualitative evidence from urban China*." Based on a series of qualitative interviews, the authors reported that during the COVID-19 period, older Chinese developed effective coping strategies, in which information and communication technology (ICT) played a significant role in obtaining information and maintaining social connections.

In China, social support from spouses and children is essential for the health of older people, especially those from rural regions where the social security system is yet underdeveloped. For this critical theme, this Research Topic presents four articles. In the article "*Widowhood and health status among Chinese older adults: The mediation effects of different types of support*," Guo et al. examined the health effect of widowhood and the role of support. They found that the negative effect of widowhood on health was partially attributable to the lack of emotional support and companionship after losing a spouse. Emotional support and companionship, as revealed, mediated the association with mental health and physical health, respectively, but such mediations were found to be significant only among women and among rural residents. In the article "*The health effect of the number of children on Chinese elders: An analysis based on Hukou category*," Long et al. found that older Chinese with only one child had poorer health than those with multiple children, though this association was not statistically significant for urban older adults. Furthermore, the authors proposed some potential mechanisms, such as intergenerational exchange, as explanations. Zhang and Harper further differentiated social support between sons and daughters in the article "*Son or daughter care in relation to self-reported health outcomes for older adults in China*." With data from the three waves of the China Health and Retirement Longitudinal

Study, they found that the Chinese older parents reported better health if being cared for by sons than by daughters, and this disparity was more remarkable in rural areas, for older mothers, and in poorer families. Last, focusing on the oldest old Chinese, Zeng et al. reported in the article "*The expected demand for elderly care services and anticipated living arrangements among the oldest old in China based on the Andersen model*" that coresidence with children is still the most preferred living arrangement of Chinese older people. This study also revealed a significant gap in meeting the health need of the Chinese oldest old people.

Lastly, this Research Topic included a few studies with significant policy and intervention relevance. For instance, in the article "*Development and implementation of couple-based collaborative management model of type 2 diabetes mellitus for community-dwelling Chinese older adults: A pilot randomized trial*," Liu et al. introduced the new model of diabetes management, which highlights the need to mobilize the family members and has a good potential of applications. Next, as smart health technology is recently proposed as an effective measure to maintain and promote the health and wellbeing of older people, we included the article "*Adoption intention and factors influencing the use of gerontechnology in Chinese community-dwelling older adults: A mixed-methods study*." In this paper, Huang et al. reported that most Chinese older adults had intentions of adopting these smart health technologies, though their intentions varied. Under this theme, we also had two papers on the health expenditure of older Chinese. In the article "*Catastrophic health expenditure associated with frailty in community-dwelling Chinese older adults: A prospective cohort analysis*," Fan et al. found that frailty was a significant predictor of catastrophic health expenditure (CHE) in Chinese older people. As CHS may be associated with the excessive financial burden on households and even lead to poverty, this paper called for interventions against frailty in old age. Moreover, Gao et al., in the article entitled "*Forecasting the health transition and medical expenditure of the future elderly in China: A longitudinal study based on Markov chain and two part model*," divided the self-rated health into different statuses, calculated age-specific transition probabilities across these statuses, estimated status-specific individual medical expenditure, and finally projected the future medical expenses of older adults in China from 2020 to 2035. Finally, in the article "*The multidimensional relative poverty of rural older adults in China and the effect of the health poverty alleviation policy*," Zeng et al. constructed the multidimensional relative poverty index (MRPI), in which health was considered a critical component. Through an empirical evaluation of the health poverty alleviation policy in rural areas of Shaanxi China, the authors validated the use of MRPI and further proposed that health promotion programs for older people, such as the introduction of basic medical insurance and long-term care insurance, should be integrated into the campaigns against poverty in China.

As introduced above, this Research Topic covers exciting topics and presents important findings on the health and wellbeing of older Chinese people. The included studies illustrate the broad scope of this field and its practical values and make up a good collection of academic work to promote healthy aging in China. The complicated context of China, we consider, may further add value to these studies in the general literature of public health and gerontology. The health and wellbeing of Chinese older adults are often affected by major social transformations and events in recent years, such as the ongoing epidemiological transition, rapid-changing households and living arrangements, large-scale rural/urban migration, economic and technological development, expanding social security system, as well as COVID-19 outbreaks. Studies in this Research Topic have addressed some of these issues above, but more work is demanded to follow up with this important line of research. Since the Chinese Government has recently announced the proactive response to population aging as the national prioritized policy rationale, we think now is never a better time to promote studies on healthy aging in China, with the sincere hope that this Research Topic could be a part of this grand mission.

Author contributions

Both authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Development and Implementation of Couple-Based Collaborative Management Model of Type 2 Diabetes Mellitus for Community-Dwelling Chinese Older Adults: A Pilot Randomized Trial

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Background: To mobilize family's positive involvement in improving and sustaining self-management activities of older adults with diabetes, we developed a couple-based collaborative management model (CCMM) for community-dwelling older Chinese.

Methods: The model was developed stepwise through applying theoretical models, interviewing older couples and community healthcare workers, as well as incorporating expert reviews. A 3-month pilot study was conducted to test the model's feasibility and its treatment effects by linear regression on 18 pairs of older couples aged 60 years+, who were equally divided into a couple-based intervention arm and a patient-only control arm.

Results: The developed CCMM covered four theory-driven intervention modules: dyadic assessment, dyadic education, dyadic behavior-change training, and dyadic monitoring. Each module was delivered by community healthcare workers and targeted at older couples as the management units. Based on interviews with older couples and healthcare workers, 4 weekly education and training group sessions and 2-month weekly behavior change booster calls were designed to address older adults' main management barriers. These modules and session contents were evaluated as essential and relevant by the expert panel. Furthermore, the CCMM showed good feasibility and acceptability in the pilot, with non-significant yet more positive changes in physiological outcomes of diabetic participants and couples' well-being and exercise levels of these in the intervention arm than their controlled counterparts.

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Conclusion: We systematically developed a couple-based collaborative management model of diabetes, which was well-received by healthcare practitioners and highly feasible among older Chinese couples living in the community. The model's treatment effects need to be verified in fully powered randomized controlled trials.

Clinical Trial Registration: http://www.chictr.org.cn/showproj.aspx?proj=42964, identifier: ChiCTR1900027137.

Keywords: coupled-based intervention, chronic disease management, model development, feasibility, implementation assessment

INTRODUCTION

China's ever-increasing diabetes burden of the older population exceeds its capacity of healthcare services (1). Under the coronavirus disease 2019 (COVID-19) pandemic, prioritizing healthcare resources and personnel into infectious disease control and treatment as well as national level quarantine measures made it even difficult for older adults with diabetes to maintain their routine treatment and healthcare services (2). Although self-management has long been recommended by Chinese clinical guidelines as an effective manner to control blood glucose levels and prevent complications, adherence to self-management activities is generally low among older adults in China (3, 4). Diabetes self-management requires lifelong commitments to multiple care regimens, which permeate daily routines and interacts with living context (5). Evidence-based interventions addressing behavioral and environmental barriers should be identified to promote self-management activities of older adults with diabetes.

Accumulating evidence has suggested that family-engaged interventions, especially these motivating support from the spouse (6), significantly improved the self-management activities of older people with diabetes (7). Marital relationship is a well-established factor for couples' health that should be considered and leveraged in disease management (7). Previous couple-based interventions on chronic disease management have revealed significant treatment effects on the depressive symptom, pain, and marital functioning of the patients (8), while evidence has been inconclusive regarding improvements in the patients' or their spouse's physical health (9–11) or their health behavior (12).

Less is clear about the effects of couple-based interventions on diabetes management. Our scoping review on couple-based random controlled trials (RCTs) of type 2 diabetes mellitus (T2DM)[1] showed insufficient evidence neither on glucose control (13, 14) or changes in self-management activities of the participants with diabetes (14, 15), nor significant changes in diet or exercise levels of their spouse (16). Most of these studies provided no theoretical bases for their intervention design and were subjected to implementation and reporting bias. Further studies equipped with theory-driven interventions and outcome measures targeting at both the participants with diabetes and their spouse are needed to clarify the treatment effects of couple-based diabetes management (10).

This paper was an interim report of the project on the couple-based collaborative management model (CCMM) of T2DM for community-dwelling older adults in China, which is a community-based multicenter RCT aiming to systematically develop and validate a CCMM integrating health professionals and family supporters (17). This report provided detailed information on the development of CCMM, grounded in theories, and tailored to the care needs of older Chinese couples with T2DM.

MATERIALS AND METHODS

Step 1: Theory-Driven Model Development

The CCMM was developed based on Berg and Upchurch's dyadic model of coping with chronic illness (DMCCI) (18) and Bandura's social cognitive theory (SCT) (19). DMCCI describes couples' dyadic appraisal of the illness severity, ownership and management responsibility, and dyadic coping strategies ranging from uninvolved (patient coping alone), supportive (spouse taking a supportive role), collaborative (spouse actively involved and the couple coping jointly) to control (spouse dominating the care responsibility) (18). If the couple both appraised the chronic disease as a shared problem needed to be coped together, a communal coping would be formed (20), which would boost their collective efficacy in managing chronic diseases, in addition to the patient's self-efficacy emphasized in the SCT (19). The collective efficacy of the couple can be strengthened by successful experiences of jointly developing and achieving management goals, alternative experiences such as acting as each other's role model, as well as language persuasion and positive physiological feedbacks (21). Intervention modules targeted at these key theoretical components were formed, with intervention contents further developed in line with the community diabetes self-management education program (22) and the Chinese clinical guideline for T2DM prevention and treatment (3). The community healthcare centers' current services were also integrated into CCMM to maximize its normalization into their routine practices.

Abbreviations: CCMM, couple-based collaborative management model; RCT, random controlled trials; T2DM, type 2 diabetes mellitus; DMCCI, the dyadic model of coping with chronic illness; SCT, social cognitive theory; HbA1c, glycosylated hemoglobin; BMI, body mass index; NPT, normalization process theory.

[1]Wang C, Wu M, Yang Y, Liao J. Effect and quality of couple-based interventions of middle-aged and older adults with type 2 diabetes mellitus: a scoping review (Unpublished) (2020).

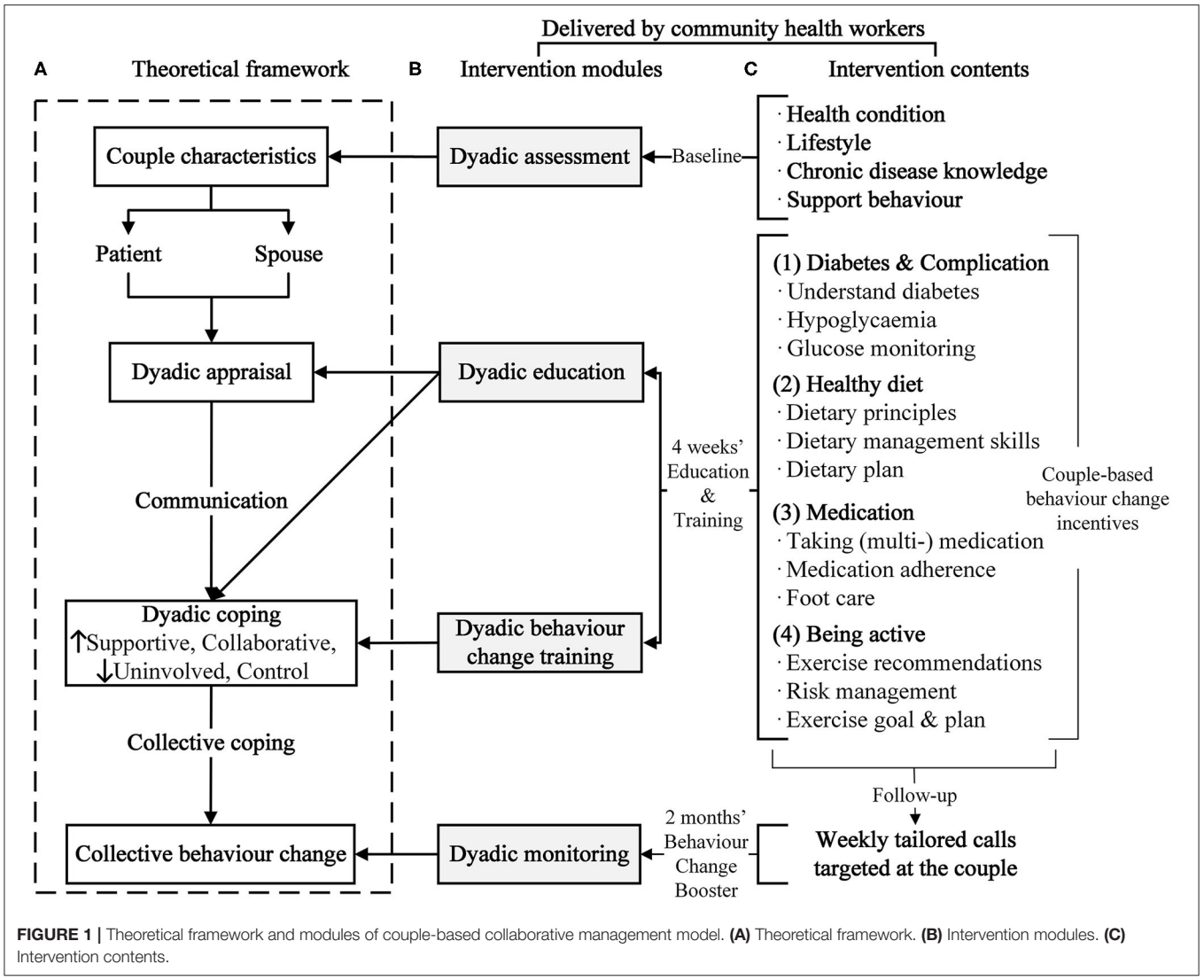

FIGURE 1 | Theoretical framework and modules of couple-based collaborative management model. **(A)** Theoretical framework. **(B)** Intervention modules. **(C)** Intervention contents.

Step 2: Management Barriers Assessment of Older Adults With Diabetes

To ensure intervention contents of CCMM that met the management needs of older couples, we conducted semistructured group interviews among couples aged 60+ years with at least one partner having diabetes and community health workers involving in diabetes care. Interviews were conducted between March to August 2019 in Guangzhou, Guangdong, China. These interviews explored couples' main barriers in daily diabetes management from couples' and care managers' perspectives. Each one and half an hour interview was composed of three researchers (a host, a recorder, and an observer) and five to six couples or seven to eight community health workers. Interviews were audio-recorded and transcribed verbatim. Detailed qualitative analyses of these interviews are presented in separate papers of the series of studies (5). The study was approved by the Institutional Review Board of the School of Public Health of Sun Yat-sen University (#SYSU 2019-064), and the drafting of this manuscript adheres to the CONSORT statement (**Supplementary Table 1**) (23). All participants read and signed the written informed consent approved by the institutional review board prior to participation.

Step 3: Incorporation of Expert Reviews

To further tailor CCMM to the focus of chronic disease management in China, the expert reviews on the intervention content of model were conducted following a Delphi approach. An independent panel was convened, including 11 experts that consist of diabetes clinicians, general practitioners, community chronic disease management officials, and social workers. Every expert assessed the content of CCMM for its necessity, relevance, and clarity with quality reviews and quantity measures (24). The evaluation was synthesized and revaluated until the panel reached 80% consensus.

TABLE 1 | Couples' sociodemographic characteristics of the 3-month pilot study (couple pairs $N = 18$).

Variables	Participants with diabetes		Spouses	
	Intervention arm ($n = 9$)	Control arm ($n = 9$)	Intervention arm ($n = 9$)	Control arm ($n = 9$)
Sociodemographic characteristics				
Age (years), mean (SD)	73.2 (8.8)	70.3 (5.5)	71.3 (8.8)	68.9 (7.1)
Male, *n* (%)	5 (56)	4 (44)	4 (44)	5 (56)
Primary school and below, *n* (%)	6 (67)	5 (56)	3 (33)	3 (33)
Retired, *n* (%)	8 (89)	9 (100)	9 (100)	9 (100)
Diabetes duration (years), mean (SD)	11.1 (4.5)	8.8 (7.8)	N/A	N/A
Had other diagnosed diseases,[a] *n* (%)	7 (78)	6 (67)	4 (44)	8 (89)

SD, standard deviation.

[a]*Diagnosed disease included hypertension, hyperlipidemia, cardiopathy, coronary artery disease, heart failure, kidney diseases, cerebrovascular diseases, and gout.*

Step 4: Feasibility Study

A 3-month feasibility study among older couples was carried out between September and December 2019. Participants with diabetes were recruited from a community of Guangzhou by community healthcare workers if they had T2DM, with the latest fasting blood glucose level > 8.0 mmol/L or glycosylated hemoglobin (HbA1c) $> 7.0\%$, aged 60+ years, cohabited with spouses, and normal cognitive and behavioral capacity. Participants with diabetes who previously participated in a similar education group were excluded. Their cohabited spouses with no mental or physical dysfunction were also recruited. In the pilot study, the partner with higher baseline blood glucose was treated as "participants with diabetes" if the couple pair both had diabetes. All participants provided informed consent.

Out of the 24 pairs of couple screened with signed informed consent, 18 eligible couple pairs were enrolled (recruitment rate = 75%) and 1:1 simple randomized into couple-based intervention arm ($n = 9$) and individual-based control arm ($n = 9$) by an uninformed researcher. The content of interventions was delivered by two community healthcare workers targeted at both the diabetic participants and their spouses for the intervention arm while only at the diabetic participants for the control arm (17). After the interventions, semistructured group interviews were conducted to evaluate the intervention's feasibility by the couples of the intervention arm and community healthcare workers. Two-month weekly behavior change booster calls were implemented afterwards.

Study Measures

To examine CCMM's treatment effects, we measured couples' physiological health [i.e., HbA1c as primary outcome measures for patients, fasting blood glucose, lipid profiles, and body mass index (BMI)], psychological health (i.e., quality of life by the 36-item short form survey as primary outcome measures for spouses, self-efficacy by the Chinese version of the diabetes management questionnaire), and self-management behaviors by the summary of diabetes self-care activities questionnaire and physical activity by the international physical activity questionnaire-short form at baseline and 3 months after the beginning of the intervention. Detailed outcome measures were provided in the study protocol (17).

The CCMM's feasibility was evaluated quantitatively by the attendance rates of education sessions, follow-up rates of booster calls, and acceptability scores of couples of intervention and participants with diabetes of control arm and qualitatively by semistructured group interviews with couples of the intervention arm and community health workers who delivered CCMM, guided by the normalization process theory (NPT) (interview script in **Supplementary Table 2**) (25).

Statistical Analyses

Intention-to-treat was applied to examine the treatment effects for the diabetic participants and spouses separately. Six percent to 6–17% couples missed the psychological measures, and 11–22% participants with diabetes missed the physiological measures (detailed information see **Supplementary Table 3**). Missing values were multiply imputed under the missing at the random assumption by intervention and control arms separately by arms to avoid biasing treatment effects toward the null (26). Fifty complete datasets for each arm were multiply imputed using individual demographic information, all physiological measures, and all psychological measures. Within-arm changes in health measures between baseline and 3 months were calculated by paired *t*-tests. Between-arm differences in the changes in health outcomes were compared by linear regression. Furthermore, differences in diabetic participants across arms and correlations between couples of the intervention arm in the implementation measures and acceptability scores were examined by Wilcoxon rank-sum test and Spearman's rank correlation, respectively, because of small sample size and non-normal distribution. All data analyses were by R Version 3.61.

RESULTS

Step 1: Theory-Driven Model Development

As shown in the CCMM theoretical framework (**Figures 1A,B**), the intervention prototype covered four modules: (1) dyadic assessment to evaluate older couples' baseline sociodemographic

TABLE 2 | Treatment effects of couple-based interventions on participants with diabetes of the 3-month pilot study (couple pair $N = 18$).

Variables of participants with diabetes	Intervention arm ($n = 9$)				Control arm ($n = 9$)				Treatment effect	
	Baseline[a] Mean (SD)	3-month[a] Mean (SD)	Difference within arm[b] Mean (SE)	P^c	Baseline[a] Mean (SD)	3-month[a] Mean (SD)	Difference within arm[b] Mean (SE)	P^c	Difference between arm[d] Mean (SE)	P^c
Physiological outcomes										
HbA_{1c} (%)	8.6 (2.1)	8.1 (2.0)	−0.3 (0.5)	0.586	7.9 (1.5)	7.8 (1.6)	−0.2 (0.4)	0.656	−0.1 (0.6)	0.848
FBG (mmol/L)	9.5 (2.3)	9.2 (2.4)	−0.3 (1.0)	0.776	8.4 (2.2)	8.6 (2.5)	0.3 (0.9)	0.781	−0.6 (1.4)	0.686
BMI (kg/m^2)	24.0 (1.3)	25.0 (2.1)	1.0 (0.7)	0.201	24.8 (2.8)	24.9 (3.1)	0.1 (0.5)	0.822	1.0 (0.9)	0.286
Total cholesterol (mmol/L)	9.8 (15.1)	5.0 (0.8)	−4.8 (4.9)	0.367	4.4 (1.0)	4.1 (0.8)	−0.2 (0.3)	0.568	−4.6 (5.0)	0.370
Triglycerides (mmol/L)	2.1 (1.0)	2.3 (1.3)	0.2 (0.4)	0.658	1.8 (1.5)	1.8 (1.4)	−0.0 (4.7)	0.987	0.2 (0.6)	0.763
LDL-C (mmol/L)	2.8 (1.0)	1.2 (0.2)	−1.7 (0.3)	0.001	2.5 (0.9)	1.3 (0.2)	−1.2 (0.3)	0.005	−0.5 (0.4)	0.415
HDL-C (mmol/L)	1.2 (0.2)	2.9 (0.9)	1.7 (0.3)	0.001	1.4 (0.3)	2.0 (0.6)	0.7 (0.3)	0.053	0.9 (0.4)	0.037
Psychosocial outcomes										
SF-36: Physical component score	49.9 (10.0)	49.7 (12.3)	0.5 (2.9)	0.868	48.6 (8.3)	49.7 (5.6)	1.0 (2.0)	0.621	−0.5 (3.5)	0.887
SF-36: Mental component score	53.0 (3.7)	53.0 (5.1)	−0.1 (2.5)	0.961	53.7 (3.8)	53.1 (2.8)	−0.6 (0.9)	0.564	0.4 (2.6)	0.872
C-DMQ score	91.6 (14.6)	101.2 (18.0)	9.7 (5.7)	0.135	82.1 (12.5)	91.6 (13.9)	9.4 (4.8)	0.092	0.2 (7.4)	0.976
Behavior outcomes										
SADCA score	33.4 (11.1)	38.2 (12.2)	4.8 (3.8)	0.252	32.4 (9.7)	38.2 (10.9)	5.8 (5.3)	0.310	−1.0 (6.5)	0.880
Metabolic equivalent scores measured by IPAQ-C (MET min $week^{-1}$)										
Exercise[e]	594.3 (797.1)	1,440.0 (2,459.3)	676.4 (723.8)	0.384	840.0 (1,313.3)	573.3 (857.8)	−62.6 (628.9)	0.924	739.0 (961.6)	0.456
Walking	1,277.6 (765.1)	1,254.0 (1,372.2)	−167.6 (294.7)	0.560	1,328.3 (635.8)	1,457.5 (893.9)	340.4 (486.9)	0.512	−507.9 (572.8)	0.392
Sitting	900.0 (921.1)	660.0 (761.3)	−51.3 (517.7)	0.924	945.0 (736.5)	1,120.0 (525.7)	378.0 (397.0)	0.381	−429.3 (653.6)	0.523

SD, standard deviation; SE, standard error; 95% CI, 95% confidence interval; HbA1c, glycosylated; FBG, fasting blood glucose; BMI, body mass index; LDL-C, low-density lipoprotein cholesterol; HDL-C, high-density lipoprotein cholesterol; SF-36, the 36-item Short Form Survey (SF-36); SADCA, the Summary of Diabetes Self-Care Activities questionnaire; IPAQ-C, International Physical Activity Questionnaire—Chinese version; MET min $week^{-1}$, minutes of metabolic equivalent per week for physical activity; C-DMQ, the Chinese version of the Diabetes Management Questionnaires.

[a] *The statistical description was based on complete cases without imputation.*

[b] *The within-arm difference was calculated as the difference between 3-month and baseline levels of given measures using the multiply imputed data.*

[c] *P-value of the within-arm difference was tested by paired t-test, and the between-arm difference was tested by Student's t-test.*

[d] *The between-arm difference was calculated as the difference between intervention and control arms using the multiply imputed data.*

[e] *The exercise was defined as moderate to vigorous physical activity measured by IPAQ-C regarding weekly frequency and duration.*

characteristics, health status, and lifestyle as the evidence base of intervention context; (2) dyadic education to address older couple's dyadic appraisal and understanding about diabetes management *via* group education base on the background of dyadic assessment; (3) dyadic behavior change training to improve couples' dyadic coping skills by promoting collaborative action for behavior change by using experience, encouragement, and positive feedback, which can enhance not only the efficacy of older adults with diabetes but also the collective behavior of couples; (4) dyadic monitoring to assess and provide timely feedback to improve dyadic behavior health. All modules had community health workers serving as care managers and older couples as management units.

Step 2: Management Barriers Assessment of Older Adults With Diabetes

Altogether, we interviewed 11 pairs of older couples with T2DM and 33 community health workers from four community healthcare centers. These interviews helped identify barriers in daily T2DM management from the perspectives of older adults with diabetes, spouses, and clinicians. The main barriers of older couples with diabetes included lack of knowledge about diabetes and complications prevention, short of authentic information on medication, and lack of support to properly conduct self-management activities, particularly regarding foot care, healthy diet, and exercise. Couples trusted community health workers who understand their condition at most and assessed them as the best suitable group delivered personalized education mentioned above. To make use of this information, we invited health workers as care managers for four modules. To address these management barriers, the intervention contents of education and training sessions were designed to improve the knowledge and skills of (1) diabetes and complications management, (2) healthy diet, (3) medication adherence, and (4) exercise (**Figure 1C**). To facilitate older couples to adopt healthy behaviors, each session further employed behavior change techniques (weekly and special training) and couple-based behavior change incentives (material and social incentives and rewards based on couples' performances). A detailed information of change techniques and incentives was shown in our protocol.

Step 3: Incorporation of Expert Reviews

The expert panel well-received the context of CCMM, evaluated as essential (the average of content validity ratio was 0.89, with a minimum acceptable value of 0.59) and relevant (the item-level content validity index was 0.72–1, and the average and union agreement of scale-level content validity index was 0.96 and 0.77, respectively, with a generally accepted value of 0.80). They commented that most of the intervention contents were well-organized and clearly presented, except for some sections that need to be tailored to the actual situation of people with diabetes (e.g., knowledge of insulin may only be useful for those using insulin). The panel further suggested that the course contents should be easily understandable by less-educated older couples. Considering expert reviews, we simplified educational content by deleting low essential and replaced one-way education with interactive activities for older couples to practice together.

Step 4: Feasibility Study

Older couples' sociodemographic characteristics were comparable between arms (**Table 1**). Participants with diabetes had a mean age of 70 years, half were male, had low education, and the majority were retired. They had diabetes for multiple years, and over two-thirds had diseases other than diabetes. Spouses had similar sociodemographic profiles, who tended to be younger and better educated.

The models' treatment effects were shown in **Table 2** for the diabetic participants and **Table 3** for the spouses. Although none of these treatment effects were statistically significant due to insufficient power (e.g., power for HbA1c was 0.1), trends in within- and between-arms differences of these measures were large as expected; namely, participants with diabetes of the intervention arm tended to have faster declines in blood glucose and lipid levels, more improvements in mental well-being, self-efficacy, and physical activities than their controlled counterparts. Nevertheless, participants with diabetes of the control arm seemed to have better outcomes in terms of BMI, self-reported physical health, and daily management activities. Similar trends showed among the spouses. Notably, spouses of the intervention arm reported increased confidence in assisting their partners in diabetes management, while an opposite tendency was shown among spouses of the control arm.

Table 4 showed the implementation measures and acceptability scores of the different arms. The intervention arm showed a higher attendance rate (83 vs. 55%) and lower dropout rate (0 vs. 22%), and refusal rate (11 vs. 33%) than the control arm. The correlation of the attendance rate between participants with diabetes and spouses of intervention arm was 0.9 ($P < 0.01$), indicating high concordance. Participants with diabetes of both arms found the interventions acceptable and helpful to improve management knowledge and skills. Correspondingly, spouses of the intervention arm rated the intervention highly (correlated spousal range from −0.2 to 0.7, all Ps > 0.05), particularly regarding promoted mutual understandings.

Group interviews guided by NPT further provided a structured analysis approach to identify facilitating and inhibiting factors of implementation of CCMM. In terms of coherence and cognitive participation, older couples and health workers all understood the purpose of CCMM and agreed to invest time and energy to practice this model, given its self-reported benefits in improving spousal interactions in daily diabetes management. Community health workers commented that a harmonious marital relationship would be critical to the implementation of CCMM. As for collective action, participants indicated that although the duration and intensity of interventions were generally acceptable, the content of some sessions was overwhelming. Healthcare workers expressed that standardized training to implement CCMM was necessary. In line with acceptability assessments, participants reflected CCMM positively. Health workers additionally suggested that the utilization of online communication tools would facilitate intervention implementation and follow-up.

TABLE 3 | Treatment effects of couple-based interventions on spouses of the 3-month pilot study (couple pair $N = 18$).

Variables of spouses	Intervention arm ($n = 9$)				Control arm ($n = 9$)				Treatment effect	
	Baseline[a] Mean (SD)	3-month[a] Mean (SD)	Difference within arm[b] Mean (SE)	P^c	Baseline[a] Mean (SD)	3-month[a] Mean (SD)	Difference within arm[b] Mean (SE)	P^c	Difference between arm[d] Mean (SE)	P^c
Psychosocial outcomes										
SF-36: Physical component score	47.0 (7.7)	46.0 (10.2)	−1.0 (2.9)	0.754	49.1 (9.4)	50.2 (7.4)	0.8 (2.6)	0.761	−1.8 (4.0)	0.657
SF-36: Mental component score	55.0 (4.5)	53.2 (5.3)	−2.0 (2.1)	0.365	56.7 (6.4)	51.8 (5.0)	−5.1 (s2.0)	0.041	3.1 (2.8)	0.297
C-DMQ score	76.7 (30.0)	84.5 (28.5)	10.0 (12.8)	0.467	87.0 (29.2)	75.8 (24.6)	−11.3 (9.8)	0.293	21.3 (16.1)	0.212
Behavior outcomes										
Metabolic equivalent scores measured by IPAQ-C (MET min week^{-1})										
Exercise[e]	440.0 (643.7)	1,500.9 (1,530.9)	1,131.2 (607.0)	0.112	1,680.0 (1,680.0)	2,425.7 (3,607.6)	695.0 (869.0)	0.454	436.3 (1,056.1)	0.686
Walking	1,666.5 (874.2)	1,287.0 (1,034.0)	−454.8 (564.3)	0.450	2,277.0 (1,369.4)	1,155.0 (832.9)	−1,043.1 (484.3)	0.073	588.3 (737.7)	0.439
Sitting	1,015.0 (585.2)	805.0 (708.0)	−360.7 (308.6)	0.300	1,560.0 (930.2)	870.0 (988.2)	−545.5 (432.2)	0.252	184.8 (532.9)	0.735

SD, standard deviation; SE, standard error; 95% CI, 95% confidence interval; HbA1c, glycosylated; SF-36, the 36-item Short Form Survey (SF-36); IPAQ-C, International Physical Activity Questionnaire–Chinese version; MET min week^{-1}, minutes of metabolic equivalent per week for physical activity; C-DMQ, the Chinese version of the Diabetes Management Questionnaires.

[a] *The statistical description was based on complete cases without imputation.*

[b] *The within-arm difference was calculated as the difference between 3-month and baseline levels of given measures using the multiply imputed data.*

[c] *P-value of the within-arm difference was tested by paired t-test and the between-arm difference was tested by Student's t-test.*

[d] *The between-arm difference was calculated as the difference between intervention and control arms using the multiply imputed data.*

[e] *The exercise was defined as moderate to vigorous physical activity measured by IPAQ-C regarding weekly frequency and duration.*

TABLE 4 | Implementation assessments of the 3-month pilot study (couple pair $N = 18$).

Variables	Participants with diabetes			Spouses of intervention arm		
	Intervention arm ($n = 9$)	Control arm ($n = 9$)	*P* for arm difference[a]	Intervention arm ($n = 9$)	Spousal correlation coefficient[b]	P for spousal correlation[b]
Implementation measures						
Group education attendance rate (%), mean (SD)	0.8 (0.3)	0.6 (0.4)	0.082	0.8 (0.3)	0.9	0.003
Booster call follow-ups						
Dropout rate, *n* (%)	0 (0)	2 (22)	0.470	–	–	
Refusal rate, *n* (%)	1 (11)	3 (33)	0.576	–	–	
Acceptability scores[c], median (25%,75% quartiles)						
Taking this course						
Improved my awareness of diabetes	4.0 (2.5,4.0)	3.0 (3.0,4.0)	0.861	3.0 (3.0,4.0)	0.7	0.065
Improved my control/assistance of blood glucose monitoring	3.0 (3.0,4.0)	4.0 (3.0,4.0)	0.928	4.0 (3.5,4.0)	0.5	0.203
Improved my diabetes management skills	4.0 (3.0,4.0)	3.0 (3.0,4.0)	0.470	4.0 (3.0,4.0)	−0.2	0.721
Increased my awareness of feet care	4.0 (3.0,4.0)	3.0 (3.0,4.0)	0.723	4.0 (4.0,4.0)	0.3	0.453
Participated in the intervention together with my spouse						
Helpful for us	4.0 (3.5,4.0)	NA	NA	4.0 (4.0,4.0)	0.7	0.117
Enhanced awareness of diabetes	4.0 (4.0,4.0)	NA	NA	4.0 (3.0,4.0)	0.6	0.090

SD, standard deviation; NA, not applicable.

[a] *P-value of arm difference was tested between participants with diabetes of intervention and control arms by Student's t-test, Fisher test, and Wilcoxon rank-sum test.*

[b] *Correlation between participants with diabetes and spouses of intervention arm was computed by Pearson correlation and Spearman's rank correlation.*

[c] *Acceptability was evaluated as the extent to which participants found CCMM were helpful to improve their knowledge and ability to conduct (or to assist, for spouse) diabetes management activities and to promote positive interactions with their partner (for the intervention arm only) on a scale from 1 (strongly disagree) to 4 (strongly agree).*

DISCUSSION

Our study developed CCMM of T2DM based on theoretical models and tailored to the care needs of older couples with diabetes in China. The constructed model was well-received by health practitioners and public health experts and demonstrated its feasibility in the small-scale pilot, with promising treatment effects on older couples to be further confirmed.

The CCMM was systematically constructed in line with the Medical Research Council's guidance for complex interventions' development and evaluation (27), including theory and evidence identification, needs assessment, and piloting. Previous studies have documented the development process of couple-based interventions on coronary artery disease (28), osteoarthritis (29), low-density lipoprotein cholesterol (30), and heart failure (31). Compared to prior couple-based models (**Supplementary Table 4**), CCMM was theoretically grounded, with four intervention modules designed correspondingly. While few studies assessed participants with disease and health practitioners' management barriers (30, 32), our intervention contents were tailored to older couples' specific needs and learning capacity. To ensure active spousal participation, CCMM engaged the spouses of participants with diabetes *via* couple-level discussions and skill practices and communal behavior change goals set, which were selectively employed by prior models (15, 28, 30) and innovatively incorporated couple-based behavior change incentives to promote collaboration between couples.

Our pilot generated interesting findings on the treatment effects of CCMM that were worth further validation. Despite statistically non-significant treatment effects identified due to the small sample size, the results also fitted the theoretical model well. In line with the DMCCI, we found that participants with diabetes and spouses in the intervention arm had a higher attendance rate and lower lost to follow-up rate than those in the control arm, which showed that spouses had the positive effect of dyadic coping in helping daily diabetes management (18). Positive dyadic coping brought improvement to self-efficacy of participants with diabetes and spousal efficacy to assist their partners with diabetes, which was shown by the better C-DMQ scores change in the intervention arm than that in the control arm (20). Furthermore, according to the self-efficacy in SCT, better self-efficacy of couples can improve the couple's health and quality of life, which was also shown in the more improvement of several physiological measures and exercise levels among participants with diabetes of the intervention arm than their controlled counterparts, alongside positive changes in spousal mental well-being and exercise levels (19). Previous studies mainly identified the psychological benefits of couple-based interventions, with mixed findings on clinical (13, 14, 30) and behavioral outcomes (14, 15) of people with diabetes, and less is clear about spousal health (16). Our follow-up studies will validate CCMM in a multicenter RCT (17), adopting adequate outcome measures for both the participants with diabetes and their spouses to provide high-quality evidence to the couple-based chronic disease management literature (11).

The current study further advanced the literature by testing the implementation process and analyzing implementation barriers and facilitators. In concordance with a systematic review of trials involving people with a disease and a support person (33), we found higher attendance and retention rates of couple-based than individual-based arms, which may be largely attributed to the spousal companion as indicated by the high spousal concordance score. Trief and colleagues studied challenges in the implementation of couple-based interventions for T2DM management *via* telephone calls. Similar to their study (32), our pilot study revealed challenges of independent assessments and spousal engagement from both intervention recipients' and providers' perspectives and the importance of adequate staff training and monitoring in maintaining intervention fidelity. Our planned RCT will modify implementation strategies incorporating challenges identified: (1) equivalent attention will be paid to recruit, assess, and engage the spouse; (2) care managers will receive 10-h training prior to group education and be equipped with a standardized intervention material package; and (3) education sessions will be recorded by structured fieldnotes and taped for fidelity evaluation.

We constructed CCMM according to the recommended practices and evaluated feasibility in a pilot study with high recruitment and retention rates. However, limited to the small sample size and short duration, the pilot study was underpowered to verify the model's treatment effects. We also did not pay equal attention to collect spouses' blood samples, which would provide objective measures to indicate spousal behavior changes in diet and physical activity. The failure to record spouses' retention rates of booster calls further prevented us from exploring spousal correlations in treatment adherence over time. We set our recruitment age of the couples with diabetes at 60+ in line with China's official retirement age to promote their participation. This approach, however, may lead our study population to an older-aged group that was more likely to be widowed and weaken the model's prevention values for these middle-aged adults at high risks for developing T2DM.

CONCLUSION

We developed a theoretically grounded couple-based collaborative model for diabetes management, addressing the main management barriers of community-dwelling older Chinese. Large-scale studies with sufficient statistical powers and longer follow-ups are needed to verify the model's long-term effectiveness in improving management behaviors and clinical outcomes of older adults with diabetes and their spouse. This model has the potential of not only enhancing diabetes management activities of older adults with diabetes but also serving as a primary prevention tool for their spouse.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Institutional Review Board of the School of Public Health of Sun Yat-sen University. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

JL, DX, and YL conceptualized the study, analyzed the results, and wrote the first draft of the manuscript. XX, CP, and WY were responsible for designing education and training sessions. TZ oversaw the booster calls. YW conducted the interviews and analyzed NPT result. LO, XC, and XW contributed to the study design and implementation. All authors contributed to revising the manuscript, have read, and approved the final manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2021.686282/full#supplementary-material

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Urban–Rural Differences in Patterns and Associated Factors of Multimorbidity Among Older Adults in China: A Cross-Sectional Study Based on Apriori Algorithm and Multinomial Logistic Regression

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Introduction: Multimorbidity has become one of the key issues in the public health sector. This study aimed to explore the urban–rural differences in patterns and associated factors of multimorbidity in China and to provide scientific reference for the development of health management strategies to reduce health inequality between urban and rural areas.

Methods: A cross-sectional study, which used a multi-stage random sampling method, was conducted effectively among 3,250 participants in the Shanxi province of China. The chi-square test was used to compare the prevalence of chronic diseases among older adults with different demographic characteristics. The Apriori algorithm and multinomial logistic regression were used to explore the patterns and associated factors of multimorbidity among older adults, respectively.

Results: The findings showed that 30.3% of older adults reported multimorbidity, with significantly higher proportions in rural areas. Among urban older adults, 10 binary chronic disease combinations with strong association strength were obtained. In addition, 11 binary chronic disease combinations and three ternary chronic disease combinations with strong association strength were obtained among rural older adults. In rural and urban areas, there is a large gap in patterns and factors associated with multimorbidity.

Conclusions: Multimorbidity was prevalent among older adults, which patterns mainly consisted of two or three chronic diseases. The patterns and associated factors of multimorbidity varied from urban to rural regions. Expanding the study of urban–rural differences in multimorbidity will help the country formulate more reasonable public health policies to maximize the benefits of medical services for all.

Keywords: multimorbidity, urban–rural, older adults, health management, associated factors, patterns

INTRODUCTION

Aging has now become a global trend, a trend that is likely to continue in the future (1). China has become one of the most rapidly aging countries in the world (2). According to data from the National Bureau of Statistics of China, there were 253.88 million older adults aged 60 years and above in China at the end of 2019, accounting for 18.1% of the total population (3). With the accelerated population aging, more attention must be paid to the health issues of older adults. Multimorbidity is regarded as one of the key issues in the global public health sector and has also become a prominent health problem among Chinese older adults (4). Multimorbidity is defined as two or more chronic diseases in one person at a certain time (5). Compared with a single chronic disease, the treatment difficulty, medical consumption, economic burden, and risk of death among older adults with multimorbidity were increased (6–9). Multimorbidity is also associated with lower functional status (10), poor quality of life, and well-being (11, 12). The health management and clinical treatment of older adults with multimorbidity have, therefore, become major challenges (13).

Since the foundation of the People's Republic of China in 1949, China has enforced a stringent urban and rural household registration system. The reasons for the formation of the urban–rural dichotomy are historical continuity, as well as institutional changes and national development strategies. With the adoption of the reform and opening up policy in 1978, the urban and rural household registration system of China was progressively dismantled, but the urban–rural dual track system still has a significant influence on the economy and society of China (14). There are significant differences in income, social resource allocation, and access to welfare policies between urban and rural areas of China due to differences in their urban and rural economic development levels, household registration system design, and employment types (the rural population is primarily engaged in agricultural activities, while the urban population is primarily engaged in industry and service) (15). There are many family tragedies in the vast rural areas of China, particularly, in the economically underdeveloped regions, where older adults commit suicide, indicating the poor situation of older adults in rural areas (16). In 2018, the per capita disposable income of urban residents in China was CNY¥39,251, and that of rural residents was CNY¥14,617, which is a large gap (17). In addition, another study has documented the trends and gaps in health disparities between urban and rural areas (18). From a nationwide perspective, there may be significant urban–rural differences in patterns and associated factors of multimorbidity among older adults in China.

Previous studies focused predominantly on the prevalence, health care utilization, and health-associated outcomes of multimorbidity among older adults (19–22). As findings from a study done in China suggest, multimorbidity is more prevalent among the rural population (58.3%) than among their urban counterparts (50.4%) (23). Despite advances, rural China has less access to quality healthcare than urban China (18), as the majority of rural primary care doctors still lack a full university degree (24). Moreover, the patterns of multimorbidity have also gradually developed into a hot topic of current research. Noe et al. study (25) described patterns of multimorbidity in low-, middle-, and high-income countries, which were limited to 12 chronic diseases. Furthermore, another study also indicated that chronic diseases often occur in pairs among older adults in China, especially those with hypertension or dyslipidemia (26). However, there is limited evidence of differences in patterns of multimorbidity between urban and rural areas in China. In terms of the economy, social security, health services, and infrastructure, there are huge gaps in urban–rural areas of China (27), so it is necessary to explore the patterns of multimorbidity among older adults in urban and rural areas of China.

A previous study showed that the burden of multimorbidity is mainly caused by a series of associated factors (28). Well-established factors associated with multimorbidity are age, gender, body mass index (BMI), and education level (29, 30). However, the previous studies on the associated factors of multimorbidity among older adults mostly focused on the individual-level factors. In order to comprehensively understand the factors associated with multimorbidity, we cannot just focus on individual-level characteristics and have to consider other contextual factors, such as the environment, society, and policy level based on the health ecological model (31). Given the fact that the economic development of Chinese cities is significantly faster than that of rural areas (32), it is particularly important to study the different risk factors for multimorbidity among older adults in urban and rural areas.

An increasing number of studies have been undertaken to explore the patterns and associated factors of multimorbidity in China. However, there is limited evidence of differences in patterns and associated factors of multimorbidity between urban and rural areas, which may not be conducive to improving health management. In a period of rapid social transformation, the development is extremely uneven between urban and rural areas (18). It can be expected that the patterns and associated factors of multimorbidity may vary between urban and rural older adults. There is a dearth of evidence on urban–rural differences in patterns and associated factors of multimorbidity in China, which is a very important consideration in determining comprehensive intervention strategies applicable to rural and urban areas (33).

Given the significant disparities in the resource allocation and welfare systems between urban and rural areas in China, these disparities may be closely related to multimorbidity prevention and control. In such a context, this study aimed to identify the urban–rural differences in patterns and associated factors of multimorbidity among older adults and to provide a scientific reference for comprehensive intervention strategies and health management measures applicable to both rural and urban areas.

This study will be helpful in promoting dynamic multimorbidity prevention and control. The research on the patterns and associated factors of multimorbidity in China, as the largest developing country in the world, could be useful in revealing the link between social resource allocation and multimorbidity, particularly, in developing or undeveloped areas of the world.

MATERIALS AND METHODS

Sample and Participants

A questionnaire-based cross-sectional study was conducted in Shanxi province, which comprises a total of 11 cities (Taiyuan, Datong, Yangquan, Changzhi, Jincheng, Shuozhou, Jinzhong, Yuncheng, Xinzhou, Linfen, and Lvliang) from June to August 2019. All the participants were interviewed face-to-face using a structured questionnaire by trained interviewers with medical knowledge. In order to get a representative sample of older adults, we used a multi-stage stratified cluster sampling method to select the participants in 11 cities. The sampling method was as follows: first, according to the order of districts (counties) on the website of the Shanxi province government, each district (county) in every city was numbered. Second, two districts (counties) in each city were selected using the random number table, and then two communities (administrative villages) were drawn from each district (county) in the same way. Last, considering that the different residential communities (natural villages) contain different numbers of older adults, only one residential community (natural village) was randomly selected from each community (administrative village), when the size of the number of older adults in the residential community (natural village) met the research requirements. If the number of older adults drawn from the residential community (natural village) is not enough, another residential community (natural village) is randomly selected as a sampling unit for supplementation. Finally, we randomly selected older adults who met the criteria in this study.

The inclusion criteria for this study were: (1) participants aged 60 years and above, and (2) having clear awareness and barrier-free communication skills. Those who had difficulty communicating were excluded. A total of 3,266 questionnaires were distributed, of which 3,250 respondents effectively completed the questionnaires; thus, the effective response rate was 99.51%.

All the study procedures were approved by the university ethics committee. All participants were informed of the purpose and procedure of the research upon their recruitment and assured of their right to refuse to participate. Their anonymity and confidentiality were guaranteed. After signing the consent, the participants were invited to participate in a face-to-face questionnaire where trained investigators collected the data.

Instruments

The questionnaire consisted of two sections: self-made general information and types of chronic diseases. To illustrate the variety of factors that may be associated with multimorbidity among older adults, the health ecological model was adopted as the theoretical framework. Considering the difficulty of quantifying the macro-system policy environment indicators, this study only summarized the independent variables in four aspects, as follows: (1) personal characteristics: age, residence, family history of genetics, and BMI; (2) behavioral characteristics: regularity of three meals, frequency of fresh fruit consumption, smoking status, and drinking status, and sleep quality; (3) interpersonal network: marital status and empty nest status; (4) socio-economic status: educational level and monthly income. Theoretically, this analysis model better illustrates the factors associated with multimorbidity of older adults with different characteristics, but it is limited by the existing literature.

The questionnaire on chronic diseases includes 26 chronic diseases (e.g., hypertension, diabetes, rheumatoid, or rheumatoid arthritis). The information about chronic diseases was collected through self-reporting, which was based on the diagnostic evidence of medical records or the prescriptions from doctors.

Statistical Analysis

The data were analyzed using IBM SPSS Version 24.0 Statistical software (IBM, NY, USA). The chi-square test was used to compare the prevalence of chronic diseases among older adults with different demographic characteristics. Confidence level with $P < 0.05$ was considered statistically significant. The Apriori algorithm in IBM SPSS Modeler Version 18.0 software was employed to analyze common patterns of multimorbidity among the older adults in the study, which mined valuable patterns in large, unordered data as association rules. It is essential to discover interesting and close correlations between items based on a large amount of data. As a data mining technology, association rules can help researchers extract valuable knowledge from huge data sets. Three kernel values are involved with association rule analysis, such as support, confidence, and lift (34). Based on this study, the support of A→B was the probability of the simultaneous occurrence of chronic diseases A and B. The confidence was the conditional probability of suffering from chronic disease B under the premise of suffering from chronic disease A. The degree of lift reflects the influence of the consequent B on the antecedent A compared to the overall. Therefore, when the degree of lift $L_{A-B} > 1$, A→B can be considered as a directional association. In the study, set the minimum conditional support to 3.0%, the minimum rule confidence to 30%, and the maximum number of preceding items to five. Multinomial logistic regression was used to examine the relationship between multimorbidity and potential associated factors. The level of significance was $P < 0.05$ (two-tailed test).

RESULTS

Prevalence of Urban–Rural Differences of Chronic Diseases Among Older Adults

Among the 3,250 older adults surveyed, 1,901 (58.5%) had chronic diseases and 985 (30.3%) had multimorbidity. The prevalence of multimorbidity among older adults in the 11 cities of Shanxi province is shown in **Figure 1**. Moreover, 26.7% of the respondents had multimorbidity in urban areas compared with 33.2% in rural areas. The number of multimorbidity ranged from 2 to 9. The coexistence of 2, 3, and 4 chronic diseases was relatively common, accounting for 54.1, 26.2, and 11.2%, respectively. The 10 most prevalent chronic diseases were hypertension, diabetes, rheumatoid or rheumatoid arthritis, hearing impairment, digestive system diseases, osteoporosis, coronary heart disease, eye diseases, respiratory diseases (bronchitis, emphysema, asthma, etc.), and stroke. **Table 1** shows the urban–rural differences and **Table 2** shows the gender

FIGURE 1 | The prevalence of multimorbidity in 11 cities of Shanxi province.

differences in the 10 most prevalent chronic diseases among older adults (1).

Urban–Rural Differences in Association Rules for Multimorbidity

The results of the Apriori algorithm showed that 10 combinations of binary chronic diseases with strong association strength were obtained among older adults in urban areas. Eleven combinations of binary chronic diseases and three combinations of ternary chronic diseases with strong association strength were obtained among older adults in rural areas (**Table 3**). The patterns of multimorbidity were dominated by hypertension, atherosclerosis, and other chronic diseases among older people in both urban and rural areas. In addition, seven multimorbidity patterns associated with rheumatic or rheumatoid arthritis were found in rural older adults.

Univariate Analysis of Associated Factors Underlying Multimorbidity

The chi-square test showed that there were significant differences in age, residence, family history of genetics, education level, monthly income, marital status, empty nest status, frequency of fresh fruit consumption, smoking status, drinking status, BMI, sleep quality, and anxiety of multimorbidity. However, there was no statistically significant difference in the regularity of three meals of multimorbidity among older adults (**Table 4**).

Results of Multinomial Logistic Regression

The results from multinomial logistic regression are shown in **Table 5**. Older age was identified as a significant risk factor for a single chronic disease (urban *OR*: 1.47, 95% *CI*: 1.10–1.97; rural *OR*: 1.57, 95% *CI*: 1.21–2.03) and multimorbidity (urban *OR*: 2.07, 95% *CI*: 1.52–2.80; rural *OR*: 1.64, 95% *CI*: 1.26–2.12). Family history of genetics was the most important independent predictor for a single chronic disease (urban *OR*: 6.53, 95% *CI*: 2.79, 15.28) and multimorbidity (urban *OR*: 13.53, 95% *CI*: 5.91, 30.98; rural *OR*: 7.98, 95% *CI*: 3.61–17.66). Those participants with elementary education and below had higher odds of multimorbidity compared with higher education and above graduates (urban *OR*: 1.72, 95% *CI*: 1.10–2.69; rural *OR*: 2.55, 95% *CI*: 1.20–5.41). Marital status had no significant impact on a single chronic disease and multimorbidity, regardless of urban–rural status. No child was found as a protective factor against multimorbidity in urban areas, but in rural areas, empty nesting was a risk factor for multimorbidity. Frequency of fresh fruit consumption had no significant impact on multimorbidity in rural areas, but in urban areas, another frequency was associated with higher odds of multimorbidity compared with eating almost every day (*OR*: 1.37, 95% *CI*: 1.04–18.2). Quit smoking and quit drinking were the associated factors of a single chronic disease and multimorbidity regardless of urban–rural status. As for BMI, being overweight was a significant predictor for a single chronic disease (*OR*: 1.84, 95% *CI*: 1.38–2.44) and multimorbidity (urban *OR*: 1.69, 95% CI: 1.25–2.30) in urban areas. Sleep quality was not significantly associated with a single chronic disease and multimorbidity in urban areas. But in rural areas, those with poor sleep had higher odds of a single chronic disease (*OR*: 2.11, 95% CI: 1.53–2.91) and multimorbidity (*OR*: 2.15, 95% CI: 1.59–2.92). The participants with anxiety symptoms were associated with higher odds of multimorbidity both in urban and rural areas (urban *OR*: 1.65, 95% *CI*: 1.22–2.23; rural *OR*: 2.09, 95% *CI*: 1.63–2.68).

DISCUSSION

The current study provides new evidence to determine the urban–rural disparity in patterns and associated factors of multimorbidity among older adults in China. The results of the current study indicated that the prevalence of multimorbidity among rural older adults (33.2%) was higher than the urban older adults (26.7%) in the study, which is significantly lower than the previous study (rural: 58.3%; urban: 50.4%) in China (23). The inconsistency may be partly due to the differences in sampling methods, sampling size, and type of chronic disease information. A comparative analysis between rural and urban areas shows that the rural areas are at a disadvantage in the prevalence of multimorbidity. Compared with urban older adults, rural older adults have lower socio-economic status, poorer social services, and lower access to quality medical services, all of which may contribute greatly to their high prevalence of multimorbidity.

TABLE 1 | The urban–rural differences of the 10 most prevalent chronic diseases among older adults.

Chronic diseases	Urban (n = 1,453)		Rural (n = 1,797)		X^2
	N (%)	order	N (%)	order	
Hypertension	426 (29.3)	1	531 (29.5)	1	0.021
Diabetes	179 (12.3)	2	173 (9.6)	3	6.029*
Rheumatoid or rheumatoid arthritis	114 (7.8)	3	220 (12.2)	2	16.844***
Coronary heart disease	95 (6.5)	4	109 (6.1)	8	0.305
Hearing impairment	92 (6.3)	5	171 (9.5)	4	10.952**
Digestive system diseases	79 (5.4)	6	132 (7.3)	6	4.820*
Osteoporosis	76 (5.2)	7	133 (7.4)	5	6.291*
Eye diseases	65 (4.5)	8	117 (6.5)	7	6.308*
Respiratory diseases	51 (3.5)	9	94 (5.2)	9	5.582*
Stroke	45 (3.1)	10	85 (4.7)	10	5.580*

*$P < 0.05$,**$P < 0.01$,***$P < 0.001$.

TABLE 2 | The gender differences of the 10 most prevalent chronic diseases among older adults.

Chronic diseases	Male (n = 1,515)		Female (n = 1,735)		X^2
	N (%)	order	N (%)	order	
Hypertension	422 (27.9)	1	535 (30.8)	1	3.459
Diabetes	159 (10.5)	2	193 (11.1)	3	0.331
Rheumatoid or rheumatoid arthritis	126 (8.3)	4	208 (12.0)	2	11.824***
Coronary heart disease	79 (5.2)	7	125 (7.2)	6	5.445*
Hearing impairment	133 (8.8)	3	130 (7.5)	5	1.799
Digestive system diseases	95 (6.3)	5	116 (6.7)	8	0.230
Osteoporosis	71 (4.7)	9	138 (8.0)	4	14.350***
Eye diseases	59 (3.9)	10	123 (7.1)	7	15.617***
Respiratory diseases	81 (5.3)	6	64 (3.7)	9	5.215*
Stroke	77 (5.1)	8	53 (3.1)	10	8.660**

*$P < 0.05$,**$P < 0.01$,***$P < 0.001$.

The study also pointed out that under the influence of the urban–rural dual structure, older adults living in rural areas had more complex patterns of multimorbidity compared with older adults living in urban areas based on the Apriori algorithm. There were more association rules pointing to osteoporosis in the rural older population than in the urban older population, and rheumatoid and rheumatoid arthritis were present in the antecedents of several association rules pointing to osteoporosis, which is in line with the results of a previous study (35). It may be largely explained by the fact that most rural older adults suffer from malnutrition as well as the need to do heavy farm work. On the one hand, attention should be paid to the bone and joint health of rural older adults. On the other hand, among patients with osteoporosis, extra attention should be paid to the comorbidity of rheumatoid arthritis for better screening and prevention.

Regardless of urban or rural areas, older age, family genetic history, lower education level, quitting smoking, quitting drinking, and anxiety are all associated factors for multimorbidity among older adults. With the increase in age, the immune function of older adults gradually weakens, and the longer the body is exposed to various associated factors, the higher the risk of multimorbidity. Family genetic history is the most significant risk factor for multimorbidity. Some studies have reported an association between family genetic history and the risk of chronic disease (36, 37). A previous study established a strong relationship between anxiety and multimorbidity (38), which was in line with the previous study showing a significant association between anxiety and multimorbidity (39).

However, there is still some variation in the factors associated with multimorbidity between urban and rural areas. In urban areas, the unique protective factor of multimorbidity is childlessness, and the unique risk factor is insufficient fresh fruit intake and high BMI. It is worth noting that being childless may prevent urban older adults to suffer from multimorbidity. They do not have to spend a lot of money and energy on cultivating their children. Hence, they have more freedom to do their own things and participate in more social activities, thereby keeping good physical health. Compared with rural areas, urban residents have been shown to exhibit higher rates of unhealthy diet,

TABLE 3 | Analysis results of urban–rural differences in association rules for multimorbidity.

Consequent	Antecedent	Support (%)	Confidence (%)	Lift
Urban				
Hypertension	Atherosclerosis	3.44	60.00	2.05
Hypertension	Stroke	3.10	55.56	1.90
Hypertension	Coronary heart disease	6.54	52.63	1.80
Hypertension	Diabetes	12.32	52.51	1.79
Hypertension	Eye diseases	4.47	50.77	1.73
Hypertension	Osteoporosis	5.23	47.37	1.62
Hypertension	Rheumatic or rheumatoid arthritis	7.85	39.47	1.35
Hypertension	Hearing Impairment	6.33	36.96	1.26
Coronary heart disease	Atherosclerosis	3.44	34.00	5.20
Diabetes	Atherosclerosis	3.44	34.00	2.76
Rural				
Hypertension	Coronary heart disease	6.07	55.05	1.86
Hypertension	Diabetes	9.63	53.18	1.80
Hypertension	Stroke	4.73	45.88	1.55
Hypertension	Eye diseases	6.51	43.59	1.48
Hypertension	Hearing Impairment	9.52	40.35	1.37
Hypertension	Hearing Impairment, Rheumatic or rheumatoid arthritis	3.28	38.98	1.32
Rheumatic or rheumatoid arthritis	Osteoporosis	7.40	36.84	3.01
Hypertension	Osteoporosis	7.40	35.34	1.20
Rheumatic or rheumatoid arthritis	Hearing Impairment	9.52	34.50	2.82
Rheumatic or rheumatoid arthritis	Hearing Impairment, Hypertension	3.84	33.33	2.72
Rheumatic or rheumatoid arthritis	Respiratory diseases	5.23	32.98	2.69
Hearing Impairment	Rheumatic or rheumatoid arthritis, Hypertension	3.90	32.86	3.45
Hypertension	Rheumatic or rheumatoid arthritis	12.24	31.82	1.08
Hypertension	Digestive system diseases	7.35	30.30	1.03

physical inactivity, and obesity (40, 41). The rapid improvement in the living conditions of urban residents is the primary factor leading to their being overweight. Moreover, the modernization of the urban industrial structure has led to a sharp decline in the proportion of manual labor, which has led to an increase in the incidence of obesity. Reasonable dietary behavior and physical exercise can enhance physical fitness and reduce the occurrence of being overweight.

In rural areas, the unique risk factors are empty nest status and poor sleep quality. In rural China, the traditional concept of "bringing up their children for old age" of older adults is relatively strong (42). Bringing up their children for old age refers to the hard work of parents pulling their children to grow up. When they are old, grown-up children can understand the rewards and take care of the older parents without leaving them alone and helpless. With the development of urbanization, an increasing number of rural young people migrate into urban areas, while their parents are left in rural areas, which may make their parents feel lonely and have less daily care (27). Older adults are at more risk of multimorbidity if they are under empty nest status. Additionally, since most rural residents are engaged in high-intensity agricultural activities every day, it is not conducive to their health. Especially during the busy agricultural season, residents get up early and stay up late, and sleep quality is not guaranteed, which may be the main reason for their increased risk of multimorbidity. Therefore, older adults should try to get enough sleep to prevent the occurrence of chronic diseases. Overall, effective prevention and control measures should be developed from multiple perspectives and at multiple levels, in order to reduce the prevalence of multimorbidity and improve the health of older adults in both urban and rural areas.

Policy Implications

The current study findings have important implications for public health policy and planning. Due to the development imbalance caused by the urban–rural dichotomy, older adults in rural areas have much less access to healthcare than their urban counterparts. Expanding the study of urban–rural differences in multimorbidity will help the country formulate more reasonable public health policies to maximize the benefits of medical services for all. First, since the rural population has a higher prevalence of multimorbidity, the priority for health system transformation to address multimorbidity lies in the rural areas, where the needs are greatest and service providers are less skilled and more sparsely distributed. Second, it is necessary to strengthen the shared construction of regional public service facilities to achieve an effective interface between urban and rural areas. Third, it is necessary to build an integrated urban–rural medical

TABLE 4 | Comparison of the types of chronic diseases among older adults.

Characteristics	Types of chronic diseases [*N* (%)]			X^2	*P*
	None	1	≥2		
Personal characteristics:					
Age				127.342	<0.001
60∼	872 (64.6)	468 (51.1)	429 (43.6)		
70∼	386 (28.7)	372 (40.6)	406 (41.2)		
80∼	91 (6.7)	76 (8.3)	150 (15.2)		
Residence				18.231	<0.001
Urban	651 (48.3)	414 (45.2)	388 (39.4)		
Rural	698 (51.7)	502 (54.8)	597 (60.6)		
Family history of genetics				88.183	<0.001
Yes	15 (1.1)	56 (6.1)	95 (9.6)		
No	1,334 (98.9)	860 (93.9)	890 (90.4)		
BMI				30.269	<0.001
Underweight	204 (15.1)	116 (12.7)	145 (14.7)		
Normal	780 (57.8)	460 (50.2)	499 (50.7)		
Overweight	365 (27.1)	340 (37.1)	341 (34.6)		
Behavioral characteristics:					
Regularity of three meals				1.292	0.524
Yes	1,207 (89.5)	829 (90.5)	876 (88.9)		
No	142 (10.5)	87 (9.5)	109 (11.1)		
Frequency of fresh fruit consumption				28.986	<0.001
Eat almost every day	544 (40.3)	315 (34.4)	292 (29.6)		
Other	805 (59.7)	58 (6.3)	80 (8.1)		
Smoking status				60.782	<0.001
Smoking	281 (20.8)	177 (19.3)	171 (17.4)		
Quit smoking	81 (6.0)	138 (15.1)	138 (14.0)		
Never	987 (73.2)	601 (65.6)	676 (68.6)		
Drinking status				49.057	<0.001
Drinking	262 (19.4)	164 (17.9)	156 (15.8)		
Quit drinking	62 (4.6)	102 (11.1)	115 (11.7)		
Never	1,025 (76.0)	650 (71.0)	714 (72.5)		
Sleep quality				102.456	<0.001
Poor	177 (13.1)	201 (21.9)	298 (30.3)		
Good	1,172 (86.9)	715 (78.1)	687 (69.7)		
Anxiety				121.837	<0.001
Yes	383 (28.4)	271 (29.6)	482 (48.9)		
No	966 (71.6)	645 (70.4)	503 (51.1)		
Interpersonal Network:					
Marital status				11.459	<0.01
Married	1,061 (78.7)	705 (77.0)	716 (72.7)		
Other	288 (21.3)	211 (23.0)	269 (27.3)		
Empty nest status				42.610	<0.001
No children	51 (3.8)	9 (1.0)	10 (1.0)		
Empty nest	595 (44.1)	483 (52.7)	503 (51.1)		
Non-empty nest	703 (52.1)	424 (46.3)	472 (47.9)		
Socio-economic status:					
Educational level				62.654	<0.001
Elementary education and below	587 (43.5)	491 (53.6)	561 (57.0)		
Secondary education	596 (44.2)	364 (39.7)	364 (37.0)		
Higher education and above	166 (12.3)	61 (6.7)	60 (6.1)		
Monthly income				17.390	0.002
Low (<1,000 RMB)	654 (48.5)	476 (52.0)	561 (57.0)		
Middle (1,000∼5,000 RMB)	632 (46.8)	393 (42.9)	386 (39.1)		
High (>5,000 RMB)	63 (4.7)	47 (5.1)	38 (3.9)		

TABLE 5 | Multinomial logistic regression for having a single chronic disease and multimorbidity.

	Urban				Rural			
	0 vs. 1		0 vs. ≥2		0 vs. 1		0 vs. ≥2	
	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI
Personal characteristics								
Age (ref. 60∼)								
70∼	1.47	(1.10–1.97)*	2.07	(1.52–2.80)***	1.57	(1.21–2.03)**	1.64	(1.26–2.12)***
80∼	1.15	(0.70–1.90)	2.64	(1.65–4.24)	1.36	(0.83–2.21)	2.60	(1.69–4.00)
Family history of genetics (ref. No)								
Yes	6.53	(2.79–15.28)***	13.53	(5.91–30.98)***	5.47	(2.40–12.50)	7.98	(3.61–17.66)***
BMI (ref. Normal)								
Underweight	0.99	(0.65–1.53)	1.40	(0.92–2.13)	0.96	(0.68–1.37)	0.89	(0.64–1.26)
Overweight	1.84	(1.38–2.44)***	1.69	(1.25–2.30)**	1.43	(1.09–1.88)	1.23	(0.95–1.61)
Behavioral characteristics								
Frequency of fresh fruit consumption (ref. Eat almost every day)								
Other	1.14	(0.87–1.48)	1.37	(1.04–1.82)*	1.39	(1.05–1.84)*	1.31	(0.99–1.72)
Smoking status (ref. Never)								
Smoking	1.07	(0.72–1.58)	1.03	(0.68–1.54)	1.02	(0.71–1.44)	0.81	(0.57–1.15)
Quit smoking	2.42	(1.53–3.82)***	1.87	(1.15–3.02)*	2.43	(1.52–3.90)***	2.06	(1.29–3.29)**
Drinking status (ref. Never)								
Drinking	1.07	(0.72–1.57)	1.39	(0.93–2.07)	0.90	(0.62–1.31)	0.80	(0.55–1.17)
Quit drinking	1.94	(1.17–3.19)*	2.22	(1.33–3.71)**	2.89	(1.67–5.00)***	2.98	(1.74–5.09)***
Sleep quality (ref. Good)								
Poor	1.27	(0.88–1.82)	1.69	(1.19–2.40)	2.11	(1.53–2.91)***	2.15	(1.59–2.92)***
Anxiety (ref. No)								
Yes	0.99	(0.73–1.34)	1.65	(1.22–2.23)**	0.85	(0.65–1.11)	2.09	(1.63–2.68)***
Marital status (ref. Other)								
Married	0.65	(0.46–0.91)	0.99	(0.68–1.43)	1.24	(0.92–1.55)	0.94	(0.71–1.24)
Empty nest status (ref. Non–empty nest)								
No children	0.26	(0.09–0.79)*	0.30	(0.10–0.96)*	0.42	(0.14–1.23)	0.38	(0.14–1.07)
Empty nest	1.49	(1.15–1.94)**	1.20	(0.91–1.59)	1.20	(0.94–1.53)	1.29	(1.01–1.64)*
Working and living environment								
Educational level (ref. Higher education and above)								
Elementary education and below	1.40	(0.92–2.14)	1.72	(1.10–2.69)*	5.33	(2.09–13.59)***	2.55	(1.20–5.41)*
Secondary education	1.31	(0.89–1.92)	1.27	(0.84–1.94)	3.21	(1.25–8.24)*	1.97	(0.92–4.20)

*$P < 0.05$,**$P < 0.01$,***$P < 0.001$.

insurance system to achieve regional equality at the national level. Moreover, it is recommended to implement relevant preferential policies to encourage and guide medical school graduates to work in rural areas, which can improve the capacity of primary care services in rural areas. Finally, considering the importance of primary care in addressing multimorbidity in a coordinated and continuous manner, it seems critical to strengthen primary care so that equally good-quality integrated services can be provided to both rural and urban people of China.

Limitations

The current study had various strengths and limitations. The strengths of the study are the large sample size and regions. Additionally, a comparative analysis between rural and urban areas suggests that rural areas are at a disadvantage in multimorbidity, which distinguishes itself from the previous studies. Although this study had certain value for the prevention and control of multimorbidity in older adults, it also had limitations. First, due to the cross-sectional design, there were information deviations when investigating and analyzing behavioral lifestyles. In addition, the prevalence of chronic diseases was self-reported, and thus, there may be information bias. To clarify these findings, longitudinal studies are necessary. Finally, the data were collected from older adults in Shanxi province, China, and other populations need to be verified in future studies.

CONCLUSION

Multimorbidity is more prevalent among rural older adults than urban older adults in the study. Future health system

development in China should transform from preventing and controlling a single chronic disease to addressing the multimorbidity of older adults. The priority for such a transformation is rural areas. Moreover, there are some differences in the patterns and factors associated with multimorbidity in urban and rural older adults. Specifically, empty nest status, frequency of fresh fruit consumption, BMI, and sleep quality, have different impacts on multimorbidity in urban and rural areas. Therefore, intervention measures for multimorbidity among older adults in urban and rural areas should be differentiated. The current study findings may have important implications for the intervention programs aimed at narrowing the gap in multimorbidity between urban and rural older adults. The allocation of resources needs changes to maintain a balance between rural and urban regions. First, it is necessary to strengthen the shared construction of regional public service facilities to achieve an effective interface between urban and rural areas. Second, it is necessary to integrate urban and rural welfare systems (medical insurance, disability care, and medical assistance) to achieve regional equality at the national level.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author/s.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Shanxi Medical university ethics committee. All participants were informed of the purpose and procedure of the research upon their recruitment, and assured of their right to refuse to participate. Their anonymity and confidentiality were guaranteed. After signing the consent, participants were invited to conduct questionnaires face to face to collect data by trained investigators. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

CZ and SX conceived the idea. FD, YX, and BX participated in data collection and statistical analysis. SX drafted the manuscript. HL, JZ, and PO edited the paper. LS and XZ gave many valuable comments on the draft and polished it. All authors have read and approved the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2021.707062/full#supplementary-material

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Catastrophic Health Expenditure Associated With Frailty in Community-Dwelling Chinese Older Adults: A Prospective Cohort Analysis

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Background: Catastrophic health expenditure (CHE) represents a key indicator for excessive financial burden due to out-of-pocket (OOP) healthcare costs, which could push the household into poverty and is highly pronounced in households with members at an advanced age. Previous studies have been devoted to understanding the determinants for CHE, yet little evidence exists on its association with frailty, an important geriatric syndrome attracting growing recognition. We thus aim to examine the relationship between frailty and CHE and to explore whether this effect is moderated by socioeconomic-related factors.

Methods: A total of 3,277 older adults were drawn from two waves (2011 and 2013) of the China Health and Retirement Longitudinal Study (CHARLS). CHE was defined when OOP healthcare expenditure exceeded a specific proportion of the capacity of the household to pay. Frailty was measured following the Fried Phenotype (FP) scale. Mixed-effects logistic regression models were employed to assess the longitudinal relationship between frailty and CHE, and stratification analyses were conducted to explore the moderation effect.

Results: The incidence of CHE among Chinese community-dwelling older adults was 21.76% in 2011 and increased to 26.46% in 2013. Compared with non-frail individuals, prefrail or frail adults were associated with higher odds for CHE after controlling for age, gender, residence, education, marriage, income, health insurance, smoking, drinking, and comorbidity (prefrail: odds ratio (OR) = 1.32, 95%CI = 1.14–1.52; frail: OR = 1.67, 95%CI = 1.13–2.47). Three frailty components including weakness, exhaustion, and shrinking contributed to a significantly increased likelihood of CHE (all $p < 0.05$), while the other two components including slowness and inactivity showed a non-significant effect (all $p > 0.05$). Similar effects from frailty on CHE were observed across socioeconomic-related subgroups differentiated by gender, residence, education, household income, and social health insurance.

Conclusions: Frailty is a significant predictor for CHE in China. Developing and implementing cost-effective strategies for the prevention and management of frailty is imperative to protect households from financial catastrophe.

Keywords: catastrophic health expenditure, frailty, older people, longitudinal, China

INTRODUCTION

A considerable number of individuals are confronted with a huge economic burden due to out-of-pocket (OOP) healthcare expenditures worldwide, and consequently, often place their families under a situation of unanticipated financial catastrophe or impoverishment (1). Although health insurance arrangements in many countries including China have achieved unprecedented progress in recent decades, particularly by expanding medical insurance coverage and increasing reimbursement benefits, their role in protecting the individuals or households from being pushed into poverty remains a challenge (2, 3). To help quantify and deal with the financial difficulties of households resulting from healthcare costs, researchers have generally agreed on a term called "catastrophic health expenditure (CHE)," which is defined as if healthcare spending exceeds a specified level of tolerance or threshold from the capacity of the household to pay (4, 5). The occurrence of CHE could absorb a large proportion of the household budget and leads to the sacrifice of the consumption of daily necessities, thereby affecting household living conditions and further deteriorating individual well-being (4, 5). Meanwhile, CHE is highly pronounced among older people, who account for the high demand for healthcare services but have limited income (3, 6). Along with the rapid and dramatic population aging, it is thus imperative to understand the CHE prevalence and its associated risk factors among elderly people.

Frailty, increasingly known as a good proxy for biological aging, is a multidimensional geriatric syndrome characterized by decreased resilience to stressors due to a generalized decline or age-related health deficits across multiple physiological systems (7, 8). In China, the first study using a nationally representative sample to estimate frailty prevalence found that frailty affected a large proportion of about 7.0% of the community-dwelling older people (9), and a further meta-analysis reported the prevalence of frailty to vary from 5.9 to 17.4% (10). Frailty, similar to many other geriatric assessments, was shown to predict adverse health outcomes and poor quality of life of older people (11, 12). In addition, previous studies demonstrated that frailty could predict poor recovery from stressors (13), as well as increased healthcare utilization and costs (14–17). For example, one Chinese study by Xu et al. (13) revealed the connection between frailty and poor recovery from activities of daily living (ADL) disability among non-disabled community-dwelling older adults (13). A recent meta-analysis demonstrated that healthcare costs increased by $79–13,423.83 in the prefrail elderly and by $616–32,549.96 in the frail elderly than the robust community-dwelling individuals, based on seven cohort studies comprised of 3,750,611 participants (17). Evidence from China also documented that frailty was an independent determinant of primarily increased outpatient and self-treatment expenditure among older adults (16).

However, an examination into solely healthcare costs seems inadequate to reveal the accurate economic burden exerted on individuals and households, considering that the same amount of healthcare spending may mean a different story for financially deprived or affluent families. A more comprehensive understanding of the disease burden can be gained if the impact of frailty on CHE is clear, which, however, remains to be elucidated. To date, there has been minimal research investigating the association between frailty and CHE, which yet concluded inconsistent findings and were limited in their cross-sectional design (18, 19). To fill in the research gap, the present study employs a national dataset to examine the longitudinal relationship between frailty and CHE among the community-dwelling older adults in China, as well as to explore whether this effect is moderated by socioeconomic-related factors to figure out subgroup inequities.

MATERIALS AND METHODS

Data and Sample

The study participants were drawn from two waves (2011 and 2013) of the China Health and Retirement Longitudinal Study (CHARLS), a nationally representative longitudinal survey of the middle-aged and older Chinese population. A detailed description of the CHARLS survey has been reported elsewhere (20). Briefly, samples in CHARLS were selected using the multistage stratified sampling design and probability proportional sampling technique from 150 county-level units in 28 provinces of China. The participant information was collected *via* face-to-face computer-assisted interviews using structured questionnaires, which contained a wide range of data such as sociodemographics, family structure, health, biomarkers, health use, and expenditure. The CHARLS team carried out the baseline survey in 2011, which recruited ∼17,000 participants, and held follow-up surveys biennially in 2013, 2015, and 2018.

In this study, we limited the sample to older adults aged adults 60 years or above in 2011 ($N = 7,423$) and included only the previous two waves of the survey due to the lack of key variables used for constructing frailty in the two latter waves. After excluding participants who did not complete the follow-up survey in 2013 ($N = 1,233$) or reported missing information on the study variables ($N = 2,913$), a final sample of 3,277 subjects were eligible for analysis in this study, and study variables for each participant were repeatedly measured at every available time point in both 2011 and 2013. The number of missing values was

primarily due to incomplete frailty assessment, which was not unanticipated because the question about the frailty component of inactivity was originally designed in CHARLS protocol to be administered in only a random subsample of half of the study participants. The CHARLS protocol was approved by the Ethics Review Committee of Peking University (No.: IRB00001052-11015), and all participants provided written informed consent at the time of enrollment.

Measurements

Frailty

Frailty was measured following the Fried frailty phenotype (FP) scale, a tool that had been rigorously validated previously, in which five items were assessed: slowness, weakness, exhaustion, inactivity, and shrinking (9, 14, 21). Slowness was defined if gait speed, measured using the average of two trials of walk tests over a 2.5 m course, was at or below the 20th percentile of the gender- and height-adjusted population distribution. The criteria for weakness were met when the maximum handgrip strength was below or equal to the 20th percentile of the population distribution, after adjusting for gender and body mass index (BMI). Exhaustion was defined when the answer to the two questions from the modified Centre for Epidemiological Studies-Depression (CES-D) scale ("I could not get going," "I felt everything I did was an effort") was "occasionally or a moderate amount of the time" or "most of the time." Participants met the criteria for inactivity if they answered "no" to the question of "during a usual week, did you walk for at least 10 min continuously?" Respondents met the shrinking criteria when they currently had a BMI $\leq$ of 18.5 kg/m^2 or self-reported loss of at least 5 kg in the previous year. Frailty was treated as missing if two or more frailty components were unavailable for each individual. We classified participants into different frailty levels according to previous literature (9, 14, 21), in which individuals fulfilling none of the five criteria were considered as "non-frail," one or two criteria as "prefrail," and three or more criteria as "frail."

Catastrophic Health Expenditure

Catastrophic health expenditure was defined when OOP payment for healthcare was matched or exceeded a specified proportion of the capacity of the household to pay (4). In this study, we defined CHE as "yes" if OOP health spending was equal to or higher than 40% of the total non-food expenditure of households, in accordance with most previous studies to facilitate comparisons (2, 22). The numerator was OOP healthcare expenditure, which was calculated by summing up the self-reported medical OOP expenditure of respondents and their spouses on outpatient and inpatient care in the last year. In this study, annual outpatient OOP expenditure was evaluated by multiplying the self-reported monthly OOP outpatient payments by 12 to get the whole-year estimate, and annual inpatient OOP expenditure was assessed by self-report of participants of OOP payments for inpatient visits in the past year. The denominator was the total annual non-food expenditure of the household as a proxy for capacity to pay, which was obtained by deducting the annual food-based spending of the household from the total annual consumption expenditure. CHE was a binary variable, indicating whether or not the household of the participant had catastrophic healthcare spending.

Covariates

The following variables were considered as potential covariates in this study: age, gender, place of residence (rural and urban), educational attainment (no former education or illiterate, literate but did not finish primary school, primary school, and middle school and above), marital status (married and others), annual household income per capita in quartiles, social health insurance (none, New Rural Cooperative Medical Scheme, Urban Employee Basic Medical Insurance, Urban Resident Basic Medical Insurance, and others), smoking behavior (never smoked, former smoker, and current smoker), drinking habit (never drunk, drink but less than one time per month, and drink more than one time per month), and physical comorbidity with the presence of two or more noncommunicable chronic diseases (no and yes).

Statistical Analysis

All statistical analyses were performed using STATA software version 16.0 (StataCorp, College Station, TX). Two-tailed $p < 0.05$ were considered statistically significant. The baseline characteristics of study participants according to frailty status were descriptively summarized with numbers and percentages and were statistically compared using the χ^2-test. CHE incidence was calculated as the percentage of individuals incurring CHE during a certain period. McNemar's Chi-square test was conducted to compare the CHE incidence between 2 years in the total sample, and the Chi-square test for independent samples was carried out to examine whether CHE incidence differed by frailty status in each year.

To take the correlated data into account, a panel data approach of mixed-effects logistic regression models was performed to explore the longitudinal effect of frailty on CHE, and the results were expressed as odds ratio (OR) and 95% CI. Five models were hierarchically conducted to account for the potential confounding. Model 1, a crude model without adjustment for any covariates; Model 2, adjusting for covariates including age and gender; Model 3, additionally adjusting for residence, education, marital status, income, and health insurance; Model 4, additionally adjusting for smoking, and drinking; and Model 5, additionally adjusting for physical comorbidity. We further conducted subgroup analyses stratified by major socioeconomic-related factors including gender, place of residence, educational attainment, household income level, and social health insurance, using the same mixed-effects logistic regression but with the stratification variable removed from the model. The likelihood-ratio test was used to explore whether the interaction effect was significant.

Sensitivity analyses were undertaken by using different thresholds for classifying CHE according to the definitions of WHO and World Bank (4). CHE was defined in alternative ways, i.e., if OOP healthcare expenditure matched or exceeded 10 and 25% of the total household consumption expenditure, and 25% of the total non-food household consumption expenditure (4).

RESULTS

Baseline Sample Characteristics

The study participants had a mean (SD) age of 66.95 (5.67) years and 52.33% of them were men. **Table 1** shows their baseline characteristics according to frailty status. The participants with older age, rural residence, no health insurance, less education, non-married status, more deprived household, and physical comorbidity were relatively more susceptible to frailty (all $p < 0.05$). The frailty status between men and women was not found significantly different in our sample, and thus were the individuals with different smoking or drinking behaviors (all $p > 0.05$).

Figure 1 presents the incidence of CHE in the total sample and according to frailty status from 2011 to 2013. The CHE incidence among community-dwelling older adults in China was 21.76% in 2011 and increased to 26.46% in 2013. More specifically, the CHE incidence equaled 31.52, 23.66, and 19.58% in 2011 for frail, prefrail, and non-frail individuals, respectively, and it was 32.69, 28.75, and 24.01% in 2013 for frail, prefrail, and non-frail individuals, respectively. Prefrail and frail adults had a significantly higher CHE incidence than those who were robust in both 2011 and 2013 ($p < 0.05$).

Longitudinal Relationship Between Frailty and CHE

Results for the longitudinal association between frailty and CHE among community-dwelling Chinese older adults are displayed in **Table 2**. When we examined frailty as a continuous variable, every one-component increase in frailty was found to significantly increase the risk for CHE in all models adjusting for covariates hierarchically (crude model: OR = 1.23, 95% CI = 1.13–1.34; fully-adjusted model: OR = 1.21, 95% CI = 1.11–1.32). Compared with non-frail individuals, prefrail or frail adults were associated with higher odds for CHE after controlling for age, gender, residence, education, marriage, income, health insurance, smoking, drinking, and comorbidity (prefrail: OR = 1.32, 95% CI = 1.14–1.52; frail: OR = 1.67, 95% CI = 1.13–2.47). Besides, we observed that three frailty components including weakness, exhaustion, and shrinking contributed to significantly increased likelihood of CHE (weakness: OR = 1.36, 95% CI = 1.14–1.63; exhaustion: OR = 1.60, 95% CI = 1.25–2.04; shrinking: OR = 1.29, 95% CI = 1.08–1.55) after controlling for the full list of predefined confounders, while the other two components including slowness and inactivity showed non-significant effect (slowness: OR = 1.08, 95% CI = 0.90–1.30; inactivity: OR = 1.03, 95% CI = 0.78–1.37). The above results remained all similar in models with adjustment for fewer covariates.

Stratification Analyses

We further conducted stratification analyses to examine whether the effect of a one-component increase in frailty on CHE was varied by different socioeconomic-related subgroups, and the results are illustrated in **Figure 2**. The forest plot indicated that a one-component increase in frailty was associated with a higher likelihood for CHE after adjusting for the aforementioned covariates, and such a pattern of effect was similarly observed across different subgroups with varied gender, place of residence, educational attainment, household income level, and social health insurance (**Figure 2**). Results from the likelihood-ratio test supported that the interaction effect was all non-significant, indicating that the effect of frailty on CHE was comparable irrespective of gender, residence, education, household income, and health insurance (all p for interaction > 0.05).

Sensitivity Analysis

Sensitivity analyses were carried out to test the robustness of our results, by using the different thresholds for classifying CHE (**Table 3**). The results were all consistent with the main findings when we defined CHE as $\geq 25\%$ of the total non-food household expenditure, ≥ 10 and $\geq 25\%$ of the total household expenditure.

DISCUSSIONS

To our knowledge, this is the first attempt to investigate the longitudinal association of frailty with CHE among older people. The major strength of our study includes the cohort study design that enables us to examine the temporal relationship, its relatively large sample size from a nationwide community-based population, and the exploration into a topic that is not adequately addressed. In our sample, the incidence of CHE at the 40% threshold among community-dwelling older adults was 21.76% in 2011 and increased to 26.46% in 2013. The increasing trend of CHE prevalence was similarly observed in other Chinese studies, which may be partly explained by the rising OOP healthcare costs over time along with the absence of effective measures to cut down expenditures or share financial risks for individuals (3, 23). Several important findings are drawn from this study as follows.

The main finding of our study is that frailty appears to predict increased risk for CHE among community-dwelling older adults in China, suggesting the substantial burden from frailty on affecting the overall quality of household living standards. The majority of previous literature showed consistent findings suggesting that health disorders, such as chronic diseases (2, 24, 25), cancer (26), disability (27, 28), injuries (29), and depression (30), were associated with healthcare-related financial catastrophe, even though they rarely studied the impact from frailty. Only two studies were identified in terms of the association between CHE and frailty, which yet yielded inconclusive results (18, 19). That is, one study conducted by Jing et al. (18) demonstrated that the co-occurrence of frailty increased the risk of incurring CHE based on a sample of 606 single empty-nest elderly with multimorbidity (18), while another study from Gao et al. (19) suggested that frailty was not significantly associated with CHE among 5,204 community-dwelling adults aged at least 60 years (19). Both studies were, however, limited in their cross-sectional study design that failed to determine the chronological sequence of events, so the present study was advantageous by adopting a panel data analysis that could lead to more convincing results. The discrepancies in the observed association between frailty and CHE may be owing to the variations in the studied population, study design, and sample size across studies. Our finding that frailty could be

TABLE 1 | Baseline characteristics of study participants according to frailty status.

Characteristics	Overall (n = 3,277)	No. (%) of participants by frailty status			p-value[a]
		Non-frail (n = 1,706)	Pre-frail (n = 1,479)	Frail (n = 92)	
Age					<0.001
60–64	1,392 (42.48)	819 (48.01)	555 (37.53)	18 (19.57)	
65–69	922 (28.14)	500 (29.31)	396 (26.77)	26 (28.26)	
70–74	570 (17.39)	261 (15.30)	284 (19.20)	25 (27.17)	
75–79	299 (9.12)	103 (6.04)	183 (12.37)	13 (14.13)	
≥80	94 (2.87)	23 (1.35)	61 (4.12)	10 (10.87)	
Gender					0.846
Male	1,715 (52.33)	886 (51.93)	782 (52.87)	47 (51.09)	
Female	1,562 (47.67)	820 (48.07)	697 (47.13)	45 (48.91)	
Residence					<0.001
Rural	2,656 (81.05)	1,327 (77.78)	1,246 (84.25)	83 (90.22)	
Urban	621 (18.95)	379 (22.22)	233 (15.75)	9 (9.78)	
Educational attainment					<0.001
No formal education or illiterate	1,113 (33.96)	514 (30.13)	557 (37.66)	42 (45.65)	
Literate but did not finish primary school	716 (21.85)	377 (22.10)	320 (21.64)	19 (20.65)	
Primary school	880 (26.85)	486 (28.49)	374 (25.29)	20 (21.74)	
Middle school and above	568 (17.33)	329 (19.28)	228 (15.42)	11 (11.96)	
Marital status					<0.001
Married	2,669 (81.45)	1,433 (84.00)	1,170 (79.11)	66 (71.74)	
Others	608 (18.55)	273 (16.00)	309 (20.89)	26 (28.26)	
Household income per capita					<0.001
Quartile 1 (deprived)	857 (26.15)	369 (21.63)	450 (30.43)	38 (41.30)	
Quartile 2	877 (26.76)	441 (25.85)	409 (27.65)	27 (29.35)	
Quartile 3	859 (26.21)	473 (27.73)	368 (24.88)	18 (19.57)	
Quartile 4 (affluent)	684 (20.87)	423 (24.79)	252 (17.04)	9 (9.78)	
Health insurance					<0.001
None	174 (5.31)	90 (5.26)	77 (5.21)	7 (7.61)	
New rural cooperative medical scheme	2,542 (77.57)	1,276 (74.79)	1,186 (80.19)	80 (86.96)	
Urban employee basic medical insurance	294 (8.97)	187 (10.96)	105 (7.10)	2 (2.17)	
Urban resident basic medical insurance	164 (5.00)	94 (5.51)	68 (4.60)	2 (2.17)	
Other insurances	103 (3.14)	59 (3.46)	43 (2.91)	1 (1.09)	
Smoking					0.371
Never	1,841 (56.18)	982 (57.56)	814 (55.04)	45 (48.91)	
Former	370 (11.29)	186 (10.90)	172 (11.63)	12 (13.04)	
Current	1,066 (32.53)	538 (31.54)	493 (33.33)	35 (38.04)	
Drinking					0.060
Never	2,253 (68.75)	1,142 (66.94)	1,043 (70.52)	68 (73.91)	
Drink but less than once per month	201 (6.13)	113 (6.62)	80 (5.41)	8 (8.70)	
Drink more than once per month	823 (25.11)	451 (26.44)	356 (24.07)	16 (17.39)	
Physical comorbidity					<0.001
No	1,900 (57.98)	1,047 (61.37)	808 (54.63)	45 (48.91)	
Yes	1,377 (42.02)	659 (38.63)	671 (45.37)	47 (51.09)	

[a]*p-values were calculated from chi-square test for categorical variables.*

a catastrophic condition is unsurprising given the following speculations: first, frailty is often associated with health decline and productivity loss, resulting in an inability to earn income (11, 12, 18); second, frail individuals are often found to incur higher medical expenditure due to more intensive health service use and heavier dependency on continuing care following the hospital discharge, which could eventually increase the likelihood of suffering from CHE (14–17).

Among the five FP components, the onset of weakness, exhaustion, and shrinking were found to be associated with CHE in this study, whereas slowness and inactivity were not significantly related to CHE. Our finding adds to the existing

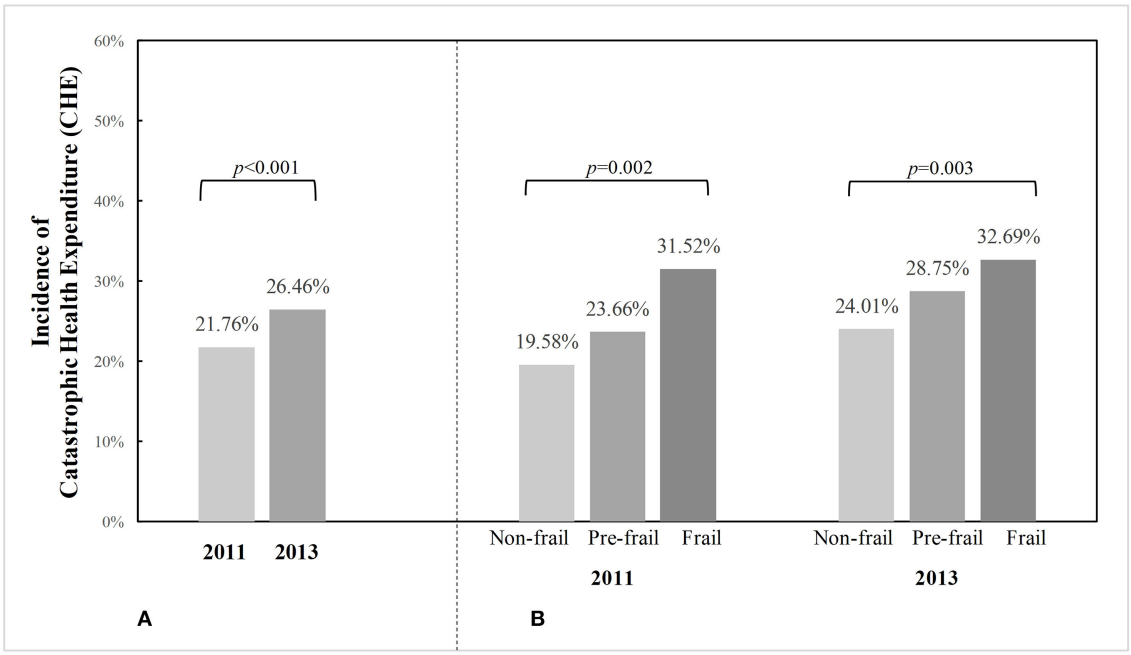

FIGURE 1 | Incidence of catastrophic health expenditure (CHE) among Chinese community-dwelling older adults from 2011 to 2013, in the total sample and by frailty status. *p*-values were calculated from McNemar's Chi-square test to examine whether CHE incidence differed between 2 years in the total sample, or Chi-square test for independent samples to examine whether CHE incidence differed by frailty status in each year. **(A)** CHE incidence in total sample. **(B)** CHE incidence in particiants according to frailty status.

TABLE 2 | Longitudinal association between frailty and catastrophic health expenditure (CHE) in community-dwelling Chinese older adults ($N = 3,277$).

Variables	Catastrophic health expenditure, OR (95%CI)				
	Model 1[a]	Model 2[b]	Model 3[c]	Model 4[d]	Model 5[e]
Every one-component increase in frailty	1.23 (1.13–1.34)***	1.23 (1.13–1.34)***	1.26 (1.15–1.37)***	1.25 (1.14–1.36)***	1.21 (1.11–1.32)***
Frailty phenotype					
Non-frail	1.00	1.00	1.00	1.00	1.00
Pre-frail	1.35 (1.17–1.55)***	1.34 (1.17–1.55)***	1.38 (1.20–1.59)***	1.36 (1.18–1.57)***	1.32 (1.14–1.52)***
Frail	1.75 (1.20–2.57)**	1.73 (1.18–2.55)**	1.83 (1.24–2.70)**	1.78 (1.21–2.64)**	1.67 (1.13–2.47)**
Frailty phenotype components					
Slowness (ref: no slowness)	1.10 (0.92–1.32)	1.09 (0.91–1.31)	1.13 (0.94–1.36)	1.12 (0.93–1.34)	1.08 (0.90–1.30)
Weakness (ref: no weakness)	1.40 (1.17–1.67)***	1.39 (1.16–1.67)***	1.44 (1.20–1.73)***	1.41 (1.18–1.69)***	1.36 (1.14–1.63)***
Exhaustion (ref: no exhaustion)	1.55 (1.21–1.98)***	1.55 (1.21–1.98)***	1.72 (1.34–2.20)***	1.70 (1.33–2.18)***	1.60 (1.25–2.04)***
Inactivity (ref: no inactivity)	1.06 (0.80–1.40)	1.05 (0.79–1.39)	1.02 (0.76–1.35)	1.02 (0.76–1.35)	1.03 (0.78–1.37)
Shrinking (ref: no shrinking)	1.35 (1.13–1.62)**	1.34 (1.12–1.61)**	1.31 (1.09–1.57)**	1.32 (1.10–1.59)**	1.29 (1.08–1.55)**

[a]*Model 1 was a crude model without adjustment for any covariates.*
[b]*Model 2 was adjusted for covariates including age and gender.*
[c]*Model 3 was adjusted for covariates including age, gender, residence, education, marital status, income, and health insurance.*
[d]*Model 4 was adjusted for covariates including age, gender, residence, education, marital status, income, health insurance, smoking, and drinking.*
[e]*Model 5 was adjusted for covariates including age, gender, residence, education, marital status, income, health insurance, smoking, drinking, and physical comorbidity.*
***p < 0.01, ***p < 0.001; OR, odds ratio; CI, confidence interval.*

literature by comprehensively ascertaining the influence of each frailty component on CHE for the first time. Despite the lack of available research investigating the impacts of FP components on CHE, accumulating evidence has attempted to figure out their relationships with healthcare costs (31–33). For example, a cross-sectional study among 2,598 older participants from Germany showed that only weight loss and exhaustion were significantly associated with total healthcare costs (31). Another longitudinal study in Germany indicated that the onset of exhaustion was the only symptom associated with an increase in total healthcare costs (32). Ensrud et al. (33, 34) conducted cohort studies among older women and men separately in the United States and

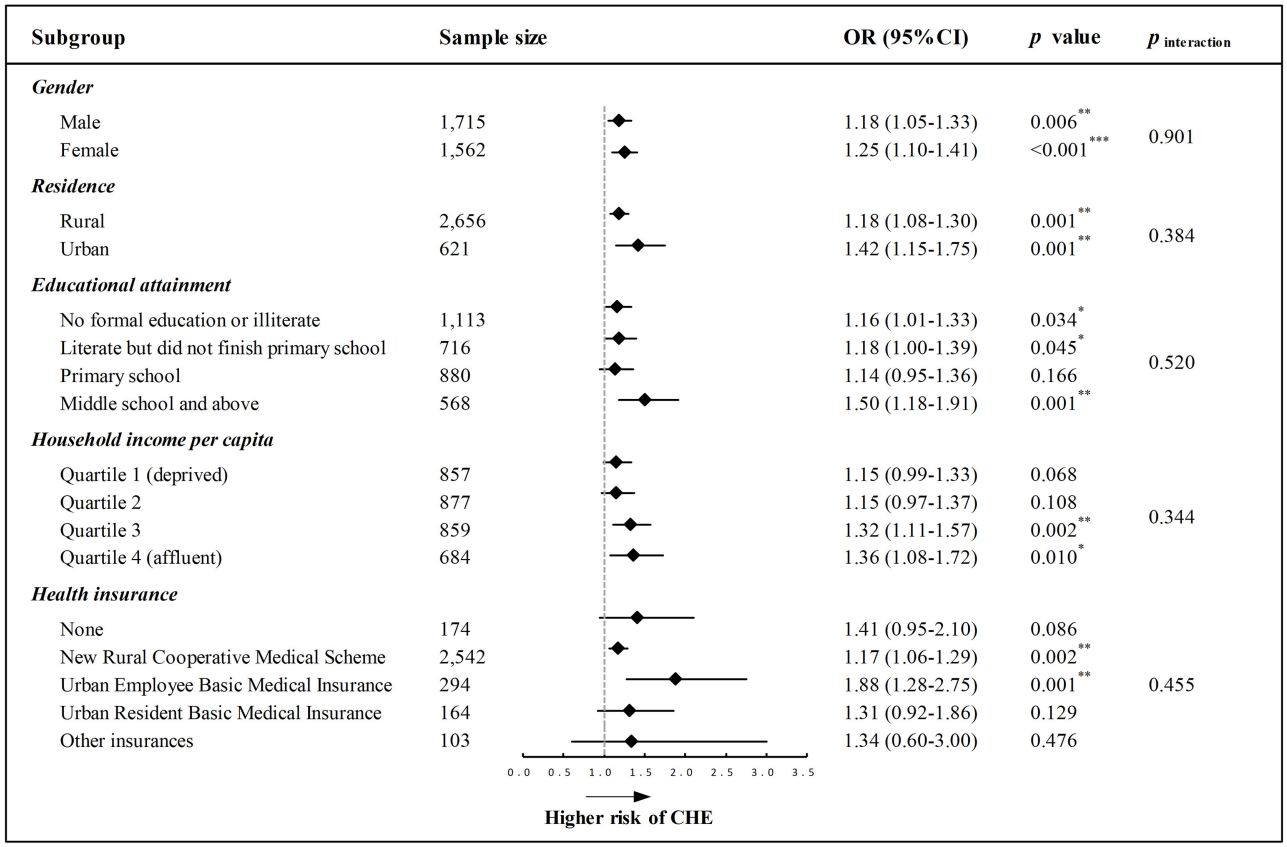

FIGURE 2 | Forest plot depicting the longitudinal association between every one-component increase in frailty and CHE across different socioeconomic-related subgroups. All models were adjusted for the predefined full list of covariates (i.e., age, gender, residence, education, marital status, income, health insurance, smoking, drinking, and physical comorbidity) except the stratification variable. *p* for interaction ($p_{interaction}$) was examined using the likelihood-ratio test. OR, odds ratio; CI, confidence interval; $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

observed that each frailty component was associated with higher total costs (33, 34). The findings are still scarce and inconsistent so that further attention is necessary to improve the identification of high-risk older adults through frailty symptom assessment.

This study additionally demonstrated that the relationship between an increasing level of frailty and CHE remained consistent irrespective of socioeconomic-related differences with regard to gender, residence, education, household income, and health insurance. This contrasted with one previous research (18) suggesting that frail people with poor economic status were more likely to incur CHE than those with higher economic status, but their study population was limited to single empty-nest elderly with multimorbidity in one province of rural China. However, another research investigating physical multimorbidity and CHE revealed similar findings as in this study, indicating that the effect of comorbidity on CHE persisted among different household economic levels and across all health insurance programs (2). Other prior studies have only examined the disparities in healthcare utilization or costs associated with frailty rather than CHE, and their results were also controversial (14, 35, 36). For instance, some studies found gender interaction in inpatient use (36) or outpatient payment (35), whereas other studies identified no gender interaction in healthcare use (14) or total healthcare payment (35). Overall, the moderation effect of socioeconomic-related factors is not yet well-understood to date, warranting further large-scale and longitudinal investigations.

Findings from the present study have important practical implications. Frailty is increasingly prevalent and has emerged as an independent risk factor for healthcare-related financial catastrophe among community-dwelling older adults, indicating that early screening or assessment of frailty in the community setting may assist with identifying the targeted population at high risk of being reduced to poverty by healthcare costs. Policy-makers, clinicians, or public health authorities shall raise awareness about the increasing burden that frailty will pose on the healthcare system as well as the substantial benefit that proactive efforts to address frailty will bring to alleviate economic burden or inequalities among older individuals. Older people themselves should also be empowered with adequate knowledge and skills to prevent or reverse frailty, such as the capacity in detecting early warning signs of frailty and responsibility in modifying their unhealthy lifestyles.

Several limitations should also be taken into consideration. First, our measurement of CHE considered only the incurred

TABLE 3 | Longitudinal association between frailty and catastrophic health expenditure with different thresholds ($N = 3,277$).

Variables	Catastrophic health expenditure with different thresholds, OR (95%CI)					
	Threshold 1: ≥25% of households' total non–food expenditure		Threshold 2: ≥25% of households' total expenditure		Threshold 3: ≥10% of households' total expenditure	
	Model 1[a]	Model 2[b]	Model 1[a]	Model 2[b]	Model 1[a]	Model 2[b]
Every one–component increase in frailty	1.25 (1.15–1.36)***	1.24 (1.14–1.35)***	1.29 (1.18–1.40)***	1.27 (1.16–1.38)***	1.27 (1.17–1.38)***	1.26 (1.16–1.37)***
Frailty phenotype						
Non–frail	1.00	1.00	1.00	1.00	1.00	1.00
Pre–frail	1.35 (1.18–1.55)***	1.33 (1.16–1.53)***	1.43 (1.24–1.66)***	1.40 (1.20–1.62)***	1.43 (1.24–1.64)***	1.40 (1.22–1.61)***
Frail	1.79 (1.22–2.63)**	1.75 (1.19–2.57)**	2.09 (1.42–3.08)***	2.01 (1.36–2.97)***	1.69 (1.14–2.48)**	1.66 (1.13–2.45)*
Frailty phenotype components						
Slowness (ref: no slowness)	1.08 (0.90–1.29)	1.06 (0.89–1.27)	1.14 (0.95–1.38)	1.13 (0.93–1.36)	1.16 (0.97–1.38)	1.14 (0.96–1.37)
Weakness (ref: no weakness)	1.39 (1.17–1.67)***	1.37 (1.14–1.63)***	1.50 (1.25–1.81)***	1.46 (1.21–1.75)***	1.40 (1.17–1.68)***	1.37 (1.15–1.64)***
Exhaustion (ref: no exhaustion)	1.66 (1.30–2.12)***	1.72 (1.34–2.19)***	1.65 (1.29–2.11)***	1.69 (1.31–2.16)***	1.61 (1.26–2.05)***	1.67 (1.30–2.13)***
Inactivity (ref: no inactivity)	1.12 (0.84–1.48)	1.11 (0.83–1.48)	1.08 (0.80–1.46)	1.06 (0.78–1.44)	1.09 (0.82–1.45)	1.08 (0.81–1.44)
Shrinking (ref: no shrinking)	1.37 (1.14–1.64)***	1.33 (1.11–1.59)**	1.39 (1.15–1.68)***	1.34 (1.11–1.62)**	1.41 (1.18–1.69)***	1.38 (1.15–1.65)***

[a]*Model 1 was adjusted for covariates including age and gender.*

[b]*Model 2 was adjusted for covariates including age, gender, residence, education, marital status, income, health insurance, smoking, drinking, and physical comorbidity.*

**p < 0.05, **p < 0.01, ***p < 0.001; OR, odds ratio; CI, confidence interval.*

outpatient and inpatient health costs. There could be healthcare spending from other sources that are not examined, so that the actual rate of CHE may be underestimated. Second, this study collected the key information *via* self-report instead of using clinical or objective measures, thus the results could be affected by recall bias. Third, due to the unavailability of whole-year data regarding outpatient expenditure, this study extrapolated monthly costs to the entire year instead to obtain the estimation of annual spending. This approach was yet not precise, and interpretation of the results would thus require caution.

CONCLUSION

In conclusion, frailty is found to be a significant predictor for CHE among the community-dwelling older adults in China, and such effect remains similar irrespective of socioeconomic-related factors including gender, residence, education, household income, and health insurance. This study sheds light on the financial catastrophe associated with the increasingly recognized public health priority of frailty. We provide scientific evidence for policy-makers to develop cost-effective strategies for community-based early prevention and management of frailty among the older population, as well as to improve the health insurance scheme and healthcare financing system to further facilitate more accessible and affordable health services.

DATA AVAILABILITY STATEMENT

The publicly available datasets were analyzed in this study, which can be found in the link: http://charls.pku.edu.cn/index/en.html.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Ethics Review Committee of Peking University (No.: IRB00001052-11015). The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

LF and WD contributed to the conception and design of the study. LF, YL, and SC conducted the data analyses. LF drafted the manuscript. All authors reviewed and approved the manuscript before submission.

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Adoption Intention and Factors Influencing the Use of Gerontechnology in Chinese Community-Dwelling Older Adults: A Mixed-Methods Study

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Objective: To explore the Chinese community-dwelling intention of older adults to adopt gerontechnology and its influencing factors.

Design: A mixed-methods sequential explanatory design with an inductive approach was employed. In phase 1, a self-made questionnaire was administered from August 2018 to December 2019. Multifactor logistic regression was used to analyze the adoption intention and factors influencing the use of gerontechnology. In phase 2, participants completed a semistructured interview to explore the adoption intention of a specific form of gerontechnology, *Smart Aged Care Platform*, from May to July 2020.

Setting: Twelve communities in three districts of Chongqing, China.

Participants: Community-dwelling older adults were included.

Results: A total of 1,180 older adults completed the quantitative study; two-thirds of them (68.7%) showed adoption intention toward gerontechnology. Nineteen participants (10 users and nine nonusers) completed the qualitative study and four themes were explored. Through a summarized understanding of the qualitative and quantitative data, a conceptual model of influencing factors, namely, predictive, enabling, and need factors, was constructed.

Conclusions: This study reveals that most Chinese community-dwelling older adults welcome the emergence of new technologies. However, there was a significant difference in the adoption intention of gerontechnology in Chinese community-dwelling older adults based on their sociodemographic and psychographic characteristics. Our findings extend previous technology acceptance models and theories and contribute to the existing resource base.

Keywords: antioxidants, crop water productivity, irrigation regimes, Mediterranean region, nano-SiO2, principal components analysis, yield contributing traits

INTRODUCTION

In 2019, the number of older people aged over 60 years in China reached 249 million, accounting for 17.9% of the total population (1). It is estimated that by 2050, the total number of older people will exceed 465 million, and 32.3% of them will be over 80 years old (2). As a result, China is not only the country with the highest proportion of elderly people in the world but also one of the countries with the fastest aging rate (3, 4). In addition to the one-child policy (5), population migration to cities (6) and an increase in the "empty nest" elderly population (7) have made it more difficult for Chinese modern families to maintain traditional home-based care (8). Furthermore, with the enhancement of living standards and lifestyles, the demand of older adults for old-age services has become varied; thus, personalized and smart services are being emphasized (9, 10). As a result, there is a growing awareness of the importance of developing and implementing comprehensive health solutions that are affordable, efficient, and of superior quality for older individuals (11).

Gerontechnology, a portmanteau of gerontology and technology and coined in Europe in the early 1990s, refers to techniques, technological products, services, and environments that are aimed at improving the daily life and aging of the elderly with technological advances (12, 13). Conceptually, gerontechnology can be divided into four categories according to its use (14): first, gathering continuous data (e.g., heart rate and motion) to monitor the performance of older adults or detect falls through wearable sensors (15); second, assisting older people cognitively and socially using, for instance, interactive robotic pets (16); third, providing care or monitoring of health from a distance, with the help of telecare or telemedicine (17); and finally, compensating for possible technology deficits in the home environment, which mainly refers to a smart home (18). Some gerontechnological solutions fulfill multiple purposes such as the Smart Aged Care Platform designed by our team (19). In this study, gerontechnology is used as an umbrella term for all the aforementioned technologies.

Gerontechnology helps older adults maintain their health and wellbeing in their homes (20), which is considered to be of positive significance to aging in place (21). Using telecommunications, gerontechnology can now provide health professionals and caregivers with remote access to older patients (22). In addition, gerontechnology has shown great potential in reducing escalating medical costs by eliminating the need for expensive and limited medical facilities (18, 23). In the context of the accelerated aging process, gerontechnology already has a broad market prospect (24), and delivering healthcare services based on gerontechnology has been one of the trends of providing care for older adults in China (25).

Compared to developed countries, the smart health technology of China is still in its infancy. It was only in 2012 that the Chinese Nation Working Commission on Aging first introduced the concept of gerontechnology (26). Thus, although several international studies have explored the perspectives of older adults on emerging technologies across the world (27–31), the data on China are still insufficient. Thus, this study aims to determine:

1. Chinese community-dwelling intention of older adults to adopt gerontechnology.
2. The factors influencing the adoption intention and use of gerontechnology.

METHODS

Study Design

A mixed-methods sequential explanatory design with an inductive approach (19) was employed. To explain the quantitative results in more depth, qualitative data comprising the perspectives of participants were collected. Such a sequence of research design had been supported by past studies (32). In phase 1, 1,180 community-dwelling older adults completed a self-made questionnaire from August 2018 to December 2019. Multifactor logistic regression was used to analyze the adoption intention and factors influencing the use of gerontechnology. In phase 2, 19 participants were recruited, who completed a semistructured interview, to explore the adoption intention of a specific form of gerontechnology, Smart Aged Care Platform, from May to July 2020. The flow diagram is shown in **Figure 1**. This method has previously been used to investigate gerontechnology adoption by using specific forms of gerontechnology such as near-field communication (NFC)-enabled light systems (33) and soft service robots (34).

The Smart Aged Care Platform was designed by our team and empirically tested in Chongqing since January 2020 (35). Up to July 2020, 180 older adults were registered on the platform. The platform was developed to improve the way of life of older adults by helping them live independently. It was designed based on a hybrid aware model (23, 36), which consists of five subsystems: physiological data sensing system, environment data sensing system, location data sensing system, activities data sensing system, and decision support system. **Table 1** summarizes the features and functions of each subsystem, and **Figure 2** presents the sleep monitoring interface of the Smart Aged Care Platform.

Setting

Chongqing, the largest city in the southwest, is one of the four major municipalities in China, and one of the most rapidly aging modern cities (37). In 2018, the number of older adults over the age of 60 in Chongqing reached 7.195 million, accounting for 21.13% of the total population. Thus, considering the economic level, the number of older people, and other comprehensive factors, 12 communities in three districts of Chongqing were selected as the main site for the study, as it is very probable that the findings would be similar throughout another metropolis of China.

Participants

Quantitative Research

Convenience sampling was carried out in 12 communities in three districts of Chongqing from August 2018 to December

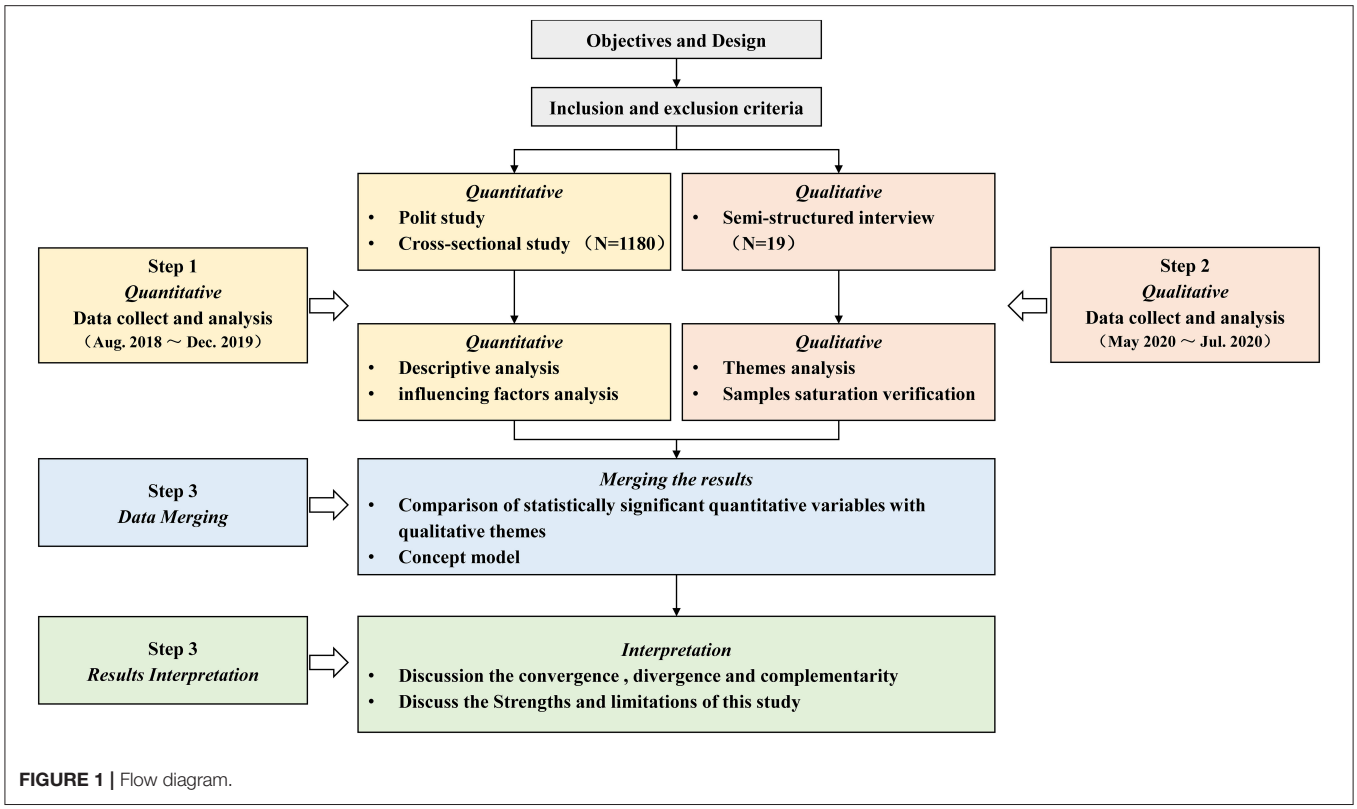

FIGURE 1 | Flow diagram.

TABLE 1 | User portal (Smart Aged Care Platform) feature summary.

Subsystem	Feature and function
Physiological data sensing system	Continuous data of the human body (e.g., breathing, pulse, blood pressure, temperature) would be collected and reported by wearable devices and multi-modal biosensors.
Environment data sensing system	Environmental data (e.g., time, temperature, humidity, sound, light) would be monitored and reported by environmental sensors.
Location data sensing system	The real-time position would be reported and the action trajectory would be recorded.
Activities data sensing system	Activity log (e.g., sleeping, rest, exercise) would be monitored based on location and the time of stay.
Decision support system	Normal and abnormal activities would be classified, and professional suggestions would be provided according to the comprehensive health report.

2019. The inclusion criteria were: (1) participants aged over 60 years, (2) those who have been living in the community for more than 6 months, (3) those who could correctly understand the contents of the questionnaire, and (4) those who do not have experience using gerontechnology. Participants who were diagnosed with critical or end-stage diseases, severe psychosis, or cognitive impairment were excluded. Based on the sample size estimation method for multivariate analysis study, the sample size should be 10–20 times the questionnaire variables (38). Hence, a sample size of approximately 260 participants was required. Finally, a total of 1,200 questionnaires were distributed, of which only 1,180 were received, with an effective recovery rate of 98.33%.

Qualitative Research

Data collection was carried out in the same communities as the first phase from May to July 2020. Due to the differences in e-health literacy and expression ability among different types of older people, the purposive sampling method was used to recruit participants to maximize the variation, in which education level, age, gender, experience using gerontechnology, and other factors were particularly considered. Subsequently, 19 participants were interviewed ($n = 10$ users; $n = 9$ nonusers). Users were those who had registered for the Smart Aged Care Platform and had logged in within the last 5–7 months. Nonusers were older adults who had neither registered for the platform nor used other kinds of gerontechnology.

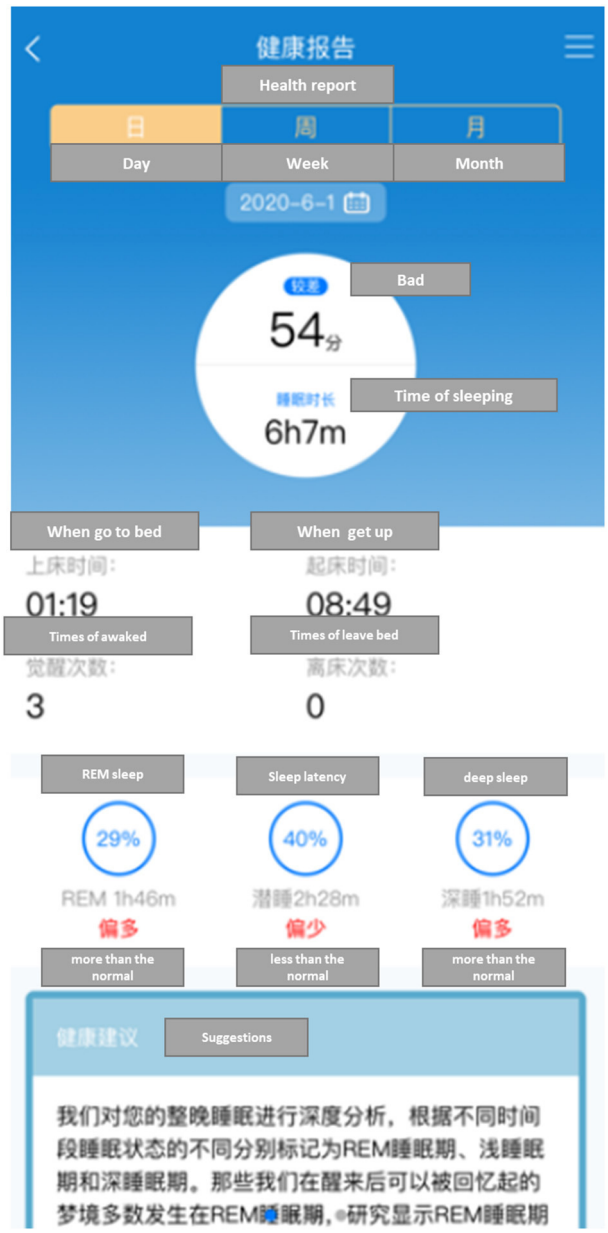

FIGURE 2 | The sleep monitoring and reporting interface of Smart Aged Care Platform.

Tools

Quantitative Research

A self-made questionnaire was used, which consisted of three parts: (1) demographic information, namely, gender, age, education level, marital status, monthly income, and type of medical insurance; (2) health status information, namely, self-assessment of health level, chronic disease, and disability; and (3) adoption intention toward gerontechnology, which was assessed by asking participants if they "would intend to use or purchase gerontechnology-related services or products in 6 months" (0 = No; 1 = Yes).

Qualitative Research

A face-to-face, semistructured interview was conducted to explore and expand the potential factors that affect the adoption intention of gerontechnology by Chinese community-dwelling older adults. Participants were asked to discuss their perceptions about the rise of gerontechnology, any good or bad experiences they have had, the main challenges they face regarding adoption, and optimization advice or anticipation of their wants.

Data Collection

Quantitative Research

The investigators are uniformly trained medical students, namely, five undergraduate and two graduate students, who were instructed to obtain the consent of the participants and their guardians before the investigation, and to inform all participants of the purpose and content of the study before it began. In the survey, a unified introduction was provided to guide participants through the process of answering questions. The filling of the questionnaire was standardized by the investigators according to the answers of the participants. After the end of the survey, data were collected, and their validity and completeness were checked.

Qualitative Research

The first and second authors are registered female nurses who have worked in geriatric nursing for a long time and have experience in conducting qualitative studies. They conducted nine and 10 interviews, respectively, and the duration of each interview was about 40–60 min. All the participants were informed of the objective and significance of this study before the interview. All the interviews were conducted as per the outline, and no specific guide was further required. All interview data were recorded and preserved after getting permission from all the interviewees.

Data Analysis

Quantitative Research

All the data were verified and checked by the two authors in phase 1, and then imported into Stata version 14.0 (StataCorp LP, 2015) for statistical analysis. Frequency, constituent ratio, and mean ± standard deviation ($\bar{x} \pm S$) were used for descriptive analysis; x^2 test was used for comparison; and multifactor logistic regression was used to analyze the influencing factors. The test level was bilateral test $\alpha = 0.05$.

Qualitative Research

NVivo version 11.0 (QSR Inc., Melbourne, Australia, 2015) was used for data transcription. A qualitative thematic analysis was used for data analysis (39). The following steps were involved: First, at the end of each interview, the third author was mainly responsible for transcription, while the fourth author was responsible for checking its consistency and accuracy. The two did not participate in the interview sessions. Second, the researchers reviewed each transcript line by line to become completely familiar with the content. Then, all the data were initially coded and similar data were classified to form different topics (40). In addition, a list of themes was returned to the participants to reach a consensus on the validity again. Themes

were defined and named until the final findings were negotiated among team members. Recruitment stopped when the data reached saturation, that is, when there were no new codes and topics obtained (41). To verify the saturation, five new participants were recruited. The results showed that the resulting topic contained all the important codes and topics put forward by the newly included participants, so it is considered that the samples at this stage are suitable (42).

Participant and Public Involvement

All the participants were recruited in two parts by the local community health center through recruitment advertisements, and the location of the study was the generally quiet and undisturbed conference room of the agency. Participants and the public were not involved in the design of the quantitative research but were invited to assist in the confirmation process of the qualitative research.

Ethics

Before the commencement of the study, approval was obtained from the ethics committee of the institution (approval number: 2019-105), and all the participants provided oral consent and willingness to complete the investigation. Transcripts and analysis records were stored on a secure cloud-based server. The anonymity of the respondents was protected in the form of digital codes.

RESULTS

Demographic Results

A total of 1,180 participants were included in the quantitative research, whereas in the qualitative research, 19 older adults were invited to be interviewed. **Table 2** provides the demographic information of all the participants.

Quantitative Results

A total of 811 (68.7%) older adults showed adoption intention toward gerontechnology. The multiple collinearity test among the variables shows that the variance inflation factor of the model is <10, so there are no multiple collinearities among the variables. Among them, the community older adults with different gender, living places, education levels, monthly income, type of medical insurance, self-health assessment, hypertension, diabetes, dyslipidemia, and disability had different intentions. The difference was statistically significant ($P < 0.05$), as shown in **Table 3**.

The adoption of gerontechnology was set as a dependent variable, and the variables with statistical differences in univariate analysis were taken as independent variables. Multivariate logistic regression analysis was carried out to test the goodness of fit of the model, as shown in **Table 4**. Omnibus tests of model coefficients showed that $x^2 = 153.721$ ($P < 0.01$), and the Hausman and Lemeshow test showed that $x^2 = 157.266$ ($P = 0.303 > 0.1$). The results showed that the most significant factors for the community-dwelling older adults to adopt gerontechnology ($P < 0.05$) included above high school education (OR = 3.595, 95% CI = 1.707–7.571), monthly income between 1,000 and 2,999 yuan (OR=2.126, 95% CI=1.326–3.407), other type of health insurance (OR=3.336, 95% CI=1.573–7.072), poor self-health assessment (OR= 0.291, 95% CI= 1.061–1.376), hypertension (OR = 1.643, 95% CI = 1.216–2.221), diabetes (OR = 0.691, 95% CI = 0.497–0.96), dyslipidemia (OR = 0.567, 95% CI = 0.397–0.809), and disability (OR = 2.515, 95% CI = 1.118–5.658).

Qualitative Results

Four themes and six subthemes were defined after thematic analysis.

Theme 1: Adoption Intention of Gerontechnology

The study found that most participants showed a positive attitude toward gerontechnology, believed that with the development of science and technology, it will be helpful to use emerging technologies to maintain and improve the quality of life in twilight years, and thought that this is a kind of care and well-being. "*The standard of living is getting higher and higher.... Even the elderly can enjoy the fruits of science and technology.", Q4.*

Some participants reported that they had begun to use a variety of digital technologies at home, such as WeChat, Internet devices, and home sensors, to establish contact with their families and medical staff, and had had a pleasant experience. "*It's great that the machine can record the data directly and upload it to the cloud, then the doctor can track the changes. That's good.", Q9.*

Theme 2: Social-Demographic Factors

Subtheme: Personality Traits

Some participants reported their confidence in the use of new technologies and products, and showed great curiosity; while others were relatively cautious, believing that the use of new technologies is time and energy consuming under the idea that traditional services can meet the demand. *"I am old in age, but young in mind. Although I am more than 70 years old, I always live with the mentality of learning.", Q1. "I feel that my life is very comfortable now, and I don't want to put an extra burden on myself.", Q13.*

Subtheme: Health Belief

Generally, most participants were worried about adverse events or complications of diseases. Those who had experienced such events before were more aware of the importance of health management in their daily life. *"Thirty percent depends on the doctor, and the rest depends on maintenance in your daily life.", Q16.* One participant who once fell recalled that using home smart technology increased her sense of security and self-confidence to live alone at home. *"I fell and couldn't take care of myself for months. I'm afraid of falling again...., technologies gave me a sense of security because I knew someone would come to help me in case of any emergency.", Q7.*

Theme 3: Resource Factors

Subtheme: Product Characteristics

The sense of control over technology and products was the biggest concern of the participants. The older adults had observed the effects of aging on their daily life, which might have limited their ability to adopt new technology. *"I am worried that I*

TABLE 2 | Demographic information of all the participants.

Variable	Items	Phase 1 (*N* = 1,180, %)	Phase 2 (*N* = 19, %)
Gender	Female	575 (48.73%)	9 (47.37%)
	Male	605 (51.27%)	10 (52.63%)
Age (year)	60–69	534 (45.25%)	13 (68.42%)
	70–79	373 (31.61%)	3 (15.79%)
	≥80	273 (23.14%)	3 (15.79%)
Living place	District	325 (27.54%)	3 (15.79%)
	Main urban	855 (72.46%)	16 (84.21%)
Education level	Illiterate	76 (6.44%)	2 (10.53%)
	Primary school	297 (25.17%)	1 (5.26%)
	Junior high school	427 (36.19%)	2 (10.53%)
	High school	221 (18.73%)	6 (31.58%)
	Above high school	159 (13.47%)	8 (42.11%)
Marital situation	Married	963 (81.61%)	13 (68.42%)
	Unmarried[a]	217 (18.39%)	6 (31.58%)
Monthly income (yuan)	<999	137 (11.61%)	2 (10.53%)
	1,000–2,999	381 (32.29%)	7 (36.84%)
	3,000–4,999	550 (46.61%)	9 (47.37%)
	>5,000	112 (9.49%)	1 (5.26%)
Type of medical insurance	New rural cooperative medical insurance	128 (10.85%)	7 (36.84%)
	Medical insurance for urban residents	281 (23.81%)	2 (10.53%)
	Medical insurance for urban workers	716 (60.68%)	10 (52.63%)
	Other[b]	55 (4.66%)	0 (0.00%)
Self-health assessment	Very poor	20 (1.69%)	0 (0.00%)
	Poor	115 (9.75%)	2 (10.53%)
	Fair	431 (36.53%)	5 (26.32%)
	Good	383 (32.46%)	10 (52.63%)
	Very good	231 (19.58%)	2 (10.53%)
Hypertension	No	638 (54.07%)	14 (73.68%)
	Yes	542 (45.93%)	5 (26.32%)
Diabetes	No	929 (78.73%)	10 (52.63%)
	Yes	251 (21.27%)	9 (47.37%)
Dyslipidemia	No	937 (79.41%)	17 (89.47%)
	Yes	243 (20.59%)	2 (10.53%)
Disability	No	1,123 (95.17%)	17 (89.47%)
	Yes	57 (4.83%)	2 (10.53%)

[a] *Unmarried includes single, divorced, and widowed.*

[b] *Other includes people with commercial health insurance or without any insurance.*

cannot use it correctly…, after all, this is a high-tech creation.", Q2. The suitability of the technical features of the products affected the adoption intention of participants. *"If the screen is too small, it will make it more difficult for me to read…," "if this product is a behemoth, I don't think most old people will like it.", Q11.*

Reliability concerns whether the efficacy of the product or service felt by the user is stable and reliable. For example, some participants reported doubts about the accuracy of home technology measurement. *"I'm not sure if the data measured by these kinds of products are accurate, just like those in hospitals.", Q5.*

Subtheme: Resource Accessibility

Participants also expressed concerns about the resources needed to use the product. The cost of technology was the biggest concern. *"Although there are many benefits, you know, there is very little money for the older adults.", Q17.* Some participants suggested that national policies need to help and support older adults. *"If this is the future trend of our country, then the government should consider how to help the low-income elderly to bear these expenses.", Q9.*

Some older people mentioned community and family resources and remarked that access to the Internet was a problem. *"If I live in the city, everything is fine, but if I go back to the countryside and I don't have Internet, then I have to abandon it.",*

TABLE 3 | Univariate analysis.

Variable	Adopt ($N = 811$)	x^2	*P*
Gender		3.461	0.043
Female	410		
Male	401		
Age (year)		0.595	0.743
60–69	373		
70–79	252		
≥ 80	186		
Living place		30.623	*P*<0.01
District	184		
Main urban	627		
Education level		56.446	*P*<0.01
Illiterate	38		
Primary school	180		
Junior high school	280		
High school	181		
Above high school	132		
Marital situation		0.991	0.32
Married	668		
Unmarried[a]	143		
Monthly income (yuan)		54.627	*P* < 0.01
<999	57		
1,000–2,999	269		
3,000–4,999	399		
>5,000	86		
Type of medical insurance		62.205	*P* < 0.01
New rural cooperative medical insurance	50		
Medical insurance for urban residents	191		
Medical insurance for urban workers	529		
Other[b]	41		
Self-health assessment		24.846	*P* < 0.01
Very poor	18		
Poor	77		
Fair	268		
Good	265		
Very good	183		
Hypertension		0.057	0.011
No	423		
Yes	388		
Diabetes		0.998	0.031
No	645		
Yes	166		
Dyslipidemia		2.924	*P* < 0.01
No	655		
Yes	156		
Disability		8.279	*P* < 0.01
No	762		
Yes	49		

[a] *Unmarried includes single, divorced, and widowed.*
[b] *Other includes people with commercial health insurance or without any insurance.*

TABLE 4 | Multivariate logistic regression analysis.

Variables	Items	Control group	β	SE	OR	95% CI
Gender	Female	Male	0.217	0.138	1.242	0.948–1.628
Living place	Main urban	District	0.246	0.162	1.279	0.931–1.757
Education level	Primary school	Illiterate	0.285	0.281	1.33	0.766–2.307
	Junior high school		0.355	0.291	1.427	0.807–2.522
	High school		1.164**	0.336	3.203	1.657–6.194
	Above high school		1.280**	0.38	3.595	1.707–7.571
Monthly income (yuan)	<2,999	<999	0.754*	0.241	2.126	1.326–3.407
	3,000–4,999		0.522*	0.267	1.685	1.998–2.844
	>5,000		0.338	0.372	1.403	0.676–2.909
Type of medical insurance	Medical insurance for urban residents	New rural cooperative medical insurance	0.784*	0.249	2.191	1.346–3.566
	Medical insurance for urban workers		0.768*	0.254	2.156	1.312–3.543
	Other[b]		1.205*	0.383	3.336	1.573–7.072
Self-health assessment	Poor	Very poor	−1.235	0.793	0.291	0.061–1.376
	Fair		−1.387**	0.775	0.25	1.055–1.141
	Good		−1.191	0.777	0.304	0.066–1.394
	Very good		−0.708	0.788	0.492	0.105–2.307
Hypertension	Yes	No	0.497**	0.154	1.643	1.216–2.221
Diabetes	Yes	No	−0.370*	0.168	0.691	0.497–0.96
Dyslipidemia	Yes	No	0.567*	0.181	0.567	0.397–0.809
Disability	Yes	No	0.922*	0.414	2.515	1.118–5.658

[a] *Unmarried includes single, divorced, and widowed.*
[b] *Other includes people with commercial health insurance or without any insurance.*
SE, standard error; OR, odds ratio; CI, confidence interval.
*$P < 0.05$; **$P < 0.01$.*

Q18. Other participants had some doubts about the ability of the community to provide timely services. *"I mean, if we are far away, the healthcare workers in the 'cloud' will not be able to arrive at home to deal with the crisis as soon as possible.", Q2.*

Theme 4: Need Factors

Subtheme: Assessed Needs

Assessed need refers to the actual poor physical condition of an individual. Many participants pointed out that if such technologies possess only conventional functions, such as measuring vital signs and environmental sensing, they would not be particularly attractive, but if the functions of these technologies and products are targeted to meet individual needs and can solve real problems in life, then they can be promoted for the well-being of the older adults. *"This is one of the doctor's suggestions, which allows me to avoid frequent hospitalization and reduce medical expenses.", Q3.*

Subtheme: Perceived Needs

Perceived needs mean that the older population were not satisfied with their current health level or were willing to have a healthier experience; therefore, they were willing to try a helpful technology in achieving the same. Some participants pointed out that walking is a common leisure activity, and smart bracelets can help them understand and visualize their heart rate and evaluate their exercise intensity. Participants also pointed out that sleep quality is another important indicator of physical health. *"I often suffer from insomnia, and smart mattresses can be linked to my phone's application to help me understand how I sleep every night.", Q1.*

Emergence of the Qualitative and Quantitative Data

We found that the results of the two phases complemented each other. For example, income, health insurance policy, self-health assessment, and actual health status were considered as influencing factors in both quantitative and qualitative results. In addition, some other factors such as personal characteristics, resource accessibility, and product characteristics were supplemented and found in interviews.

Therefore, we created a loose conceptual model based on the technology acceptance model (43) and health behavioral model of Anderson (44) to classify and visualize the factors found. As adoption intention is the main concern of this study, it is selected as the central action, which links the main results (**Figure 3**).

The definitions are determined as: (1) predictive factors, namely, personality traits and health beliefs, refer to the social-demographic characteristics that affect the adoption intention of older adults and use of gerontechnology. (2) Enabling factors, namely, product characteristics and resource accessibility, refer to the requirements of realizing technology utilization. (3) Need factors, namely, assessed and perceived needs, refer to the needs

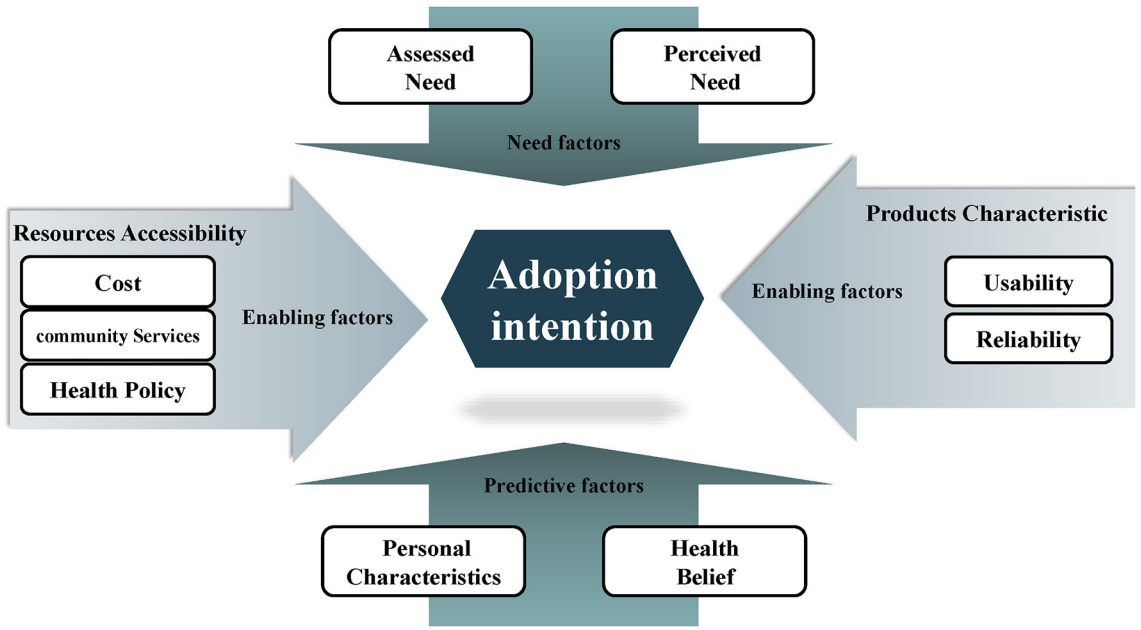

FIGURE 3 | Conceptual model of influencing factors.

of community-dwelling older adults regarding the use of gerontechnology.

DISCUSSION

The results show that about two-thirds (68.7%) of the older population in this study shows adoption intention of gerontechnology, and welcomes the emergence of these technologies, which is consistent with the findings of many previous studies (45, 46).

However, we found a significant difference in the adoption intention of gerontechnology in Chinese community-dwelling older adults based on their sociodemographic characteristics. This result differs from the findings of a study conducted by Lim et al. (47), in which the subsequent impacts of usefulness evaluations on the intentions of older adults to use the NFC light system were explored. It was consequently found that older adults do not differ in their intentions to use gerontechnology when demographics and psychographics are considered. We feel that the results of our study differed because, in phase 1, the investigation was conducted with community-dwelling older adults, who do not have experience of using gerotechnology. Hence, their perceptions were based partly on their imagination and expectations regarding gerotechnology. According to existing literature, the evidence of the impact of demographic variables on the adoption of gerontechnology is inconsistent and weak (46, 48). Vroman et al. (31) proposed that age, education, and attitude are related to the adoption of technology. In addition to the above factors, de Veer et al. (46) found that men are more likely to adopt e-healthcare than women. Therefore, in the future, it is necessary to focus on the quantitative investigation of the impact of social-demographic characteristics on the adoption of technology.

More importantly, this study focused on the reasons, thoughts, and factors influencing the adoption intention of a specific gerontechnology from the perspective of community-dwelling older persons. The findings revealed that the factors influencing adoption intention are complex and systematic (49, 50), which involve predictive, enabling, and need factors. This knowledge can be applied to the design, improvement, optimization, and promotion of the technology industry, products, and services in the future.

Predictive Factors

This study found that personality traits and health beliefs are important influencing factors and are deemed as predictive factors.

This study supports the evidence of the influence of personality traits on the adoption of technology. Qualitative research found that older users with optimistic characteristics and curiosity were more willing to try new products and technologies, which suggests that product developers should consider the psychological characteristics of the target consumers (49).

In addition, it was found that health beliefs were related to the behavior and willingness of older adults, which is consistent with previous research results (51–53). It is suggested that while formulating marketing strategies for geriatric technology, seminars must be designed simultaneously to raise awareness of its possible significant health benefits.

Enabling Factors

Product characteristics are a significant part of enabling factors. One is usability, which mainly refers to the external features of technology, whose importance has been demonstrated in previous studies (51, 54, 55). Another is reliability, which emphasizes more on the inherent quality of technology, however, there are different views on this factor (45). Kaium et al. (56) found that system quality, expected performance, convenience, and social influence are of great significance to the continuous adoption intention of older adults in developing countries; however, service and information quality are not. While Hsieh et al. (57) found that system quality has the greatest impact on use intention and service quality has the strongest overall impact on user satisfaction (57). Overall, our study suggested that usability is as important as reliability; usability allows the participants to use the product correctly and reliability ensures that they can achieve the desired results. At present, more and more engineers and gerontologists are beginning to collaborate on issues at the intersection of technology, and listen extensively to the views of older users to find innovative solutions that are acceptable to older users (58).

In addition, we found that resource accessibility is also an important enabling factor, which consists of community services, cost, and health policy.

Our research results imply that the ability to obtain community services, such as medical care and the Internet, would influence the adoption intention of gerontechnology, which is consistent with related studies. Kohnke et al. (59) found that the support and assistance available during difficult times encourage the intention to use healthcare telemedicine equipment. This suggests that the design of health technologies for older persons should consider the obstacles that they may encounter in using the tool and carefully assess their current level of understanding.

This study suggests additional, potentially fruitful areas of inquiry. For example, our qualitative results found that older adults hope to ease economic pressure with the help of policies. A possible explanation is that since the long-term insurance system of China has not yet been established, most older people who lack a reliable and sustainable income are not willing to take the huge risk of losing money for owning these emerging technologies. Thus, this study suggests that bringing some gerontechnology into the reimbursement category of long-term care insurance in the future could be considered, to encourage older adults to stay at home longer and improve their quality of life with the help of technology.

Cost is examined in the research on almost all types of technologies and appears in various adoption models (51, 54, 55). According to Alsulami et al. (60), the cost of technology poses a great challenge to the behavioral intentions of older adults, in which the costs of installation, maintenance, and running are considered to be the main obstacles (61).

Need Factors

This study shows that the technology adoption intention of the older population is mainly driven by demand, which can be the assessed need for real health situations and the perceived need for health promotion, which is similar to the results of a large number of previous studies (49). However, some studies believe that, compared with the two kinds of demand, the impact of perceived demand is less than that of assessed demand (51). Lee et al. (62) found that the adoption intention of information technology has nothing to do with self-assessed health. Therefore, it is necessary to further study the relationship between the adoption of communication technology and the physical and mental health of older adults in the future.

CONCLUSIONS

This study used a mixed-methods approach to explore the complex factors that affect the adoption intention of older adults and constructed a conceptual model, comprising predictive, enabling, and need factors. This study provides theoretical insights on the adoption willingness of the older population in China and is expected to expand the previous technology acceptance models and theories, and to contribute to the existing knowledge database.

LIMITATIONS

This study has four main limitations that could pave the way for further research. First, the relationships between the influencing factors in the conceptual model need to be verified statistically. Second, questionnaires measuring the intention to use gerontechnology have been developed by other scholars (63, 64) recently, and thus, it is suggested that these tools be translated into Mandarin to quantify and verify the intention to gerontechnology. Third, in phase 2, the data or description of the frequency, depth, and types of use of specific gerotechnology could be added to increase analytical depth. Finally, considering the close interaction among stakeholders, perspectives of informal caregivers toward gerontechnology are worth exploring.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding authors.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the hospital research ethics committee (approval number: 2019-105) and all the participants provided oral consent and willingness to complete the investigation.

AUTHOR CONTRIBUTIONS

QHZ, MZX, and LLX: conceptualization, validation, and supervision. HHH, SMC, and ZYC: methodology. HHH: software and writing original draft preparation. ZYC: formal analysis and visualization. HHH and SMC: investigation. SMC and ZYC: writing, reviewing, and editing. QHZ and MZX:

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Hypertension Prevalence Rates Among Urban and Rural Older Adults of China, 1991–2015: A Standardization and Decomposition Analysis

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Objectives: The prevalence of hypertension (HTN) among older adults is becoming an important issue in public health in China as it is now stepping into the super-aged society with high pressure of a chronic disease burden. With urban–rural differences in population composition and health facilities, this study aimed to assess the gaps in the prevalence trends of HTN among older adults by considering demographic factors such as age, gender, education level, and regional differences during 1991–2015 in China.

Methods: We adopted the consistent sampling design and measure of HTN of the cross-longitudinal surveys of the China Health and Nutrition survey, and we compared the HTN prevalence rates between urban and rural older adults by taking each wave of the survey as a cross-sectional sample of the Chinese population by the following and supplementary samples. The classic standardization and decomposition analysis method was utilized with four factor-specific rates, and contributions were calculated, i.e., age, gender, education, and region, which reflects the aspect of demographic and social development differences between urban and rural areas of China.

Results: The prevalence rates of HTN of the whole of older adults were increasing in 1991–2015. However, the gaps of prevalence rates of HTN between urban and rural areas show different trends accompanied by the health policies launched by the government. Namely, the gap was narrowed during 1993–1997 and then enlarged during 1997–2011 and narrowing again. Those trends reflect the policy effects with the health resource allocation and utilization of health services for urban and rural older adults.

Conclusions: With the four factors of decomposition analysis, the differences reflect the results of health policy effects, considering the urban–rural discrepancy on older adults with different demographic characteristics. Hence, the differentiated policies should be considered with the urban–rural population, such as HTN prevention and the population health promotion.

Keywords: the elderly, urban and rural, regional difference, standardization and decomposition analysis, trend

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INTRODUCTION

Hypertension (HTN), as a chronic medical condition in which the blood pressure in the arteries is elevated, is becoming a major threat to population health, especially in older people accompanied with other chronic diseases. The economic burden of disease caused by HTN accounted for 7.0% of the global disability-adjusted life years (DALYs) in 2010 (1). With the acceleration of the aging process, China is facing a very serious situation of HTN. Since the beginning of this century, more and more investigations on HTN have been conducted nationwide. From 1991 to 2011, the standardized prevalence of HTN in adults aged 18 years and above increased from 23.9 to 33.6% (2). The prevalence of HTN of older adults (aged 60 years old and over) was 54.6% (3), which was significantly higher than that in the young population (2).

In developed countries, 60% of individuals after age 65 suffer from HTN (4). As one of the largest developing countries, China is challenged even more by HTN as a growing urgency in public health. Due to its long-term urban–rural dual social structure, the prevalence of HTN in urban and rural areas have been different for a long time. Some studies suggest that the prevalence of HTN in rural adults is higher than in urban areas (5). Yet other studies have found different results. There is some evidence that HTN is very common among urban Chinese (6). Between 1993 and 2011, the HTN rate in urban areas was higher than in rural areas, and the rural–urban gaps were narrowed from 7.75 to 1.12% for adults (5). The prevalence of HTN in rural areas was 34.3 and 63.9% in urban areas for the aged in 2013 (7). These inconsistent results mean further investigation is needed, especially among the older population.

However, when comparing HTN rates among older people or exploring temporal trends within a period, the results are usually influenced by the composition of the target population, especially age structure, gender proportion, education levels, and other demographic-social factors, which reveal different exposure factors for HTN. Thus, factor standardization on the rates is necessary. Taking age as an example, there is a significant difference in whether the prevalence of HTN was age-standardized or not. With age-standardization, the prevalence of HTN was 14.0 and 15.3% for crude and age standardization in 1991 although the crude and age standardization rates were 34.1 and 25.6%, respectively, in 2015 (8). Without the age standardization, the crude prevalence rates of HTN are overestimated or underestimated. Standardization by demographic and sociological factors is essential when estimating the prevalence of HTN and policy making on prevention.

As crude rates cannot be directly compared in two or more populations without standardization, there are two ways of obtaining the "true rate," i.e., the standardization rate, which excludes the effects of population structures. One is to perform decomposition on cross-classified data, which involves one or more factors, and the other can be expressed as a function of two or more factors; decomposes the rates into composition and the composition-specific rate (9–11). The HTN rates of older adults in urban and rural areas can be decomposed and standardized by considering the different structures of two populations. Then, we can get the "true" HTN rates to compare and evaluate each factor's contribution, and then find out the targeting policy on prevention of HTN among older adults.

The prevalence of HTN is affected by social-economic situation and individual behavior factors. The former usually relates to social development and health resources allocation and utilization among different areas of people, and the latter mainly includes personal demographic characteristics and behavior variables, such as income situation, smoking, alcohol consumption, and others. We selected demographic and social development factors, including age, gender, and urban/rural as well as education level as the composition factors of the population and measure their effects by decomposition.

Facing the social-economic development gaps between urban and rural areas in China, the changes in age distribution may be more pronounced for older populations in urban areas. Besides this, age is the basic character of the population that influences all the other factors we analyze—gender, education, and region—all the other factors are disaggregated by age. There are significant gender differences in the prevalence of HTN. The prevalence of HTN in males is significantly higher than in females due to factors such as genes, hormones, lifestyle, and psycho-social factors with age standardization (8). However, people in urban areas tend to face more work pressure and eat more fatty food in their daily life than the people in rural areas, especially with fast urbanizing in China. As a result, the accumulation of risk factors can lead to the higher prevalence of HTN among urban older adults than rural. For educational attainment, different educational levels are usually related to knowledge of HTN and then the prevention and control of it. With higher education levels, people are well-educated and increase their knowledge of health behaviors, and HTN patients among older adults are expected to decline, especially for rural areas. The region represents the different living habits and economic development, which are related to health resources allocation and utility of health services. For example, people in the central region have a relatively high intake of oil and salt: Shaanxi was 17.9 g and Guangxi was 7.6 g daily salt intake (12). Great changes have taken place with economic development in China, and to some extent, it reflects the process of urbanization and medical and health care. However, there are still obvious regional differences in China's economic development, notably the rapid development in the east and the relatively backward development in the west. There are also obvious regional differences between urban and rural areas.

To sum up, when studying the urban–rural gaps in the prevalence of HTN and temporal trends, most previous studies focus on all Chinese adults with less specific focus on older adults in an aging society. It is not clear to what extent the rural–urban gap exists in the prevalence of HTN among Chinese older adults, especially in terms of crude prevalence. This may confuse the prevalence of HTN among older adults and is not conducive to identifying the influence of different demographic factors on HTN. Because China has social differences between urban and rural and social and economic development, the HTN rates among older adults in those areas may have different characteristics. Most studies directly compare crude rates of

HTN, which is a major drawback. We focus on the population factors—age, gender, education, and region—aiming to identify the influencing factors on the prevalence of HTN, utilizing 1991–2015 China Health and Nutrition Survey data. We compare the HTN rates between urban and rural older adults over time, and further discuss the main factors influencing the urban–rural gaps to help policymakers develop more targeted public health policies to address the health differences between urban and rural older adults.

METHODS

Data

This study used data from the China Health and Nutrition Survey (CHNS), which is a national survey on nutritional status, health risk factors, and health status among people aged over 2 years in China. The CHNS has conducted 10 waves (1989, 1991, 1993, 1997, 2000, 2004, 2006, 2009, 2011, and 2015) and is designed to provide representation of urban, suburban, and rural areas. It employs a multistage, random-cluster process to ensure good representation of the general Chinese population (13). It selects samples by province that vary in socioeconomic development and geography in each wave (14) and focuses on health during urbanization and economic development (15).

Although the CHNS was a cross-longitudinal survey, this study took each wave as a cross-sectional survey. There are nine waves of sampled data (1991, 1993, 1997, 2000, 2004, 2006, 2009, 2011, and 2015) analyzed, taking advantage of the fact that CHNS surveys employ a unified sampling and HTN measurement criteria, and new samples in each wave to ensure representative coverage for the Chinese. We calculated the prevalence and time trend of HTN for older adults (age 60 and above) after excluding missing data.

Variables

The HTN rates were calculated with the numerator as the number of respondents diagnosed with HTN by doctors and the denominator as the total number of respondents in a survey year. Participants in the survey were also measured three times at 1- to 2-min intervals to get systolic (SBP) and diastolic blood pressure (DBP) with 5 min rest. Thus, in cases of missing diagnosis information, the mean values of SBP and DBP were obtained from three measurements. An individual is considered hypertensive if the person's SBP $\geq$ 90 or DBP $\geq$140.

The responses were divided into three groups by age as 60–69, 70–79, and 80+ years old. Education level is divided into uneducated and educated according to whether or not they went to school. We grouped 15 provinces into three regions: east (Beijing, Liaoning, Jiangsu, Shandong, Zhejiang, and Shanghai), central (Heilongjiang, Henan, Hubei, and Hunan), and west (Yunnan, Chongqing, Guangxi, Guizhou, and Shaanxi).

Standardization and Decomposition Method

The decomposition method (10, 11, 16) was used to identify the changes of HTN rates and the attributes of demographic and social development compositions, including age, gender, education, and region. Both the standardization and decomposition analysis were calculated on rural and urban older adults separately. The algebraic formula for two-population standardization and decomposition analysis with four factors can be expressed as the following steps.

First, the crude HTN rate for rural and urban older adults is equal to the total number of people who have HTN divided by the total number of older adults in that population. The crude rates can be expressed as

$$T_{....} = \sum_{ijkl} \frac{T_{ijkl} N_{ijkl}}{N_{....}}, \tag{1}$$

$$t_{....} = \sum_{ijkl} \frac{t_{ijkl} n_{ijkl}}{n_{....}}. \tag{2}$$

There are four factors: i, j, k, and l, which are age, gender, region, and education; $N_{....}$ and $T_{....}$ are the number of older adults and the crude HTN rate in urban areas; N_{ijkl} and N_{ijkl} denote the number and HTN rate of older adults for the (i,j,k,l) categories in urban areas in formula (1). Similarly, the crude HTN rate in rural areas can be seen in formula (2).

In formulas (1) and (2), $N_{ijkl}/N_{....}$ and $n_{ijkl}/n_{....}$ can be written as

$$\frac{N_{ijkl}}{N_{....}} = A_{ijkl} B_{ijkl} C_{ijkl} D_{ijkl},$$

where

$$\begin{aligned}
A_{ijkl} &= \left(\frac{N_{ijkl}}{N_{.jkl}}\right)^{\frac{1}{4}} \left(\frac{N_{ijk.}}{N_{.jk.}} \cdot \frac{N_{ij.l}}{N_{.j.l}} \cdot \frac{N_{i.kl}}{N_{..kl}}\right)^{\frac{1}{12}} \left(\frac{N_{i..l}}{N_{...l}} \cdot \frac{N_{i.k.}}{N_{..k.}} \cdot \frac{N_{ij..}}{N_{.j..}}\right)^{\frac{1}{12}} \left(\frac{N_{i...}}{N_{....}}\right)^{\frac{1}{4}} \\
B_{ijkl} &= \left(\frac{N_{ijkl}}{N_{i.kl}}\right)^{\frac{1}{4}} \left(\frac{N_{ijk.}}{N_{i.k.}} \cdot \frac{N_{ij.l}}{N_{i..l}} \cdot \frac{N_{.jkl}}{N_{..kl}}\right)^{\frac{1}{12}} \left(\frac{N_{.j.l}}{N_{...l}} \cdot \frac{N_{.jk.}}{N_{..k.}} \cdot \frac{N_{ij..}}{N_{i..}}\right)^{\frac{1}{12}} \left(\frac{N_{.j..}}{N_{....}}\right)^{\frac{1}{4}}, \\
C_{ijkl} &= \left(\frac{N_{ijkl}}{N_{ij.l}}\right)^{\frac{1}{4}} \left(\frac{N_{ijk.}}{N_{ij..}} \cdot \frac{N_{i.kl}}{N_{i..l}} \cdot \frac{N_{.jkl}}{N_{.j.l}}\right)^{\frac{1}{12}} \left(\frac{N_{..kl}}{N_{...l}} \cdot \frac{N_{.jk.}}{N_{..j.}} \cdot \frac{N_{i.k.}}{N_{i..}}\right)^{\frac{1}{12}} \left(\frac{N_{..k.}}{N_{....}}\right)^{\frac{1}{4}} \\
D_{ijkl} &= \left(\frac{N_{ijkl}}{N_{ijk.}}\right)^{\frac{1}{4}} \left(\frac{N_{ij.l}}{N_{ij..}} \cdot \frac{N_{i.kl}}{N_{i..k}} \cdot \frac{N_{.jkl}}{N_{.j.k}}\right)^{\frac{1}{12}} \left(\frac{N_{..kl}}{N_{...k}} \cdot \frac{N_{.j.l}}{N_{..j.}} \cdot \frac{N_{i..l}}{N_{i...}}\right)^{\frac{1}{12}} \left(\frac{N_{...l}}{N_{....}}\right)^{\frac{1}{4}}
\end{aligned} \tag{3}$$

where A_{ijkl}, B_{ijkl}, C_{ijkl}, and D_{ijkl} denote the (age, gender, region, and education) category distribution for urban older adults. The ratio $n_{ijkl}/n_{....}$ can be calculated in a similar way by using lowercase a, b, c, d, and n. Then, the differences of older adults' HTN rates between the rural and urban population are as follows:

$$\begin{aligned}
T_{2..} - T_{1..} &= \mathrm{I-effect} + \mathrm{J-effect} + \mathrm{K-effect} + \mathrm{L-effect} \\
&\quad + \text{Rate effect} \\
&= [R(\overline{T}) - R(\overline{t})] + [I(\overline{A}) - I(\overline{a})] + [J(\overline{B}) - J(\overline{b})] \\
&\quad + [K(\overline{C}) - K(\overline{c})] + [L(\overline{D}) - L(\overline{d})].
\end{aligned} \tag{4}$$

Standardization rates for older adults in urban areas can be calculated as follows:

$$R(\overline{T}) = (I, J, K, L) - \text{standardized rate} = \sum_{ijkl} \frac{\frac{N_{ijkl}}{N_{....}} + \frac{n_{ijkl}}{n_{....}}}{2} T_{ijkl}$$

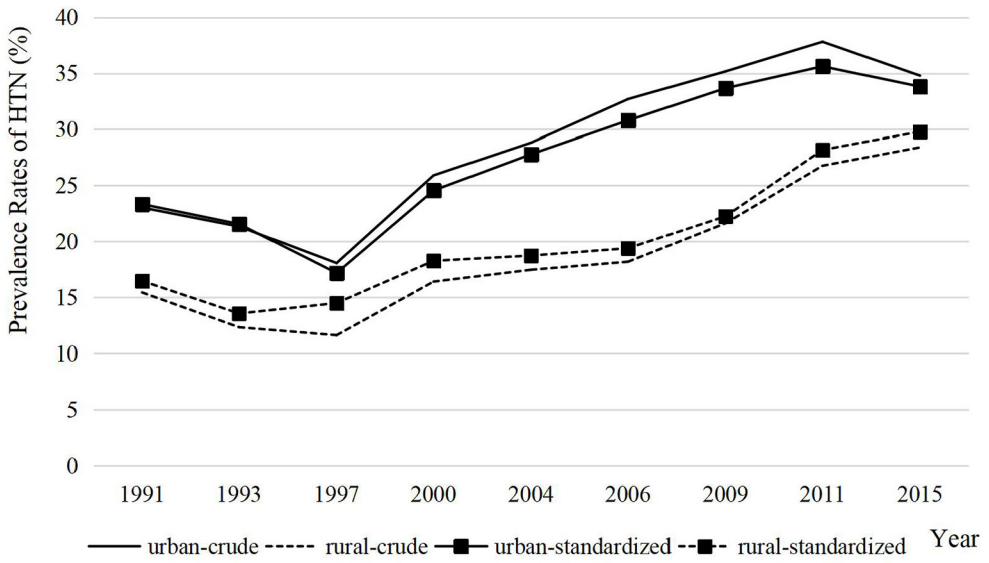

FIGURE 1 | Crude and standardized prevalence rates of HTN in older adults in urban and rural areas, 1991–2015.

$$\begin{aligned} I(\overline{A}) &= (J,K,L,R) - \text{standardized rate} = \sum_{ijkl} \frac{T_{ijkl}+t_{ijkl}}{2} \\ J(\overline{B}) &= (I,K,L,R) - \text{standardized rate} = \sum_{ijkl} \frac{T_{ijkl}+t_{ijkl}}{2} \\ K(\overline{C}) &= (I,J,L,R) - \text{standardized rate} = \sum_{ijkl} \frac{T_{ijkl}+t_{ijkl}}{2} \\ L(\overline{D}) &= (I,J,K,R) - \text{standardized rate} = \sum_{ijkl} \frac{T_{ijkl}+t_{ijkl}}{2} \end{aligned} . \quad (5)$$

The standardized rates $R(\overline{T})$, $I(\overline{A})$, $J(\overline{B})$, $K(\overline{C})$, and $L(\overline{D})$ are the rate effect and (age, gender, region, and education) effect for urban older adults, respectively. We can also obtain $R(\overline{t})$, $I(\overline{a})$, $J(\overline{b})$, $K(\overline{c})$, and $L(\overline{d})$ by replacing the letters in (5) for the rural population.

Besides this, the bootstrap resample was used to estimate the standard errors and confidence intervals for the component effects, which were based on 100 bootstrap resamples (16). Taking the $\hat{\sigma}_{\hat{\theta}}$ as the component effect estimated by bootstrapping resamples, the distribution of $\hat{\theta}_b$ represents the sample distribution of component effects, and $\hat{\theta}_{(.)}$ denotes the mean value of $\hat{\theta}_b$. Then, the standard deviation of $\hat{\theta}_b$ value is

$$\begin{aligned} \hat{\sigma}_{\hat{\theta}} &= \left\{ \left[\sum \left(\hat{\theta}_b - \hat{\theta}_{(.)} \right)^2 \right] / (B-1) \right\}^{1/2} \\ \hat{\theta}_{(.)} &= \sum \hat{\theta}_b / B \end{aligned} . \quad (6)$$

In this way, we can get the standardized HTN rates and the factor effect to compare the "true rate" between the two populations and identify the most important influencing factor for each year.

RESULTS

The crude and standardized HTN rates of urban and rural older adults during 1991–2015 are plotted as **Figure 1**. There are three characteristics during this period. First, the HTN rates of Chinese older adults increased in 1991–2015 with the HTN rates in urban areas being higher than in rural areas throughout the period. Second, the gaps between urban and rural areas showed a dynamic change characteristic with a decreasing trend during 1993–1997, an expanding trend during 1997–2011, and a decreasing trend during 2011–2015 again. Third, the gaps for HTN area rates were narrower with standardization than without over the entire period, especially in 1997 when the gap was only about 2% with standardization. It illustrates that direct calculation of crude rates would exaggerate the urban–rural gaps.

The decomposition results of demographic and social development factors (age, gender, education, and region) are shown in **Table 1**, and it reveals two facts of prevalence of HTN. First, all the factors contributed to the trend among older adult HTN rates over 1991–2015, and almost all factor-specific differences were statistically significant. In particular, region had the biggest impact on HTN rates of older adults, and the influence on the urban population was significantly greater than rural. This fact indicates that the regional difference was the main factor driving the trend change of HTN rates of older adults in urban and rural areas during the period. For example, the contribution of region to older adult HTN rates in urban areas was 32.38 and 30.46% in rural areas in 2015 with a statistical significance difference (1.92%). Second, the standardization rates of each factor showed two stages for both areas during this period. Namely, the factor-specific standardization rates showed a downward trend during 1991–1997 and an upward trend in 1997–2015.

Table 2 presents each factor's varying contributions to older adult HTN rates during 1991–2015 in both urban and rural areas. To facilitate understanding, we used a plot to exhibit the contribution differences among each factor (**Figure 2**). The plus and minus signs represent directions of factors. For example, the

TABLE 1 | Results of standardization HTN rates (%) and gaps between urban and rural areas of the older adults by demographic and social development factors, 1991–2015.

		N	Age	Gender	Education	Region	Standardized rates	Crude rates
1991	Urban	*n* = 343	19.26	19.14	19.31	19.26	23.34	23.03
	Rural	*n* = 349	18.97	19.21	19.03	19.04	16.47	15.44
	Gap		0.29*	−0.07	0.28*	0.22*	6.87*	7.59*
1993	Urban	*n* = 321	16.82	16.58	17.13	16.42	21.56	21.34
	Rural	*n* = 403	16.36	16.65	16.13	16.79	13.56	12.33
	Gap		0.46*	−0.07	1*	−0.37*	8*	9.01*
1997	Urban	*n* = 461	15.36	15.17	15.92	15.51	17.18	18.07
	Rural	*n* = 575	14.62	14.99	14.1	14.49	14.49	11.62
	Gap		0.74*	0.18*	1.82*	1.02*	2.69*	6.44*
2000	Urban	*n* = 525	21.02	20.85	21.37	21.59	24.56	25.91
	Rural	*n* = 683	20.63	20.8	20.2	19.99	18.27	16.41
	Gap		0.39*	0.05	1.17*	1.6*	6.29*	9.5*
2004	Urban	*n* = 729	23.13	23.07	23.03	23.89	27.79	28.82
	RURAL	*n* = 1,052	22.88	22.91	22.93	22.09	18.74	17.47
	Gap		0.25*	0.16*	0.1	1.8*	9.05*	11.35*
2006	Urban	*n* = 803	25.16	24.86	25.09	25.49	30.8	32.7
	Rural	*n* = 1,242	24.36	24.68	24.43	24.02	19.4	18.19
	Gap		0.8*	0.18*	0.66*	1.47*	11.4*	14.51*
2009	Urban	*n* = 937	27.9	27.77	27.64	28.58	33.67	35.17
	Rural	*n* = 1,584	27.51	27.67	27.78	26.82	22.25	21.63
	Gap		0.39*	0.1	−0.14*	1.76*	11.42*	13.54*
2011	Urban	*n* = 1,563	31.73	31.67	31.87	32.78	35.62	37.82
	Rural	*n* = 2,072	31.39	31.49	31.24	30.32	28.18	26.77
	Gap		0.34*	0.18*	0.63*	2.46*	7.44*	11.04*
2015	Urban	*n* = 1,981	31.54	31.45	31.61	32.38	33.81	34.79
	Rural	*n* = 2,752	31.38	31.51	31.25	30.46	29.8	28.41
	Gap		0.16*	−0.06	0.36*	1.92*	4.01*	6.38*

*$P < 0.05$.

TABLE 2 | Contributions (%) of each factor in HTN rates of older adults by decomposition, 1991–2015.

	Age	Gender	Education	Region	Standardized rates	Crude rates
1991	3.8205	−0.9222	3.6887	2.8983	90.5054	99.9907
1993	5.1071	−0.7772	11.1024	−4.1079	88.8192	100.0327
1997	11.4855	2.7938	28.2482	15.8314	41.7514	99.955
2000	4.1069	0.5265	12.3208	16.849	66.2375	100.0408
2004	2.2024	1.4095	0.881	15.8574	79.7277	99.9899
2006	5.5137	1.2406	4.5488	10.1313	78.5697	100.004
2009	2.8811	0.7387	−1.0342	13.0017	84.3634	100.0245
2011	3.0785	1.6298	5.7044	22.2742	67.3658	99.9622
2015	2.5072	−0.9402	5.6412	30.0863	62.8366	99.9744

contribution of gender effect in 1991 was −0.9222, meaning the gender effect tended to narrow the urban–rural gaps of older adults' HTN rates. Similarly, the contribution of age effect in 1991 was 3.8205, representing that age increased the urban–rural gap.

Two main discoveries could be found through **Table 2** and **Figure 2**. First, all the factors have contributions to older adults HTN rates, and almost factors had a positive effect on HTN rates and tended to enlarge the urban–rural gap. Second, by comparing the contributions of factors in different years, on the whole, region contributed the most, age and education were also relatively important, and gender was the least. In addition, as time went by, the region effect contributed more and more, especially in 2009 and beyond, and the contributions of the other three factors showed a steady trend. This means that the influence of regional differences on HTN rates is becoming more and more obvious by comparison with other factors, which is also the focus of regional prevention and control of HTN for older adults in the future.

DISCUSSION

With the acceleration of the aging process, the prevalence of HTN and the economic burden of the disease caused by HTN among older adults are increasing. Due to the influence of confounding factors of social and demographic components, the traditional crude rates cannot truly reflect the distribution characteristics of

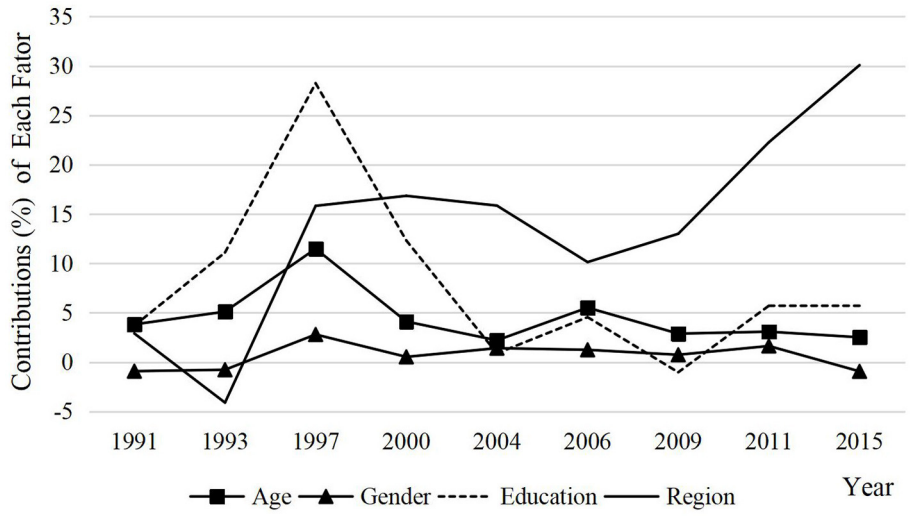

FIGURE 2 | Contributions (%) of each factor in HTN rate of older adults by decomposition, 1991–2015.

HTN. In this case, it is necessary to standardize and decompose the HTN rates of older adults to identify the prevalence trend and distribution characteristics of HTN and to clarify the most critical affecting factors. These will help policymakers to formulate more targeted and accurate policies for the prevention and control of HTN.

The study focused on how social and demographic factors affected the trend of HTN rates among urban and rural older adults by a standardizing and decomposing method. First, our results reveal an increasing trend of HTN rates for Chinese older adults in 1991–2015, and the HTN rates in urban areas were higher than the rural. In many developing countries, the prevalence of HTN is going upward, including China, especially with the acceleration of the aging society (17). National-level research found that nearly half of 35- to 75-year-old adults in China had HTN (18), and the rates are still increasing rapidly in recent years (19). With age- and sex-standardization, the HTN rates have increased from 60.1% to 65.2% from 2001 to 2010 in urban areas (19). However, the rates were consistently found to be higher in urban areas than rural areas throughout 1991–2015 as some previous studies in the 1990s and 2010 prove (20–22). Two reasons might help explain those findings. On one hand, compared with rural areas, the occupational pressure and interpersonal relationships in urban areas are more intense, so are unhealthy lifestyles, which are all important risk factors of HTN. On the other hand, as confirmed in some studies (5), the accessibility and utilization of health services in cities are much higher, and the awareness of health care is stronger. Therefore, the detection rates of HTN are higher. This also suggests that the relatively lower HTN rates in rural areas may also be caused by insufficient medical and health resources, which still needs further verification.

Second, we found that HTN rates of urban–rural gaps for older adults showed a dynamic change trend, and this helps us to identify temporal factors that influence the prevalence of HTN by standardization. We found that the urban–rural gaps experienced a decreasing trend during 1993–1997, then increased in 1997–2011, and decreased in 2011–2015 again. The dynamic change trend of the urban–rural gaps in 1997–2015 exactly show that the Chinese government has been issuing relevant policies to promote urban–rural equity. We conclude that this trend was mainly realized by adjusting medical insurance policies. Basic Medical Insurance for Urban Employees has been carried out in some enterprises since 1988 and was officially launched nationwide in 1998. As compulsory insurance, it covered all employees in urban areas. Before 1998, the urban–rural gap in HTN was relatively narrow. Taking 1997 as the inflection point, older adults living in urban areas may enjoy preferential policies to improve the utilization of medical and health services, which promotes HTN prevention to a certain extent. As a result, after the implementation of the medical insurance policy in cities, the urban–rural gaps show a significant trend of expansion. However, since the New Rural Cooperative Medical scheme was adjusted around 2011, the gaps between urban and rural areas of HTN changed accordingly. The New Rural Cooperative Medical scheme was implemented for rural residents in 2003 and had basically covered all rural residents by 2010. This study concludes that the coverage of medical insurance policies for the rural population has greatly improved the economic security of medical care for them. Therefore, the urban–rural gaps of HTN took 2011 as the turning point, showed a large trend before 2011, decreasing after that. This dynamic change trend coincides with the change of the medical insurance policy in China, which reflects the important role of medical insurance policies in the prevention of HTN. However, other studies also using China Health and Nutrition Survey data have found that the urban–rural gaps of HTN prevalence were gradually narrowed during 1993–2011 (5). We consider that the difference between the two results is most likely due to whether the HTN rates were standardized. Because the composition of populations

may be different, it is necessary to standardize rates when we compare two or more populations. Standardized rates give us an opportunity to understand the true rates of HTN and identify the period factors of urban–rural gaps, namely, medical insurance policies. This also shows that a medical insurance policy is an important measure to promote health equity for older adults in both urban and rural areas. It can provide economic security, improve the utilization of medical and health services, and carry out early prevention and intervention of diseases. Therefore, an important way to prevent and treat HTN is to provide strong economic support for medical treatment, especially for the rural areas. For example, the reimbursement ratio should be increased, and more HTN prevention and treatment drugs should be included in the reimbursement scope to promote the health equity of the older adults in urban and rural areas.

Third, comparing different compositions, region was the most crucial driving force in the trends of older adults' HTN rates with an ever-rising impact over time. Although age, gender, and education level were all influencing factors for HTN, their effects were relatively limited and stable in recent years. This result is different from other studies, which have found that there are significant statistical differences in the effect of demographic compositions, such as age, gender, and education, on HTN rates (23). However, this is not a contradiction. We do not deny the differential influence of demographic factors on the prevalence of HTN. Whereas, with the gradual adaptation of society to aging and urbanization as well as the improvement of education levels, the influence of demographic factors, such as age and education, on HTN tends to be stable. Instead, social development factors might be making more important contributions. Due to the dualistic social structure that has existed for a long time, urban–rural gaps are typical representatives of socioeconomic differences in China, which further lead to other differences, such as utilization of health services and lifestyles. The regional differences may be related to economic development; as we discuss earlier, higher HTN rates are found in urban areas than rural. This is similar to regional gaps, suggesting that the gaps may be caused by economic development. The differences of economic development across regions could influence behavior and lifestyles, medical and health conditions, and other aspects (23). For example, it can lead to poor lifestyles, such as less exercise and eating more foods high in fat, calories, and salt, all of which are personal factors. Besides this, medical conditions and awareness of health care are crucial factors that highly correlate to regional development levels and need to be further improved by the government. Compared with urban areas, rural areas have higher HTN prevalence but lower awareness, treatment, and control in China (18), and the detection rates of HTN in developed areas is significantly higher than that in economically backward areas (24). This further indicates that we should pay more attention to the differences in health care between rural and urban areas. In particular, as shown in our study, the effect of region on urban areas was obviously higher than rural areas, suggesting that regional differences have become more and more critical with the economic development, especially health care. Therefore, in both urban and rural areas, different prevention and control measures should be taken according to their characters and medical conditions. Especially in rural areas, the lower awareness, treatment, and control rates of HTN can be improved by guaranteeing the financial support for medical treatments and improving the utilization level of medical and health services.

LIMITATIONS

Although we have obtained some meaningful results by standardization and decomposition methods, there are several limitations in this study. First, we decomposed and standardized the HTN rates of older adults in urban and rural populations. That is, we divided older adult patients with HTN into urban and rural populations based on the assumption that there are plenty of differences in the population structure between urban and rural areas in China. Yet, if the compositions of populations to compare were similar, the efficiency of this method would be reduced. Second, when more factors are included, the required sample size also increases. In this study, the annual data sample size is not large enough, especially in the beginning years. Therefore, we cannot include more factors in our study.

CONCLUSIONS

By analyzing the HTN rates of older adults in urban and rural China over the past 25 years from 1991 to 2015, we found that the prevalence of HTN in Chinese older adults was on the rise, and the standardization gaps were not as big as crude rates. The urban–rural gaps showed a trend of fluctuation over time; the gaps showed decreasing trends during 1993–1997, then increased during 1997–2011, and declined again. This dynamic change trend was mainly related to the medical security policy formulated by the Chinese government. As for the component contributions, the effects of age, education, and gender on the HTN rates tended to be limited and stable, whereas regional differences had the greatest impact on HTN for both urban and rural older adults in 1991–2015, especially in urban areas. This indicates that the trends of HTN rates and gaps for urban and rural areas mainly come from the variation of regional differences. However, one of the major factors contributing to regional differences in HTN is the medical situation, which needs to be further improved by health policymakers in the formulation of public health policies due to the large gap in medical and health resources between urban and rural areas.

DATA AVAILABILITY STATEMENT

The data used in the study are openly available in the CHNS website at: https://www.cpc.unc.edu/projects/china.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the University of North Carolina at Chapel Hill, and the National Institute of Nutrition and Food Safety and the Chinese Centre for Disease Control and Prevention. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

JW and QY designed the study. QY drafted the first version. SL and JW revised the manuscript. All authors contributed to the article and approved the submitted version.

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The Expected Demand for Elderly Care Services and Anticipated Living Arrangements Among the Oldest Old in China Based on the Andersen Model

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Objective: The first aim of this study was to explore expected demands of the oldest old and their determinants for different types of elderly care services. The second aim was to investigate preferred choices of living arrangements among the oldest old and the influencing factors.

Methods: Data of 4,738 participants aged ≥80 years were extracted from the Chinese Longitudinal Health Longevity Survey carried out in 2014. Using the Andersen model as the analysis framework, a multiple logistic regression analysis was performed to analyze the relationship between the expected elderly care services and living arrangements and other influencing factors. The odds ratios were calculated to indicate the relationship between the influencing factors and the dependent variables.

Results: From the descriptive analysis results, we found that the oldest old showed high anticipated needs for home visits (83.5%) and health education (76.4%). Further, there existed a huge imbalance between the supply and demand of care services for the aged. Living with children is still the most important way of providing for the oldest old. The regression results showed that the expected demands for elderly care services and anticipated living arrangements among the oldest old in China are influenced by age, residence, housing property rights, economic status, loneliness, and activities of daily living (ADLs). The oldest old who are older without housing property rights, childless, and have restricted ADLs were more frequently observed to live in long-term care institutions.

Conclusions: There is an inequality of the supply and expected demand for elderly care services, and living with children is still a preferred choice of the Chinese oldest old. Our findings indicate that when planning how to promote elderly care services among the oldest old, it is important to consider their expectations, especially for the subgroup that is relatively disadvantaged. Related policies should be developed to offer incentives to family caregivers when they live with the oldest old.

Keywords: elderly care services, anticipated living arrangement, Andersen model, Chinese, oldest old

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INTRODUCTION

The population of the oldest old (aged ≥80 years) is rapidly growing worldwide (1). In China, the oldest old are assumed to account for 22% of the total population, and the old age support ratio is projected to decline from about 8:1–2:1 by 2050 (2). This situation is among the greatest challenges currently faced by societies, particularly challenging the policymakers. With growing age, the oldest old have a high risk of suffering from health conditions, such as geriatric syndromes, frailty, comorbidities, dementia, and functional decline (3–6). As their functioning worsens, they are most likely cared for by resources from their informal support networks, community services, and government-supported policies or programs.

Given the aging process, how to provide elderly care services has raised urgent concerns in China. The government has proposed that, in the 14th Five-Year period (2021–2025), it is required to develop an elderly care system with high quality. Nevertheless, for rapidly increasing demands for elderly care services, the actual supply of these services has been seriously inadequate. Approximately 60% of older adults needed home visit services, and more than one third needed psychological consulting or daily care services although the proportion of these services provided by the community only accounted for 20% (7). Furthermore, in addition to medical care, there is an upward trend in the diversified needs for rehabilitation, nursing, and spiritual comfort among the older. To promote the development of elderly care services, it is imperative to identify the actual and expected demands of the elderly. That is one of the most important issues we should address as it may further result in more serious health problems and pose higher health burdens on individuals and households. The oldest old is part of the disadvantaged groups that urgently need elderly care services due to their relatively worse physical condition.

In Chinese culture, older adults enjoy a comprehensive status and role in the family through the Confucian norm of filial piety. Living with aging family members and taking care of them is the primary moral principle endorsed by generations of Chinese people. However, with rapid social transitions, including low fertility, increase of urbanization, and individual independence, family size has shrunk on average. According to the seventh national census, the average number of people in each household is fewer than three. Meanwhile, the proportion of the elderly living alone or empty-nest elderly has increased. Family care functions are severely weakened. Although the elderly, as a whole, prefer to live alone (or with spouse only), the preference to live with children was greater in older age groups (8). Therefore, there may be some oldest-old populations who cannot get timely care services. It is required to understand their anticipated living arrangements to provide better support resources.

With respect to care services, previous studies focus on the healthcare service (outpatient and inpatient service) among relatively younger old individuals (9, 10), disabled older people (11), and empty-nest elderly (12). In recent decades, the growth of the older population has increased the demand for elderly care services. Several studies focus on elderly care services among older adults (13, 14). Various factors that influence the demand for these services are taken into consideration and certain contributions made. It is found that gender, career before retirement, family structure, educational attainment, financial strain, and instrumental activities of daily living (ADL) were associated with the need for elderly care services (15, 16). However, the oldest old, at higher demands for elderly care services, remains an understudied and underserved population. Additionally, elderly care services were usually grouped into some categories, such as medical and rehabilitation, instrumental care and support, and psychosocial services, which could limit the purview of these services.

With regard to living arrangements, it has long been regarded as the foundation of elderly care because each household type contained a distinct configuration of demands and resources (17). Previous studies show that living arrangements are critical to health in old age (18, 19). Several factors are suggested to be important in determining the living arrangements of the oldest old, e.g., marital status (20), home ownership (21), and health status (22). However, this research tends to focus on the actual rather than anticipated living arrangement. The actual living arrangement could result from either active or passive acceptance, which may not represent the preferred living arrangement. So far, very little attention has been paid to the role of the preferred living arrangement. Few studies have found that a discrepancy between actual and preferred living arrangements could influence life satisfaction (23) and subjective well-being (24) of older adults. To the best of our knowledge, no study has investigated the influencing factors of anticipated living arrangements among the oldest old. It is important in policy implementation to improve the physical and psychological well-being of the oldest old and social resources allocation.

To address these limitations, this study investigated an extensive range of elderly care services that fit within the Chinese context and anticipated living arrangements among the oldest old. We compared differences between the expected demand and actual supply of various elderly care services for the oldest old. We further identified the factors influencing expected demand for elderly care services and anticipated living arrangements using the Andersen model as a theoretical framework. This study can benefit policymakers in aging countries, such as China, by providing effective and specific policy advice to develop a comprehensive care system.

METHODS

Data Source

The data was extracted from the seventh wave (2014) of the Chinese Longitudinal Healthy Longevity Survey (CLHLS), which was conducted by the Healthy Ageing and Development Research Center at Peking University, China. It was a high-quality, nationally representative survey, conducted in a random half of the counties and cities in 22 of 31 provinces, covering ∼85% of the total population of China (25). The survey adopted a stratified multistage cluster sampling design and was carried out via face-to-face interviews in respondents' homes. It provided rich information on the socioeconomic and demographic characteristics, health-related behaviors and

lifestyles, ways of living, and care needs of the population with functional limitations.

From a total of 7,192 individuals, we included 4,738 who were aged ≥80 years and provided answers of expected demand for elderly care services. Subsequently, 549 individuals with missing key data with regard to anticipated living arrangements were excluded from the respective analysis. Therefore, 4,738 and 4,189 oldest-old respondents were included in the analysis on expected demand for elderly care services and anticipated living arrangements, respectively.

The study was approved by the Ethics Committee of Duke University and Peking University (Ethics Number: IRB00001052-13074). Written informed consent was provided by all participants or their legal representatives at baseline and follow-up surveys.

TABLE 1 | Descriptive characteristics of the study sample.

Independent variables	Classification	*N* (%)
Age (years)	80–89	2,207 (46.6)
	90–99	1,654 (34.9)
	≥100	977 (18.5)
Gender	Male	1,957 (41.3)
	Female	2,781 (58.7)
Residence	Urban	2,074 (43.8)
	Rural	2,664 (56.2)
Years of schooling	0	3,192 (67.4)
	1–6	1,224 (25.8)
	≥7	322 (6.8)

Dependent Variable

To measure the actual supply and expected demand for elderly care services, participants were asked the following questions in the CLHLS: What kind of social services are available in your community? What kind of social services do you expect to be provided by your community? Their answers with respect to the care services were categorized into the following eight elements of care: (1) daily care services, (2) home visits, (3) psychological consulting, (4) daily shopping, (5) social and recreation activities, (6) legal aid, (7) health education, and (8) neighboring relations. To gather data on anticipated living arrangements, each participant was asked, "Which living arrangement do you prefer?". One selection was made from a possible four answers: (1) living alone or with spouse no matter how far children live, (2) living alone or with spouse but children living nearby, (3) coresidence with children, or (4) living in a long-term care (LTC) institution.

Independent Variables

The independent variables in the present study were determined by referring to the Andersen theoretical model. This model was helpful in providing a reasonable scope of factors for investigating the utilization of healthcare services, health-related quality of life, and LTC services (26). It included three groups of factors: predisposing (i.e., age, gender, education, ethnicity, and family), enabling (i.e., financial resources, number of children, and social support network), and need factors (i.e., health status and ADLs) (27). Because this model comprises a variety of factors that may influence the pension system, it can be adopted as an analytical framework to explore problems arising in an aging population. Based on these three domains, we have made conceptual expansions and refinements to make this model more suitable to our research objectives.

The predisposing factors included age (1 = aged 80–89, 2 = aged 90–99, and 3 = aged ≥100), gender (1 = male and 2 = female), residence (1 = urban and 2 = rural), and educational background (1 = no formal education, 2 = elementary school, and 3 = middle school and above). The enabling factors were expressed by housing property rights (1 = own, 2 = rent, and 3 = other), number of children (1 = none, 2 = 1–2, and 3 = ≥3), and economic status (1 = poor, 2 = fair, and 3 = rich). The need factors were measured by self-rated health (1 = bad, 2 = fair, and 3 = good), feeling lonely and isolated (1 = always/often, 2 = sometimes, and 3 = seldom/never), and ADLs (1 = strongly limited, 2 = limited, and 3 = not limited).

Data Analyses

The analysis started with a description of sample characteristics. We then compared differences in the distribution of elderly care services between expected demand and actual supply and anticipated living arrangements between different age groups. Last, multiple bivariate logistic regressions were used to identify factors that related to every kind of expected demand for elderly care services. To explore the influencing factors on anticipated living arrangements, we performed multivariate logistic regression analysis with "living alone or with spouse no matter how far children live" as our base category. A value of $P < 0.05$ was considered statistically significant. The results are reported as coefficients (β), odds ratios (OR), and 95% confidence intervals (95% CI). Missing data of individual study variables were modest (the highest was 10.6% for educational background), we handled with multiple imputation using the Markov Chain Monte Carlo Simulation. All analyses were conducted in Stata 14.0 for Windows 10.

RESULTS

Descriptive Analysis

The main characteristics of the sample are presented in **Table 1**. Approximately half of the respondents were aged between 80 and 89 years. More than half were female and rural respondents. In addition, approximately two thirds of respondents were illiterate. **Figure 1** shows information on expected demand and actual supply of various elderly care services. Generally, relatively fewer services were provided to the participants compared with the demands and did not exceed 40% of the demand. However, a majority of the respondents reported a higher percentage of expected demands being met with regard to elderly care services. The needs for home visit services were the highest, followed by needs for health education, psychological consulting, social and recreation activities, neighboring relations, legal aid, daily care, and daily shopping, in that order. **Table 2** presents the anticipated

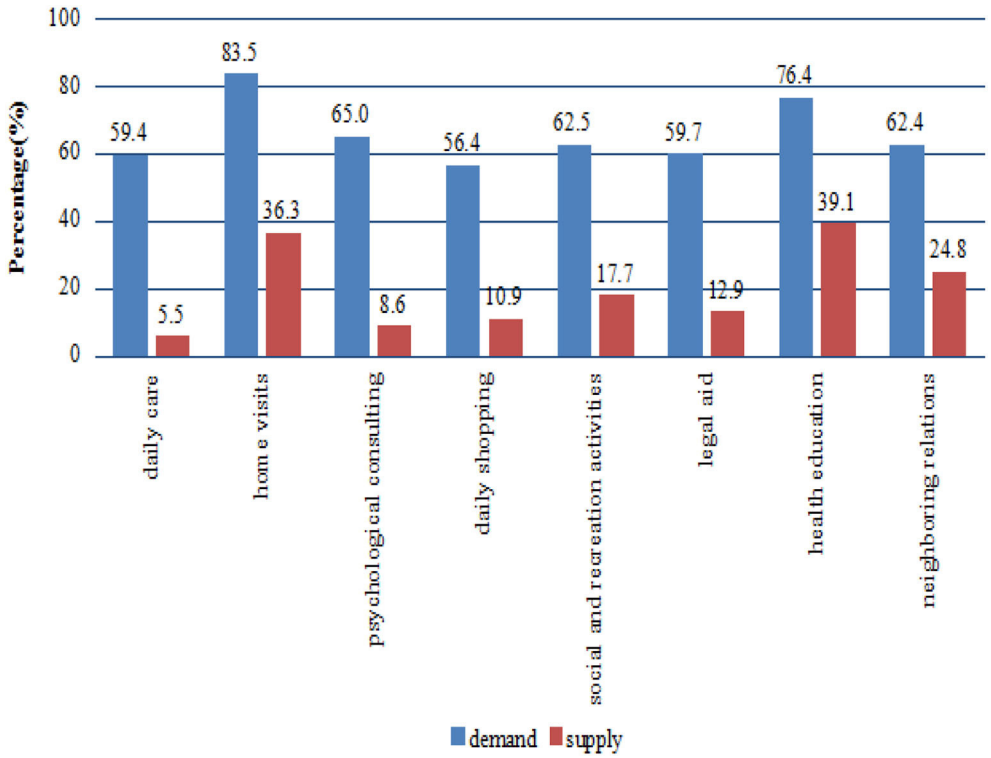

FIGURE 1 | Expected demand and actual supply of various elderly care services for the oldest old.

TABLE 2 | Anticipated living arrangement categorized based on the age group.

Dependent variables	Age (%)		
	Aged 80–89	Aged 90–99	Aged ≥100
Living alone or with spouse no matter how far children live	294 (14.4)	95 (6.6)	34 (4.8)
Living alone or with spouse but children living nearby	706 (34.5)	335 (23.3)	126 (17.9)
Co-residence with children	1,002 (49.0)	964 (66.9)	526 (74.8)
Living in an LTC institution	44 (2.2)	46 (3.2)	17 (2.4)

N = 4,189.

living arrangements among different age groups. As can be seen, the most common anticipated living arrangement was to live with children. Less than 4% of the oldest old chose to go to LTC institutions.

Logistic Regression Analysis

The results of the binary regression analyses of expected demand for elderly care services are displayed in **Table 3**. The oldest old aged 80–89 years had a higher demand for social and recreational activities than the other age groups (OR = 0.784, $P < 0.01$). Participants living in rural areas were in more need of home visit services than those living in urban areas (OR = 1.507, $P < 0.001$). Furthermore, the oldest old without formal education were in greater need for home visits (OR = 0.621, $P < 0.05$) and neighboring relations services (OR = 0.730, $P < 0.05$). In contrast to the oldest old who own a house, those with other housing property rights had an increased need for daily care services (OR = 1.330, $P < 0.05$) and less need for health education (OR = 0.653, $P < 0.01$). Compared with individuals with a low socioeconomic status, those with a rich status needed less daily care services (OR = 0.710, $P < 0.01$). Furthermore, the oldest old with good self-rated health were less likely to report various elderly care service needs except legal aid. The oldest old who sometimes felt lonely and isolated were more inclined to engage in home visits (OR = 1.485, $P < 0.05$), psychological consulting (OR = 1.312, $P < 0.05$), social and recreation activities (OR = 1.471, $P < 0.01$), and health education services (OR = 1.522, $P < 0.01$). Moreover, the oldest old without limited ADLs had a higher demand for social and recreation activities (OR = 1.354, $P < 0.001$), health education (OR = 1.486, $P < 0.001$), and neighboring relations (OR = 1.435, $P < 0.001$) than those with strongly limited ADLs.

The results of the multivariate regression analyses of factors related to the anticipated living arrangement are shown in **Table 4**. Compared with individuals aged 80–89 years, those aged 100 or more were more likely to be living with their children (OR = 3.206, $P < 0.001$) or living in LTC institutions (OR = 2.815, $P < 0.001$). Females were more inclined to coreside with their children than males (OR = 1.907, $P < 0.001$). The oldest old who completed junior high school or above were less likely to report "living alone or with spouse but children living nearby"

TABLE 3 | Elderly care service demand for the oldest old (binary logistic regression).

Independent variables	Daily care		Home visits		Psychological consulting		Daily shopping		Social and recreation activities		Legal aid		Health education		Neighboring relations	
	β	OR (95% CI)	β	OR (95% CI)	β	OR (95% CI)	β	OR (95% CI)	β	OR (95%CI)	β	OR (95% CI)	β	OR (95% CI)	β	OR (95% CI)
PREDISPOSING FACTORS																
Age (Ref. Aged 80-89)																
Aged 90–99	0.054	1.056 (0.925, 1.206)	0.048	1.050 (0.879, 1.253)	0.043	1.044 (0.911, 1.197)	−0.025	0.975 (0.855, 1.112)	−0.161	0.851* (0.744, 0.974)	−0.129	0.879 (0.770, 1.004)	−0.047	0.954 (0.818,1.113)	−0.134	0.874 (0.764,1.001)
Aged ≥100	0.130	1.139 (0.960, 1.351)	0.040	1.040 (0.828, 1.308)	0.047	1.048 (0.880, 1.248)	0.012	1.012 (0.856, 1.197)	−0.244	0.784** (0.661, 0.929)	−0.074	0.929 (0.784, 1.100)	−0.018	0.982 (0.808, 1.194)	−0.188	0.829* (0.699,0.984)
Gender (Ref. Male)																
Female	−0.057	0.944 (0.822, 1.085)	−0.090	0.914 (0.759, 1.100)	0.014	1.014 (0.880, 1.169)	−0.035	0.965 (0.842, 1.107)	−0.055	0.947 (0.822, 1.090)	−0.059	0.942 (0.821, 1.082)	−0.046	0.955 (0.813, 1.122)	−0.071	0.931 (0.809, 1.072)
Residence (Ref. Urban)																
Rural	−0.012	0.988 (0.874, 1.117)	0.410	1.507*** (1.282, 1.772)	−0.052	0.950 (0.837, 1.077)	0.062	1.064 (0.943, 1.201)	−0.063	0.939 (0.829, 1.063)	−0.057	0.944 (0.836, 1.067)	0.022	1.022 (0.887, 1.178)	−0.034	0.967 (0.854, 1.094)
Years of schooling (Ref. 0)																
1–6	−0.022	0.979 (0.838, 1.143)	−0.145	0.865 (0.704, 1.062)	−0.011	0.989 (0.844, 1.160)	0.049	1.050 (0.901, 1.224)	0.035	1.035 (0.884, 1.213)	0.025	1.026 (0.878, 1.198)	0.035	1.036 (0.864, 1.241)	−0.094	0.910 (0.777, 1.065)
≥7	−0.061	0.941 (0.731, 1.210)	−0.476	0.621** (0.460, 0.839)	−0.110	0.896 (0.693, 1.158)	−0.105	0.900 (0.702, 1.154)	−0.178	0.837 (0.649, 1.079)	−0.181	0.835 (0.650, 1.072)	−0.234	0.792 (0.597, 1.050)	−0.314	0.730* (0.567, 0.940)
ENABLING FACTORS																
Housing property rights (Ref. Owned)																
Rented	−0.105	0.900 (0.635, 1.277)	−0.237	0.789 (0.518, 1.203)	−0.081	0.922 (0.645, 1.319)	−0.248	0.780 (0.552, 1.101)	−0.059	0.943 (0.662, 1.343)	−0.271	0.763 (0.540, 1.078)	−0.164	0.849 (0.575, 1.254)	−0.237	0.789 (0.557, 1.119)
Others	0.285	1.330* (1.001, 1.768)	−0.237	0.789 (0.564, 1.104)	0.138	1.147 (0.860, 1.531)	0.186	1.205 (0.916, 1.585)	0.167	1.181 (0.889, 1.569)	0.006	1.006 (0.765, 1.324)	−0.426	0.653** (0.488, 0.875)	−0.049	0.952 (0.722, 1.256)
Number of children (Ref. 0)																
1–2	−0.214	0.808 (0.537, 1.214)	−0.445	0.641 (0.352, 1.167)	−0.047	0.954 (0.633, 1.436)	−0.004	0.996 (0.675, 1.471)	0.059	1.060 (0.712, 1.579)	−0.073	0.929 (0.625, 1.383)	−0.141	0.869 (0.543, 1.390)	0.018	1.018 (0.681, 1.521)
≥3	−0.291	0.747 (0.510, 1.096)	−0.431	0.650 (0.367, 1.150)	−0.131	0.877 (0.599, 1.285)	−0.134	0.875 (0.608, 1.259)	−0.094	0.910 (0.628, 1.318)	−0.244	0.783 (0.541, 1.135)	−0.238	0.788 (0.508, 1.223)	−0.157	0.854 (0.588, 1.242)

(Continued)

TABLE 3 | Continued

Independent variables	Daily care		Home visits		Psychological consulting		Daily shopping		Social and recreation activities		Legal aid		Health education		Neighboring relations	
	β	OR (95% CI)	β	OR (95% CI)	β	OR (95% CI)	β	OR (95% CI)	β	OR (95%CI)	β	OR (95% CI)	β	OR (95% CI)	β	OR (95% CI)
Economic status (Ref. Poor)																
Fair	−0.176	0.838 (0.689,1.020)	−0.179	0.836 (0.636,1.099)	0.083	1.087 (0.893,1.322)	−0.052	0.949 (0.785,1.146)	0.188	1.207 (0.998,1.460)	0.108	1.114 (0.922,1.346)	−0.037	0.963 (0.772,1.203)	0.086	1.090 (0.899,1.322)
Rich	−0.343	0.710** (0.559, 0.902)	−0.299	0.742 (0.537, 1.026)	0.025	1.026 (0.804, 1.308)	−0.151	0.860 (0.680, 1.087)	0.175	1.192 (0.939, 1.512)	0.016	1.016 (0.803, 1.286)	0.107	1.113 (0.843, 1.470)	0.037	1.037 (0.817, 1.318)
NEED FACTORS																
Self–rated health (Ref. Bad)																
Fair	−0.157	0.855 (0.712, 1.027)	−0.085	0.918 (0.716, 1.179)	−0.086	0.917 (0.760, 1.107)	−0.066	0.936 (0.783, 1.119)	−0.048	0.954 (0.794, 1.144)	−0.024	0.976 (0.815, 1.168)	−0.068	0.934 (0.758, 1.152)	0.020	1.021 (0.850, 1.225)
Good	−0.334	0.716*** (0.590, 0.869)	−0.308	0.735* (0.566, 0.954)	−0.244	0.783* (0.642, 0.955)	−0.272	0.762** (0.630, 0.921)	−0.210	0.810* (0.667, 0.984)	−0.157	0.854 (0.706, 1.034)	−0.250	0.779* (0.624, 0.972)	−0.202	0.817* (0.674, 0.992)
Feeling lonely and isolated (Ref. Always/Often)																
Sometimes	0.118	1.125 (0.885, 1.430)	0.395	1.485* (1.092, 2.020)	0.272	1.312* (1.028, 1.675)	0.205	1.228 (0.973, 1.550)	0.386	1.471** (1.162, 1.861)	0.232	1.262 (0.998, 1.595)	0.420	1.522** (1.168, 1.984)	0.200	1.222 (0.962, 1.552)
Seldom/Never	−0.149	0.862 (0.685,1.083)	0.252	1.286 (0.963,1.717)	−0.068	0.934 (0.741,1.177)	0.030	1.031 (0.825,1.288)	0.184	1.202 (0.961,1.504)	0.027	1.028 (0.822,1.285)	0.161	1.174 (0.915,1.507)	−0.058	0.944 (0.752,1.186)
ADLs (Ref. Strongly limited)																
Limited	0.186	1.205 (0.997, 1.456)	0.229	1.257 (0.980, 1.613)	0.184	1.201 (0.990, 1.458)	0.165	1.179 (0.979, 1.420)	0.162	1.176 (0.974, 1.420)	0.124	1.132 (0.939, 1.365)	0.188	1.206 (0.978, 1.488)	0.187	1.205 (0.999, 1.455)
Not limited	0.163	1.177 (0.984, 1.409)	0.204	1.227 (0.970, 1.552)	0.190	1.209* (1.006, 1.453)	0.242	1.273** (1.067, 1.520)	0.303	1.354*** (1.131, 1.622)	0.216	1.241* (1.038, 1.484)	0.396	1.486*** (1.214, 1.819)	0.361	1.435*** (1.199, 1.718)

*N = 4,738. Binary logistic regression was adopted. β represents partial regression coefficient; 95% confidence intervals are shown in brackets. *p < 0.05, **p < 0.01, ***p < 0.001.*

TABLE 4 | Anticipated living arrangement for the oldest old (multivariate logistic regression).

Independent variables	Living alone or with spouse but children living nearby		Co–residence with children		Living in LTC institutions	
	β	OR (95% CI)	β	OR (95% CI)	β	OR (95% CI)
PREDISPOSING FACTORS						
Age (Ref. Aged 80–89)						
Aged 90–99	0.320	1.377* (1.052, 1.801)	1.007	2.738*** (2.128, 3.524)	1.222	3.394*** (2.004, 5.749)
Aged ≥100	0.232	1.261 (0.832, 1.910)	1.165	3.206*** (2.185, 4.705)	1.035	2.815** (1.288, 6.153)
Gender (Ref. Male)						
Female	0.192	1.211 (0.934, 1.571)	0.646	1.907*** (1.491, 2.440)	−0.194	0.824 (0.475, 1.428)
Residence (Ref. Urban)						
Rural	0.020	1.020 (0.807, 1.289)	−0.072	0.931 (0.746, 1.162)	−0.158	0.854 (0.514, 1.419)
Years of schooling (Ref. 0)						
1–6	−0.163	0.850 (0.645, 1.120)	−0.254	0.776 (0.596, 1.009)	−0.138	0.871 (0.484,1.565)
≥7	−0.442	0.643* (0.421, 0.981)	−0.409	0.664* (0.446, 0.989)	−0.498	0.608 (0.238, 1.555)
ENABLING FACTORS						
Housing property rights (Ref. Owned)						
Rented	−0.413	0.662 (0.379, 1.156)	−0.687	0.503* (0.296, 0.856)	0.359	1.432 (0.487, 4.212)
Others	−0.195	0.823 (0.469, 1.444)	−0.396	0.673 (0.394, 1.149)	2.773	16.012*** (8.302, 30.882)
Number of children (Ref. 0)						
1–2	0.210	1.234 (0.493, 3.087)	−0.079	0.924 (0.409, 2.090)	−2.125	0.119*** (0.043, 0.333)
≥3	0.474	1.606 (0.670, 3.851)	0.038	1.038 (0.478, 2.255)	−2.503	0.082*** (0.033, 0.202)
Economic status (Ref. Poor)						
Fair	0.285	1.330 (0.911, 1.943)	0.100	1.105 (0.777, 1.571)	−0.659	0.517* (0.273, 0.982)
Rich	0.345	1.412 (0.888, 2.245)	0.378	1.459 (0.948, 2.248)	−0.358	0.699 (0.292, 1.674)
NEED FACTORS						
Self-rated health (Ref. Bad)						
Fair	0.361	1.434 (0.989, 2.081)	0.080	1.083 (0.766, 1.533)	−0.218	0.804 (0.415, 1.558)
Good	0.228	1.256 (0.855, 1.845)	−0.077	0.926 (0.647, 1.325)	−0.455	0.635 (0.307, 1.310)
Feel lonely and isolated (Ref. Always/Often)						
Sometimes	0.332	1.394 (0.873, 2.225)	0.232	1.261 (0.811, 1.961)	0.004	1.004 (0.438, 2.301)
Seldom/Never	0.007	1.007 (0.650, 1.560)	0.127	1.135 (0.753, 1.712)	−0.304	0.738 (0.334, 1.629)
ADLs (Ref. Strongly limited)						
Limited	−0.473	0.623 (0.381, 1.019)	−0.691	0.501** (0.314, 0.798)	−0.283	0.753 (0.338, 1.681)
Not limited	−0.708	0.493** (0.308, 0.788)	−0.955	0.385*** (0.247, 0.601)	−0.717	0.488 (0.224, 1.065)

*N = 4,189. Taking "living alone or with spouse no matter how far children live" as reference, multivariate logistic regression analyses were performed. β represents partial regression coefficient; 95% confidence intervals in brackets; *p < 0.05, **p < 0.01, ***p < 0.001.*

(OR = 0.643, $P < 0.05$) and "coresidence with children" (OR = 0.664, $P < 0.05$) compared with those without formal education. With regard to housing property rights, those who did not own or rent a house more often tended to live in LTC institutions (OR = 16.012, $P < 0.001$). Compared with the oldest old without children, those who had three or more children were less likely to live in LTC institutions (OR = 0.082, $P < 0.001$). The oldest old without limited ADLs were less likely to live alone or with spouse but with children living nearby (OR = 0.493, $P < 0.001$) or live with children (OR = 0.385, $P < 0.001$).

DISCUSSION

With a rapidly aging population in China, the development of health and social care systems and transition of elderly household patterns are hot topics. In this study, more than half of the oldest old report care service expectations in at least one of these areas. However, the eight types of elderly care services that are available actually only account for small percentages. This result suggests that, despite government efforts to develop elderly care services, there is a relatively marked imbalance between the actual supply and expected demand. For the oldest old, the most important needs were home visits and health education services; thus, these should be focused upon when developing elderly care service systems. In addition, coresidence with children is still the main anticipated living arrangement, which is consistent with previous studies (12). It is important to address the question of the capacity of a family to provide care for elderly parents. Furthermore, we followed the Anderson model to explore factors influencing the needs of Chinese oldest adults with regard to elderly care services and anticipated living arrangements. There were some important findings.

Expected Demand for Elderly Care Services

First, many predisposing factors were analyzed. For example, we support the effect of residence as mentioned by many other studies (28). In rural areas, the oldest old had a greater need for home visit services than in urban areas, which is very consistent with the reality. The limited access to healthcare services, such as lack of safe, reliable, and accessible public transportation systems and affordable alternatives, are some of the challenges that the rural oldest old encounter (29). Thus, it is not surprising that this group in our study seemed to prefer receiving care services at home.

Second, enabling factors play an important role. The oldest old with more difficult economic circumstances had a greater demand for daily care services. As previous studies indicate, a low income may exacerbate the vulnerability of the oldest old (30). One possible explanation for this phenomenon is that this group tends to have worse health-related outcomes, such as a greater number of chronic diseases and depressive symptoms, which needs more daily care services.

Third, with regard to need factors, our results found that the oldest old who sometimes feel lonely and isolated had a higher demand for psychological consulting and social and recreation activity services. Professional help and support networks of friends may prevent psychological problems and promote social and emotional support. A stable social network is the key factor for preventing loneliness in the oldest old despite their age-related limitations, particularly for those who live alone (31). This reminds us to pay attention to these support services of the oldest old.

Anticipated Living Arrangements

First, among the predisposing factors, age had a significant impact on the anticipated living arrangements of the oldest old. Compared with people aged 80–89, those aged 100 or older were more likely to live with their children or in LTC institutions and were reluctant to live alone. A possible explanation for this may be that as the age increases, health deteriorates; the oldest old who are aged 100 or older are more vulnerable to poor perceived health and chronic diseases (32), accompanied by functional loss (33) and memory disorder (34). Therefore, it is not surprising that they require informal and formal care services provided by their children or professional nursing staff.

Second, in terms of enabling factors, we found that the oldest old who did not own or rent a house tended to live in LTC institutions. Home ownership can potentially affect an aging parent in determining where and with whom he or she lives (21). A plausible explanation could be that this group without a stable place to live is not able to "age in place" like the homeowners. In addition, living in LTC institutions may be a way to lighten the burden of providing formal care services on their children and family.

Third, in terms of need factors, the oldest old without limited ADLs had lesser likelihood of living with children. In other words, when the oldest old experienced high levels of disability in their ADLs, they were more likely to live with their children, consistent with other research results (34). With regard to ADL limitations, the oldest old have more difficulties with basic ADLs, such as bathing, eating, and dressing, among others. Furthermore, a deterioration in ADLs is a sign of intellectual disability or is associated with other age-related medical conditions (2). Thus, moving in with children may serve as a functional alternative to a nursing home for the oldest old (35).

Study Limitations

The present study has certain limitations. First, this study used a cross-sectional survey. Therefore, the relationship between identified factors and demand for elderly care services and anticipated living arrangements cannot be interpreted as cause and effect. Second, predisposing, enabling, and need factors included in the analysis are not very comprehensive, and there may be some potential influencing factors not found. Third, perceived economic and health status and loneliness were self-reported, which could lead to the possibility of subjective bias.

Study Implications

Despite these study limitations, the findings have implications for developing elderly care service systems. Considering the widespread service demands found in this study, the Chinese

government needs to develop and improve elderly care services to meet the multilevel and diversified service needs of the oldest old and promote the equilibrium of basic elderly care services. First, driven by demand expression, communities should enrich the content of old-age services and increase high-demand old-age services, such as home visits, health education, and spiritual comfort. Second, targeted services should be provided based on different age groups, places of residence, and health status among the oldest old. Third, it is urgent to highlight the management of service quality and help to promote the refinement of the care services.

With regard to the anticipated living arrangements of the oldest old, living with children is still the most preferred living arrangement for the oldest old in contemporary China. That accords with typical Chinese traditional cultural values, especially filial piety. Considering the changes in the family structure, developing policies related to offering incentives encouraging coresidence is critical. For this, the government could reduce the family caregiver's personal income taxes when they live with the oldest old (13). This is also an effective way to provide assistances for caregivers and reduce the burden of formal care support.

CONCLUSIONS

The dramatic increase in numbers of the oldest old is an urgent concern, presenting a major challenge for existing health and social care systems. In this study, based on findings in the Chinese context, we could afford a reference value for other countries, especially those that similarly emphasize home- and community-based care and familial relationships. We observed an imbalance of the supply and expected demand for elderly care services. Supplies for personal daily care and psychological consulting services were far behind the requirements. Diversified demands for elder care services among the oldest-old individuals were related to age, residence, educational attainment, economic status, and self-rated health. That demonstrated greater shared efforts ought to be devoted to providing adequate elderly care services by assessing their specific service needs of the oldest-old population with different characteristics. Moreover, living with children is still a preferred choice. The anticipated living arrangements were influenced by age, gender, housing property rights, and ADLs. Considering the importance of family care, it is critical to develop incentive policy to encourage coresidence.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Institutional Review Board (IRB) of the Health System of Duke University. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

YZ and YF conceived and designed the study and supervised the data analysis. YZ, SQ, and CL wrote the paper. SQ and CL performed all statistical analyses. YZ contributed to revising the paper. All authors contributed to the article and approved the submitted version.

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Trends in Cognitive Function Among Chinese Elderly From 1998 to 2018: An Age-Period-Cohort Analysis

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Objectives: To investigate the effects of age, period, and cohort (APC) on trends in cognitive function among the Chinese elderly, and to explore how gender gaps in cognitive function change with age, period, and cohort.

Methods: This study used data from the Chinese Longitudinal Healthy Longevity Survey (CLHLS) from 1998 to 2018, and included 90,432 participants aged above 65 years old. The measurement of cognitive function was the score of the Mini-Mental State Examination (MMSE). Cross-classified random-effect models were used to investigate age, period, and cohort trends in cognitive function.

Results: Mini-Mental State Examination scores decreased with age at an increasing rate. While the cohort effect was nearly stable, the period effect demonstrated a downward trend from 1998 to 2002 followed by a nearly flat line. Females were associated with lower MMSE scores than males. When age increased, the gender gaps in MMSE scores further increased. The period-based gender gaps in MMSE scores diverged throughout the 20 years, while the cohort-based gender disparities in MMSE scores converged with successive cohorts.

Conclusions: Age, period, and cohort had different and independent effects on cognitive function among the Chinese elderly. The effect of age was stronger than that of period and cohort. Gender disparities in cognitive function increased with age and period, and decreased with successive cohorts.

Keywords: age-period-cohort, cognition, China, elderly, gender disparity

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INTRODUCTION

Population aging is one of the major challenges worldwide, such as in China (1). In 2020, there were 190.59 million people aged over 65 years old in China, accounting for 13.5% of the total population (2). In China, life expectancy at birth reached 76.62 years in 2015 (3). The elderly are relatively more vulnerable to cognitive impairment or dementia (4), which would place heavy care burdens on families and societies (5, 6). Therefore, the study on health among Chinese elderly, with expanded scales and increased longevity has important significance.

A better understanding of cognitive function trends is crucial to both the aging population and society because cognitive impairment will decrease the quality of life for the elderly and place care burdens on families of the elderly and social care systems (5, 7). Numerous studies have reported that cognitive function improved among the elderly in Sweden (8, 9), Denmark (10), Germany (11), the United States (12–14), and China (15). For example, US data suggested that the prevalence of cognitive impairment among the elderly decreased from 1993 to 2004 (14). However, other studies reported opposite trends for cognitive function. For example, findings from a Swedish study indicated that the cognitive function of individuals older than 77 years in 2002 was significantly worse compared with that of individuals interviewed in 1992 (16). Zeng determined that cognitive impairment increased among the Chinese elderly between 1998 and 2008 (1); whereas, these previous studies rarely adjusted for three unique effects related to health trends, which are age, period, and cohort (APC) effects. The effect of age reflects the biological and social processes of aging specific to individuals (17). The effect of period refers to external factors that simultaneously affect all age groups at a particular calendar time. The effect of period often results from shifts in social, technological, historical, and cultural environments, such as technology breakthroughs, world wars, famine, pandemics of infectious diseases, and public health interventions (18). For example, the advent and diffusion of new medical technology, which could prevent the spread of a kind of infectious disease, would reduce mortality rates of all age groups simultaneously (19). This example reflects period effects (20). The effect of cohort reflects different formative life experiences of successive generations (21, 22). Cohort effects subsume the effects of early life conditions and continuous exposure to socioeconomic, behavioral, and environmental factors that act persistently over time to produce differences in life course outcomes for specific cohorts (23). One example for the cohort effects would be, for instance, the research of Yang on happiness of Americans from 1972 to 2004 demonstrated that baby boomers experienced less happiness on average than both earlier and later cohorts. Yang explained that this may be closely related to early life conditions and formative experiences. The cohort of baby boomers experienced more competition to enter schools and the labor market because of larger cohort sizes, which might decrease the happiness level of the baby boomers (24). Furthermore, in the past several decades, China has experienced huge societal changes and rapid economic growth, and its people had undergone powerful social forces (15). These societal changes were expected to influence living conditions and the health of populations with distinct effects on different periods and birth cohorts. Since age, period, and cohort had distinct effects on health, these temporal sources of variations in cognitive function need to be distinguished (22).

To examine the cognitive function trends accurately, studies began to explore some of the APC effects which could be improved further. Wu et al. (25) reviewed 70 prevalent studies on dementia in mainland China, Hong Kong, and Taiwan from 1980 to 2012. They identified no significant variation across periods but a potentially increasing cohort effect. However, this study did not conduct complete APC modeling and robust statistical tests because of limited information and considerable variations across different studies. Another study in China reported that the prevalence of cognitive impairment remained stable from 1998 to 2014. Regarding the effect of cohort, cognitive impairment remained stable after a decline in early birth cohorts (25). While this study used the intrinsic estimator method for APC analyses, this method may be a poor approximation of the process of social change (18). Meanwhile, it only focused on the elderly aged 80 years and above, which may provide an incomplete picture of the effects of age. Given these limitations in the literature, studies using advanced methods to explore APC effects on cognitive function trends are required.

Substantial studies had demonstrated that women had worse cognitive function than men in cultural settings such as China (18). For both cultural and historical reasons, females were significantly disadvantaged in nutrition, education, and occupational achievement compared with their male counterparts in traditional China, all of which were associated with cognitive development and maintenance (26). While Chinese females experienced huge transitions and improvement in their living conditions and socioeconomic status across periods and cohorts in this century, the gender gaps in cognitive function may also change. However, few studies explored how gender differentials in cognitive function changed over APC among the Chinese elderly (22). Thus, it is necessary to explicate APC effects on trends of gender gaps in cognitive function, as these effects had been demonstrated in previous studies to be significant contributors to temporal health trends (19, 27).

Using data from the Chinese Longitudinal Healthy Longevity Survey (CLHLS), one of the best sources of data on Chinese elderly with multiple birth cohorts from 1998 to 2018, this study intends to investigate the effects of APC on trends of cognitive function among the Chinese elderly and delineate gender disparity trends of cognitive function by APC.

MATERIALS AND METHODS

Data Sources

This study used data from the CLHLS, which focused on shedding new light on a better understanding of determinants of healthy longevity. Zeng and Vaupel (28) had introduced the survey design in detail previously. The baseline survey was conducted in 1998; seven follow-up surveys with replacements for deceased samples were conducted in 2000, 2002, 2005, 2008, 2011, 2014, and 2018. These surveys occurred in randomly selected counties and cities in 22 Chinese provinces (28). All centenarians (aged 100+ years) from these regions who voluntarily agreed to participate in the CLHLS were interviewed. For each centenarian, one nearby octogenarian (aged 80–89 years) and one nearby nonagenarian (aged 90–99 years) were matched and interviewed concerning gender and residence. From the 2002 wave, the CLHLS expanded the range of participants to those above 65 years old. Sample weights were made according to the age-gender-residence distribution of the elderly population (28). According to a previous assessment of the CLHLS, the quality of the CLHLS

data was high regarding data completeness, reliability, and validity (29).

The CLHLS questionnaires comprised questions about basic information, self-reported life evaluation and personality, lifestyle, background, and cognitive function (28). The interview, along with some basic physical examinations, was conducted at the home or nursing institution of each participant by skilled interviewers. Every participant provided written informed consent before the survey. The Research Ethics Committees of Duke University and Peking University granted approval for the protection of human subjects for the CLHLS.

Study Samples

Considering the CLHLS conducted over 20 years from 1998 to 2018 included the elderly across successive birth cohorts, it was suitable for the exploration of the APC effects on cognitive function trends. There were 92,860 participants aged over 65 years in all eight waves. As the self-reported age after 105 years old was not reliable (28), we excluded 2,202 participants aged over 105 years. Additionally, 226 participants were excluded, as they missed information on cognitive function. Thus, the final sample size in analyses was 90,432.

Variables

Cognitive Function

To adapt to Chinese culture, cognitive function in this study was measured by the Chinese version of the Mini Mental State Examination (MMSE), which was modified based on the international standard MMSE questionnaire (30) and tested through pilot survey interviews (28). The MMSE is widely used in clinical and research settings to assess global cognitive function and screen for cognitive impairment (31). The Chinese version of the MMSE included items such as recall, orientation, language, reaction time, and calculation. The participants scored 1 for each correct answer (6). Thus, the range of MMSE score was from 0 to 30, with relatively high scores indicating better cognitive function.

Age, Period, and Cohort

For ease of interpretation of the intercept values, the age of the participants divided by 10 was the grand mean-centered (18). Period indicated the year the survey was conducted (1998, 2000, 2002, 2005, 2008, 2011, 2014, and 2018). Cohort was the year the participants were born. Participants who were born before 1900 or after 1940 were grouped separately to ensure a sufficient number of participants (32). We subsequent*ly grouped other birth cohorts into 5-year bands.*

Covariates

Gender (male = 0; female =1) is the key stratification factor to explore age-period-cohort effects on gender disparity in cognitive function. We also adjusted for the samples' demographic characteristics, socioeconomic status (SES), health behaviors, chronic diseases and prior test exposure (representing their associations with cognitive function in previous studies) (33). Demographic characteristics included ethnicity, current residence, birthplace, marital status, and co-residence. Ethnicity was defined as Han and minority (including all ethnic groups except Han). Current residence and birthplace were both dichotomized as urban and rural. Marital status was defined as married and not married (we combined divorced, separated, widowed, and never married as not married). Co-residence was defined as alone and living with others (such as household members and living in a nursing home). SES included education and job. Education was defined as illiterate (had not received any education) and literate. The CLHLS collected job information of the participants through the following question: "What was your main occupation before age 60?" Considering most people were farmers at that time, we defined job as farmers and others (such as professional and technical personnel; industrial worker; governmental, institutional, or managerial personnel; commercial or service worker; military personnel, and others). Health behaviors indicating the lifestyle of the participants at survey time included smoking, drinking, and physical exercise, which were dichotomized as yes and no. Chronic diseases included four common diseases among the elderly, hypertension, diabetes, heart disease, and stroke. Prior test exposure was used to adjust for potential practice effects of repeat cognitive function testing (14). Participants who had participated in previous waves of the survey was defined as "yes," otherwise was defined as "no."

Statistical Methods

First, we summarized the basic characteristics of study samples in all the eight waves using means ± standard deviation or frequency (percentages).

We applied hierarchical APC (HAPC) models to simultaneously estimate the age, period, and cohort trends of the MMSE score for repeated cross-sectional data. The HAPC model was developed by Yang and her colleague, in which the three effects are not assumed to be additive at the same level of analysis (18). The HAPC model could address a classical APC identification problem in two ways (18). First, we grouped individuals born in a 5-year range into a single cohort to break the linear dependence among the dimensions of APC. Second, the nonlinear transformations approach suggested applying a parametric nonlinear transformation, such as polynomials, to at least one of the APC dimensions to break their linear relationships (24). According to this strategy and previous findings on curvilinear age effects on health (18), this study proposed models of MMSE scores as a quadratic function of age.

Thus, we fit HAPC cross-classified random effect regression models (HAPC-CCREMs) to examine the effects of APC on cognitive function. In each regression model, MMSE scores were regressed on age in linear and squared terms and other confounding variables as required. The coefficients of period, cohort, and gender were allowed to have random effects (24). This design made it possible to explore the period-based and cohort-based trends of gender gaps in cognitive function. In total, the model took the following form:

TABLE 1 | Basic characteristics of samples in the eight surveys.

Variables	ALL	1998	2000	2002	2005	2008	2011	2014	2018
N	90,432	8,682	10,976	15,751	15,296	15,542	7,025	6,708	10,452
Age	87.48 ± 10.63	92.61 ± 7.46	91.36 ± 7.26	86.50 ± 11.44	86.26 ± 11.41	87.30 ± 11.02	85.31 ± 10.20	85.18 ±9.66	85.60 ±11.24
Gender									
Male	39,145 (43.3)	3,484 (40.1)	4,611 (42.0)	6,781 (43.1)	6,639 (43.4)	6,670 (42.9)	3,253 (46.3)	3,159 (47.1)	4,548 (43.5)
Female	51,287 (56.7)	5,198 (59.9)	6,365 (58.0)	8,970 (56.9)	8,657 (56.6)	8,872 (57.1)	3,772 (53.7)	3,549 (52.9)	5,904 (56.5)
Residence									
Urban	43,580 (48.2)	3,231 (37.2)	6,776 (61.7)	7,260 (46.1)	6,837 (44.7)	6,315 (40.6)	4,033 (57.4)	3,120 (46.5)	6,008 (57.5)
Rural	46,852 (51.8)	5,451 (62.8)	4,200 (38.3)	8,491 (53.9)	8,459 (55.3)	9,227 (59.4)	2,992 (42.6)	3,588 (53.5)	4,444 (42.5)
Ethnicity									
Han	84,972 (94.0)	8,056 (92.8)	10,311 (93.9)	14,895 (94.6)	14,368 (93.9)	14,578 (93.8)	6,636 (94.5)	6,216 (92.7)	9,912 (94.8)
Minority	5,460 (6.0)	626 (7.2)	665 (6.1)	856 (5.4)	928 (6.1)	964 (6.2)	389 (5.5)	492 (7.3)	540 (5.2)
Marriage									
Not married *	63,458 (70.2)	7,251 (83.5)	8,892 (81.0)	11,021 (70.0)	10,520 (68.8)	10,881 (70.0)	4,410 (62.8)	4,069 (60.7)	6,414 (61.4)
Married	26,974 (29.8)	1,431 (16.5)	2,084 (19.0)	4,730 (30.0)	4,776 (31.2)	4,661 (30.0)	2,615 (37.2)	2,639 (39.3)	4,038 (38.6)
Co-residence									
With others	77,583 (85.8)	7,790 (89.7)	9,665 (88.1)	13,632 (86.5)	13,229 (86.5)	13,150 (84.6)	5,909 (84.1)	5,420 (80.8)	8,788 (84.1)
Alone	12,849 (14.2)	892 (10.3)	1,311 (11.9)	2,119 (13.5)	2,067 (13.5)	2,392 (15.4)	1,116 (15.9)	1,288 (19.2)	1,664 (15.9)
Job									
Famer	65,690 (72.6)	6,529 (75.2)	7,873 (71.7)	11,239 (71.4)	10,867 (71.0)	11,603 (74.7)	5,093 (72.5)	5,171 (77.1)	7,315 (70.0)
Others &	24,742 (27.4)	2,153 (24.8)	3,103 (28.3)	4,512 (28.6)	4,429 (29.0)	3,939 (25.3)	1,932 (27.5)	1,537 (22.9)	3,137 (30.0)
Education									
Illiterate	54,483 (60.2)	5,868 (67.6)	6,997 (63.7)	9,679 (61.5)	9,270 (60.6)	9,732 (62.6)	3,915 (55.7)	3,720 (55.5)	5,302 (50.7)
Literate	35,949 (39.8)	2,814 (32.4)	3,979 (36.3)	6,072 (38.5)	6,026 (39.4)	5,810 (37.4)	3,110 (44.3)	2,988 (44.5)	5,150 (49.3)
Birthplace									
Urban	13,068 (14.5)	1,250 (14.4)	1,857 (16.9)	2,475 (15.8)	2,399 (15.7)	2,087 (13.4)	844 (12.0)	662 (9.9)	1,494 (14.3)
Rural	77,252 (85.4)	7,432 (85.6)	9,116 (83.1)	13,222 (84.2)	12,896 (84.3)	13,451 (86.6)	6,177 (88.0)	6,036 (90.1)	8,922 (85.7)
Missing^	112 (0.1)	–	3 (<0.1)	54 (0.3)	1(<0.1)	4 (<0.1)	4 (<0.1)	10 (<0.1)	36 (0.3)
Smoking									
No	74,455(82.3)	7,196 (82.9)	9,131 (83.2)	12,832 (81.5)	12,318 (80.5)	12,856 (82.7)	5,717 (81.4)	5,577 (83.1)	8,828 (84.5)
Yes	15,966 (17.7)	1,484 (17.1)	1,845 (16.8)	2,919 (18.5)	2,978 (19.5)	2,686 (17.3)	1,308 (18.6)	1,131 (16.9)	1,615 (15.5)
Missing^	11 (<0.1)	2 (<0.1)	–	–	–	–	–	–	9 (<0.1)
Drinking									
No	73,484 (81.3)	6,628 (76.4)	8,775 (79.9)	12,538 (79.6)	12,201 (79.8)	12,907 (83.0)	5,770 (82.1)	5,685 (84.7)	8,980 (86.0)
Yes	16,937 (18.7)	2,052 (23.6)	2,201 (20.1)	3,213 (20.4)	3,095 (20.2)	2,635 (17.0)	1,255 (17.9)	1,023 (15.3)	1,463 (14.0)
Missing^	11 (<0.1)	2 (<0.1)	–	–	–	–	–	–	9 (<0.1)
Physical exercise									
No	62,416 (69.0)	6,349 (73.1)	7,320 (66.7)	10,731 (68.1)	10,563 (69.1)	11,280 (72.6)	4,252 (60.5)	4,851 (72.3)	7,070 (67.7)
Yes	28,005 (31.0)	2,331 (26.9)	3,656 (33.3)	5,020 (31.9)	4,733 (30.9)	4,262 (27.4)	2,773 (39.5)	1,857 (27.7)	3,373 (32.3)
Missing^	11 (<0.1)	2 (<0.1)	–	–	–	–	–	–	9 (<0.1)
Hypertension									
No	69,319 (76.7)	7,313 (84.2)	9,221 (84.0)	13,087 (83.1)	12,193 (79.7)	12,365 (79.6)	4,799 (68.3)	4,345 (64.8)	5,996 (57.4)
Yes	21,112 (23.3)	1,369 (15.8)	1,755 (16.0)	2,664 (16.9)	3,103 (20.3)	3,177 (20.4)	2,226 (31.7)	2,362 (35.2)	4,456 (42.6)
Missing^	1 (<0.1)	–	–	–	–	–	–	1 (<0.1)	–
Diabetes									
No	87,296 (96.5)	8,600 (99.1)	10,808 (98.5)	15,375 (97.6)	14,869 (97.2)	15,122 (97.3)	6,668 (94.9)	6,330 (94.4)	9,524 (91.1)
Yes	3,135 (3.5)	82 (0.9)	168 (1.5)	376 (2.4)	427 (2.8)	420 (2.7)	357 (5.1)	377 (5.6)	928 (8.9)
Missing^	1 (<0.1)	–	–	–	–	–	–	1 (<0.1)	–
Heart disease									
No	80,214 (88.7)	7,916 (91.2)	10,021 (91.3)	14,235 (90.4)	13,726 (89.7)	14,055 (90.4)	5,965 (84.9)	5,749 (85.7)	8,547 (81.8)
Yes	10,217 (11.3)	766 (8.8)	955 (8.7)	1,516 (9.6)	1,570 (10.3)	1,487 (9.6)	1,060 (15.1)	958 (14.3)	1,905 (18.2)

(Continued)

TABLE 1 | Continued

Variables	ALL	1998	2000	2002	2005	2008	2011	2014	2018
Missing^	1 (<0.1)	–	–	–	–	–	–	1 (<0.1)	–
Stroke									
No	84,354 (93.3)	8,345 (96.1)	10,485 (95.5)	14,848 (94.3)	14,369 (93.9)	14,572 (93.8)	6,391 (91.0)	6,071 (90.5)	9,273 (88.7)
Yes	6,077 (6.7)	337 (3.9)	491 (4.5)	903 (5.7)	927 (6.1)	970 (6.2)	634 (9.0)	636 (9.5)	1,179 (11.3)
Missing^	1 (<0.1)	–	–	–	–	–	–	1 (<0.1)	–
Prior test exposure									
No	51,099 (56.5)	8,682 (100.0)	6,448 (58.7)	9,651 (61.3)	7,387 (48.3)	8,313 (53.5)	47 (0.7)	2,085 (31.1)	8,486 (81.2)
Yes	39,333 (43.5)	0 (0.0)	4,528 (41.3)	6,100 (38.7)	7,909 (51.7)	7,229 (46.5)	6,978 (99.3)	4,623 (68.9)	1,966 (18.8)
MMSE score	21.80 ± 9.23	21.15 ± 8.96	21.22 ± 9.11	22.02 ± 8.80	22.07 ± 9.31	20.79 ± 10.03	22.60 ± 8.84	23.12 ± 8.71	22.37 ± 9.22

MMSE, Mini Mental State Examination. Data are presented as mean ± standard deviation or n (%).

^Missing data were excluded from other percentage calculation.

**This category included divorced, separated, widowed, and never married.*

&This category included professional and technical personnel; industrial worker; governmental, institutional or managerial personnel; commercial or service worker; military personnel, and others.

Level 1 model:

$$MMSE_{ijk} = \beta_{0jk} + \beta_1 A_{ijk} + \beta_2 A_{ijk}^2 + \beta_{3jk} S_{ijk} + \sum_{p=4}^{P} \beta_p X_{pijk} + e_{ijk},\ e_{ijk} \sim N\left(0, \sigma^2\right)$$

where $MMSE_{ijk}$ stands for scores of MMSE for respondent i (for $i = 1, 2, \ldots, n_{jk}$) within period j (for $j = 1, 2, \ldots, 7$) and cohort k (for $k = 1, 2, \ldots, 10$); A and A^2 denote age and age-squared, respectively; S denotes gender; X_p denotes the vector of other individual-level variables, such as age by gender, to test how the gender gap in cognitive function varies from age and covariates. β_{0jk} is the intercept indicating the cell mean for the reference group at the mean age interviewed in period j and belonging to cohort k; β_1 and β_2 denote the fixed coefficients for age; β_{3jk} denotes the random coefficients for gender; β_p denotes the fixed coefficients for covariates; P is the maximum number of covariates included; e_{ijk} is the random individual effect or cell residual, which is assumed to be normally distributed with mean 0 and a within-cell variance σ^2. Age divided by 10 is the grand mean-centered for ease of interpretation of the intercept values.

Level 2 model:

$$\beta_{0jk} = \gamma_0 + u_{0j} + v_{0k}$$
$$\beta_{3jk} = \gamma_3 + u_{3j} + v_{3k}$$

The level 2 models test whether with gender disparities in MMSE scores or not, varied by period or cohort through the specifications of random variance components for the random intercept and coefficients. β_{0jk} denotes a random intercept, which specifies that the overall mean varies from period to period and from cohort to cohort. γ_0 is the expected mean at zero values of all level 1 variables averaged over all periods and cohorts; u_{0j} is the overall period effect regarding residual random coefficients of period j averaged over all cohorts with variance σ_{u0}; v_{0k} is the overall cohort effect regarding residual random coefficients of cohort k averaged over all periods with variance σ_{v0}. β_{3jk} denotes the random coefficients for gender; γ_3 is the level 2 fixed-effect coefficient that represents the fixed effects of gender. To test whether the gender stratifications of MMSE scores varied by period or cohort, we specify that coefficients have period effects (u_{3j}) and cohort effects (v_{3k}) whose corresponding random variance components are σ_{u3} and σ_{v3}. These random variance components of period and cohort for the intercept and coefficients are assumed to have multivariate normal distributions (24).

Therefore, in the level 1 model, we could test whether the gender disparity in MMSE scores varied with age by the interaction term of age with gender. The level 2 model could test whether this gap varied by period or cohort. Based on the combination of two-level models, we used six models to explore the effects of APC on trends of MMSE scores and change in gender disparities in MMSE scores with APC. Model 1 was a two-level model with a fixed effect for age and random effects for period and cohort to explore the net effects of APC on MMSE scores. Model 2 added the key independent variable, gender, to explore its influence on MMSE scores. Model 3 added the interaction between age and gender to explore how the gender disparity in MMSE scores varied with age. Model 4 adjusted confounding variables based on Model 3. Model 5 added random effects of coefficients of gender to explore how gender disparities in MMSE scores varied by period and cohort. Model 6 added covariates based on Model 5 to use a full model. Analyses were conducted using SAS PROC MIXED (18). Bayesian Information Criterion (BIC) was used to compare models concerning the goodness of fit, with a smaller BIC value indicating better model fit (34).

RESULTS

Basic Characteristics of Samples

Table 1 presents basic characteristics of the samples in the eight surveys from 1998 to 2018. In total, there were 90,432

TABLE 2 | Hierarchical age–period–cohort cross-classified random-effect model estimates of MMSE scores.

	Model 1		Model 2		Model 3		Model 4		Model 5		Model 6	
	Coef.	SE	Coef.	SE	Coef.	SE	Coef.	SE	Coef.	SE	Coef.	SE
Fixed effects												
Intercept	22.899 ***	0.225	24.311 ***	0.262	24.368 ***	0.263	22.433***	0.264	24.337 ***	0.269	22.413***	0.251
Age	−4.585 ***	0.086	−4.597 ***	0.064	−4.018 ***	0.074	−3.462 ***	0.070	−4.165 ***	0.070	−3.449 ***	0.067
Age^2	−0.937 ***	0.037	−1.015 ***	0.032	−0.944 ***	0.033	−0.942 ***	0.032	−0.958 ***	0.033	−0.931 ***	0.032
Gender (female = 1)			−2.159 ***	0.053	−2.241 ***	0.054	−0.868***	0.064	−2.107 **	0.446	−0.872***	0.114
Age * Gender					−0.917 ***	0.052	−0.880 ***	0.051			−0.892 ***	0.055
Residence (rural = 1)							−0.174**	0.057			−0.170 **	0.057
Ethnic (minority = 1)							0.969 ***	0.106			0.968 ***	0.106
Marriage (married = 1)							0.971 ***	0.070			0.974 ***	0.070
Living condition (alone = 1)							1.403 ***	0.076			1.403 ***	0.076
Job (farmer = 1)							−0.266 ***	0.070			−0.271 ***	0.070
Education (literate = 1)							1.611 ***	0.064			1.615 ***	0.064
Birthplace (rural = 1)							−0.589***	0.079			−0.584***	0.079
Smoking (yes = 1)							0.234**	0.073			0.233 **	0.073
Drinking (yes = 1)							0.785***	0.069			0.785 ***	0.069
Physical exercise (yes = 1)							2.504***	0.058			2.508 ***	0.058
Hypertension (yes = 1)							0.257***	0.064			0.259 ***	0.064
Diabetes (yes = 1)							−0.261	0.142			−0.260	0.142
Heart disease (yes = 1)							0.018	0.083			0.020	0.083
Stroke (yes = 1)							−2.976***	0.103			−2.980 ***	0.103
Prior test exposure (yes = 1)							−0.185**	0.060			−0.187 **	0.060
Variance components												
Period												
Intercept	0.355 *	0.194	0.453 *	0.248	0.451 *	0.248	0.380*	0.210	0.482 *	0.272	0.340 *	0.191
Gender									0.314 *	0.185	0.062	0.043
Cohort												
Intercept	0.039	0.028	0.087 *	0.051	0.098 *	0.056	0.074 *	0.043	0.089	0.072	0.062	0.038
Gender									1.563 *	0.757	0.007	0.015
Model fit												
BIC	708,261.5		628,065.5		627,755.3		622,020.3		627,809.3		621,999.8	

MMSE, Mini Mental State Examination; SE, standard error; Coef., coefficient; BIC, Bayesian Information Criterion.
$^*p \leq 0.05$; $^{**}p \leq 0.01$; $^{***}p \leq 0.001$.

participants with an average age of 87.48 years old. Most of the respondents were Han, living with others, born in a rural area, illiterate, working as farmers, and not married. About 80% of the participants did not smoke and drink. The average MMSE score of all the samples was 21.8 and ranged from 20.79 to 23.12 among the eight surveys.

Age-Period-Cohort Trends and Differentials in MMSE Scores

Table 2 presents estimates of fixed effects of all individual-level covariates and random-effect variance components. Model 1 showed that with only APC effects included in the model, the predicted average overall MMSE score was 22.9. Age had a significant negative quadratic effect on MMSE scores (coef. for age $= -4.585$, $p < 0.001$; coef. for $age^2 = -0.937$, $p < 0.001$), which suggested that after period and cohort effects were taken into consideration, MMSE scores declined at an accelerated rate with age. Level 2 results suggested that MMSE scores varied in a smaller magnitude by period and cohort (coef. for period $= 0.355$, $p = 0.034$; coef. for cohort $= 0.039$, $p = 0.081$), relative to the effect of age. **Figure 1** presents the overall trends of cognitive function in terms of predicted MMSE scores, estimated from model 1. **Figure 1A** showed curvilinear age effects. **Figure 1B** shows the effect of estimated period, which was calculated as $\hat{\beta}_{0j} = \hat{\gamma}_0 + u_{0j}$, where $\hat{\gamma}_0$ was the intercept or estimated overall mean and $u_{0j}$was the period-specific random-effect coefficients estimated from model 1. The effect of period demonstrated a downward trend from 1998 to 2002, followed by a nearly flat line. **Figure 1C** displays the estimated cohort effects in terms of the predicted MMSE scores at the mean age and averaged over all periods. Similar to the effect of period, the effect of cohort effect was calculated as $\hat{\beta}_{0k} = \hat{\gamma}_0 + v_{0k}$, where v_{0k} was the cohort-specific random-effect coefficients estimated from model 1. The

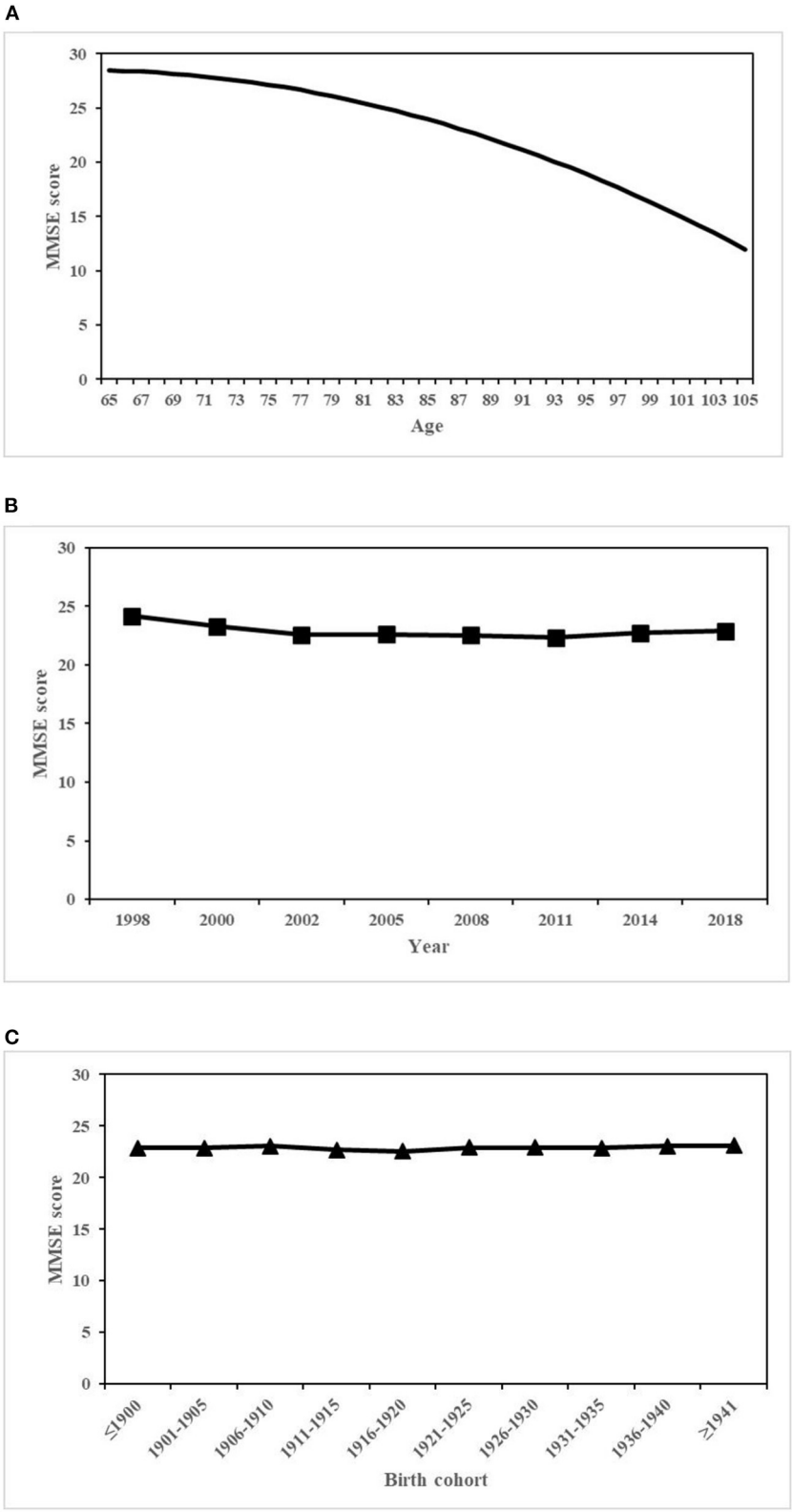

FIGURE 1 | Overall age, period, and cohort effects on MMSE scores. **(A)** Age. **(B)** Period. **(C)** Cohort.

effect of cohort was not significant, demonstrating a trend with little change.

Age-Period-Cohort Trends of Gender Disparities in MMSE Scores

Model 2 indicated that the females had significantly lower MMSE scores (coef. $= -2.159$, $p < 0.001$) relative to the males when the effects of APC were considered. Model 3 indicated that the gender disparity in MMSE scores varied significantly with age (coef. $= -0.917$, $p < 0.001$). When age increased, the gender gap further increased (**Figure 2A**). Model 4 revealed that rural residence, ethnicity, marital status, living condition, job, education, birthplace, smoking, drinking, physical exercise, hypertension, stroke, and prior test exposure had significant influences on MMSE scores. Those participants who were born in a rural area, illiterate, farmers, not in a marriage, living with others, and suffering from stroke had lower MMSE scores. Comparing model 3 with model 4, the interaction effect of gender with age remained highly significant but decreased a little in size when confounding variables were considered.

When it came to the effects of period on gender disparities in MMSE scores, model 5 demonstrated that the gender gap in MMSE scores varied significantly with period net of age and cohort (coef. $= 0.314$, $p = 0.046$). **Figure 2B** displays the estimated random period effects on gender disparities in MMSE scores, which was calculated as $\hat{\beta}_{0j} + \hat{\beta}_{3j} = \hat{\gamma}_0 + \hat{\gamma}_3 + u_{0j} + u_{3j}$ (where $\hat{\gamma}_0$ was the intercept or estimated overall mean, $\hat{\gamma}_3$ was the estimated fixed gender effect coefficient, u_{0j} was the period-specific random-effect coefficients, and u_{3j} was the gender-specific random period effects). **Figure 2B** shows that the gap in MMSE scores between the males and females further increased throughout the 20 years. Although the MMSE scores for both genders indicated decreasing trends, those of the females declined more.

Cohort effects on the gender disparity in MMSE scores were also significant when age and period were considered (coef. $=$ 1.563, $p = 0.019$) (model 5 in **Table 2**). **Figure 2C** displays the estimated random cohort effect on gender disparities in MMSE scores, which was calculated as $\hat{\beta}_{0k} + \hat{\beta}_{3k} = \hat{\gamma}_0 + \hat{\gamma}_3 + v_{0k} + v_{3k}$ Similar to the period effect, v_{0k} was the cohort-specific random-effect coefficient and v_{3k} was the gender-specific random cohort effect. From **Figure 2C**, we identified that the gap in MMSE scores between genders decreased across cohorts, which was largely because of the increasing trend of MMSE scores for females and the relatively stable trend for males among successive cohorts. Model 6, the final model, showed that period and cohort effects on gender differentials in MMSE scores were not statistically significant when covariates were taken into account.

DISCUSSION

Using eight waves of the CLHLS data from 1998 to 2018, we applied HAPC-CCREMs to explore trends of cognitive function among the Chinese elderly. Our findings indicated that the MMSE scores decreased with age at an accelerated rate. While the effect of cohort was nearly stable, the effect of period demonstrated a downward trend from 1998 to 2002 followed by a nearly flat line. The females were associated with lower MMSE scores than males. When age increased, the gender gap in cognitive function further increased. The period trends of gender gaps in MMSE scores widened throughout the 20 years, while the cohort trends of gender disparities in MMSE scores narrowed with successive cohorts.

The results of the APC model analysis indicated that the effect of APC on cognitive function among the Chinese elderly were distinct and independent of each other. These different effects suggested that it is of vital importance to test variations formally in all three time-related dimensions in studies on trends in health (24). In line with previous studies (22), we identified that the MMSE scores decreased with age at an accelerated rate. Compared with the effect age, the effect of period and cohort was smaller. The effect of period demonstrated a downward trend from 1998 to 2002, followed by a nearly flat line. The downward trend may partly be because of in 1998 and 2000 waves of the survey, CLHLS mainly focused on elders above 80 years old. Those oldest-olds who could survive to advanced ages usually had relatively better health status (35), resulting in higher MMSE scores in the 1998 and 2000 waves than scores in the follow-up waves of survey including elders above 65 years old. The stable period trend from 2002 to 2018 was consistent with previous research (22). Zhang also determined that with the net of age and cohort effect, the period-based trend among the Chinese elderly was relatively stable (22). The effect of cohort was not significant, demonstrating a trend with little change from our results, which were different from another Chinese study (22). According to the results of Zhang, cognitive impairment declined across birth cohorts. Zhang used the rate of cognitive impairment as the dependent variable, while our studies used scores of cognitive function, including both the rate and severity of cognitive impairment, which may have different results.

We identified that the females had significantly worse cognitive function than the males, consistent with the results from Taiwan (36) and India (37) but different from the results from developed countries (31, 38). This may be due to the long-lasting preference for sons in traditional Chinese society; compared with males, most females had a relatively tough early life with bad nutrition (33) and few opportunities to obtain education (39), all of which were associated with disadvantages in cognitive development and maintenance (26). Furthermore, this gender disparity in cognitive function further increased with increase in age from our results, supporting the cumulative disadvantage theory (40). According to the cumulative disadvantage theory, early disadvantages would accumulate over the life course by setting people onto different life trajectories, resulting in increasing disparities in health as people age (33). Considering the bad cognitive function and longevity of females, more attention and resources should be given to them to ensure they obtain adequate care.

Gender disparities in MMSE scores enlarged significantly from 1998 to 2018. Although the MMSE scores for both genders indicated decreasing trends, those of the females declined more. Similarly, Zeng determined that the elderly had lower MMSE scores than those of the same age interviewed 10 years ago;

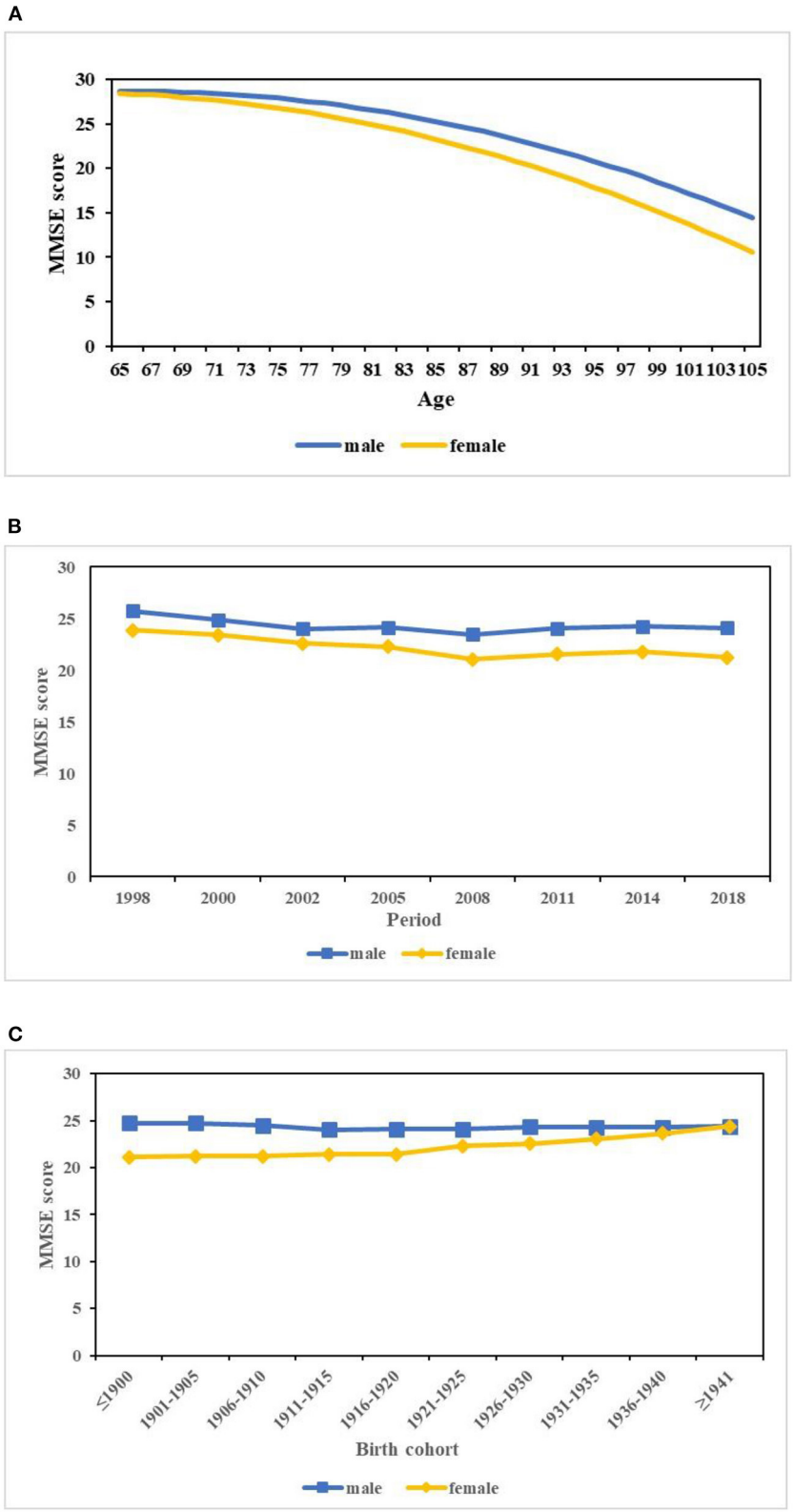

FIGURE 2 | Predicted age, period, and cohort trends in the gender disparity in MMSE scores. **(A)** Age. **(B)** Period. **(C)** Cohort.

meanwhile, the cognitive function of females declined faster than that of males (1). This finding could be explained by the expansion of the morbidity theory, indicating that improvements in medical conditions and living standards in recent years may result in some frail elderly individuals being saved from dying but surviving with poor cognitive function, which may reduce the whole scores of cognitive function (10).

We observed that the cohort trends of gender disparities in cognitive function narrowed with cohorts, which may largely be because of the increase in MMSE scores for females among successive cohorts. The improvement in cognitive function for females in late-born cohorts that we found was consistent with previous studies (22, 41). We speculated that the decreasing gender gap in cognitive function with cohort could be substantially explained by differential exposures to various social correlates of cognitive function, especially the access of women to schooling had improved significantly over time in China (42). Numerous studies from different countries had demonstrated the association between education and late-life cognition as measured by cognitive tests, cognitive impairment, or dementia (33). Education would not only promote cognitive development in early life, but also lead to higher SES, better living condition, and more cognitive reserve in later life (26, 43). Thus, public policy targeting education is required, which will not only improve the lives of children but also enhance cognitive well-being and bridge the gender gaps of the elderly ultimately.

While our results provided new insights into the trends of cognitive function among the Chinese elderly, there were some limitations. First, we performed MMSE to evaluate cognitive function rather than comprehensive clinical evaluations. MMSE is a screening tool and provides global cognitive function. The clinical evaluations are more accurate; hence further analyses by different domains of cognitive function are needed. Second, because of data limitation, the earliest and latest birth cohorts did not capture a full age distribution, which may bias the estimates for cohort trends. Third, we focused on the basic effects of APC and individual-level variables in this study; effects from macroeconomic and medical variables on cognitive function should be further explored.

In conclusion, we assessed the trends of cognitive function among the Chinese elderly using the APC model. The gender gaps in cognitive function increased with age and period but decreased with cohorts. The significance of APC effects in shaping social inequalities in cognitive function implied the relevance of both biological forces and historical context. These findings might help inform healthcare planning and priorities for medical resource allocation accordingly.

DATA AVAILABILITY STATEMENT

Publicly available datasets were analyzed in this study. This data can be found here: https://sites.duke.edu/centerforaging/programs/chinese-longitudinal-healthy-longevity-survey-clhls/.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Research Ethics Committees of Duke University and Peking University. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

XH, SG, XZ, XS, YG, and HD contributed to study conception and design. Material preparation and analysis were performed by XH, SG, XZ, XS, and YG. The first draft of the manuscript was written by XH. All authors commented on previous versions of the article. All authors contributed to the article and approved the submitted version.

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The Health Effect of the Number of Children on Chinese Elders: An Analysis Based on Hukou Category

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Based on the 2018 China Health and Retirement Longitudinal Study (CHARLS 2018), from the perspective of urban-rural disparity, this paper investigates how fertility affects Chinese elders' health. We exploit the enactment of the one-child policy in 1979 to construct instrumental variables capturing the health effect of having only one child rather than multiple children. The empirical results show that the health condition of rural elders having only one child is worse than elders having multiple children, while the negative health effect of lower fertility becomes statistically insignificant for urban elderly parents. After considering the selection on both levels and gains, the results are still robust in marginal treatment effect (MTE) estimation. We investigate the potential mechanism in four ways, the results suggest that having only one child instead of multiple children depresses the upstream intergenerational transfer payments more for rural parents; ameliorates offspring's educational attainment more for urban parents; improves housing conditions more for urban elders; and decreases the visit frequency of children to both urban and rural parents. Our findings have important implications, in the context of increasing population aging, the urban-rural inequality caused by the hukou system has been magnified by the declining fertility rate. The Chinese government should pay more attention to rural elders with only one child, and more public-funded socioeconomic resources are needed for one-child parents in rural areas to improve their health. Moreover, the empirical results also imply that urbanization in China may be able to soften the health deterrent effect of lower fertility.

Keywords: lower fertility, hukou system, elderly health, number of children, China

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INTRODUCTION

China is the most populous developing country in the world. With the population rapidly aging across China, many scholars have been attracted by the potential elements affecting elders' health (1, 2). Some researchers are concerned about the impact of individual micro-factors such as income, education level, and Internet use on the health of the elderly (3, 4); several scholars pay attention to the health effect of meso-level factors such as social capital, social support, and social network on the elderly (5, 6); there are also some studies concentrating on the health effect of macro policy factors such as the household registration system (also known as hukou system), social security, and public services on the elderly (7, 8). In general, the existing studies, whether from micro, meso, or macro level analysis, all provided important insights for advancing the understanding of elderly health and its influencing factors.

The research regarding the health effect of the number of children on elders' health is relatively insufficient. Since the late 1970s, China has implemented a strict one-child policy on the Han majority for a long time, and the number of one-child families has increased incessantly. Nowadays, more and more one-child parents have entered old age, and their health status deserves more attention. The hukou system has colonized its role of allocating various socioeconomic resources across mainland China since the 1950s, and the urban-rural dualization development mode has been forged accordingly, putting agricultural hukou holders at a disadvantage in accessing resources such as education, medical services, housing, social security, etc. (9, 10). In the context of the urban-rural dualization, the social and medical resources that rural hukou holders can access are far more scarce than their urban counterparts, consequently, children are more irreplaceable for rural parents seeking old-age support. Meanwhile, with the advancement of urbanization, many rural young adults migrate to cities in order to seek economic opportunities. However, due to the restrictions the hukou system has exerted, rural elders cannot migrate to cities with their children, and therefore the number of empty-nest elders living in rural areas has continuously risen. Under the dual insufficiency of social resources and children, rural elders with only one child may face higher risks in various aspects of old-age support, their health condition deserves more extensive attention from all social circles. So, how does the number of children affect the health of the elderly? Through what channels does it work? The answers to the above questions could lead to better understanding of the health effect of fertility on elders, and shed new light on facilitating a healthy aging process.

Under the background of urban-rural dualization, from the perspective of different hukou categories, and drawing support from the latest released CHARLS 2018, we provide empirical answers to the above questions by exploiting the implementation of the one-child policy in 1979 to construct instrumental variables (IVs), and further employ two-stages least square (2SLS) and marginal treatment effect (MTE) techniques.

LITERATURE REVIEW

The Urban-Rural Elderly Health Inequality Led by the Hukou System

Before the reform and opening-up of China, the "scissors gap" system defined the developmental pattern throughout mainland China, and the authority depressed the price of agricultural goods boost the relative price of industrial goods, accumulate industrial capital, and further facilitate rapid industrialization. Although the wages of urban workers in industrial sectors had also been trimmed, the urban government provided them with certain social welfare, such as education of children, housing allowance, and medical services, which were far beyond rural residents' accessibility. Consequently, the real income of urban citizens was significantly higher than their rural counterparts, which created a strong motivation for migrating to cities among rural residents. In order to preclude the massive internal migration and the potential collapse of the "scissors gap" developmental pattern, a household registration system (also known as the hukou system) based on birthplace and lineage emerged as the authority required. With the reform of this system, as market-oriented economy gradually renewed the mainland, the restrictions the hukou system imposed on internal mobility gradually lightened. However, the hukou system still dominates social resources allocation to a certain extent, and in large cities where the population migrates to, some important social welfare and public resources are still only available for citizens with local hukou, and those with agricultural hukou could be denied in accessing local government-funded welfare (10). Existing literature has substantiated that the multi-dimensional social welfare disparities caused by the hukou system have adversely affected the health of agricultural hukou holders (11, 12). Intertwined with these urban-rural disparities, the intensified aging process has made the health status of agricultural elders worse than their non-agricultural counterparts (8, 13).

Song and Smith (12) summarize four principles explaining the health effect of the hukou system: (1) Historical time and place, huge differences exist in the growth trajectory between urban and rural hukou holders, rural hukou holders always lack medical and educational resources during their growth stage, in both quantity and quality, which contributes to worse childhood health compared to urban hukou holders. For instance, Hu (14) found that completing junior high school would improve urban hukou holders' health efficiently, in contrast, only when rural hukou holders completed senior high school could the improvement effect of education on their health be observed. This is because schooling in rural areas is always inferior to that in urban areas. (2) Timing of lives, rural hukou holders tend to access health care and value personal hygiene at a later life stage, adding to lower health than urban hukou holders. Chen et al. (15) point out that China's social old-age medical security system is far from flawless, the problem of "valuing the city over the countryside" is particularly prominent, therefore, the probability of rural elders enjoying medical insurance is much lower than that of urban elders. (3) Linked lives, adult children are the primary old-age support for rural elders, as more and more rural young adults migrate to cities in search for better economic opportunities, the left-behind rural elders tend to show lower health status and more severe depressive symptoms. In addition, Wang et al. (16) found that the hukou category is the critical indicator for the choice of old-age care. The rural elders mainly rely upon their children to provide old-age support, while the urban elders mostly depend on their own pensions. (4) Human agency principle, urban hukou holders always possess more work opportunities and higher socioeconomic status, according to cumulative dis/advantage theory, various inequalities created by the hukou system could accumulate over the life course, eventually leading to a significant health gap between rural and urban hukou holders in the middle and late life stage. Through natural experimentation in Beijing, Afridi et al. (10) found that making students' hukou status salient evokes the inferior background of rural migrant students, impairs their confidence, and further significantly reduces their performance in the assigned task compared to their peers with local urban hukou. The accumulation of dis/advantages from

childhood will inevitably affect the health level of adulthood. Chan and Buckingham (17) reveal that a series of reforms belie the significance of the hukou system, which remains intact and potent in determining people's access to various socioeconomic resources, and entrenching the urban-rural divide.

Ge et al. (18) indicate that the aging process in China has far outpaced not only most developing countries, but also many developed countries. Successful aging must be healthy aging, which is no longer just a future-oriented policy idea, but a pressing strategic option. In recent years, with the deepening of China's aging, sociologists and economists have extensively discussed the factors affecting elders' health. On the macro level, the health disparity driven by the hukou system have been widely documented (8, 12, 13). The inequality formed on the macro level spontaneously impacts the health effect of micro-level factors. For example, Li and Zhao (19) found that the improvement effect of education on the health of urban hukou holders is significantly greater than that of rural hukou holders. Zhao and Liu (20) demonstrate that Internet usage could ameliorate urban elders' health; this health-improving effect is insignificant for rural elders.

Thus, it can be seen that rural elders might be exposed to higher health risks relative to non-agricultural elders. The tighter socioeconomic resource constraints facing rural elders may make their health more sensitive to the decline in the number of children.

One-Child Policy and the Health Effect of Depressed Fertility

After the termination of the Cultural Revolution[1] in 1976, China's authority was shocked by the fact that although the Chinese population increased by almost 50% from 1955, the grain production in 1977 still stagnated at its 1955 level. So, China's authority enacted the one-child policy to rigorously limit the children Han majority families could have (21). As the birth-controlling policy gradually strengthened its grip throughout mainland China, the number of one-child families grew continuously, the burden of population has eased as a result. However, as one-child parents gradually entered into their old-age stage, a series of social problems caused by low fertility have stirred concerns among many sociologists. Chen (22) points out that a one-child family holds natural structural deficiencies and systemic risk. In developing countries where social security and public welfare are relatively insufficient, the sudden reduction in the number of children is likely to reduce the necessary support for the elderly, thereby impairing the health of the elderly. Guo (1) found that parents with multiple children have higher life satisfaction and lower depression compared with parents with only one child. Xv and Feng (23) suggest that China's one-child families face many risks, the deficiencies in economic and emotional support are especially prominent. Liu et al. (2) reveal that only-child parents in rural areas have lower incomes than parents with multiple children, and showing worse physical and mental health. Ma (24) thinks that an important pathway for children to affect their parents' health and cognitive abilities lies in the financial support provided by children to their parents. Oliveira (25) shows that the amount of upstream intergenerational transfer payments was associated positively with the number of children. In other words, parents with only one child receive significantly less intergenerational transfer payments than parents with multiple children. Wang et al. (16) point out that compared with the urban elderly, the rural elderly are more inclined to choose their children as the basis for providing future elderly care. Sun (26) reveals that the average income of the non-agricultural elderly is 4.5 times that of the agricultural elderly. Judging from existing literature, the negative effect of low fertility on upstream intergenerational transfer payments may create a health gap between parents having only one child and parents having multiple children.

Furthermore, the change driven by lower fertility may not be all bad for parents, for instance, the "quantity-quality tradeoff" theory has been verified by many scholars against China's context; raising fewer children would translate into higher educational attainment for the offspring within the family (27, 28), and children's better educational achievement would improve parental health conditions (24). Torssander (29) reveals the significantly negative association between the education of children and parental mortality risk in Sweden. In addition, scholars in rich countries highlight the motherhood penalty in the labor market, in which fertility often curtails mothers' competitiveness in her career (30, 31). Ruppanner (32) finds that births pose more time pressure on mothers than fathers in Australia, which may explain why mothers tend to concentrate on part-time work. Besides, lower fertility also means loosened pecuniary budget constraints facing a family, parents thus have a chance to improve their life quality and curb the negative impact of decreased fertility. However, dwindling intergenerational contact frequency may result from having fewer children, Chen and Fang (33) find that birth controlling did reduce contacts and visits from children. Therefore, decreased fertility may have a mixed effect on parental health; the hukou system may even further complicate the results.

Through reviewing existing literature, we find that there are few studies that explore the impact of the number of children on parental health from the perspective of the hukou system. From this, we draw support from the latest released CHARLS 2018, and explore the above question by exploiting the enactment of the one-child policy in 1979 to construct IVs. We have contributions in the following aspects: (1) Considering the urban-rural dualization in China, we investigate the health effect of the number of children on urban and rural parents, respectively, which supplements previous research. (2) We exploit the one-child policy enactment in 1979 to construct IVs, the empirical strategy we employed shares some characteristics of a natural experiment, which effectively assuages endogenous concern. (3) In addition to the well-known IVs method, we also employ the MTE approach, solving problems of selection on both levels and gains, which makes our results more robust.

[1]Proletariat Cultural Revolution, launched by Chairman Mao Zedong in 1966, aimed to maintain the purity of the Party and seek China's own road to building socialism initially, leading to a decade long violence, social turmoil, and stagnation of economic development throughout mainland China until 1976.

DATA

We capitalize upon the 2018 wave of the China Health and Retirement Longitudinal Study (CHARLS 2018) to complete our research. CHARLS mainly collects national representative samples of Chinese citizens aged 45 and older to facilitate scientific research related to elderly people, which is supported by Peking University, the National Natural Science Foundation of China, the National Institute on Aging, and the World Bank. The baseline of CHARLS was introduced in 2011 and incorporates ∼10,000 households and 17,500 individuals across 150 counties/districts and 450 villages/resident committees. CHARLS is suitable for our research, it contains copious indicators pertaining to individuals' demographic characteristics, family information, and health status, etc. As aforementioned, the one-child policy mostly targeted the Han majority, and ethnic minorities still had the rights to have two children. Moreover, life expectancy for Chinese men is 73.64, and the average for Chinese women is 79.43, incorporating individuals over 80 years old may cause survival selection bias (34), and previous research studying Chinese elders' health focuses on people aged 80 and below (35), so we limited our sample to those who were between 50 and 80, belonged to the Han majority, and had at least one child in CHARLS 2018. **Table 1** presents the descriptive

TABLE 1 | Descriptive statistics of mainly used variables.

VarName		Obs_ urban	Mean_ urban	Obs_ rural	Mean_ rural	Difference
adl_index	Activities of daily living index, composed of seven specific indicators (Cronbach's α = 0.7932; overall Kaiser-Meyer-Olkin (KMO) value = 0.8712), with a higher value indicating better health condition	3,116	86.917	11,827	82.693	4.224***
iadl_index	Instrumental activities of daily living index, composed of six specific indicators (Cronbach's α = 0.8149; overall Kaiser-Meyer-Olkin (KMO) value = 0.8444), with a higher value indicating better health condition	3,116	94.955	11,833	92.495	2.460***
only_child	Having only one child = 1, having multiple children = 0	1,874	0.340	6,805	0.099	0.241***
$I[c_i \geq c_0]$	The birth year of the first child, after or in 1979 = 1, before 1979 = 0. I[.] is an indicator function	3,137	0.735	11,874	0.742	−0.006
$I[c_i \geq c_0] \times (c_i\text{-}c_0)$	The interaction item combining whether the first child born in and after 1979 with the distance between the birth year of first child and 1979, i.e., I[the first child born in and after 1979 ≥ 1] × (the birth year of first child−1979)	1,871	3.897	6,800	3.614	0.283*
Agrihk	Hukou category, agricultural hukou = 1, non-agricultural hukou = 0	3,137	0.000	11,874	1.000	−1.000
Female	Gender, female = 1, male = 0	3,137	0.479	11,874	0.529	−0.050***
Age	Respondents' age in 2018	3,137	63.392	11,874	62.259	1.134***
Education	Degree of education, illiterate = 0, completed elementary school and below = 1, completed middle school = 2, completed high school and above = 3	3,137	1.916	11,874	1.087	0.829***
Single	Marital status, single = 1, having a partner = 0	3,137	0.130	11,874	0.128	0.002
CPC	Political partisanship, the Communist Party of China member = 1, others = 0	3,137	0.223	11,874	0.063	0.160***
Sibling	Number of siblings	1,713	3.917	6,495	4.092	−0.175***
Insurance	Which type of health insurance could you access and benefit from it? No insurance = 0, new rural cooperative medical insurance = 1, urban and rural resident medical insurance or urban resident medical insurance = 2	3,128	1.071	11,852	0.629	0.442***
Pension	Which type of pension do you currently receive, expect to receive, or contribute to? Haven't participated in any pension scheme = 0, new rural resident pension = 1, urban and rural resident pension or urban resident pension = 2, basic pension for enterprise employees = 3, public pension for public servants or institution employees = 4	3,073	2.565	11,281	1.133	1.433***
Alcohol	Did you drink any alcoholic beverages in the past year? How often? None = 0, less than once a month = 1, more than once a month = 2	3,117	0.687	11,837	0.588	0.100***
Smoke	Have you ever chewed tobacco, smoked a pipe, smoked self-rolled cigarettes, or smoked, cigarettes/cigars? Yes = 1, no = 0	3,117	0.444	11,841	0.435	0.009
lntrans_from	The natural logarithm of the amount of intergenerational contact received from offspring during the last year	2,996	0.835	10,981	0.263	0.572***
Housing	The housing condition factor, covering seven specific indicators (Cronbach's α = 0.6383; overall KMO = 0.7626), with a higher value indicating better housing condition	1,582	6.409	6,302	6.756	−0.348***
mean_edu	Average number of years of education for children	3,110	0.542	11,821	−0.135	0.676***
mean_vispermon	Average number of days children not living with you/visit you in person per month	1,641	12.096	6,492	8.750	3.346***
Son	How many sons who are still alive do you have?	1,576	7.267	6,272	4.842	2.425***
Daughter	How many daughters who are still alive do you have?	3,137	0.715	11,874	0.901	−0.186***

$^{***}p < 0.001$, $^{*}p < 0.05$.

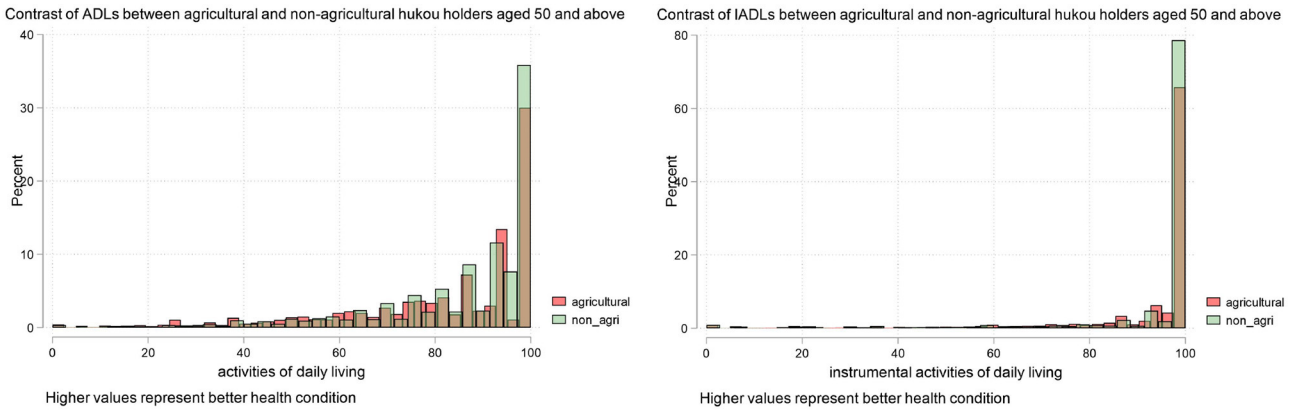

FIGURE 1 | Contrast of health status between non-agricultural and agricultural hukou holders (left: ADLs index; right: IADLs index; samples have been restricted to those who are Han majority, and aged 50 and above).

statistics of variables satisfying our sample restriction standards in this research.

We select seven specific indicators in CHARLS 2018, using the principal factor method of iterative common factor variance to construct the factor of activities of daily living (ADLs) (Cronbach's $\alpha = 0.7932$, overall KMO $= 0.8712$). According to Hamilton (36), the factor analysis using iterated communalities could find the latent dimensions that best explained correlated patterns among variables. The same method is used again to construct factor measuring people's housing condition to examine the potential mechanism. After factor-rotated, we adopt range standardization to convert this factor to a continuous index ranging from 0 to 100, with a higher value indicating a better health condition (37). The seven specific questions are: Do you have any difficulty with (1) running or jogging about 1 km; (2) getting up from a chair after sitting for a long period; (3) climbing several flights of stairs without resting; (4) stooping, kneeling, or crouching; (5) reaching or extending your arms above shoulder level; (6) lifting or carrying weights over 5 kg, like a heavy bag of groceries; (7) picking up a small coin from a table? Then, we select another six specific indicators[2] using the same methods to construct an instrumental activities of daily living (IADLs) index (Cronbach's $\alpha = 0.8149$, overall KMO $= 0.8444$) ranging from 0 to 100, also with a higher value representing a better health condition. The details of factor loadings are presented in the **Supplementary Material**.

Before we further employed an empirical technique, we first illustrate our dependent variables in **Figure 1**, it is obvious that non-agricultural hukou holders' health status is better than agricultural hukou holders.

EMPIRICAL STRATEGY

Benchmark Regression

As previously discussed, Chinese authorities imposed a strict birth-planning policy, i.e., the one-child policy on the Han majority in 1979, and many studies make rational and effective use of individuals' birth cohorts (i.e., born after 1979 or not) to explore the social influence of changing fertility (2, 21). We also utilize the birth year of individuals' first child to construct our instrumental variables (IVs), and draw support from two-stage least square (2SLS) to further investigate the health effect of lower fertility. The effectiveness of the IV method lies in the exogeneity of excluded IVs, anecdotal evidence suggests that the requirement is very likely to be satisfied in this case. As aforementioned, one-child policy enactment came as a shock to Chinese households. During the Cultural Revolution, they could not legitimately anticipate the sudden changing of fertility rights, and even though few officials had speculated the looming radical birth-planning policy, pregnancy lasts ∼10 months, meaning that they were barely capable of having another child in such a pressing situation. Besides, cesarean section and other artificial birth control techniques were underdeveloped in the 1970s in mainland China. As a result, they were practically unable to manipulate the child birth cohort to avoid the unexpected strict one-child policy.

At the preliminary stage, the extent of rigidity and the specific launch time varied across mainland China, therefore, the discontinuity at the cutoff might be relatively small. As China's authority gradually promoted a series of decrees strengthening birth-planning, the one-child policy unfolded throughout mainland China[3]. So the change of fertility may not

[2]Because of health and memory problems, do you have any difficulties with (1) doing household chores; (2) preparing hot meals; (3) shopping for groceries; (4) making phone calls; (5) taking medications; (6) managing your money, such as paying your bills, keeping track of expenses, or managing assets?

[3]For example, in September 1982, the 12th National Congress of the Communist Party of China (CPC) established family planning as a basic national policy, and it was written into the Constitution in December of that year. In May 1991, the Central Committee of the CPC and the State Council made the *Decision on Strengthening Family Planning and Strictly Controlling Population Growth*, clearly enacting the birth-planning policy and strictly controlling population growth. In September 2002, the *Population and Family Planning Law of the People's Republic*

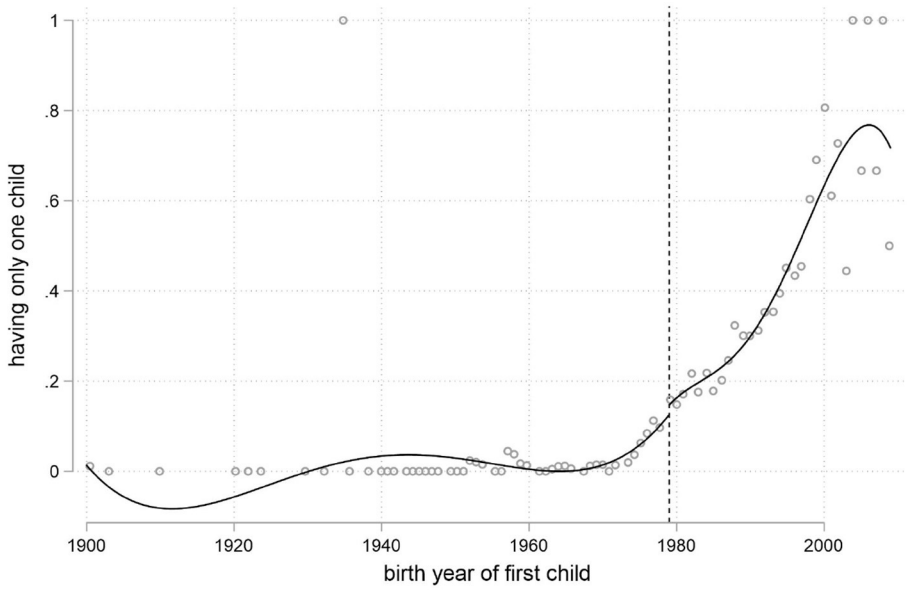

FIGURE 2 | The impact of the one-child policy on individuals' fertility.

be fully reflected in the level (i.e., the intercept), and be expressed more adequately in the tendency (i.e., the slope). In other words, the level (jump) and slope (kink) would both change at the cutoff due to the different extent of exposure to the one-child policy. Generally, the later the birth year of people's first child, the higher probability of having only one child. Before 2011, having a second child was officially and nationally permitted for parents who did not have any siblings. Considering that individuals with a first child born before 1979 could conceive another child before the policy came into effect, to better identify the health effect of fertility, we use both jump and kink formed around the cutoff to construct our IVs: (1) $I[c_i \leq c_0]$, which is an indicator function, if the first child of individual *i* had been born in and after 1979, it equals 1, before 1979, then it equals 0. (2) $I[c_i \leq c_0] \times (c_i\text{-}c_0)$, the interaction item combining $I[c_i \leq c_0]$ with the difference of the birth year of the first child minus 1979.

$$\begin{aligned} only\_child_i &= \beta_1 I[c_i \geq c_0] + \alpha_1 I[c_i \geq c_0] \times (c_i - c_0) \\ &+ \delta_1 controls_i + \lambda_p + \varepsilon_i \qquad (1) \\ (i)adl\_index_i &= \beta_2 I[c_i \geq c_0] + \alpha_2 I[c_i \geq c_0] \times (c_i - c_0) \\ &+ \delta_2 controls_i + \lambda_p + \mu_i \qquad (2) \end{aligned}$$

The two-stage least square (2SLS) technique has been used to identify the health effect of lower fertility. Equation (1) depicts the first stage estimation, $only\_child_i$ is the critical independent variable–whether people have only one child or not, if individual *i* only has one child, let $only\_child_i = 1$, if he or she has multiple children, let $only\_child_i = 0$. Equation (2) denotes the reduced-form specification we used earlier to construct the ADLs index and IADLs index as our dependent variables, respectively, to represent individuals' health status. We select 10 control variables presented as "$controls_i$" in equations (1, 2): gender, age, marital status, and number of siblings as demographic variables; CPC membership, the degree of education, and health care insurance possession as socioeconomic variables; whether they smoke and the frequency of drinking alcohol as health behavior variables.

Local governments were given certain discretionary powers to adjust the rigidity of the enactment of the one-child policy based on local demographic and socioeconomic condition, which may results in different strictness of birth planning, and loosened grip on certain parents, we thus incorporate a provincial dummy variable in our estimation framework to capture the potential heterogeneity among different provinces, "λ_p" is the provincial fixed effect. "μ_i" and "ε_i" represent the error term. The flexibility of imposing fertility controlling of local government may also loosen the ties restricting childbirth, so the proportion of parents with only one child is relatively lower, only 15%, which can be seen in **Table 1**. The 2SLS approach therefore provides an identification of health effect of having only one child instead of multiple children, which could be calculated as $\frac{\omega_1\hat{\beta}_1+\omega_2\hat{\alpha}_1}{\omega_1\hat{\beta}_2+\omega_2\hat{\alpha}_2}$, $\omega_1 = cov(D_i, I[c_i \leq c_0])$, and $\omega_2 = cov(D_i, I[c_i \leq c_0] \times (c_i\text{-}c_0))$, which represent the weights reflecting the relative strength of the two IVs.

As illustrated in **Figure 2**, the intercept and slope of having only one child instead of multiple children for the Han majority both demonstrate an obvious change at 1979, especially for the change of slope, justifying our IVs construction.

of China came into effect, etc. Although there existed a temporary period of time in which families in certain rural areas were allowed to have a second child if the first one was a daughter in 1984, the central government later felt the laxity and call for stronger compliance to birth-planning, then proclaimed the *Central Document 13* in 1986 more rigorously regulating the one-child policy than before.

TABLE 2 | The health effect of having only one child.

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	urban_adl		rural_adl		urban_iadl		rural_iadl	
	adl_index	only_child	adl_index	only_child	iadl_index	only_child	iadl_index	only_child
only_child	−1.085		−9.165*		−3.356		−12.083***	
	(2.743)		(3.827)		(2.355)		(3.256)	
$I[c_i \leq c_0]$		0.284***		0.061***		0.284***		0.060***
		(0.031)		(0.012)		(0.030)		(0.012)
$I[c_i \leq c_0] \times (c_i\text{-}c_0)$		0.028***		0.019***		0.028***		0.019***
		(0.003)		(0.001)		(0.003)		(0.001)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Minimum eigenvalue	93.921		145.802		93.921		147.557	
Observations	1,677	1,677	6,149	6,149	1,677	1,677	6,154	6,154

*Standard errors in parentheses; ***p < 0.001, *p < 0.05. For simplicity, the sample group of urban hukou holders is labeled as "urban," and the sample group of rural hukou holders is labeled as "rural." The samples are restricted to those aged between 50 and 80, have at least one child, and belong to the Han majority.*

TABLE 3 | The mechanism analysis.

Variables	(1) Urban Intrans_ from	(2) Rural Intrans_ from	(3) Urban housing	(4) Rural housing	(5) Urban mean_ edu	(6) Rural mean_ edu	(7) Urban mean_ vispermon	(8) Rural mean_ vispermon
only_child	−3.605***	−9.388***	0.279*	0.003	1.774**	0.746	−9.111***	−6.909**
	(0.784)	(0.973)	(0.123)	(0.150)	(0.559)	(0.594)	(2.228)	(2.118)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,428	5,716	1,670	6,141	1,543	5,991	1,421	5,685

*Standard errors in parentheses; ***p < 0.001, **p < 0.01, *p < 0.05. For simplicity, the sample group of urban hukou holders is labeled as "urban," and the sample group of rural hukou holders is labeled as "rural." The samples are restricted to those aged between 50 and 80, have at least one child, and belong to the Han majority.*

Table 2 presents the results of the benchmark regression. The coefficients of our IVs in the even-numbered columns are all positive and significant at the 1% level, empirically justifying the strong correlation between having only one child and the jump and kink, and the minimum eigenvalues are all far greater than the critical value 19.93, rejecting the null hypothesis of the existing weak IV. Moreover, the magnitude of the coefficients of IVs in the urban group is noticeably higher than that in the rural group, this may be because families in several rural areas were permitted to have two children if the first one was a daughter in 1984 for a temporary period, besides, disobeying the one-child policy might cause more harm for urban citizens, since their career could be destroyed once they get caught having multiple children, especially when urban citizens have been working in public sectors. In columns (1) and (5), the coefficients of having only one child are both statistically insignificant, suggesting that lower fertility does not harm Chinese urban parents' health. By contrast, in columns (3) and (7), the coefficients of having only child for rural hukou holders are also both significantly negative, and the magnitude increases dramatically compared to the urban group, assuming that the imposition of the one-child policy dampened China's rural parents' health more.

Mechanism Analysis

Next, we further investigate through which channel Chinese rural hukou holders bear the brunt of the lower fertility brought by the one-child policy. Scholars have emphasized the important role intergenerational transfers played in supporting elders in China (38, 39), and the amount of intergenerational transfers often correlated negatively with the number of children (26, 40). As shown in **Table 3**, we first examine the impact of having only one child on upstream intergenerational transfer, in columns (1) and (2), the dependent variable is the natural logarithm of the aggregate of the amount of financial support received from children during the last year, which consists of both pecuniary and in-kind payment-received support, and its coefficients are all significantly positive. The same 2SLS framework using both jump and kink as IVs is applied again, the coefficients of having only one child are negative and significant at the 1% level for both urban and rural hukou holders, but the magnitude of having only one child of the urban group only accounts for 38.5% of the rural group, suggesting that lower fertility depresses rural hukou holders' upstream intergenerational transfers more, therefore the health condition of rural hukou holders are more negatively responsive to lower fertility than their urban counterparts. Song and Smith (12) pointed out that rural hukou holders are

always entitled to education resources inferior to their non-agricultural counterparts in their earlier life stage, and they often face occupational segregation and wage arrears in their adulthood. Consequently, for agricultural elders, the reduction in the number of children may metamorphose into lower upstream transfers than their non-agricultural peers.

While, having fewer children could spare more resources redirected to parents to improve their life quality, next, we explore how lower fertility affects parental housing condition. In columns (3) and (4), the dependent variable is housing condition factor[4] rotated through the same factor analysis method previously conducted to construct ADLs and IADLs indexes, with a higher value indicating a better housing condition. The coefficient of having only one child is positive and significant at the 5% level for the urban group, suggesting that raising fewer children did translate into better housing condition for urban parents, which therefore might curb the negative health effect of lower fertility, while, rural elders may be less lucky, the coefficient of only having one child is statistically insignificant for rural parents, and its magnitude plummets drastically compared with their urban counterparts. Given the consistently inferior socioeconomic status linked with rural hukou, it is unsurprising that elders are unable to improve their housing condition in rural areas despite the decline in number of children they have to raise.

As aforementioned, the "quantity-quality tradeoff" theory may play a role in improving offspring's educational attainment within a smaller family, thus providing a chance for elderly parents to benefit from their children's higher educational achievement (24). In columns (5) and (6), we use children's average number of years of education as the dependent variable, the coefficient of having only one child in 2SLS estimation is positive and significant at the 1% level in the urban group, in contrast, its magnitude and statistical significance both plunge for rural elderly parents, implying that diminishing fertility may not effectively transform into increased educational attainment in China's rural areas. Hu (14) finds that receiving elementary education could effectively improve China's urban citizens' health condition, by comparison, the positive health effect of education becomes statistically significant for rural residents only when they finished senior high school. The relatively inferior education quality and infrastructure concomitant with rural hukou and cumulative dis/advantage theory may lead to impairment of the efficiency of the "quantity-quality tradeoff" theory in China's rural families, and undermine the potential advantage of having fewer children for rural elders.

[4]We selected seven variables (overall KMO value = 0.7626) to construct a housing condition factor: the type of structure of the current residence (concrete = 1, others = 0); the type of toilet (with a seat = 1, without a seat = 0); whether current residence has electricity (yes = 1, no = 0); whether current residence has running water (yes = 1, no = 0); whether current residence is equipped with an in-house shower or bath facility (yes = 1, no = 0); whether current residence has a coal gas or natural gas supply (yes = 1, no = 0); and whether current residence has a broadband Internet connection (yes=1, no=0). The factor analysis using the aforementioned iterated communalities were employed again to rotate the housing condition factor.

The deterrent effect of lower fertility on the contacts and visits from children are also well-documented by economists (24, 33). We next choose the average number of days receiving visits from children per month as our dependent variable. In columns (7) and (8), the coefficients of having only one child rather than multiple children are both statistically negative, indicating that a downsized number of children trims the frequency of vis-à-vis contact between parents and offspring. The magnitude and statistical significance are both more pronounced for the urban group, considering the hard-pressed lifestyle adopted in many of China's cities, it is natural that adult children would put more energy and time in the labor market, thus reducing the amount of time visiting parents.

Through exploring various potential mechanisms, **Table 3** presents a relatively mixed result of how having fewer children affects elderly parents, on the one hand, dwindled childbirth paired with upstream intergenerational transfer, dragged down the frequency of visits from offspring for both urban and rural parents; on the other hand, it increased children's educational attainment and improved parental housing condition, while, the positive effects are only statistically significant for the urban group in the 2SLS framework, which may shed light on why raising fewer children only dampened rural parents' health.

Heterogeneous Analysis

In this section, we construct interactive items to analyze the heterogeneity of having only one child on peoples' health. The extended regression model (ERM) has been used in this part. ERM could estimate the interactions of endogenous covariates, and interactions of endogenous with exogenous covariates (41), which earlier STATA commands like ivregress, ivprobit, and ivtobit could not. In addition, Jiang and Wang (42) point out that bidirectional causality, omitting variables, and sample selection bias could be addressed simultaneously in ERM. Since our previous results demonstrate that the health effect of having only one child instead of multiple children only exhibits statistical significance for rural elderly parents, we principally analyze the potential heterogeneity within the rural group in this subsection. As **Table 4** shows, rural female elders tend to benefit more from lower fertility. Mothers often have a more intimate connection with children, the relatively higher emotional support may dilute the negative health effect of lower fertility at some point, moreover, the motherhood penalty in the labor market has been well-documented by scholars (30, 31), raising fewer children might boost mothers' labor market performance and increase their income, therefore acting as a cushion against the potential negative impact of having only one child in the old-age stage. In addition, as the direct bearer of pregnancy, mothers often bear the brunt of the negative health effects of giving birth, diminished fertility would thus naturally lower the risks facing women (43, 44). Meanwhile, the coefficients of the interaction term are all statistically insignificant in columns (2–8), suggesting universality of our earlier results.

Further Discussion

China has seen its hukou system experience a variety of reforms, which gradually allowed rural residents to migrate to cities as

TABLE 4 | The heterogeneous analysis.

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	ERM							
	adl_index	iadl_index	adl_index	iadl_index	adl_index	iadl_index	adl_index	iadl_index
only_child × female	2.687+	1.126						
	(1.503)	(1.268)						
only_child × age			−0.003	0.118				
			(0.118)	(0.100)				
only_child×edu_level					−1.148	0.260		
					(0.896)	(0.756)		
only_child × single							2.359	1.318
							(2.004)	(1.694)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	6,149	6,154	6,149	6,154	6,149	6,154	6,149	6,154

Standard errors in parentheses; +p < 0.1. For simplicity, the sample group of urban hukou holders is labeled as "urban," and the sample group of rural hukou holders is labeled as "rural." The samples are restricted to those aged between 50 and 80, have at least one child, and belong to the Han majority.

reform and opening-up unfolded throughout mainland China and the market regained its ascendancy of signaling permission. While, the accessibility of multifarious socioeconomic resources determined by the hukou category may not vary very much, rural residents without local urban hukou could still be denied schooling, housing, and medical care after they migrate to cities, which retains the urban-rural divide bestriding China's society (12, 17). In 2014, CHARLS provided Life History data, we draw people's initial hukou status from this data set and identify those who have experienced rural-to-urban hukou conversion, to further explore the health effect of having fewer children more thoroughly. As **Table 5** presents, in columns (1) and (2), only having one child barely affects parental health for those who were born with urban hukou. In comparison, the coefficients of having only one child rather than multiple children are both significantly negative in columns (3) and (4), revealing the deterrent impact of decreased fertility on the health condition for people whose first hukou belongs to the rural category. What is more intriguing is the results in columns (5) and (6), for those who initially had rural hukou but later changed their hukou to the urban category, even though the magnitude of the coefficients of having only one child exhibits an uptick compared with columns (1) and (2), the statistical significance still remains absent, assuming that overcoming the hukou barrier would effectively dilute the negative impact of lower fertility. Considering that Confucian culture has long been ingrained in China, and rural areas especially emphasize obedience and filial piety, having fewer children might be seen as defiance to family and clan. Silverstein et al. (45) notice that conforming to prevailing cultural norms has a health-enhancing effect, therefore having fewer children may pose more of a burden on rural residents' health. Once the hukou threshold has been surmounted, several factors including waning pressure from family, urbanization overtaking traditional culture, and improved resources concomitant with urban hukou combined to result in counteracting the negative influence from lower fertility.

TABLE 5 | The health effect considering initial hukou and rural-to-urban conversion.

Variables	(1)	(2)	(3)	(4)	(5)	(6)
	initial_urban		initial_rural		rural-to-urban conversion	
	adl_index	iadl_index	adl_index	iadl_index	adl_index	iadl_index
only_child	0.461	−1.757	−7.320*	−9.502***	−2.941	−3.610
	(3.521)	(2.658)	(3.211)	(2.748)	(4.507)	(3.963)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Observations	584	584	6,569	6,572	843	843
R-squared	0.196	0.190	0.191	0.073	0.223	0.095

*Standard errors in parentheses; ***p < 0.001, *p < 0.05. For simplicity, the sample group of those whose initial hukou is urban-labeled is marked as "initial_urban," the sample group of those whose initial hukou is rural-labeled is marked as "initial_rural," and the sample group of those who have changed from rural hukou to urban hukou is labeled as "rural-to-urban conversion." The samples are restricted to those aged between 50 and 80, have at least one child, and belong to the Han majority.*

Robustness Check

In this subsection, we provide several robustness checks. Considering that previously used dependent variables are obtained through factor analysis, we firstly substitute the construction method with directly summing specific indicators to examine the health effect of only having one child rather than multiple children on parental health. As aforementioned, ADLs consist of seven indicators, and IADLs consist of six, so the range of the sum of ADLs and IADLs is 28 and 24, respectively, and with a higher value indicating a better health status.

As **Table 6** shows, the estimation results of first-stage estimation are identical with the benchmark regression in **Table 2**, and the effect of decreased fertility on parental health demonstrates the same pattern, the coefficients of only having

TABLE 6 | The robustness check (1).

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	urban_adl		rural_adl		urban_iadl		rural_iadl	
	adl_index	only_child	adl_index	only_child	iadl_index	only_child	iadl_index	only_child
only_child	−0.211		−1.863*		−0.555		−2.456***	
	(0.600)		(0.822)		(0.411)		(0.595)	
$I[c_i \leq c_0]$		0.284***		0.061***		0.284***		0.060***
		(0.031)		(0.012)		(0.030)		(0.012)
$I[c_i \leq c_0] \times (c_i\text{-}c_0)$		0.028***		0.019***		0.028***		0.019***
		(0.003)		(0.001)		(0.003)		(0.001)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Minimum eigenvalue	93.921	145.802	93.921	147.557				
Observations	1,677	1,677	6,149	6,149	1,677	1,677	6,154	6,154

*Standard errors in parentheses; ***p < 0.001, *p < 0.05. For simplicity, the sample group of urban hukou holders is labeled as "urban," and the sample group of rural hukou holders is labeled as "rural." The samples are restricted to those aged between 50 and 80, have at least one child, and belong to the Han majority.*

one child are both negative and significant in columns (3) and (7), respectively, revealing the deterrent effect of having fewer children on China's rural elders. In comparison, the coefficients of having only one child are both statistically insignificant in columns (1) and (5), showing again that lower fertility barely affects urban parents' health, which aligns with our benchmark regression, and suggests that the results are insensitive to the method of constructing the dependent variables adopted.

Commonly used local average treatment effect (LATE) estimated by IVs methods only solve selection bias on levels, however, the problems of selection on both levels and gains often occur in more reasonable cases (46). In this article, this means that more motivated people tend to decide on having only one child instead of multiple children as the potential gains could be expected, this selection on returns is called essential heterogeneity, so we next employ marginal treatment effects (MTEs) to further explore the health effect of having only one child on non-agricultural and agricultural hukou holders. Andresen (46) points out that MTEs could capture the unobserved resistance to treatment (in this case, having only one child), the expectation of higher gains from being treated underpins the lower resistance to treatment, thus catalyzing certain people with lower resistance into the treatment group.

MTEs are based on the generalized Roy model:

$$Y_j = \mu_j(X) + U_j, \quad j = 1, 2 \tag{3}$$

$$Y = DY_1 + (1 - D)Y_0 \tag{4}$$

$$D = 1\left\{\mu_D(Z) > U_D\right\}, \quad Z = (X, Z\_) \tag{5}$$

Where Y_1 and Y_0 are the potential outcomes in the treated and untreated state, respectively. They are both modeled as functions of observed explanatory variables X. Equation (5) is an indicator function which is a reduced-form way of modeling selection into treatment as a function of observed X in equation (1) and excluded IVs $Z\_$. U_D represents the quantile of unobserved resistance to treatment, which can be normalized to a uniform distribution on the unit interval. Thus, $\mu_D(Z)$ can be interpreted as the propensity score measuring the conditional probability of entering the treatment.

TABLE 7 | The robustness check (2).

Variable	(1) Urban adl_index	(2) Rural adl_index	(3) Urban iadl_index	(4) Rural iadl_index
Average treatment effect (ATE)	2.442	−10.071	1.059	−8.889
	(3.438)	(7.696)	(2.895)	(6.513)
Average treatment effect on the treated (ATT)	−6.806+	−11.514**	−9.841**	−9.706**
	(3.548)	(4.021)	(2.989)	(3.406)
Average treatment effect on the untreated (ATU)	7.350	−9.912	6.846+	−8.802
	(4.794)	(8.542)	(4.038)	(7.231)
Local average treatment effect (LATE)	−1.881	−12.231**	−3.043	−9.396**
	(2.999)	(4.271)	(2.526)	(3.631)
Controls	Yes	Yes	Yes	Yes
Observations	1,665	6,090	1,665	6,095

*Standard errors in parentheses; **p < 0.01, +p < 0.1. For simplicity, the sample group of urban hukou holders is labeled as "urban," and the sample group of rural hukou holders is labeled as "rural." The samples are restricted to those aged between 50 and 80, have at least one child, and belong to the Han majority.*

There are usually two ways to estimate MTEs: (1) a local IV, which recognizes MTE as the derivative of the conditional expectation of Y regarding the propensity score; and (2) a separate approach, which estimates the conditional expectations of Y_1 and Y_0 in the treated and untreated samples separately (in this case, Y_1 and Y_0 represent the health status of parents with only one child and multiple children, respectively). Brinch et al. (47) point out that local IV cannot identify the linear MTE model with a binary instrument, so we only selected the "jump" as our IV in this part, and use the separate approach to perform the

MTE estimation.

$$E(Y_1|X = x, D = 1) = x\beta_1 + E(U_1|U_D \leq p) = x\beta_1 + K_1(p) \quad (6)$$

$$E(Y_0|X = x, D = 0) = x\beta_0 + E(U_0|U_D \leq p) = x\beta_0 + K_0(p) \quad (7)$$

$$\begin{aligned} MTE(x, u) &= E(Y_1|X = x, U_D = u) - E(Y_0|X = x, U_D = u) \\ MTE(x, u) &= x(\beta_1 - \beta_0) + k_1(u) - k_0(u) \end{aligned} \quad (8)$$

In equations (6, 7), D denotes the treatment status (having only one child = 1, having multiple children = 0), $K_j(p)$ is the control function capturing the essential heterogeneity, the separate approach could control selection through $K_j(p)$, which is in line with Heckman selection (46), and $k_j(u) = \mathrm{E}(U_j|\ U_D = u)$. We demonstrate commonly used treatment effect parameters provided by MTEs in **Table 7**, ATT does not exhibit much variation between the urban and rural groups, LATE in the rural group is significantly negative, which is consistent with the previous 2SLS estimation; lower fertility tends to put more pressure on rural hukou holders' health condition.

We also illustrate the MTEs and relevant results in **Figure 3**. ATEs of the rural group are clearly below the urban group in both cases of explained variables being the ADLs and IADLs indexes, implying that having only one child instead of multiple children may dampen rural hukou holders' health more. The upward sloping pattern of MTE suggests that people with lower resistance bear more of the health burden of lower fertility. Furthermore, the resulting potential outcomes delineate individuals' health condition alongside the resistance to treatment. The MTE is the difference between Y_1 and Y_0, so we can examine whether the upward sloping pattern of MTE plotted in **Figure 3** is created by upward sloping Y_1 or downward sloping Y_0, or a combination. As illustrated in **Figure 3**, in the urban group, there is a combination of upward Y_1 and downward Y_0, suggesting that urban citizens with only one child and higher resistance have a better health condition, and

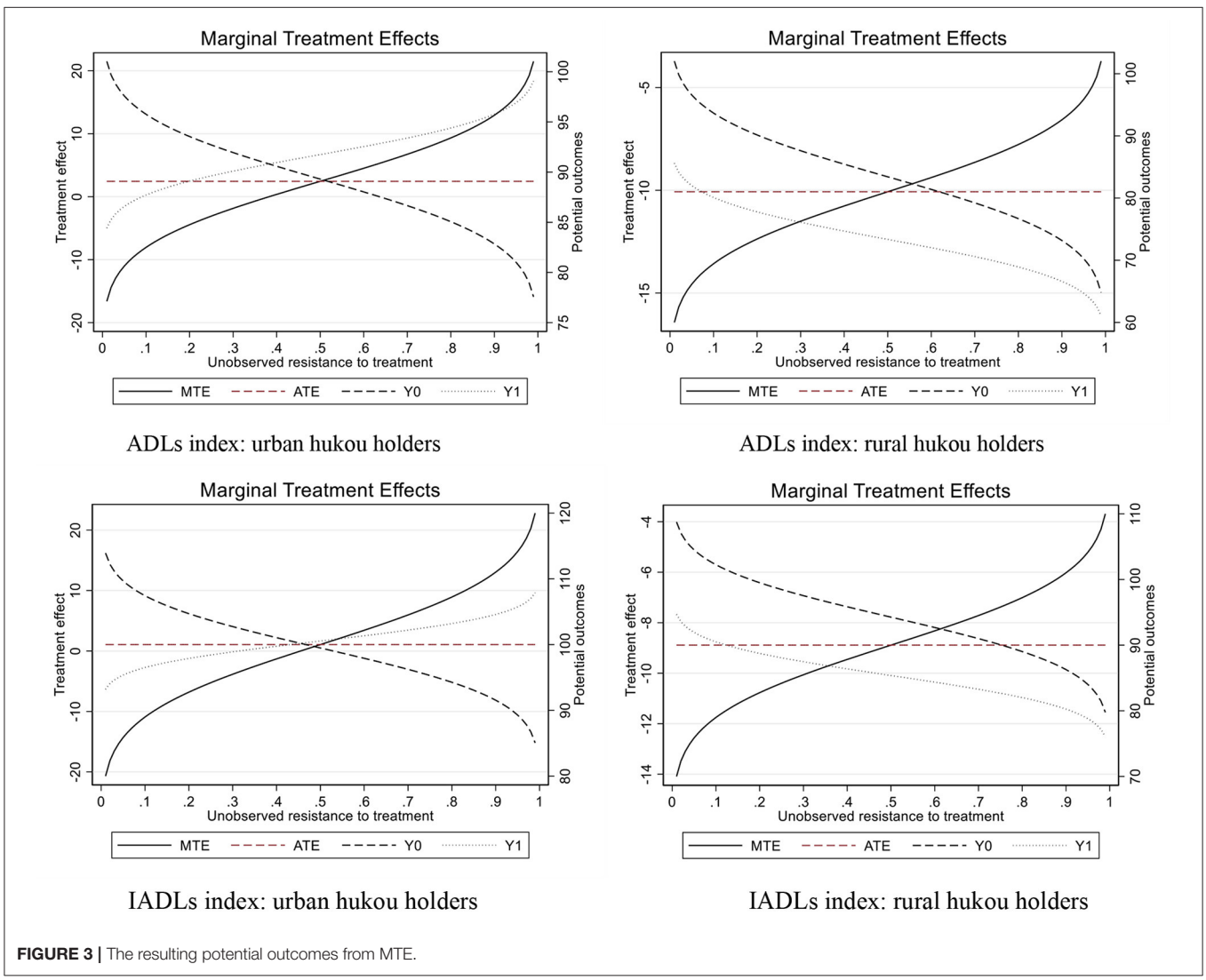

FIGURE 3 | The resulting potential outcomes from MTE.

TABLE 8 | The robustness check (3).

Variables	(1) Urban adl_index	(2) Urban adl_index	(3) Rural adl_index	(4) Rural adl_index	(5) Urban iadl_index	(6) Urban iadl_index	(7) Rural iadl_index	(8) Rural iadl_index
Son	0.157		7.076**		0.048		4.895*	
	(2.737)		(2.554)		(2.340)		(4.718)	
Daughter		0.195		11.532*		0.059		8.004*
		(3.385)		(4.869)		(2.895)		(3.867)
Observations	1,677	1,677	6,150	6,708	1,677	1,677	6,155	6,155

*Standard errors in parentheses; **p < 0.01, *p < 0.05. For simplicity, the sample group of non-agricultural hukou holders is labeled as "non-agriculture," and the sample group of agricultural hukou holders is labeled as "agriculture." The samples are restricted to those aged between 50 and 80, have at least one child, and belong to the Han majority.*

those who have multiple children and lower resistance have better health. In comparison, the rural group demonstrates both downward potential outcomes, assuming rural residents with higher resistance have worse health.

For consistency, in the last part, we also only use "jump"–individuals' first child is born in or after 1979 as our IV, and substitute having only child or multiple children with the number of sons and daughters as our core explanatory variables to construct 2SLS estimation. As shown in **Table 8**, the coefficients of the number of sons and daughters are all positive in the rural group, showing that having multiple children instead of only one child could improve rural parents' health condition. Moreover, no matter which explained variables we choose (ADLs or IADLs index), no matter what the gender of individuals' children (son or daughter), the coefficients of the number of offspring in the rural group always demonstrate higher magnitude and statistical significance compared to the urban group, suggesting that relatively higher fertility may benefit Chinese rural hukou holders more, this agrees with previous research; rural hukou holders are mainly biased toward choosing children as the basis for future support in their old age (16).

CONCLUSION

Since China's authority promoted the one-child policy in 1979, the number of one-child families has continued to rise. In recent years, as parents with only one child enter into their old-age stage, how does their health compare with parents having multiple children? Combining the background of urban-rural duality, this paper uses the one-child policy as an exogenous shock to construct IVs, and examines the health effect of having only one child rather than multiple children for urban and rural hukou holders aged between 50 and 80. The empirical results show that: (1) Having only one child instead of multiple children significantly depresses rural parents' health, while urban parents are relatively immune to this negative health impact. (2) Our mechanism analysis suggests that only having one child scaled down the upstream intergenerational transfer payments, and the received financial support of rural parents creates more pressure; the "quantity-quality tradeoff" theory is chiefly efficient in promoting the educational attainment for urban only children; similarly, having fewer children principally improves urban parents' housing condition; while, lower fertility trims the frequency of visits from offspring both for urban and rural parents, and urban parents tend to receive fewer visits than their rural counterparts with only one child. Therefore, raising fewer children may dampen rural parents' health more. (3) The heterogeneous analysis finds that the negative health effect of having only one child is relatively moderate for rural female residents, we attribute this heterogeneity to more intimacy between mothers and children, motherhood penalty in the labor market, and the risk ensued from pregnancy and giving birth.

This article carries important implications. The hukou system colonizes its role of allocating resources across mainland China, which has disadvantaged rural hukou holders for a long time. Rural hukou holders are always at a disadvantage in accessing various resources, such as housing, medical care, education, etc. Consequently, their health status is worse than urban hukou holders. Many scholars find that rural parents tend to rely on their children providing old-age support in their late life stage (16, 48). In recent years, as the aging process has continued to accelerate throughout China, as more and more one-child parents are approaching old age, and as rural parents with only one child face the dual scarcity of socioeconomic resources and upstream intergenerational support, their health condition deserves more attention from the government. In addition, China's countryside zones are often imbued with emphasis on conformity and filial piety, which definitely exacerbates the negative health effect of decreased fertility, in contrast, urbanization could slash the cost of disobeying cultural norms, and urban elders often have larger pensions thus rely less on their offspring to provide support in old age than their rural counterparts. On the one hand, China's authority should further ease or even neutralize the connection between individuals' hukou category and the accessibility of socioeconomic resources as well as facilitate urbanization; on the other hand, government should enhance old-age support for parents with only one child, especially for rural parents, their compliance to the one-child policy deserves more social care and public welfare, which would serve as a cushion against the negative health effect of lower fertility.

DATA AVAILABILITY STATEMENT

Publicly available datasets were analyzed in this study. This data can be found at: The data of CHARLS 2018 is publicly available by application through http://charls.pku.edu.cn.

AUTHOR CONTRIBUTIONS

CL and JH: conceptualization. JH: methodology. JH, CL, and CY: writing-original draft preparation. CL and CY: writing-review and editing. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2021.700024/full#supplementary-material

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Widowhood and Health Status Among Chinese Older Adults: The Mediation Effects of Different Types of Support

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Although many studies have suggested that widowhood is related to worse health conditions among older adults, few have examined the mediation effects of social support between widowhood and health. Employing mediation analysis to a sample of data from the 2014 wave of China Longitudinal Aging Social Survey (CLASS), this study examined the mediation effects of social support, including emotional support, instrumental support, and companionship, in the widowhood-health association among older adults. The results indicated that the negative effect of widowhood on older adults' health was in part attributable to decreased emotional support and companionship. Specifically, emotional support exerted a significant role in the widowhood-mental health association, and companionship exerted a significant role in widowhood-physical health and widowhood-mental health associations. In the subsample analysis, the mediation effects were only significant among female older adults, and among rural older adults. Our findings highlight the importance of emotional support and companionship in maintaining health among widowed older adults and strategies should pay more attention to female and rural widowed older adults.

Keywords: widowhood, social support, health, mediation effects, older adults

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INTRODUCTION

The loss of a spouse is one of the most painful and stressful events faced by older adults, as well as an inevitable role transition (1–3). Surviving spouses must bear the grief of losing a partner who provides daily support and companionship (4, 5). This may have adverse effects on mental and physical health (6–9). Even if widowhood is universal for all older adults, its impact on health varies according to gender, cultural norms, and social structure (10, 11).

A recent study indicates that widowhood alone may not lead to depression in older adults, but those who are widowed and socially isolated have an increased risk of depression (11). Social support seems to be a potential mediator in the pathway from widowhood to health. Lots of research has proved that social support as an important protective factor for mental and physical health, can lower the mortality risk, prevent depression, and maintain good physical health among older adults. However, social support tends to shrink with age, particularly after the death of a spouse who may be the primary support provider (12, 13). Currently, we know little about the role of social support and its subtypes in the relationship between widowhood and health. Besides, considering

the characteristics of social support formed by different social structures and cultural norms are different (11, 12), it is necessary to explore the role of support in the pathway from widowhood to health, under the background of urban-rural dual structure and rigid gender division.

Therefore, using the 2014 wave of China Longitudinal Aging Social Survey (CLASS), this paper aimed to examine: (1) whether the relationship between widowhood and the health status of older adults is mediated by social support, especially the different types of social support; (2) whether the mediation effects of social support vary according to gender and rural-urban areas. Below, we first introduced the literature review, which provides an overview of the relationship between widowhood, social support, and health status, and a brief introduction of the Chinese context. Second, the data and methods section outlines the sample adopted, the measurement of variables, and the analytic strategy. Third, the results section demonstrates the role of social support in the widowhood-health relationship, including gender and rural-urban specific findings. Finally, the discussion and conclusions section compares the findings to the existing literature and considers the contribution to the existing knowledge base. And the limitations of the study and suggestions for further research are also considered.

LITERATURE REVIEW

Widowhood and Health Status

Many studies have shown that the health of older adults tends to deteriorate after losing a spouse (14–16). According to the "marriage protection effect" hypothesis, marriage can promote good health through support for healthy behaviors (17). For example, spouses can motivate or encourage each other to quit smoking, engage in physical activities, and maintain a healthy diet, all of which are important for somatic health (18). On the other hand, marriage can also promote good health due to the available companionship, economic, and material resources (19, 20). A study by Emanuele reported that co-residency of couples provides companionship, better financial status, and health care resources (21).

The association and the mechanisms between widowhood and health seem not the same for all age groups (5, 10, 22). It is more detrimental to be bereaved at a younger age than it is to be widowed later in life (10). Widowhood, for example, raises the risk of death in older people, but the link is weaker for those aged 75 and above (22). Based on a sample of 75 years old and blow, Golden et al. (23) found that a higher prevalence of depression in widows with a higher prevalence of loneliness and isolation. While Forster et al. (24) found that widowhood alone is not necessarily related, only the oldest widowers, those socially isolated, face an increased risk of depressive symptoms.

Further studies also suggest this protection effect differs by gender. Nonetheless, the findings are mixed. For example, several studies hold that men are perceived to gain more health benefits from marriage than women (6, 25), and thus men are always more vulnerable during the transition to widowhood (26, 27). While some other scholars believe that in the context of patriarchy, such as in China, women gain more health benefits from marriage due to gender inequality (11, 28). Because women tend to experience disadvantages in labor markets and face a greater risk of poverty than men, staying in marriage allows women to enjoy better living conditions and health benefits. Thus, women are more negatively affected and are more likely to suffer from poor health after being widowed (29).

Widowhood and Social Support

An abundance of research has shown that widowhood is linked to a decrease in social support (23, 30–32). Widowhood means the loss of primary support from the deceased spouse. More importantly, with the death of a spouse, relatives, and friends who relied on the spouse to maintain close relationships gradually move away, and the support from their relatives and social networks gradually decline (5, 33), resulting in less social support for the older adults (5). Furthermore, widowhood also leads to poor health status among older adults, creates barriers to social participation and maintaining social connections, and results in changes in social networks and less social support (34). Although some research focused on marital status, and found that widowers received less support than their coupled counterparts (14, 29), little has differentiated the types of social support, such as emotional and instrumental support (29).

Further research suggests that the change in social support for widowed older adults differs by gender. That is, for husbands, widowhood means the loss of the wives' companionship and daily care. And for wives, widowhood means a decline in financial and practical support more than in companionship and daily care. Meanwhile, in marriage, husbands tend to benefit from their wives' network of social support, whereby men might experience difficulty in maintaining relationships with relatives and friends after becoming widowed (35–37).

Social Support and Health

Social support refers to the actual or perceived availability of resources from the individual's social networks (38), and it has been proven to have a significant positive association with health throughout one's lifespan (39–41). Social support can be classified into emotional support (e.g., providing empathetic understanding and warm care, talking about problems), instrumental support (e.g., entailing help with household tasks or financial aid through goods or services), and companionship (e.g., daily meetings and contact) (42–44). Instrumental support refers to tangible help, such as providing goods or services. Emotional support implies psychological help, entails talking about problems, privacy, and providing advice, and companionship focused on the accompanying of a variety of daily activities (43, 44).

Different types of social support may exert different protective effects on health. Most researchers are interested in emotional and instrumental support and hold it strongly associated with overall health and well-being (42), and it can reduce the risk of dementia and mortality (45, 46), help older adults stay

Abbreviations: CLASS, The China Longitudinal Aging Social Survey; CES-D, Center for Epidemiological Studies Depression Scale; ADL, activities of daily living; S.E., Standard errors; CI, confidence interval.

healthy and relieve their psychological stress and burden (13, 47). There are fewer concerns about companionship support, however, they are often supportive in their own right (48, 49). Some researchers focus on the influence of social contacts on health and show significant and meaningful associations between contact frequency and health outcomes (50). Companionship means daily meeting and spending time together, which further influences health status by affecting the mood, attitude, and cognition of widowed older adults (51).

Men and women may receive different types and levels of social support, which may result in different outcomes in health (52). For example, a study found that men benefit from social support in terms of improved mental health, while women benefit from social support in terms of improved physical health (53). Another study on marital loss discovered that perceived social support has a moderate and significant effect on marital transition in men but not in women (29).

Chinese Context

China has a large population of widowed older adults. The number of widowed older adults in China has continued to increase since the country transitioned into an aging society in 2000. According to recent survey data, 27.9% of the population aged 65 and older in China are widowed (16.0% for men and 38.6% for women), accounting for a large share of the global population of widowed older adults (2, 54).

Family orientation and gender division are rooted in Chinese society and culture. Family members, especially spouses, are always the primary provider of support. This situation is particularly typical in rural China, where it is characterized as "hollowing," that is, young people go out to work, leaving the elderly parents to live alone and support each other. Therefore, widowhood may deal a heavier blow to the elderly in China than in western countries. Besides, the Chinese culture is characterized by patrilocality, patrilineality, and patriarchy, in which wives depend heavily on their husbands (55). In such a context, the death of the spouse, who is the most essential and longest-standing family member with older adults, can generate an even more adverse effect on the health of China, and this impact may have gender differences.

Moreover, there is a long-standing urban-rural dual system in China which has in some ways created a marked difference in social networks (56, 57) and medical resources (58, 59). This too could pose a mechanism affecting the health status of widowed older adults. Besides, the social security system in China is less developed and inadequate to provide comprehensive protection for widowed older adults (60), especially in rural areas.

The Present Study

Based on the overview of previous studies, although many studies have examined the relationship between widowhood and health, few have explored whether social support, as well as subtypes, play a mediating role in the relationship between widowhood and health, and the potential gender and urban-rural differences. Our study aims to examine the role of social support in the widowhood-health association of older adults and provide gender and rural-urban-specific analysis. Understanding this can inform policymakers to take more effective measures to help bereaved older adults adjust to life after widowhood and improve their health, which is essential for healthy aging.

DATA AND METHODS

Data

The data used in this study was from the China Longitudinal Aging Social Survey of 2014 (CLASS). CLASS is a nationwide, continuous, large-scale social survey project conducted by the Renmin University of China in 2014. Applying the multi-stage stratified probability sampling method and face-to-face interview, CLASS covered 462 villages or communities across 29 provinces, a total of 11,511 participants aged 60 and above in China (excluding Hong Kong, Taiwan, Macau, Hainan, Xinjiang, and Tibet). The data collection was approved by the Ethics Committee of Renmin University of China, and each participant was informed of the purpose of this survey. The participation of each participant in the study was voluntary, and they were assured that their privacy would be strictly protected. Given the purpose of this study that examined the mediating role of social support between widowhood and older adults' health status, all participants who had never been married or divorced were excluded. Additionally, we excluded participants who did not complete the mental health questionnaire due to cognitive impairment (61, 62). Finally, participants with missing values in the variables of interest were excluded. The final analysis sample includes 7,647 participants, among whom 28% were widowed, 46% were women, and 45% lived in rural areas.

Variables

Health Status

Health status, which usually includes mental health and physical health, is a crucial indicator of successful aging (63, 64). For mental health, it was measured using the abbreviated 12-item Center for Epidemiologic Studies Depression scale (CES-D) (65). This instrument is widely used to measure the mental health of older and widowed adults (66–68). The scale includes three questions on positive affect (feeling happy, enjoying life, feeling pleasure), two questions on negative affect (feeling lonely, upset), five questions on marginalization (feeling useless, having nothing to do, unaccompanied, isolated, and neglected) and two questions on somatic symptoms (poor appetite, trouble sleeping). Each item was scored on a scale (0 = most time; 1 = sometimes; 2 = hardly ever), suggesting the frequency of the symptom they experienced last week (the positive items were reverse coded). The sum score ranged from 0 to 24, with higher scores indicating better mental health (Cronbach's $\alpha = 0.756$).

For physical health, it was assessed by using 10 basic items of the Activities of Daily Living scale (ADL): cleaning, dressing, bathing, self-feeding, controlling bowel and urine, toileting, transferring from bed to chair, indoor transferring, and climbing stairs. Each item was rated on a 3-point scale based on the

individual's ability to perform the activities (0 = unable; 1 = with help; 2 = on my own). Higher final sum scores (range = 0–20) are associated with better physical health (Cronbach's α = 0.887).

Widowhood Status

According to the purpose of the study, we focused on older adults whose marital status is widowed or married with a spouse (non-widowed). Widowhood status was measured by asking the participants' current marital status, and widowhood status was coded as 1 if widowed; otherwise, coded as 0.

Social Support

Social support was measured using the Lubben Social Network Scale (LSNS), a 6-item scale assessing the availability of social support from friends, relatives, and neighbors. The scale estimates the number of people to talk about privacy, help in need, and contact or meet, using items such as "How many families/relatives do you feel comfortable talking about private matters with?" "How many families/relatives are available to you when you need them?", and "How many families/relatives do you see or contact at least once a month." And then the same set of questions were prompted in regards to their relationship with friends. According to the previous research using CLASS data and the scores assigned by the CLASS questionnaire: none (0), one person (1), two persons (2), three to four persons (3), five to eight persons (5), and nine persons and above (9). We added up the scores for each question for each type of support and created a variable whose values ranged from 0 to 54 (69) (Cronbach's α = 0.778). Further, we use the total number of friends, relatives, and neighbors who can talk, help and meet to measure the emotional, instrumental and companionship support. Each subtype of social support ranges from 0 to 18. A higher value indicates stronger perceived social support.

Covariates

Many covariates were controlled in this study based on prior research (70, 71), including age (60–74 = 0, 75 and above = 1), gender (male = 0, female = 1), ethnicity (Han = 0, minority = 1), hukou type (agricultural = 0, non-agricultural = 1), education level (primary and below = 0, junior high = 1, secondary = 2, university and above = 3), whether with religion (no = 0, yes = 1), participation in community activities (policing patrols, caring for other older adults, environmental protection, mediating disputes, etc.) (no = 0, yes = 1) and living with someone (no = 0, yes = 1).

TABLE 1 | Descriptive statistics for widowed vs. non-widowed participants (*N* = 7,647).

Variables	Widowhood status		*P*-value
	Non-widowed (*N* = 5,518)	Widowed (*N* = 2,129)	
Mental health	12.66 ± 2.24	11.93 ± 2.76	<0.001
Physical health	19.70 ± 1.35	19.42 ± 1.80	<0.001
Social support	19.85 ± 11.39	18.91 ± 10.77	<0.010
Emotional support	5.06 ± 4.10	4.80 ± 3.75	<0.010
Instrumental support	6.51 ± 4.42	6.36 ± 4.25	0.175
Companionship	8.28 ± 4.59	7.76 ± 4.43	<0.001
Gender (%)			<0.001
Male	61.44	32.60	
Female	38.56	67.40	
Age (%)			<0.001
60–74	85.85	58.48	
≥75	14.15	41.52	
Ethnicity (%)			0.047
Han	93.71	93.24	
Ethnic Minority	6.29	6.76	
Hukou type (%)			<0.001
Agricultural	43.64	48.90	
Non-agricultural	56.36	51.10	
Education level (%)			<0.001
Below elementary school	51.54	70.88	
Junior high school	26.21	15.97	
High school	13.56	8.97	
College and above	8.70	4.18	
Religion (%)			<0.001
No	90.16	84.78	
Yes	9.84	15.22	
Social participation (%)			0.023
No	70.66	73.27	
Yes	29.34	26.73	
Live with someone (%)			0.226
No	0.05	0.14	
Yes	99.95	99.86	

Numerical variables were reported as mean ± standard deviation (SD); Categorical variables were reported as proportions (%); P-value denotes statistical significance for comparison between non-widowed and widowed old adults, based on chi-square or t-statistics test.

Analytic Strategy

We used SPSS Macro PROCESS to test the mediation effect of social support in the relationship between widowhood and health among older adults. PROCESS adopts a bias-corrected percentile bootstrap method which is one of the most valid and robust methods for testing mediation effects. Results obtained using this procedure have a higher likelihood of being devoid of Type I error and also estimated more accurate confidence intervals (72–74). An indirect effect is considered significant when the confidence interval does not include a zero.

Below we first described the characteristics of the variable used in this study by adults' widowhood status. Mediation analysis was conducted to examine the mediation effect of social support between widowhood and older adults' health status in the total, male-female subsample, and rural-urban subsample. We conducted a causal mediation analysis to test the reliability of the results. The mediation effect of social support calculates using a sequential approach proposed by Hick and Tingley (75). Following Robins and Greenland (76) and Pearl (77), this method calculates the average of the mediation effects between the actual outcome and counterfactual outcomes to estimate the

indirect effects. This causal mediation analysis was performed using STATA 15.1.

RESULTS

Descriptive Results

Descriptive and chi-square test results between widowed and non-widowed participants are shown in **Table 1**. Numerical variables were reported as mean ± standard deviation (SD). Categorical variables were reported as proportions (%). As shown in **Table 1**, there are significant differences in health status and social support between non-widowed and widowed older adults. Specifically, widowed older adults have poorer mental and physical health status, and receive less emotional, instrumental, and companionship support.

Mediation Analysis

We further follow the procedure of mediation effects analysis proposed by Zhao et al. (72) and refer to the bootstrap test for mediation effects proposed by Preacher and Hayes (73, 78), with 5,000 bootstrap samples to obtain the bias-corrected 95% confidence intervals for the total indirect effect and the specific indirect effects.

Figure 1 shows the results for mediation effects of social support between widowhood status and health status after controlling for socio-demographic characteristics. It can be seen that the coefficient of widowhood on both mental and physical health is reduced after the inclusion of social support. Widowhood has a significant and inverse relationship with social support, that is, older adults perceive less social support in widowhood ($\beta = -0.7111$, $p < 0.05$). Social support did exert a significant but small role in the relationship between widowhood and mental health [$\beta = -0.0325$, CI (-0.0610, -0.0049)] as well as physical health [$\beta = -0.0065$, CI (-0.0126, -0.0009)]. While it implies that widowhood reduces social support and further affects health.

Further analyses evaluate the subtypes of social support as mediators in the pathways from widowhood to health (see **Table 2**). The results revealed detective small mediation effects through emotional support and companionship for mental health [emotional support: $\beta = -0.0076$, CI (-0.0161, -0.0004); companionship: $\beta = -0.0191$, CI (-0.0338, -0.0063)]. For physical health, companionship was exerted as a significant mediator. However, the effects were also small [companionship: $\beta = -0.009$, CI (-0.0163, -0.0029)]. The direct effect of widowhood on mental and physical health was still significant, indicating that social support plays a partial mediating role. Partial mediation does not mean that the data results are not perfect, but implies that it is not the only relationship path.

Then we conducted another set of analyses for different gender and rural-urban subsamples, reviewing the different role of social support in it. Significant mediation effects were only found in women and rural older adults. For women (see in **Table 3**), instrumental support and companionship have significant mediated effects in the relationship between widowhood and mental health [instrumental support: $\beta = -0.0106$, CI (-0.0243, -0.001); companionship: $\beta = -0.0239$, CI (-0.0419, -0.0087)]. Companionship significantly mediated the relationship between widowhood and physical health [companionship: $\beta = -0.0172$, CI (-0.0306, -0.0071)]. For males (see in **Table 4**), however, the mediating effect of social support was not significant because the impact of widowhood on social support was not significant.

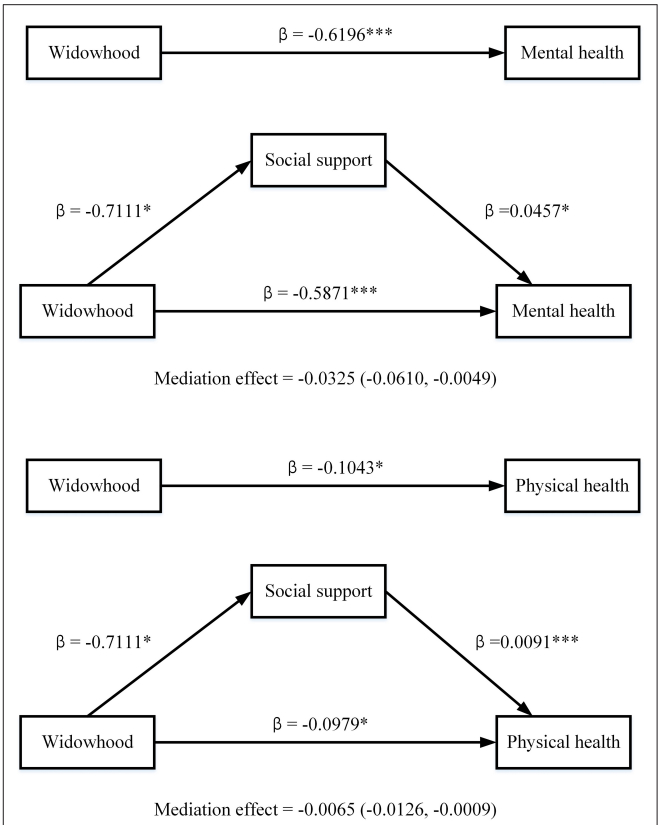

FIGURE 1 | Mediating effects of social support in the association between widowhood and health ($N = 7{,}647$). Adjusting for gender, age, ethnicity, hukou, education, religion, social participation, and living arrangement; * $p < 0.05$, *** $p < 0.001$; Confidence intervals do not cross zero means the relationship is significant.

For rural older adults (see in **Table 5**), the mediating effect of companionship in the pathways from widowhood to mental ($\beta = -0.0175$, CI (-0.0345, -0.0044)] and physical health was significant [physical heath: $\beta = -0.0079$, CI (-0.0173, -0.0012)]. For urban older adults (see in **Table 6**), the mediating effect of social support was not significant.

Causal Mediation Analysis

Table 7 shows the results of causal mediation analysis. Becoming widowed was significantly associated with a mean score reduction in mental and physical health. When emotional support and companionship were modeled as mediators, the estimated indirect effect was significant, indicating the indirect effect through emotional support and companionship can explain the change in mental health and physical health. This is consistent with the findings of our main analysis.

TABLE 2 | Mediation effects of the subtypes of social support in the association between widowhood and health status in the whole sample ($N = 7,647$).

Health outcomes	Indirect effects	Coefficient	S.E.	Bootstrap 95%CI	
				Lower	Upper
Mental health	Total	−0.0303	0.0139	−0.0572	−0.0030
	Emotional support	−0.0076	0.0041	−0.0161	−0.0004
	Instrumental support	−0.0036	0.0059	**−0.0153**	**0.0080**
	Companionship	−0.0191	0.0070	−0.0338	−0.0063
Physical health	Total	−0.0095	0.0034	−0.0165	−0.0031
	Emotional support	−0.0006	0.0012	**−0.0033**	**0.0018**
	Instrumental support	0.0001	0.0006	**−0.0012**	**0.0015**
	Companionship	−0.0090	0.0034	−0.0163	−0.0029

S.E., standard errors; CI, confidence interval; Bold means not significant; Adjusted for gender, age, ethnicity, hukou, education, religion, social participation, and living arrangement.

TABLE 3 | Mediation effects of the subtypes of social support in the association between widowhood and health status in the female subsample ($N = 4,084$).

Health outcomes	Indirect effects	Coefficient	S.E.	Bootstrap 95%CI	
				Lower	Upper
Mental health	Total	−0.0388	0.0118	−0.0625	−0.0155
	Emotional support	−0.0043	0.0035	**−0.0124**	**0.0010**
	Instrumental support	−0.0106	0.0059	−0.0243	−0.0010
	Companionship	−0.0239	0.0084	−0.0419	−0.0087
Physical health	Total	−0.0174	0.0057	−0.0302	−0.0076
	Emotional support	0.0021	0.0023	**−0.0013**	**0.0080**
	Instrumental support	−0.0023	0.0026	**−0.0084**	**0.0021**
	Companionship	−0.0172	0.0060	−0.0306	−0.0071

If confidence intervals do not cross zero, then the relationship is significant; S.E., standard errors; CI, confidence interval; Bold means not significant; Adjusted for gender, age, ethnicity, hukou, education, religion, social participation, and living arrangement.

TABLE 4 | Mediation effects of the subtypes of social support in the association between widowhood and health status in the male subsample ($N = 3,563$).

Health outcomes	Indirect effects	Coefficient	S.E.	Bootstrap 95%CI	
				Lower	Upper
Mental health	Total	0.0015	0.0107	**−0.0193**	**0.0227**
	Emotional support	−0.0021	0.0027	**−0.0085**	**0.0022**
	Instrumental support	0.0058	0.0058	**−0.0047**	**0.0187**
	Companionship	−0.0022	0.0048	**−0.0122**	**0.0072**
Physical health	Total	−0.0076	0.0058	**−0.0194**	**0.0035**
	Emotional support	−0.0034	0.0030	**−0.0105**	**0.0011**
	Instrumental support	−0.0019	0.0025	**−0.0080**	**0.0018**
	Companionship	−0.0023	0.0049	**−0.0121**	**0.0072**

If confidence intervals do not cross zero, then the relationship is significant; S.E., standard errors; CI, confidence interval; Bold means not significant; Adjusted for gender, age, ethnicity, hukou, education, religion, social participation, and living arrangement.

CONCLUSION AND DISCUSSION

Using data from the 2014 wave of China Longitudinal Aging Social Survey, this study examined the mediation effects of social support, as well as different types including emotional support, instrumental support, and companionship, on the association between widowhood and older adults' health status. It was found that emotional support and companionship exerted a mediation effect on the influence of widowhood and health status. It indicates that older adults perceive significantly less emotional support and companionship after widowhood, leading to poorer mental health and physical health. Furthermore, women and rural older adults are more likely to be affected by the reduced emotional support and companionship caused by widowhood.

TABLE 5 | Mediation effects of the subtypes of social support in the association between widowhood and health status in the rural subsample ($N = 3,449$).

Health outcomes	Indirect effects	Coefficient	S.E.	Bootstrap 95%CI	
				Lower	Upper
Mental health	Total	−0.0223	0.0150	**−0.0522**	**0.0071**
	Emotional support	−0.0039	0.0039	**−0.0131**	**0.0024**
	Instrumental support	−0.0010	0.0078	**−0.0169**	**0.0151**
	Companionship	−0.0175	0.0078	−0.0345	−0.0044
Physical health	Total	−0.0115	0.0053	−0.0225	−0.0017
	Emotional support	−0.0035	0.0031	**−0.0109**	**0.0011**
	Instrumental support	0.0000	0.0012	**−0.0027**	**0.0024**
	Companionship	−0.0079	0.0042	−0.0173	−0.0012

If confidence intervals do not cross zero, then the relationship is significant; S.E., standard errors; CI, confidence interval; Bold means not significant; Adjusted for gender, age, ethnicity, hukou, education, religion, social participation, and living arrangement.

TABLE 6 | Mediation effects of the subtypes of social support in the association between widowhood and health status in the urban subsample ($N = 4,198$).

Health outcomes	Indirect effects	Coefficient	S.E.	Bootstrap 95%CI	
				Lower	Upper
Mental health	Total	−0.0094	0.0076	**−0.0247**	**0.0057**
	Emotional support	−0.0018	0.0022	**−0.0073**	**0.0016**
	Instrumental support	−0.0021	0.0034	**−0.0095**	**0.0042**
	Companionship	−0.0055	0.0043	**−0.0152**	**0.0018**
Physical health	Total	−0.0070	0.0052	**−0.0181**	**0.0029**
	Emotional support	0.0009	0.0016	**−0.0018**	**0.0048**
	Instrumental support	0.0004	0.0012	**−0.0018**	**0.0033**
	Companionship	−0.0083	0.0059	**−0.0205**	**0.0028**

If confidence intervals do not cross zero, then the relationship is significant; S.E., standard errors; CI, confidence interval; Bold means not significant; Adjusted for gender, age, ethnicity, hukou, education, religion, social participation, and living arrangement.

TABLE 7 | Causal mediation effects of the subtypes of social support in the association between widowhood and health status in the whole sample ($N = 7,467$).

Health outcomes	Indirect effects	Coefficient	95%CI	
			Lower	Upper
Mental health	Emotional support	−0.0285	−0.0517	−0.0078
	Instrumental support	**−0.0162**	−0.0415	0.0073
	Companionship	−0.0533	−0.0793	−0.0297
Physical health	Emotional support	−0.0051	**−0.0102**	**−0.0013**
	Instrumental support	−0.0028	**−0.0077**	**0.0013**
	Companionship	−0.0145	−0.0228	−0.0079

If confidence intervals do not cross zero, then the relationship is significant; CI, confidence interval; Bold means not significant; Adjusted for gender, age, ethnicity, hukou, education, religion, social participation, and living arrangement.

This study found that social support is an essential path through which widowhood is negatively associated with the health of old adults. It is consistent with other findings suggestive of the fact that social support explains part of the effects of widowhood on health (66, 79–81). Specifically, emotional support and companionship play a significant role in the relationship between widowhood and mental health as well as physical health. However, the contribution of social support here is small, as has also been found in other research exploring the mechanism of health outcomes (82–84). But this kind of small mediating role does exist, especially the mediating effect of emotional support and companionship.

Emotional support assumes a partial mediating role in the relationship between widowhood and mental health. It suggests that the negative effect of widowhood on the mental health of older adults is partly due to the reduced emotional support from

family, relatives, and friends. This is consistent with previous studies which have shown that emotional support may be linked to widowhood and mental health (66, 85). And support is most helpful for widowed older adults to have the opportunity to freely express themselves (86). For older adults, a spouse is the main person to share private thoughts, boredom, depression. However, if a spouse who plays such an important role becomes deceased, it may create a void and, in the long run, may affect psychological health. And after the death of a spouse, older adults may be overwhelmed with grief and nostalgia for their spouse. For example, they will close themselves off and no longer share their hearts with others. This finding underscores the fact that emotional support is key in ameliorating the harmful effects of widowhood among older adults. Also, that older adults need communication and care to alleviate the intense psychological toll of widowhood.

Companionship plays an indispensable role in the pathway from widowhood to health outcomes. Companionship partially mediates the relationship between widowhood and health. That is, the negative association of widowhood with the mental and physical health of older adults is due to the decreased social interaction with family, relatives, and friends. Older people with close relationships tend to engage more in physical activities, have better dietary behavior, and have better access to information that may be beneficial to health (87, 88). However, the shrunken social network that is likely to characterize widowhood in older adults may be detrimental to health. Specifically, besides the void created when a spousal intimate relationship once relied upon is no longer available, widowed older adults may develop negative emotions like depression, pessimism, guilt, or fear of becoming a burden unto others. This may culminate in an unwillingness to interact with others or seek help. Such alienation amplifies the feelings of loneliness and loss, which may, in turn, impact physical functioning as well as both mental and physical health (89).

After taking gender into account, the mediation role of social support is only significant for women. This is consistent with some previous studies. Using data from Korea, Jeon found that social ties better explained the effect of widowhood on depression in women than in men (66). This phenomenon may be explained by the fact that with the transition to widowhood, women are more sensitive to such changes and tend to experience broader changes in social networks (90, 91). Furthermore, in a strongly patriarchal society such as China, women in marriage rely heavily on their husbands' status, power, and social resources, and are more affected by the changes caused by widowhood (92–94). In contrast, compared to women, elderly males have smaller social networks and are less likely to initiate or engage in social outdoor activities (52). Thus, widowhood has little effect on changes in social network size for elderly males, and the mediating role of social support is not significant either.

The mediating role of social support was only significant among rural older adults rather than urban older adults. That is, companionship significantly mediated the relationship between widowhood and mental as well as physical health in rural older adults. This may occur due to the disparities in the conception of marriage and the availability of social support between rural and urban areas (10, 95). In rural China, multigenerational cohabitation is very common, and social relationships are still dominated by family or clan; therefore, widowhood is more affected by changes in this network (56). While in urban areas, older adults have a wider social network and more social security resources, such as community-based care and scientific spiritual comfort. In addition, there are elderly colleges sponsored by the government and the community, to provide older residents with health information and creative enlightenment, as well as a place to meet new friends (96). As a result, the elderly have more opportunities to engage in social activities. All these may serve as a potential resource for social support, compensating for the decrease in social support resulting from the death of a spouse. Moreover, although it is seldom to hold multigenerational families in urban China, older adults tend to cohabitate with their children after being widowed, in order to provide care and nurturing for their grandchildren. This may provide a sense of belonging and continued engagement in family functions (97).

Our results did not find a significant difference in instrumental support between widowed and non-widowed older adults, and instrumental support did not play a mediating role in the relationship between widowhood and health status. Indeed, influenced by the Confucian ideology, the young generation should support the elderly, ensuring they are well-fed and clothed. Although this kind of support is mainly focused on material support and is always less mandatory in the aspects of spiritual, psychological care, and affection (98, 99), it does not change due to widowhood. So the mediating role of instrumental support is not significant.

This study still has several limitations to this study, which highlight the need for future research to better understand the connection between widowhood and health. First, analyses are limited by using self-report measures of mental and physical health scales, and they may differ when using objective assessments. Besides, we use the limitation of activities as a measure of physical health. While ADLs are an important component of health status, addressing functional status, other key components of health status in older adults include perceived health status, cognitive status, pain, and perceived quality of life, which need further research. Second, although we used a large sample size, it is cross-sectional data. This study only established a correlation but cannot make a causal inference. Further studies are needed to identify the causal mechanism of widowhood's effects on health based on longitudinal data. Thirdly, we only evaluated the partial mediation effects between widowhood and health status, and the effects of the mediator are small. Therefore, we urge some caution in interpreting our results. And there may likely be a case of missed variables that needs further research. For example, previous studies indicate that different sources and structures (relatives, friends, community, government agencies, etc.) of social support may differ in their functions (100–102). Thus, more work needs to be done to explore the role of social support in this association. Finally, it is also a limitation that CLASS doesn't provide other important contextual information about widowhood, such as time since the death of the spouse, age at the time of spouse's death, widowed person's perceived closeness to the spouse, or size of support

system before widowhood. This limits our ability to meaningfully interpret the findings. Further research is needed.

Despite these limitations, our study extends the body of literature by providing evidence as to how widowhood may have deleterious effects on health, and how it differs across gender and urban vs. more remote residential areas. This study proposed that emotional support and companionship could potentially mediate the extent to which widowhood affects health. The evidence also suggests that it is only among rural and older women that social support plays a significant role in the association between widowhood and health. It underscores the evidence that emotional support and companionship may be associated with measures that improve the impact of widowhood on the health of older adults, particularly women and rural older adults.

DATA AVAILABILITY STATEMENT

Publicly available datasets were analyzed in this study. This data can be found here: http://class.ruc.edu.cn/.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Ethics Committee of Renmin University of China. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

YG and TG designed the study, performed the statistical analysis, and drafted the manuscript. LM, LW, and JL collaborated with the study and revised the manuscript. All authors have given approval to the final version for publication.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2021.745073/full#supplementary-material

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Is Olfactory Impairment Associated With 10-year Mortality Mediating by Neurodegenerative Diseases in Older Adults? The Four-Way Decomposition Analysis

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Background: Literature shows that olfactory impairment (OI) is associated not only with neurodegenerative diseases (NDDs), but also with increased mortality. In this study, we analyzed data collected from the prospective phase of the 10-year follow-up of the Shanghai Aging Study (SAS) to explore the mediation effect of NDDs on the OI-mortality relationship.

Methods: We analyzed data collected from the prospective phase of the 10-year follow-up of the SAS. We included 1,811 participants aged 60 years or older who completed both an olfactory identification test and a cognitive assessment at baseline (2010–2011). Survival status of the participants from baseline to December 31, 2019 was obtained from the local mortality surveillance system. We used the four-way decomposition method to attribute effects to interaction and mediation and to explore the mediation effect of NDDs on the OI-mortality relationship.

Results: The four-way decomposition method revealed a statistically significant association of OI with death. Overall, 43% higher risk for death was associated with OI [excess relative risk (ERR) = 0.43, 95% CI: 0.06–0.80, $p = 0.023$]. Excluding the mediation from NDDs and interaction between OI and NDDs, the controlled direct effect of OI on death was even higher in NDDs participants, with an ERR of 77% (95% CI: 0.00–1.55, $p = 0.050$). Statistically significant association was found for failure to identify coffee (ERR = 0.77, 95% CI: 0.18–1.36, $p = 0.010$) and marginally significant associations were found for failure to identify cinnamon (ERR = 0.33, 95% CI: −0.02–0.68, $p = 0.068$) and rose (ERR = 0.33, 95% CI: −0.01–0.67, $p = 0.054$) with death.

Conclusion: OI was associated with the long-term mortality in older adults and the association was even stronger in those with NDDs. Failure to identify coffee or rose was associated with a higher mortality risk, and the association was mediated by NDDs.

Keywords: olfactory, neurodegenerative disease, mortality, prospective, elderly

INTRODUCTION

About 50–70% of people aged 65 years or older exhibit olfactory impairment (OI) (1). OI has been observed in patients with neurodegenerative diseases (NDDs) such as Alzheimer's disease (2), Parkinson's disease (PD) (3), or progressive supranuclear palsy (4); therefore, OI might be an early biomarker for a broad spectrum of NDDs. For example, in the neuropathological progression of PD, the olfactory bulb and the anterior olfactory nucleus are one of the first lesions within the central nervous system during the pathogenesis of PD. The lesions would continue to extend into more remote olfactory sites during the three to four pathological stages onward (5). Thus, olfactory impairment might be a manifestation and a potential diagnostic marker for early PD (6). Published literature indicates that OI is associated not only with NDDs, but also with increased mortality. A few longitudinal studies have shown an excessive relative risk for mortality as high as 20–112% in the elderly with OI, adjusted for age, sex, and other covariates (7, 8). Some studies have demonstrated the OI-mortality relationship in the middle-aged group (9, 10). In addition, some evidence indicates that the NDD is one of the leading causes of death and probably would overtake cancer by 2040 as the top one killer (11). Therefore, the NDD was considered as a possible mediator in the relationship between OI and mortality and explains the relationship partly (8, 12, 13).

However, the question arises as whether OI could proceed with the onset of neuropathological lesions or simply cause or potentiate by the neuropathologies (14)? Furthermore, cognitive performance at baseline may also tangle with the relationship (15), which makes the question even more complicated. So far, few studies have addressed the question and the findings remain controversial because of the diverse study design and data analysis method. In this study, we analyzed data collected from the prospective phase of the 10-year follow-up of the Shanghai Aging Study (SAS) to explore the mediation effect of NDDs on the OI-mortality relationship.

METHODS

Study Participants

The SAS is a population-based prospective cohort study conducted among the older adults residing in a community of downtown Shanghai, China. The study design and recruitment process of the cohort have been described in detail elsewhere (16). A total of 1,811 participants aged 60 years or older (mean age = 70 years) who completed both an olfactory identification test and a cognitive assessment at baseline (2010–2011) were included in this study.

Baseline Data Collection

Baseline data collection has been described in detail previously (17). Information on demographics and lifestyle of the participants including age, sex, education, smoking, and alcohol drinking were collected *via* an interviewer-administered questionnaire. The body mass index (BMI) of each participant was calculated by using his/her height and weight measured by a research nurse. Physical activity was measured in metabolic equivalent (MET) value. Information on previous and/or current chronic diseases was inquired based on the medical records. Apolipoprotein E (APOE) genotyping was conducted by using the blood or saliva samples of the participants and APOE-$\varepsilon 4$ allele positive was defined as the presence of at least one $\varepsilon 4$ allele.

Olfactory function was assessed by using the Sniffin' Sticks Screening Test-12 (SSST-12), which consists of 12 odors (orange, leather, cinnamon, peppermint, banana, lemon, liquorice, coffee, cloves, pineapple, rose, and fish) presenting on felt-tip sticks (18).

Diagnosis of Neurodegenerative Diseases

At baseline, participants were invited for a clinical interview. Cognitive function was evaluated by using a battery of neuropsychological tests including the Mini-Mental State Examination (MMSE), Conflicting Instructions Task, Modified Common Object Sorting Test, Auditory Verbal Learning Test, and Renminbi (Chinese currency) Test. The normative data and detailed description of the assessment battery were reported elsewhere (19). A panel of experts reached a consensus for diagnosis of dementia and mild cognitive impairment (MCI) based on the criteria of the Diagnostic and Statistical Manual of Mental Disorders, the 4th edition, and the Peterson criteria (20, 21). PD, Huntington's disease, and other NDDs were reported by the participants and confirmed with their medical records.

Mortality During Follow-Up

Survival statuses of the participants from baseline to December 31, 2019 were obtained from the mortality surveillance system of the local Centers for Disease Control and Prevention, which is responsible for verifying the date of death and causes of death from the death certificate (22).

Statistical Methods

The continuous variables were presented as mean with standard deviation (SD) and the categorical variables were presented as count and percentage (%). In this study, OI was defined as the total SSST-12 score < 8 (the median of the SSST-12 scores). The Pearson's chi-squared test was used to test the differences between the OI and non- or mild OI groups for categorical variables and the Student's t-test and the Mann–Whitney U test were used for continuous variables.

The directed acyclic graph in **Figure 1** illustrates the hypothetical association paths between OI and the survival status of the participants mediated by NDDs. The four-way decomposition method was used to attribute effects to interaction and mediation (23). Association between OI and death was evaluated by using the Cox proportional hazards regression model. The proportional hazards assumption was tested on the basis of Schoenfeld residuals. Association between OI and the mediator, i.e., NDDs was assessed by using the logistic regression model. To exclude the multicollinearity between the independent variables included in the logistic regression models, the bidirectional stepwise variable selection method was implemented before the mediation and interaction analysis.

The total effect of OI on death in excess relative risk (ERR) scale, i.e., a hazard ratio (HR) from the Cox proportional

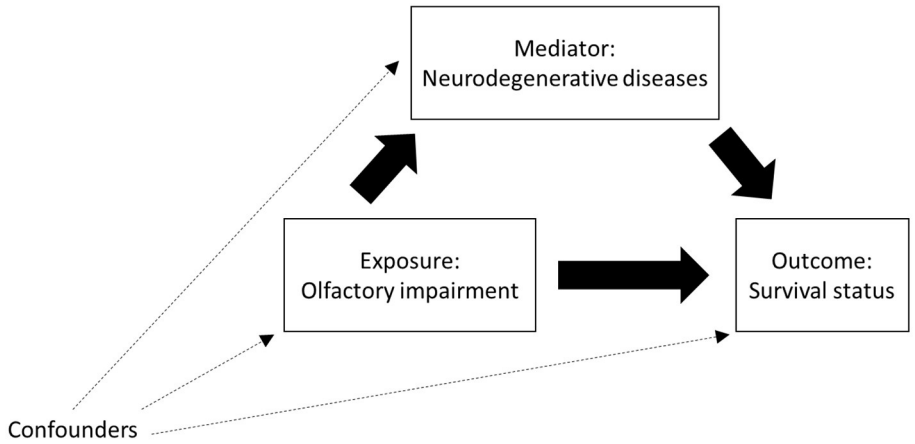

FIGURE 1 | Directed acyclic graph for the association of olfactory impairment **(OI)** with mortality, mediated by neurodegenerative diseases **(NDDs)**, adjusted for the associations of potential confounders with OI, NDDs, and mortality.

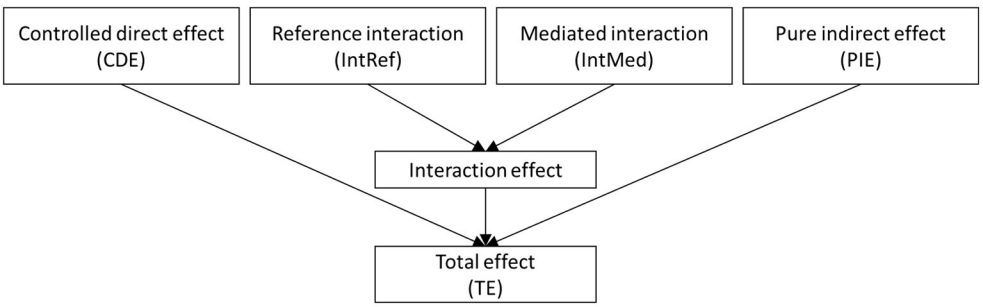

FIGURE 2 | The four-way decomposition method encompasses both the components for mediation and interaction.

hazards regression model minus one, was decomposed into four components: controlled directed effect (CDE) due to OI only, mediated main effect or pure indirect effect (PIE) due to mediation only, reference interaction (IntRef) due to interaction only, and mediated interaction (IntMed) due to mediation and interaction (24). The relationship of the four components is shown in **Figure 2**. The effect decomposition analysis was conducted for both the OI and failure to identify individual odors.

All the statistical analyses were conducted in Stata 16.1 (StataCorp LLC, College Station, Texas, USA). A two-sided p-value was considered as statistically significant and a 95% CI was provided for each estimated effect.

RESULTS

Baseline Characteristics of the Participants and Outcomes

In the total 1,811 participants recruited in the SAS cohort, 662 participants were identified as OI at baseline, 378 participants were diagnosed as NDDs (29 dementia, 5 PD, and 344 MCI), and 258 participants died during an averagely 9.4 years of follow-up. Baseline characteristics of the participants and the outcomes during the follow-up are shown in **Table 1**. Compared to the non-OI group, the OI group was older, less educated, with a higher proportion of hypertension, stroke, chronic bronchitis, the lower MMSE score, higher activities of daily living (ADL) score, lower total cholesterol (TC) and low-density lipoprotein (LDL), and a higher proportion of failure to identify individual odors, NDDs, and death (**Table 1**).

Association Between OI and Mortality Mediated by NDDs

No statistically significant association was found between OI and death in the general Cox proportional hazards regression model (HR = 1.25, 95% CI: 0.90–1.72, $p = 0.181$); however, OI was statistically significantly associated with ND [odds ratio (OR) = 2.30, 95% CI: 1.80–2.94, $p < 0.001$] (**Table 2**). The four-way decomposition method revealed a statistically significant association of OI with death. Overall, 43% higher risk for death was associated with OI (ERR = 0.43, 95% CI: 0.06–0.80, $p = 0.023$). Excluding the mediation from NDDs and interaction between OI and NDDs, the controlled direct effect of OI on death was even higher in NDDs participants, with an ERR of 77% (95% CI: 0.00–1.55, $p = 0.050$) (**Table 2**).

TABLE 1 | Baseline characteristics of the participants and follow-up outcomes.

Variable	All	Non-OI	OI	*p*-value
N	1,811	1,149	662	
Female (%)	983 (54.3)	621 (54.0)	362 (54.7)	0.832
Age, years (mean ± SD)	70.22 (7.21)	68.92 (6.81)	72.47 (7.34)	<0.001
BMI, kg/m^2 (mean ± SD)	24.28 (3.66)	24.38 (3.73)	24.09 (3.52)	0.108
Education, years [median (IQR)]	12.00 [9.00, 15.00]	12.00 [12.00, 16.00]	12.00 [9.00, 15.00]	<0.001
Smoking (%)	186 (10.3)	119 (10.4)	67 (10.1)	0.937
Drinking (%)	142 (7.8)	84 (7.3)	58 (8.8)	0.310
Physical activity [median (IQR)]	21.00 [9.80, 37.10]	21.00 [10.03, 37.10]	21.00 [9.80, 38.30]	0.748
NDDs (%)	378 (20.9)	163 (14.2)	215 (32.5)	<0.001
Coronary heart disease (%)	200 (11.0)	117 (10.2)	83 (12.5)	0.144
Hypertension (%)	983 (54.3)	593 (51.6)	390 (58.9)	0.003
Diabetes (%)	251 (13.9)	153 (13.3)	98 (14.8)	0.417
Depression (%)	285 (15.7)	169 (14.7)	116 (17.5)	0.129
Stroke (%)	212 (11.7)	118 (10.3)	94 (14.2)	0.015
Cancer (%)	191 (10.5)	129 (11.2)	62 (9.4)	0.245
Chronic kidney disease (%)	108 (6.0)	63 (5.5)	45 (6.8)	0.301
Anemia (%)	24 (1.3)	16 (1.4)	8 (1.2)	0.907
Urinary tract infections (%)	574 (31.7)	352 (30.6)	222 (33.5)	0.221
Chronicbronchitis (%)	262 (14.5)	146 (12.7)	116 (17.5)	0.006
MMSE score (mean ± SD)	28.20 (2.30)	28.61 (1.69)	27.47 (2.95)	<0.001
ADL score (mean ± SD)	20.54 (3.34)	20.26 (2.04)	21.03 (4.80)	<0.001
TC, mmol/L (mean ± SD)	5.40 (1.05)	5.46 (1.07)	5.29 (1.00)	0.001
TG, mmol/L (mean ± SD)	1.71 (1.05)	1.75 (1.02)	1.65 (1.09)	0.067
HDL, mmol/L (mean ± SD)	1.34 (0.35)	1.34 (0.35)	1.32 (0.35)	0.242
LDL, mmol/L (mean ± SD)	3.25 (0.87)	3.29 (0.89)	3.18 (0.84)	0.011
APOEε4 positive (%)	312 (17.2)	199 (17.3)	113 (17.1)	0.971
Fail to identify odor (%)				
Orange	432 (23.9)	175 (15.2)	257 (38.8)	<0.001
Leather	797 (44.0)	353 (30.7)	444 (67.1)	<0.001
Cinnamon	1,034 (57.1)	530 (46.1)	504 (76.1)	<0.001
Peppermint	172 (9.5)	34 (3.0)	138 (20.8)	<0.001
Banana	632 (34.9)	248 (21.6)	384 (58.0)	<0.001
Lemon	836 (46.2)	426 (37.1)	410 (61.9)	<0.001
Liquorice	844 (46.6)	395 (34.4)	449 (67.8)	<0.001
Coffee	150 (8.3)	12 (1.0)	138 (20.8)	<0.001
Cloves	884 (48.8)	461 (40.1)	423 (63.9)	<0.001
Pineapple	562 (31.0)	215 (18.7)	347 (52.4)	<0.001
Rose	691 (38.2)	276 (24.0)	415 (62.7)	<0.001
Fish	322 (17.8)	95 (8.3)	227 (34.3)	<0.001
Death (%)	258 (14.2)	115 (10.0)	143 (21.6)	<0.001

Physical activity: in metabolic equivalent (MET) value.

BMI, body mass index; NDDs, neurodegenerative diseases; MMSE, mini-mental state examination; ADL, activities of daily living; TC, total cholesterol; TG, triglyceride; HDL, high-density lipoprotein; LDL, low-density lipoprotein; APOE, Apolipoprotein E.

Association Between Failure to Identify Individual Odors and Mortality Mediated by NDDs

Statistically significant association was found for failure to identify coffee (ERR = 0.77, 95% CI: 0.18–1.36, $p = 0.010$) and marginally significant associations were found for failure to identify cinnamon (ERR = 0.33, 95% CI: −0.02–0.68, $p = 0.068$) and rose (ERR = 0.33, 95% CI: −0.01–0.67, $p = 0.054$) with death (**Figure 3**). No statistically significant interaction was found between failure to identify the three individual odors and NDDs. Interestingly, statistically significant mediation by NDDs was found for failure to identify coffee and rose with PIEs of 0.07 (95% CI: 0.00–0.14, $p = 0.039$) and 0.09 (95% CI: 0.02–0.16, $p = 0.016$), respectively (**Figure 3**). However, the

TABLE 2 | Results of the four-way decomposition analysis for the association between OI and mortality.

	Estimates	95% CI	*p*-value
Model for outcome (Cox regression, HR*)			
OI	1.25	0.90–1.72	0.181
NDDs	1.35	0.87–2.12	0.178
OI × NDDs	1.28	0.73–2.25	0.387
Model for mediator (logistic regression, OR*)			
OI	2.30	1.80–2.94	< 0.001
Decomposition of excess relative risk (ERR)*			
TE(olfactory-death)	0.43	0.06–0.80	0.023
CDE			
NDDs	0.77	0.00–1.55	0.050
Non NDDs	0.23	−0.14–0.61	0.223
IntRef			
NDDs	−0.46	−1.15–0.23	0.193
Non NDDs	0.08	−0.04–0.20	0.195
IntMed	0.07	−0.04–0.19	0.202
PIE	0.05	−0.03–0.12	0.231

**Adjusted for sex, age, coronary heart disease, ADL, anemia, LDL, and chronic kidney disease.*

ADL, higher activities of daily living; LDL, low-density lipoprotein. HR, hazard ratio; OI, olfactory impairment; NDDs, neurodegenerative diseases; TE, total effect; CDE, controlled directed effect; IntRef, reference interaction; IntMed, mediated interaction ; PIE, pure indirect effect.

mediation from NDDs only contributed to a small part (9.1%) of the association of failure to identify coffee with death, while a considerable mediation (27.2% of total ERR) from NDDs was found in the association between failure to identify rose and death. Besides, the controlled direct effect of failure to identify coffee on death was statistically marginally significant, with ERRs of 0.82 (95% CI: −0.12–1.77, $p = 0.089$) and 0.64 (95% CI: −0.06–1.34, $p = 0.071$) for NDDs and non-NDDs participants, respectively. No statistically significant association was found for failure to identify any other odor and death (**Figure 3**).

DISCUSSION

Olfactory dysfunction is reported as the only sensory, which has been associated with mortality, when compared with hearing or visual impairment (2). Although the OI-mortality relationship has been identified independently from incidence of dementia (7), current findings support the relationships between OI, NDDs, and mortality risk and some studies have further shown that cognitive function might be a potential mediator in the relationship (3, 12, 13). Devanand et al. found that the OI-mortality association was weaker when controlled for dementia, yet still statistically significant (13). Liu et al. showed that dementia could account for 22% of the higher 10-year mortality linked to poor olfactory function (3). Our findings have confirmed that OI was associated with mortality in older adults during a 9.4-year follow-up and the association was even stronger in the NDDs participants.

We also found that failure to identify certain odors, especially coffee or rose, was associated with a higher mortality risk and the association was mediated by NDDs. Failure to identify a specific odor-like coffee was also suggestive of reduced survival in another study (25); however, failure to smell rose has not been reported for this potential connection. The mediation of NDDs on the associations of coffee is weak. One hypothetical explanation for the absence or weak mediation of NDDs might be that OI happened, while the clinical cognitive function is not yet affected and, thus, undiagnosed (26); postmortem markers of NDDs existing in the brains of subjects without a diagnosis of NDDs have supported this speculation (27).

There are several strengths in this study. First, although a causal relationship between OI and mortality and the mediation by NDDs cannot be established in the observational study, the study design and the sequential happening of the exposure, mediator, and outcome have ruled out a reversed conclusion. Second, cognitive function at baseline has been controlled in this study. Third, abundant demographic and medical historical variables collected in the SAS offered us a unique opportunity to use the four-way decomposition method to attribute effects to interaction and to assess mediation. The four-way decomposition methods used in published related literature were essentially special cases of the four-way decomposition. The four-way decomposition method could provide maximum insight into how much of an effect is mediated by a potential mediator in an exposure-mediation-outcome causal pathway (23).

Limitations of this study cannot be ignored. First, besides the complicated diagnosis procedure of cognitive impairment, we defined participants with other NDDs only based on their medical records, not used standard inclusion/exclusion criteria. Some participants might have NDDs, but they ignored that and did not go to see doctors. So, the NDDs in this study might be underestimated. On the other hand, there may be misdiagnosis existed because NDDs diagnoses on the medical records were made by doctors from different levels of hospitals. Second, NDDs include a large spectrum of disorders with remarkable differences. In this study, it is not appropriate to take dementia, MCI, and PD into account as the homogeneous NDD. Third, the instrument we used to assess the olfactory function only has 12 sticks for 12 odors. This limited us in seeking odors that were more sensitive than these 12. Fourth, the SSST-12 evaluated the olfactory identification, which cannot completely present the olfactory function. Together with the odor discrimination, detection thresholds should be administered to define the olfactory impairment. Fifth, this study was an observational study with relatively small sample size. The association and the mediation effects resulting from the statistical analysis only could reflect the phenomenon or clue. Future studies should focus on the biological mechanism, which could deeply explain our findings.

CONCLUSION

This study indicated that OI was associated with the long-term mortality in older adults and the association was even stronger in

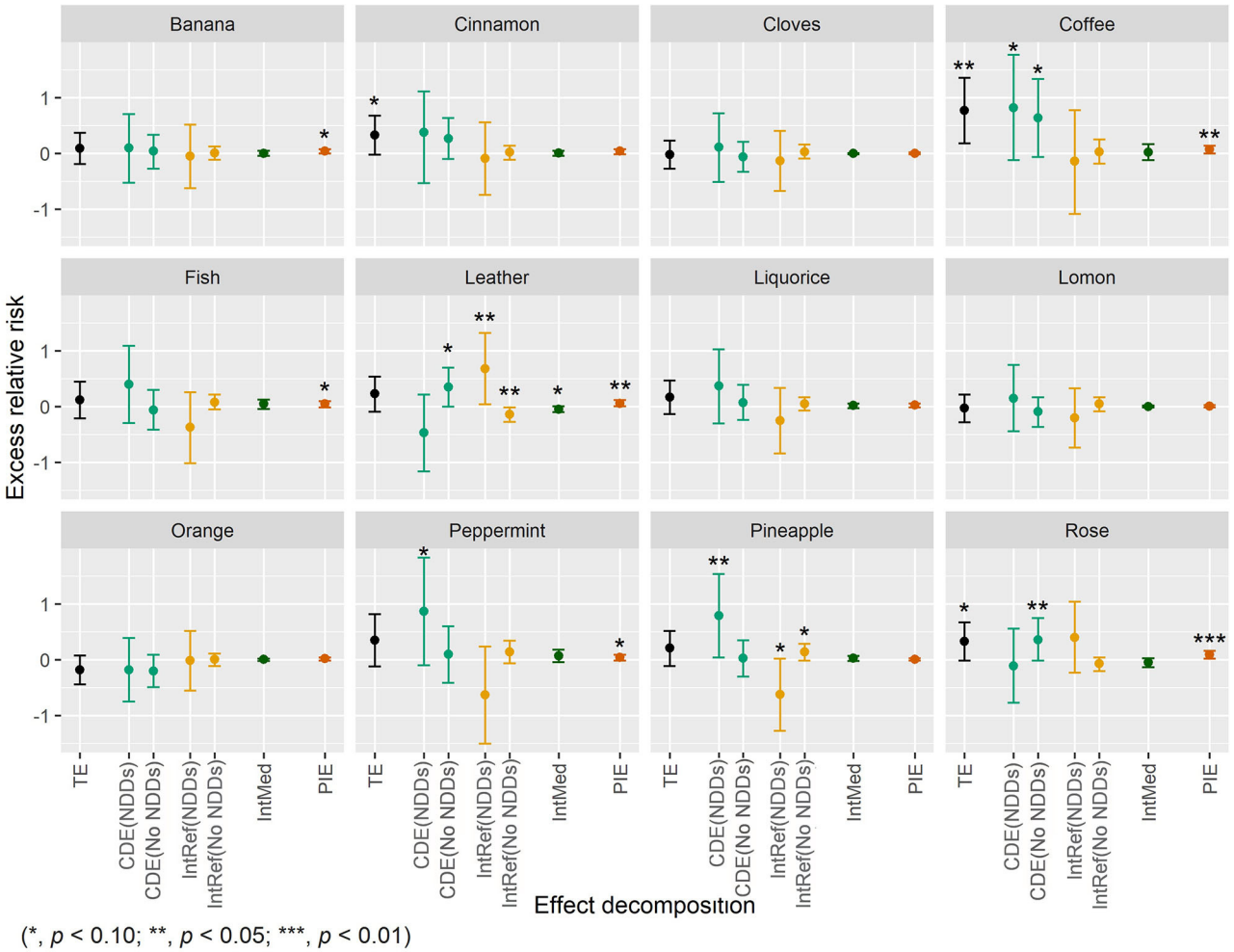

FIGURE 3 | The four-way decomposition method of excess relative risk of mortality for individual odors.

those with NDDs. Failure to identify coffee or rose was associated with a higher mortality risk and the association was mediated by NDDs. This study result suggests a potential signal for predicting survival in the elderly, especially those with NDDs. The findings need to be further confirmed with larger cohort studies or with interventional design.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Shanghai Aging Study was approved by the Medical Ethical Committee of Huashan Hospital, Fudan University, Shanghai, China (approval number: 2009-195). The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

YC and DD contributed to the design of the study, data analysis and interpretation, and drafting of the manuscript. ZX contributed drafting of the manuscript and data analysis. ZX, WW, and QZ contributed to the data collection of the study. All authors contributed to the critical revision of the manuscript for important intellectual content.

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Lifestyle Behaviors and Quality of Life Among Older Adults After the First Wave of the COVID-19 Pandemic in Hubei China

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Background: Older adult quality of life (QoL) is facing huge challenges during the COVID-19 pandemic. New normal lifestyle behaviors, including getting adequate physical activity (PA), consuming sufficient fruits and vegetables (FV) and enacting individual preventive behaviors (frequent hand washing, facemask wearing, and social distancing), as a significant determinant for QoL, have not been adequately addressed in older adults during the pandemic. This study aimed to investigate the characteristics of QoL in Chinese older adults after the first wave of the COVID-19 pandemic in Hubei China. The objective of the study was to examine any associations of lifestyle behaviors with QoL, and to identify the moderating role of socioeconomic indicators in the associations identified.

Methods: A cross-sectional study was conducted in Hubei, China, from June 15, 2020, to July 10, 2020. Five hundred sixteen older adults completed an online survey (mean age = 67.6 ± 6.6; 57.9% women). The questionnaire consisted of demographic information, covariates (chronic diseases and infected cases of acquaintances), lifestyle behaviors [PA stage, FV intake (FVI) stage and three preventive behaviors], and QoL. *T*-tests, ANOVA tests, multiple linear regression models with simple slope analyses were used to test the hypotheses.

Results: QoL significantly differed in relation to economic situation, chronic diseases, marital status, education, living situation, age group, and professional status. Participants' economic situation ($\beta_{\text{average vs. below average}} = 0.17$, $p < 0.01$; $\beta_{\text{above average vs. below average}} = 0.15$, $p < 0.01$), chronic diseases ($\beta_{\text{yes vs. no}} = 0.19$, $p < 0.001$), FVI stage ($\beta = 0.21$, $p < 0.001$), and preventive behaviors ($\beta = 0.10$, $p < 0.05$) indicated a significant association with QoL. Education level and economic situation significantly interacted with preventive behaviors on QoL, respectively ($\beta_{\text{preventive behaviors} \times \text{educational level}} = -1.3$, $p < 0.01$; $\beta_{\text{preventive behaviors} \times \text{economic situation}} = -0.97$, $p < 0.05$).

Conclusions: Findings emphasize the importance of enhancing FVI and preventive behaviors on QoL improvement in older adults during the COVID-19 pandemic. Older adults who are in a lower economic situation with lower education levels should be given priority when implementing interventions to improve preventive behaviors and QoL in older adults.

Keywords: physical activity, fruit and vegetable intake, preventive behaviors, quality of life, socioeconomic status, older adults, COVID-19 pandemic

BACKGROUND

The novel coronavirus disease (COVID-19), a global health emergency and worldwide threat, contributed to over 161 million confirmed cases and over 3 million deaths worldwide as of 20th July 2021, including 119,784 confirmed cases and 5,617 deaths in China (1). Considerable evidence demonstrates that the likelihood of suffering from severe illness and death related to COVID-19 increases with age (2). Older adults (60 years old and above) are one of the most susceptible and vulnerable populations for being infected with COVID-19 (3).

During the COVID-19 pandemic, healthy aging advocacy is facing a big challenge. Maintaining a relatively high quality of life (QoL) in the elderly is an important indicator of healthy aging. QoL is considered, in general, a broad-ranging concept affected in a complex way by physical health, psychological state, personal beliefs, individual social relationships, and their relationships with the environment (4). A recent systematic review indicated that individuals' quality of life worsened during the COVID-19 pandemic and was more serious for older adults (5). Thus, it is crucial to identify and understand the factors contributing to a good QoL among older adults during the pandemic.

Many studies have indicated that healthy lifestyle behaviors relevant to health promotion and disease prevention present a considerable contributor to improved quality of life and lower morbidity and mortality among older adults (6–9). Performing adequate physical activity and consuming sufficient fruit and vegetables have been identified as two important health promotion behaviors because of their effective roles in improving physical and mental health in older adults (10–14). However, self-isolation and restrictions during the pandemic dramatically reduced the opportunities for the public to be physically active (15). In addition, there has been a high prevalence of unhealthy diets (e.g., insufficient fruit and vegetable intake) during the pandemic (16). These behavior changes may lead to negative health consequences and a low level of QoL among older adults (17).

Also, during the COVID-19 pandemic, individual disease preventive behaviors, including frequent hand washing, facemask wearing, and social distancing in public areas, play an important role in reducing the transmission of COVID-19 in the community (18). Because there is still not enough vaccination prevention for COVID-19 worldwide and in anticipation of rapidly mutating viruses which transitions may not be prevented by vaccinations, performing individual preventive behaviors in daily life, as a new healthy lifestyle behavior, will be paramount in preventing the spread of the virus. A recent study indicated that preventive behaviors could directly affect the QoL among the general population (19). As older adults are at a higher risk of infection of COVID-19, investigating the impact of preventive behaviors on QoL in older adults should be prioritized. To the best of our knowledge, few studies have examined the relationship between all three healthy lifestyle behaviors (two health promotion behaviors including physical activity, fruit and vegetable intake, as well as one disease preventive behavior) and QoL among old adults during the COVID-19 pandemic.

Socioeconomic status (SES), including educational level, professional status, and economic situation, have been demonstrated to be important predictors for physical activity, diet, preventive behaviors and QoL in the general population, respectively (20–23). For example, many studies have reported positive associations with adequate physical activity, healthy eating, and performing preventive behaviors with high economic status during the COVID-19 pandemic (16, 24–26). In addition, a recent systematic review indicated that low education levels, unemployment status, and low economic situation correlated with poorer QoL (26). However, the moderating effects of SES on the association between lifestyle behaviors and QoL among older adults are still unknown. This deserves further examination and can help to develop tailored strategies to enhance the efficacy of an intervention to improve QoL of the elderly. This can be achieved using PA, healthy diet, and preventive behaviors during the COVID-19 outbreak and future pandemics (26).

The current study aimed to (1) investigate the characteristics of QoL among Chinese older adults during the COVID-19 pandemic; (2) examine the associations of three lifestyle behaviors (physical activity, fruit and vegetable intake, and preventive behaviors) with older adults' QoL levels; (3) identify the moderating role of SES indicators (education level, professional status, and economic situation) in the associations between lifestyle behaviors and QoL levels among Chinese older adults. It was hypothesized that (1) older adults' QoL levels would differ significantly for several demographic characteristics; (2) taking up healthier lifestyle behaviors would be significantly associated with higher QoL levels among Chinese older adults; (3) specific SES indicators would significantly moderate the associations between lifestyle behaviors and QoL levels in Chinese older adults. The research may assist in understanding

Abbreviations: COVID-19, coronavirus disease 2019; PA, physical activity; FVI, fruit and vegetable intake; QoL, quality of life; SES, socioeconomic status; WHO, World Health Organization; BMI, Body Mass Index; SD, standard deviation; CI, confidence interval.

older adults' QoL and their potential contributors. Such information may provide useful information to inform public health and social policies focused on maintaining the overall well-being of older adults during the COVID-19 pandemic.

METHODS

Participants

A cross-sectional study design with a convenient sampling approach was used in this study. The sample size was calculated by using G*Power 3.1 software with Linear Multiple Regression Fixed Model (27). For achieving a medium effect size (Cohen's $f^2 = 0.15$) on the association between PA and QoL in previous studies in older adults (28, 29), with an alpha of 0.05, the statistical power of 80%, and a response rate of 60%, a total of 205 participants were required. Seven hundred and twenty-seven community-dwelling older adults aged 60 years and above were contacted from five cities in the Hubei province of China, including Wuhan, Xiaogan, Jingzhou, Shiyan, and Xiangyang. A total of 609 older adults (609/727, 83.8%) agreed to participate in this online survey. Participants met the eligibility criteria, including (1) aged 60 years and above; (2) not infected with COVID-19; (3) having no cognitive disorders or impairments; (4) having access to mobile phones or computers; and (5) having sufficient reading skills in Chinese. Finally, data of 516 eligible participants were included in the analysis, where 93 participants were excluded due to following reasons (1) no access to mobile phones or computer; (2) having reading disorders, and (3) repeated completion. For participants who had difficulties using mobile phones or computer operations, their family members and friends were invited to assist them in completing the online survey. The survey was conducted from 15th June 2020 to 10th July 2020, which were 3 months after the first wave of the COVID-19 pandemic in Hubei province with no lockdown restrictions in this region.

Procedure

The online questionnaire survey was administered using an online survey platform in China, namely SOJUMP (Changsha Ranxing Information Technology Co., Ltd., China). All recruitment posters and the survey hyperlink were disseminated through mobile Short Message Service (SMS) and popular social media platforms in China such as WeChat, Weibo, and QQ. There were three approaches used for recruiting participants: (1) Relying on the researchers' social networks in five cities of Hubei province, the eligible family members, friends, and relatives of researchers were also invited. These initial participants then encouraged their friends to join the survey. (2) Researchers contacted the directors of community neighborhood committees in Wuhan and Xiaogan and sought their collaboration and support. Upon receiving the directors' agreement, researchers were permitted to enter their community neighborhood WeChat groups to recruit eligible participants. (3) Researchers contacted officials who oversaw the retirement in two universities in Wuhan. With the support of officials, a recruitment poster and survey hyperlink were delivered to their internal WeChat group, especially for retirement colleagues.

The duration of the online survey was around 15 min. Participants who completed the online survey was offered a 30 RMB incentive by electronic transfer *via* WeChat or Alipay or by prepaid telephone recharge. Participants were asked to sign an informed consent form prior to completing the questionnaire. Ethical approval for the study was obtained from the Research Ethics Committee of Hong Kong Baptist University (REC/19-20/0490).

Measures

Demographic Information

Demographic characteristics included age, gender (male/female), marital status (single/married/divorced or widowed), living situation (alone/with others such as a spouse, partner or children), and three socioeconomic status (SES) related variables (26), which included educational level (primary school or below/middle or high school/college or above), professional status (unemployed/pensioner or retired/employed), and economic situation (below average/average/above average). Body weight and height were also collected for calculating the body mass index [BMI, body weight (kg)/body height squared (m^2)]. The BMI was categorized into four levels (underweight BMI $<$ 18.5/ healthy weight 18.5 $\leq$ BMI $<$ 23/overweight 23 $\leq$ BMI $<$ 26/obese BMI $\geq$ 26) based on previous studies for Chinese populations (30, 31).

Covariates

Having chronic diseases and infected cases of acquaintances were considered as health-related covariates (32, 33). Participants were asked if they had a chronic disease (e.g., heart diseases, diabetes, cancer, respiratory illnesses, liver, or kidney diseases) and if any acquaintances were (or had been) infected with COVID-19 (e.g., friends, family members, and neighbors). Answers were recorded as Yes/No.

Lifestyle Behaviors

Physical activity (PA) was measured using the algorithm of the stages of change for PA, adapted from a previous study (34). Participants were asked one question about PA; "Currently, do you perform at least 150 min of moderate-intensity (slightly sweating and some increase in respiration) physical activity (e.g., brisk walking, bicycling, or swimming) every week?" Answers were given on a five-point Likert-scale with "1 = No, I don't intend to start, 2 = No, but I'm considering it; 3 = No, but I seriously intend to start; 4 = Yes, but only during the outbreak of COVID-19; and 5 = Yes, this was true for a long time before the outbreak of COVID-19." A higher score indicated a higher PA level, at which participants performed more PA.

Fruit and vegetable intake (FVI) was measured using the algorithm of the stages of change for FVI, adapted from a previous study (34). Participants were asked one question about "Currently, do you eat at least five servings of fruit and vegetable every day?" Answers were given on a five-point Likert-scale with "1 = No, I don't intend to start, 2 = No, but I'm considering it; 3 = No, but I seriously intend to start; 4 = Yes, but only during the outbreak of COVID-19; and 5 = Yes, this was true for a long period before the outbreak of COVID-19." A higher score

indicated a higher FVI level, at which participants eat more fruits and vegetables.

COVID-19 preventive behaviors include hand washing, facemask wearing, and social distancing in public areas according to the recommendations of WHO (35). A six-item structured scale was used to measure preventive behaviors, with two items for each of the three behaviors (36). In particular, the items for hand washing were "during the previous week, I adhered to washing my hands frequently with soap and water or alcohol-based hand rub (for at least 20 s, on all surfaces of the hands)" followed by two situations including "(a) in a daily life situation, e.g., before eating, and (b) in a disease-related situation, e.g., after caring for the sick." The items for facemask wearing were "during the previous week; I adhered to wearing a face mask properly", followed by two situations including "(a) when visiting public places, and (b) when caring for the sick." The items for social distancing were "during the previous week, I adhered to social distancing" followed by two situations including "(a) staying out of crowded places and avoiding mass gatherings when going outside of my home, and (b) keeping space (at least 1.5 m) between myself and other people who were coughing or sneezing." All responses were indicated on a four-point Likert scale ranging from "1 = strongly disagree" to "4 = strongly agree." A mean score of the total six items was then computed.

Quality of Life (QoL)

The self-reported scale of the World Health Organization Quality of Life (WHOQOL)-BREF (37) was used to assess QoL. Two items were used from general QoL in this study based on the parsimonious principle. One item assessed the overall rating of each participant's QoL using a 5-point Likert-scale with "1 = very bad; 2 = bad; 3 = ordinary; 4 = good; 5 = very good." The other one assessed how participants were satisfied with health using a 5-point Likert scale ranging from "1 = very dissatisfied" to "5 = very satisfied." A mean score of two items was then calculated. The Cronbach's alpha coefficient was 0.761. In addition, the QoL was classified into three categories, including low level (mean score <3), middle level (mean score = 3), and high level (mean score >3) (38).

Data Analysis

Data were analyzed using the IBM SPSS version 26.0. The diagnostic testing (e.g., outlier screening and distribution checking) was first conducted, and all data adhered to the normal distribution and the absolute values of skewness and kurtosis were <2. Descriptive statistics including means, standard deviation, and percentages were used to describe characteristics. *T*-tests and One-way analyses of variance (ANOVAs) tests were applied to assess the characteristics of QoL. To examine the association of PA stage, FVI stage and preventive behaviors with QoL, multiple linear regression models were used. First, the significant demographics were set as predictors entered into Model 1. Then, two covariates were added to Model 2. Subsequently, the PA stage, FVI stage, and preventive behaviors were included in Model 3.

The role of SES indicators in moderating the associations of PA stage, FVI stage, and preventive behaviors with QoL were examined using multiple linear regression analyses, respectively. Before the regression analysis, Pearson correlation analyses was used to assess the association between SES and QoL. Only SES showing significant correlation with QoL were included in the multiple linear regressions. For each multiple linear regression analysis, the significant SES were entered into Model 1. Then the significantly correlated behavior was entered into Model 2. Finally, the interaction terms between SES and significantly correlated behavior were entered into Model 3. Finally, to test the interaction terms, all the variables were mean-centered. For significant interaction terms, simple slope analyses were conducted to assess the association between QoL and behavior at low and high levels (+ 1 standard deviation) of SES. The 5% level (two-tailed) was taken as the statistical significance cutoff point.

RESULTS

Characteristics of the Participants

Five hundred and sixteen eligible participants aged 60–90 years old (Mean age = 67.6 ± 6.6 yrs.) participated in the study. As shown in **Table 1**, the sample includes 57.9% females, and 68.6% of the participants were aged between 60 and 69 years. Most of the elderly were married (83.7%) and reported living with their spouse, partner, or children (90.7%). Nearly half (46.5%) of the old adults received college or above education, and more than half (57.9%) reported an average household income level. A total of 92.6% were pensioners/retired. 52.1% of the elderly participants were identified as overweight or obese (BMI $\geq$ 26 kg/m^2). In terms of medical history, about half of the participants (50.8%) suffered from chronic diseases (e.g., heart diseases, diabetes, or cancer). A few participants reported that their acquaintances (e.g., family members, friends, or neighbors) had been confirmed with COVID-19 (9.7%). According to QoL levels, the majority of the participants (78.5%) reported high-level QoL, while 6.0% of the elderly reported low-level QoL and 15.5% of the elderly indicated middle-level QoL during the outbreak of COVID-19. The means of behaviors are shown in **Table 1** [mean $_{\text{PA stage}}$ = 3.83 (1.54); mean $_{\text{FVI stage}}$ = 3.77 (1.49); mean $_{\text{PB}}$ = 3.61 (0.40)].

Characteristics of Quality of Life

As shown in **Table 2**, older adults' QoL differed significantly for different characteristics. There were no significant differences in QoL across gender [$t_{(514)} = -0.26$, $p = 0.796$], BMI intervals [$F_{(3, 512)} = 1.96$, $p = 0.119$], and infected cases of acquaintances [$t_{(514)} = -1.61$, $p = 0.109$]. The QoL was significantly higher for participants who had better economic situations [$t_{(2, 513)} = 14.52$, $p < 0.001$] and reported no chronic diseases [$t_{(514)} = -5.43$, $p < 0.001$]. Old adults who were married [$F_{(2, 513)} = 5.18$, $p < 0.01$] with better education [$F_{(2, 513)} = 6.98$, $p < 0.01$] reported significantly better QoL. The poorer QoL was identified among those who lived alone [$t_{(514)} = -2.43$, $p < 0.05$] and were aged over 80 years old [$F_{(2, 513)} = 4.38$, $p < 0.05$]. The employed old adults reported better QoL compared with those who were unemployed, pensioners and those who retired elderly [$F_{(2, 513)} = 4.25$, $p < 0.05$].

TABLE 1 | Descriptive characteristics of the study sample ($n = 516$).

Variable	*N* (%)
Gender, *n* (%)	
Male	217 (42.1%)
Female	299 (57.9%)
Living situation, *n* (%)	
Live alone	48 (9.3%)
Live with others	468 (90.7%)
Age group, *n* (%)	
60–69 years old	354 (68.6%)
70–79 years old	128 (24.8%)
80 years old and above	34 (6.6%)
Marital status, *n* (%)	
Single	14 (2.7%)
Married	432 (83.7%)
Divorced or widowed	70 (13.6%)
Educational level, *n* (%)	
Primary school or below	45 (8.7%)
Middle or high school	231 (44.8%)
College or above	240 (46.5%)
Professional status, *n* (%)	
Unemployed	22 (4.3%)
Pensioner or retired	478 (92.6%)
Employed	16 (3.1%)
Economic situation, *n* (%)	
Below average	113 (21.9%)
Average	299 (57.9%)
Above average	104 (20.2%)
Body mass index (BMI), *n* (%)	
BMI < 18.5 kg/m^2	19 (3.7%)
18.5 kg/m^2 $\leq$ BMI < 23 kg/m^2	228 (44.2%)
23 kg/m^2 $\leq$ BMI < 26 kg/m^2 $\leq$ BMI < 26 kg/m2	206 (39.9%)
BMI ≥ 26 kg/m^2	63 (12.2%)
Chronic diseases, *n* (%)	
Yes	262 (50.8%)
No	254 (49.2%)
Infected cases of acquaintances, *n* (%)	
Yes	50 (9.7%)
No	466 (90.3%)
QoL, mean (SD): 3.76 (0.61)	
Low	31 (6.0%)
Middle	80 (15.5%)
High	405 (78.5%
Lifestyle behaviors	
PA stage, mean (SD): 3.83 (1.54)	
FVI stage, mean (SD): 3.77 (1.49)	
Preventive behaviors, mean (SD): 3.61 (0.40)	

SD, standard deviation; PA, physical activity; FVI, fruit and vegetable intake.

TABLE 2 | Characteristics of quality of life ($n = 516$).

Variable	QoL mean (SD)	*F/t*	*P*
Gender, *n* (%)		$t_{(514)} = -0.26$	0.796
Male	3.75 (0.60)		
Female	3.77 (0.62)		
Living situation, *n* (%)		$t_{(514)} = -2.43$	**<0.05**
Live alone	3.51 (0.77)		
Live with others	3.78 (0.59)		
Age group, *n* (%)		$F_{(2, 513)} = 4.38$	**<0.05**
60–69 years old	3.80 (0.60)		
70–79 years old	3.70 (0.61)		
80 years old and above	3.51 (0.68)		
Marital status, *n* (%)		$F_{(2, 513)} = 5.18$	**<0.01**
Single	3.64 (0.82)		
Married	3.80 (0.57)		
Divorced or widowed	3.54 (0.74)		
Educational level, *n* (%)		$F_{(2, 513)} = 6.98$	**<0.01**
Primary school or below	3.44 (0.78)		
Middle or high school	3.77 (0.59)		
College or above	3.81 (0.58)		
Professional status, *n* (%)		$F_{(2, 513)} = 4.25$	**<0.05**
Unemployed	3.41 (0.68)		
Pensioner or retired	3.77 (0.60)		
Employed	3.90 (0.58)		
Economic situation, *n* (%)		$F_{(2, 513)} = 14.52$	**<0.001**
Below average	3.50 (0.68)		
Average	3.83 (0.57)		
Above average	3.86 (0.58)		
Body mass index (BMI)			
BMI < 18.5 kg/m^2	3.82 (0.630)	$F_{(3, 512)} = 1.96$	0.119
18.5 kg/m^2 $\leq$ BMI < 23 kg/m^2	3.72 (0.61)		
23 kg/m^2 $\leq$ BMI < 26 kg/m^2 $\leq$ BMI < 26 kg/m^2	3.84 (0.59)		
BMI ≥ 26 kg/m^2	3.67 (0.61)		
Chronic diseases, *n* (%)		$t_{(514)} = -5.43$	**<0.001**
Yes	3.62 (0.61)		
No	3.90 (0.58)		
Infected cases of acquaintances			
Yes	3.63 (0.67)	$t_{(514)} = -1.61$	0.109
No	3.78 (0.60)		

SD, standard deviation. Bold values denote statistical significance p-value < 0.05.

Association of PA Stage, FVI Stage, and Preventive Behaviors With QoL

Based on the characteristics of QoL, 6 significant demographic variables (living situation, age group, marital status, educational level, professional status, and economic situation) were entered as predictors in Model 1. Dummy variables were applied for all categorical predictors. Model 1 explained 9% of the variance in QoL ($p < 0.001$). Medical history of chronic diseases and infected cases of acquaintances were entered as covariates into Model 2 contributing to the additional explanation of 5% of the variance in QoL ($\Delta R^2 = 0.05$, $p < 0.001$). After controlling demographics and covariates, PA stage, FVI stage and preventive behaviors the lifestyle behaviors were entered to Model 3, contributing to a significant improvement in the variance explanation ($\Delta R^2 = 0.06$, $p < 0.001$). Model 3 accounted for 20% explanation

TABLE 3 | Multiple linear regression analysis of demographics, covariate, and lifestyle behaviors with QoL ($n = 516$).

Variable	Model 1			Model 2			Model 3		
	B (SE)	95%CI	β	B (SE)	95%CI	β	B (SE)	95%CI	β
BLOCK 1: DEMOGRAPHICS									
Living situation									
Live alone	Reference	N/A	N/A	Reference	N/A	N/A	Reference	N/A	N/A
Live with others	0.12 (0.10)	(−0.08, 0.33)	0.06	0.13 (0.10)	(−0.07, 0.32)	0.06	0.90 (0.10)	(−0.10, 0.28)	0.04
Age group									
60–69 years old	Reference	N/A	N/A	Reference	N/A	N/A	Reference	N/A	N/A
70–79 years old	−0.04 (0.06)	(−0.16, 0.09)	−0.03	0.01 (0.06)	(−0.11, 0.13)	0.01	0.02 (0.06)	(−0.09, 0.14)	0.02
80 years old and above	−0.25 (0.11)	(−0.47, −0.04)	−0.10*	−0.20 (0.11)	(−0.41, 0.01)	−0.08	−0.13 (0.11)	(−0.34, 0.07)	−0.05
Marital status									
Single	Reference	N/A	N/A	Reference	N/A	N/A	Reference	N/A	N/A
Married	0.13 (0.16)	(−0.19, 0.45)	0.08	0.11 (0.16)	(−0.20, 0.42)	0.07	0.09 (0.15)	(−0.22, 0.39)	0.05
Divorced or widowed	0.06 (0.18)	(−0.29, 0.40)	0.03	0.06 (0.17)	(−0.28, 0.39)	0.03	0.04 (0.17)	(−0.29, 0.36)	0.02
Educational level									
Primary school or below	Reference	N/A	N/A	Reference	N/A	N/A	Reference	N/A	N/A
Middle or High school	0.16 (0.11)	(−0.05, 0.37)	0.13	0.21 (0.11)	(0.00, 0.42)	0.17*	0.14 (0.10)	(−0.06, 0.34)	0.12
College or above	0.13 (0.11)	(−0.09, 0.35)	0.11	0.19 (0.11)	(−0.02, 0.41)	0.16	0.11 (0.11)	(−0.10, 0.32)	0.09
Professional status									
Unemployed	Reference	N/A	N/A	Reference	N/A	N/A	Reference	N/A	N/A
Pensioner or retired	0.16 (0.14)	(−0.11, 0.44)	0.07	0.21 (0.14)	(−0.06, 0.48)	0.09	0.17 (0.13)	(−0.09, 0.43)	0.07
Employed	0.24 (0.21)	(−0.16, 0.65)	0.07	0.26 (0.20)	(−0.13, 0.65)	0.07	0.29 (0.19)	(−0.09, 0.67)	0.08
Economic situation									
Below average	Reference	N/A	N/A	Reference	N/A	N/A	Reference	N/A	N/A
Average	0.30 (0.07)	(0.16, 0.43)	0.24***	0.26 (0.07)	(0.13, 0.39)	0.21***	0.21 (0.07)	(0.08, 0.33)	0.17**
Above average	0.32 (0.09)	(0.16, 0.49)	0.21***	0.29 (0.08)	(0.12, 0.45)	0.19***	0.23 (0.08)	(0.07, 0.39)	0.15**
BLOCK 2: COVARIATES									
Chronic diseases									
Yes	–	–	–	Reference	N/A	N/A	Reference	N/A	N/A
No	–	–	–	0.26 (0.05)	(0.16, 0.36)	0.21***	0.24 (0.05)	(0.14 0.34)	0.19***
Infected cases of acquaintances									
Yes	–	–	–	Reference	N/A	N/A	Reference	N/A	N/A
No	–	–	–	0.12 (0.09)	(−0.05, 0.29)	0.06	0.10 (0.09)	(−0.07, 0.27)	0.05
BLOCK 3: LIFESTYLE BEHAVIORS									
PA stage	–	–	–	–	–	–	0.01 (0.02)	(−0.03, 0.04)	0.02
FVI stage	–	–	–	–	–	–	0.08 (0.02)	(0.05 0.12)	0.21***
Preventive behaviors	–	–	–	–	–	–	0.16 (0.07)	(0.03 0.29)	0.10*

** Coefficient is significant at the 0.01 level; ** Coefficient is significant at the 0.05 level, *** Coefficient is significant at the 0.0001 level.*

power of the variance in QoL. The economic situation ($\beta_{\text{average vs. below average}} = 0.17$, $p < 0.01$, 95%CI = 0.08–0.33; $\beta_{\text{above average vs. below average}} = 0.15$, $p < 0.01$, 95%CI = 0.07–0.39), chronic diseases ($\beta = 0.19$, $p < 0.001$, 95%CI = 0.14–0.34), FVI stage ($\beta = 0.21$, $p < 0.001$, 95%CI = 0.05–0.12) and preventive behaviors ($\beta = 0.10, p < 0.05$, 95%CI = 0.03–0.29) can significantly predict the QoL of old adults. Details of regression analysis is shown in **Table 3**.

Moderating Effect of Socioeconomic Status

Correlation analyses revealed that educational level ($r = 0.13$, $p < 0.01$), professional status ($r = 0.12$, $p < 0.01$), and economic situation ($r = 0.20$, $p < 0.001$) were significantly associated with QoL. In addition, except PA stage ($r = 0.02, p = 0.449$), FVI stage ($r = 0.21$, $p < 0.001$), and preventive behaviors ($r = 0.10$, $p < 0.05$) were significantly related to QoL.

In terms of the moderating effects of socioeconomic status between FVI and QoL, **Table 4** shows that educational level, professional status, and economic situation significantly predicted old adults' QoL in model 1 ($R^2 = 0.22$, $p < 0.001$), FVI stage significantly contributed to model 2 ($\Delta R^2 = 0.14$, $p < 0.001$), the interactions of SES with FVI stage did not significantly contribute to model 3 ($\Delta R^2 = 0.00$, $p = 0.510$). In terms of moderating effects of socioeconomic status between preventive behaviors and QoL, **Table 5** shows that economic situation significantly predicted old adults' QoL in model 1 ($R^2 = 0.22$, $p < 0.001$), preventive behaviors significantly contributed

TABLE 4 | Multiple linear regression examining main and interaction effects of socioeconomic status and FVI measures on QoL ($n = 516$).

Variable	Model 1			Model 2			Model 3		
	B (SE)	95%CI	β	B (SE)	95%CI	β	B (SE)	95%CI	β
Educational level	0.05 (0.04)	(−0.03, 0.14)	0.06	0.03 (0.04)	(−0.05, 0.11)	0.03	0.14 (0.11)	(−0.08, 0.36)	0.15
Professional status	0.17 (0.10)	(−0.03, 0.37)	0.08	0.17 (0.10)	(−0.02, 0.36)	0.08	0.28 (0.22)	(−0.15, 0.7)	0.12
Economic situation	0.16 (0.04)	(0.07, 0.24)	0.17***	0.14 (0.04)	(0.05, 0.22)	0.14***	0.07 (0.11)	(−0.14, 0.29)	0.08
FVI stage	–	–	–	0.12 (0.02)	(0.08, 0.15)	0.28***	0.23 (0.11)	(0.01, 0.45)	0.56*
FVI stage × Educational level	–	–	–	–	–	–	−0.03 (0.03)	(−0.09, 0.02)	−0.23
FVI stage × Professional status	–	–	–	–	–	–	−0.04 (0.06)	(−0.15, 0.08)	−0.18
FVI stage × Economic situation	–	–	–	–	–	–	0.02 (0.03)	(−0.04, 0.07)	0.11

*FVI, fruit and vegetable intake; B, unstandardized coefficient; SE, standard error; β, standardized coefficient; –, data do not include in this model. *$p < 0.05$; ***$p < 0.001$, 2 tailed. Model 1 $R^2 = 0.22$; Model 2 $R^2 = 0.36$; Model 3 $R^2 = 0.36$.*

TABLE 5 | Multiple linear regression examining main and interaction effects of socioeconomic status and preventive behaviors on QoL ($n = 516$).

Variable	Model 1			Model 2			Model 3		
	B (SE)	95%CI	β	B (SE)	95%CI	β	B (SE)	95%CI	β
Educational level	0.05 (0.04)	(−0.03, 0.14)	0.06	0.03 (0.04)	(−0.06, 0.11)	0.03	1.11 (0.39)	(0.34, 1.87)	1.16**
Professional status	0.17 (0.10)	(−0.03, 0.37)	0.08	0.17 (0.10)	(−0.02, 0.37)	0.08	−0.41 (0.76)	(−1.91, 1.08)	−0.18
Economic situation	0.16 (0.04)	(0.07, 0.24)	0.17***	0.13 (0.04)	(0.05, 0.22)	0.14**	0.95 (0.37)	(0.24, 1.67)	1.01**
Preventive behaviors	–	–	–	0.28 (0.07)	(0.15, 0.41)	0.18***	1.09 (0.43)	(0.24, 1.93)	0.71*
Preventive behaviors × Educational level	–	–	–	–	–	–	−0.30 (0.11)	(−0.51, −0.09)	−1.30**
Preventive behaviors × Professional status	–	–	–	–	–	–	0.16 (0.22)	(−0.27, 0.58)	0.32
Preventive behaviors × Economic situation	–	–	–	–	–	–	−0.23 (0.10)	(−0.43, −0.03)	−0.97*

*B, unstandardized coefficient; SE, standard error; β, standardized coefficient; –, data do not include in this model. *$p < 0.05$; ***$p < 0.001$, 2 tailed. Model 1 $R^2 = 0.22$; Model 2 $R^2 = 0.28$; Model 3 $R^2 = 0.33$.*

to model 2 ($\Delta R^2 = 0.06$, $p < 0.001$), the interactions of SES with preventive behaviors significantly contributed to model 3 ($\Delta R^2 = 0.05$, $p < 0.01$). In particular, 2 out of 3 interaction terms (preventive behaviors * educational level, $\beta = -1.3$, $p < 0.01$, 95%CI = −0.51 to −0.09; preventive behaviors * economic situation, $\beta = -0.97$, $p < 0.05$, 95%CI = −0.43 to −0.03) were significantly associated with QoL among old adults.

To further analyze the significant interaction effects, simple slopes analyses was conducted. In terms of the moderating effects of education level on the relationship between preventive behaviors and QoL, **Figure 1** shows that preventive behaviors were significantly associated with QoL at primary school or below of educational level [$\beta = 0.78$, $t_{(510)} = 3.86$, 95%CI = 0.38–1.18, $p < 0.001$] and at the middle or high school educational level [$\beta = 0.34$, $t_{(510)} = 3.79$, 95%CI = 0.16–0.52, $p < 0.001$], while the association was not significant at college or above for educational level [$\beta = 0.09$, $t_{(510)} = 0.82$, 95%CI = −0.13 to 0.32, $p = 0.411$]. In terms of the moderating effects of economic situation on the relationship between preventive behaviors and QoL, **Figure 2** shows that preventive behaviors were significantly associated with QoL at the below average level for economic situation [$\beta = 0.58$, $t_{(510)} = 4.46$, 95%CI = 0.33–0.84, $p < 0.001$] and at the average economic situation [$\beta = 0.18$, $t_{(510)} = 2.06$, 95%CI = 0.01–0.36, $p = 0.040$], while the association was not significant at the above average level for economic situation [$\beta = 0.11$, $t_{(510)} = 0.73$, 95%CI = −0.18 to 0.41, $p = 0.464$].

DISCUSSION

To the best of our knowledge, this is the first online cross-sectional study to explore the characteristics of QoL, to examine the association between lifestyle behaviors and QoL, and to identify the moderating role of SES on the association between lifestyle behaviors and QoL among Chinese older adults during the COVID-19 pandemic. The findings from the study have fully supported the proposed hypotheses. Specifically, during the outbreak of COVID-19, older adults' QoL differed significantly for demographic characteristics; healthy lifestyle behaviors significantly associated with higher QoL and SES indicators such as economic situation and educational level moderated the association between lifestyle behaviors and QoL levels in Chinese older adults.

In terms of the characteristics of QoL, as suggested in previous studies, older adults with better economic situations showed higher levels of QoL than those with lower economic conditions (39, 40). In line with previous evidence, the findings revealed that the elderly with higher levels of education showed higher QoL levels (41, 42). Employed participants and the elderly below 69 years of age showed higher QoL, confirming previous research results (42). As suggested in previous studies (41), the elderly with lesser family associations demonstrated significantly poorer QoL than those with sufficient socialization. Therefore, it is not surprising that older adults who were married and lived

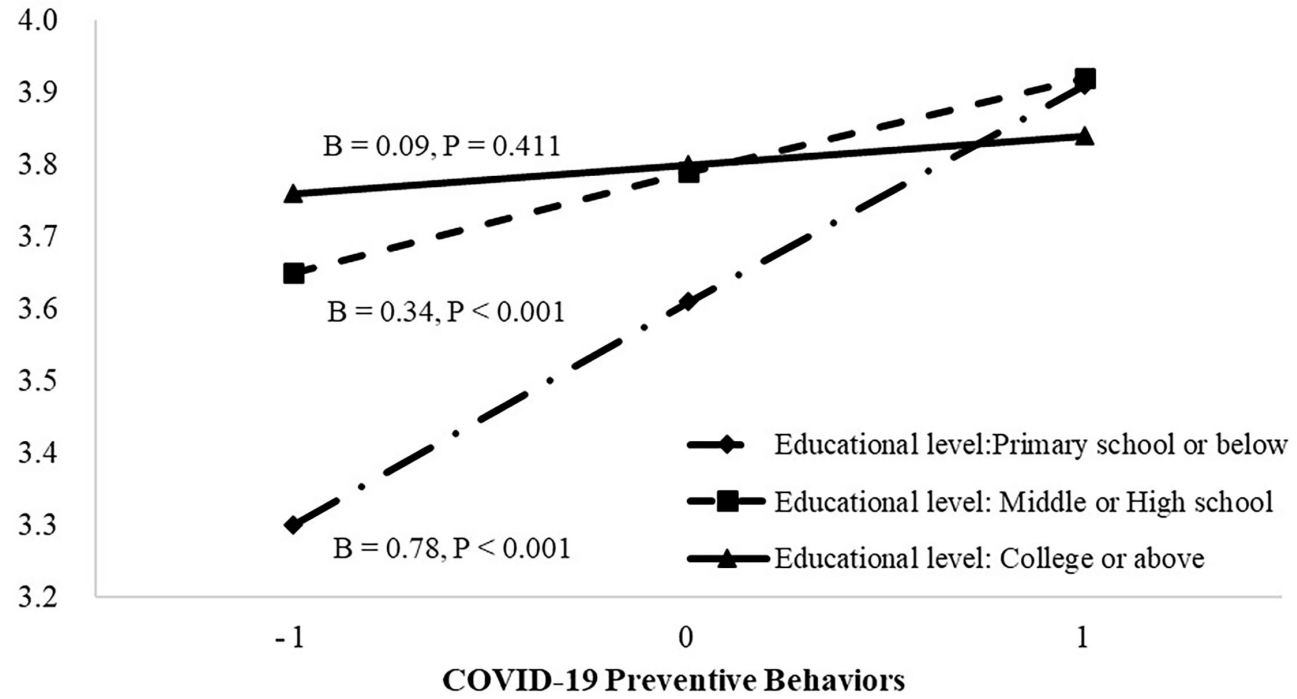

FIGURE 1 | The association between COVID-19 preventive behavior and quality of life (QoL) at different categories of educational level. The plot shows the predicted values of QoL at mean and ±1 SD of preventive behavior and educational level.

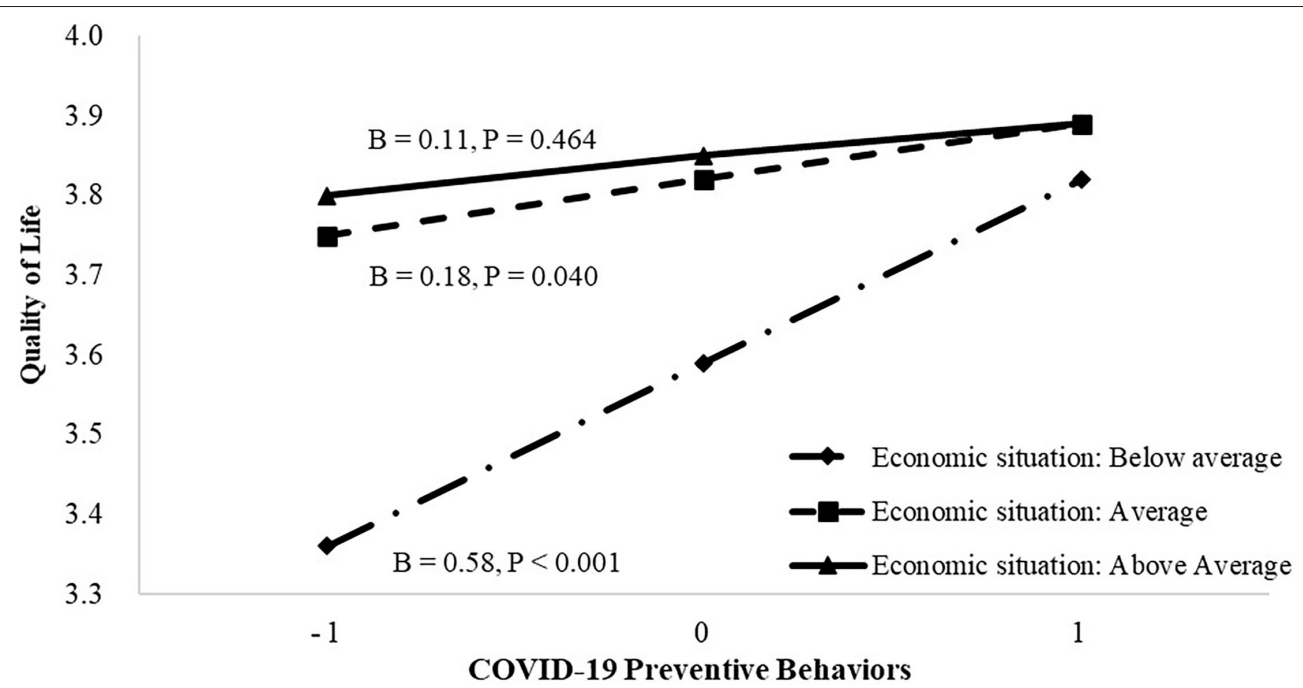

FIGURE 2 | The association between COVID-19 preventive behavior and quality of life (QoL) at different categories of economic situation. The plot shows the predicted values of QoL at mean and ±1 SD of preventive behavior and economic situation.

with others (e.g., spouse, partner, or children) indicated higher QoL. Also, the older adults with chronic diseases showed a significantly poorer QoL. This finding is consistent with a recent study in Moroccan populations, which observed that the impact of COVID-19 on QoL was more marked in people with chronic health problems (43). Consistent with previous evidence, the

current study did not indicate significant differences in gender and BMI (44, 45). A discrepancy with previous evidence occurred in the infected cases of acquaintances (39) where no significant differences were found in this study. This may be attributed to the reason that most of our participants reported no infected cases of acquaintances (90.3%).

In terms of the association of lifestyle behaviors with QoL, our findings were consistent with a recent cross-sectional study among polish adults (46). Older adults who were at a higher FVI stage (eating more fruits and vegetables) and adopted more individual preventive behaviors (e.g., hand washing, facemask wearing, and social distancing) were more likely to show higher QoL during the COVID-19 pandemic. Notably, the lifestyle behaviors during the COVID-19 pandemic accounted for 6% of the variance in QoL, while economic situation, SES and chronic diseases as covariates also played an important role in predicting older adults' QoL status. These findings emphasize the significance of promoting FVI and preventive behaviors during the COVID-19 pandemic among older adults. The findings also highlight the importance of considering economic and health conditions when making relevant policies and designing interventions to enhance QoL among older adults.

In terms of the moderating effects of SES indicators in the association between lifestyle behaviors and QoL, educational level, and economic situation were found to be significant moderators in preventive behaviors and QoL association. To the best of our knowledge, there are no previous studies revealing such findings. Our recent study found that economic situations could modify the relationship between COVID-19 preventive behaviors and depression among Chinese older adults (36). As depression is significantly associated with QoL in older adults (47) we infer that the moderating role of economic situation might also occur between preventive behaviors and QoL. However, more empirical research using similar study designs among older adults from other regions and countries are needed in the future. The findings of the SES moderating role in the current study revealed that when authorities motivate older adults to enact COVID-19 preventive behaviors to improve their QoL status, they need to especially focus on older adults who are at a lower economic status with lower education levels. From a social policy aspect, the findings indicate the importance and necessity of public welfare targeting socioeconomic-specific population during the pandemic prevention. For example, local government can provide relief funding and epidemic prevention appliances (e.g., face masks, disinfection alcohol, and hand sanitizer) for low-income households to facilitate their preventive behaviors (48). In addition, community administrators can organize workshops and campaigns for older adults who are at lower education levels to increase their health literacy about preventive behaviors. All these policies and measures are useful for those older adults with socio-economic disadvantages to enact more preventive behaviors, which in turn can improve their level of health-related QoL during the pandemic.

Limitations of the current study should be acknowledged. Firstly, older adults who were at low socioeconomic status may have no access to mobile phones or computers to participate in this online survey. In addition, we applied snowball sampling approach to recruit older adults from Hubei province in China. Such investigation mode and sampling method may weaken the representativeness of samples and findings. Future studies should enlarge sample size, employ randomized sampling approaches, and administrate both online and offline surveys to enhance the generalization. Secondly, all the variables were measured using self-reported subjective scales, which might lead to recall bias and social desirability effects. In addition, due to the consideration on the parsimonious mode of online survey among older adults, only two general items of QoL were addressed in this study. We acknowledge that these items were not representative enough to capture the specific domains of QoL. For PA and FVI, only the simple algorithms were used to measure the stages of change of behaviors although the validity and reliability of the questionnaire were approved in previous studies (34). Therefore, applying comprehensive questionnaires to measure QoL, PA, and FVI should be warranted in future studies. Thirdly, the socio-demographic and behavioral factors identified in the present study only explained 20% of the variance of QoL. Hence, more socio-demographics such as the number of children an older adult has, how much financial support older adults receive from their children (49) and other healthy behaviors such as restful sleep (6) should be investigated in future studies among older adults. Notwithstanding the limitations, this study provides important information on the association between lifestyle behaviors and QoL during the COVID-19 pandemic. The study also provides detail relating to the role of SES indicators in moderating lifestyle behaviors and QoL among Chinese older adults. The research findings from this study inform interventions and policy makers to improve the health and QoL of older adults by means of enhancing their lifestyle behaviors (FVI and preventive behaviors) during the COVID-19 outbreak and future pandemics.

CONCLUSION

The current study investigated how Chinese older adults' demographic characteristics differ in QoL during the COVID-19 pandemic. The study also examined the association of lifestyle behaviors and QoL and identified the role of SES indicators in moderating the behavior–QoL relationship. All the study hypotheses were supported. The QoL of older adults differed significantly for living situations, age group, marital status, educational level, professional status, economic situation, and chronic diseases. The positive association of FVI and preventive behaviors with QoL was also identified in the current study. For SES indicators, only education level and economic situation significantly moderated the relationships between preventive behaviors and QoL. The research findings highlight the need for enacting preventive behaviors and FVI on enhancing QoL among older adults during the COVID-19 pandemic. The findings also revealed the importance of considering socioeconomic disparities such as economic status and education level when promoting preventive behaviors and QoL among the elderly during the pandemic. The findings presented here could be informative in implementing public health and social policies

to maintain the overall well-being of older adults during the COVID-19 pandemic.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by REC/19-20/0490 Hong Kong Baptist University. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

YD and WL conceived and designed the study. YD, WL, CH, and BS contributed to the preparation of study materials. YD, WL, MY, CH, and BS collected the data. MY, WL, and YD screened and analyzed the data. MY, DP, and YD drafted the manuscript. YD, JB, and WL revised and polished the manuscript. All authors have read and agreed to the published version of the manuscript.

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Stressful Life Events and Chinese Older People Depression: Moderating Role of Social Support

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Aim: This study analyzes the effects of retrospective stressful life events on current depression among Chinese older people and how these effects are moderated by social support. Stressful life events comprise bereavement, divorce, health adversities, accidents, and financial losses due to fraud.

Data and Method: Data were drawn from the China Health and Retirement Longitudinal Study (CHARLS) of the 2015 panel, and responses from 9,619 older people aged over 60 years were used. The least-squares regression method was applied to measure the linear effects. Propensity score matching minimized selection bias and enabled the measurement of the net effects of stressful life events. The bias-corrected matching estimator was also used to correct the inexact matching bias from propensity score matching.

Result: Experienced stressful life events and exposure to cumulative stressful life events were found to lead to depression in older people. When older people experienced stressful life events but with more social activities, and higher satisfaction and frequent contact with children, their depressive levels were lower. The results of the propensity score matching showed that stressful life events resulted in depression in older people. Furthermore, individuals with family support were able to moderate stressful life events effects; however, the moderating effects of social activity separately were negligible. In sum, with the moderating role of family support and social activity, the average differences in older people depression caused by stressful life events decreased.

Conclusion: Experiencing stressful life events is detrimental to the psychological health of the older people. Social support, including family support and social activity, has buffered detrimental effects on depression caused by stressful life events.

Interpretations: The study underscores the need to supply effective interventions for the older people who experienced stressful life events. First, society should improve the capability of community care centers to supply mental health services. Second, family members should pay attention to mental condition of older people, and specific support should concord with the needs of Chinese older people. In addition, support suppliers can move from being confined to kinship relationships to close relationships, such as the community partners and neighbors.

Keywords: stressful life event, depression, Chinese older people, social support, family support, social activity

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INTRODUCTION

Mental illness is a significant public health problem. In 2015, 4.4% of the global population was diagnosed with depression, over an estimated 300 million people (1). In recent years, the prevalence of mood and anxiety disorders in China has been on the rise, with a point prevalence of 1.1% in both 1982 and 1993, a 12-month prevalence of 7.0% in 2002, and a lifetime prevalence of 1.3% in 1982, 1.4% in 1993, and 13.2% in 2002 (2). The weighted prevalence of any mental disorder excluding dementia was reported to be 9.3% for the preceding 12 months and 16.6% for lifetime prevalence; the prevalence of depression was 4.2% in 2017, as estimated by the World Health Organization (1, 2). Depression is a long-term and easily recurrent mental disorder that can cause considerable loss in health and functioning, including functional impairment, low quality of life, high risk of suicide, and immense burdens not only for individuals but also for families and societies (1, 3–6). Depression is ranked as the largest single factor of disability worldwide (1). Furthermore, there is a huge imbalance between mental disorder burdens—which account for 12% of the global burden of disease—and mental health expenditures, which account for <1% of health expenditures in most countries (7, 8). The World Health Organization (1) quantifies the health losses from mental disorders in terms of years lived with disability, which is the product of the prevalence of mental disorders and the average level of disability related to them. Chinese depressive disorders contributed 7.3% of the total years lived with disability as a health loss.

Depression in old age is common; indeed, the prevalence of depression peaks between 55 and 74 years of age (1, 5, 9). According to the Chinese National Censuses, the proportion of the population aged 60 and over was 10.45% in 2000, 13.31% in 2010, and 18.70% in 2020, and that aged 65 and over was 7.09% in 2000, 8.91% in 2010, and 13.50% in 2020 (10–12). These proportions have been increasing gradually with the increase in the Chinese population.

Stressful life events are risk factors for depression (1, 13). 70% of respondents report experiencing at least one traumatic event in their life course, and the majority have been exposed to multiple events (14). Old age is a period of constant loss: Various risks, such as disease, widowhood, and departure of loved ones, are difficult to avoid in old age (15, 16). Therefore, older people, as high-risk groups, are exposed to the prevalence of depression and experience stressful life events.

The perceived social support to the older people can influence the possibility of their depression (17, 18). As a country influenced by Confucian culture, the tradition of filial piety and respect for older people in the Chinese culture encourages family support to play a certain role to moderate the effects of depression resulting from stressful life events.

Currently, research is focused on Chinese older people, but few studies have investigated depression in Chinese older people (5, 15, 19, 20). These studies were mostly based on medical theories describing current conditions and risk factors for depression. Furthermore, some societal studies explore effects on depression from social support and stressful life events separately. Through this process, social support has covered diversified interpretations and its referral is ambiguous. Some studies use social support to refer to social activities, where social support and social activities are overlapped in contents and are interchangeable (21–23). Otherwise, social support has narrowed its definition to family support, used as a factor similar with social activity to discuss health problems (24–26).

Therefore, this study mainly discusses two aspects: first, the relationship between stressful life events experienced by the Chinese older people and depression, and second, how social support moderates the effects of stressful life events on depression in older people. Depression was measured in terms of depressive feelings and behaviors rather than clinical diagnoses. Furthermore, the study first describes social support broadly in this paper as interactions from certain contexts, either in the society or community or in the family to enhance individual's well-being; second, the study differentiates social support into two types based on the place of references, inside or outside of family: family support and social activities. The study makes use of the 2015 China Health and Retirement Longitudinal Study (CHARLS) panel data, applies multiple regression to detect the risk factors for depression, and carries out propensity score matching (PSM) to quantify, first, the effects on depression from stressful life events, and second, the buffering effects on depression from stressful life events via social activities, family support and social support, under the counterfactual framework.

LITERATURE REVIEW

Risk Factors for Depression

Age has been regarded as a high-risk factor for depression because events such as bereavement, illnesses, and disabilities are inevitable in old age (9, 15, 19, 27). In general, women are at a higher risk for depression than men. However, such gender differences decrease in old age (4–6, 20, 28, 29). Indeed, females are distressed by network relationships, but males are affected by job or financial problems, both of which lead to depression (19). Illnesses, functional impairment, and perceived deteriorating health are also highly correlated with depression (5, 6, 9, 19, 27, 28). Chronic illnesses, that leads to functional decline, can be regarded as a risk factor for depression (30). Further, low educational levels and low socioeconomic status have been shown to result in a high risk of depression (4, 5, 29).

Bereavement, including widowhood and loss of offspring, is consistently and strongly related to depression (28, 31–33). However, when facing widowhood, older women are less vulnerable than older men (34). Stressful life events are still risk factors for depression and are predictors of the onset and relapse of depression (5, 6, 15, 19, 28, 35–37). However, previous research has covered many risk factors related to depression but only partly underlined the association between stressful life events and depression (20).

Stressful Life Events and Depression

Life stress is caused by adverse social-environmental experiences, which include economic circumstances, physical health, mental states, and social relationships (36). Stressful life events are

defined as transitions that prompt a need to readjust the daily life routine, especially emotional and physical readjustment, and include events, such as death and dying, and issues related to healthcare, finances, and family (15, 35, 38). Furthermore, stressful life events for older people include social losses, illnesses, changes in social roles, and changes in daily life patterns (15). In previous studies, stressful and negative life events have been treated as similar and interchangeable (20, 35).

Stressful life events have a modest but significant relationship with depression, but whether this is a causal effect is unclear (20, 32, 37, 39). There is a stronger association between stressful life events and depression when the event is more severe or there are more events (32, 39). Social readjustment rating scale measures the required social life adjustments associated with various life events, including some undesirable ones that are regarded as stressors (40). Research based on the social readjustment rating scale has shown a significant association between exposure to stressful life events and stress-related symptoms (37, 38, 41). However, in some studies, stressful life events have been shown to be causally associated with depression, and even early exposure to life stress can predict depression in later life (39, 42, 43). Furthermore, the causal association between stressful life events and depression is not unilateral: genetic risk factors and personality traits both result in stressful life events and depression (43).

However, most studies collectively consider effects from stressful life events on mental health, and do not differentiate the effects from cumulative stressful life events, which are a quantity of stressful life events older people once experienced. Cumulative violence exposures positively associate with the risk for poor health, and each additional violence exposure may increase 38% of the risk of poor health (44). The total number of stressful life events is related to current depression and depression in later life, where an increase in stressful life events has decreased a health score (20, 45, 46). Indeed, lifetime cumulative adversity rather than discrete stressful life events has a more lasting effect on health (47). For example, individuals who have more cumulative adversities will experience more health problems later (14).

There are two steps of assessing whether a life event is a stressor: first, determining whether the event occurred in a particular time span; second, appraising the event level (48). Time span, either short term or long term, has been regarded as an essential measure between stressful life events and depression. Events that occurred more recently were associated more strongly with severe stress symptoms (5, 37). Stress diminishes when events occurred at a more distant point in time. In contrast, lifetime traumatic events have been shown to have long-term impacts on physical and mental health (14, 49, 50). Indeed, events occurring earlier are still associated with late-life depression (20). Adults continue to experience emotional pain from bereavement for decades after the event (51). In addition, some studies do not set time limits when discussing stressful life events and depression.

Social Support and Depression

The World Health Organization regards social support as an essential factor in health; indeed, family members, friends, and communal members are the main suppliers of social support (33). Social support is a perception of specific help from network partners and has different effects on individuals, either to enhance positive effects and further increase their well-being or to reduce the negative impacts of depression (6, 26, 52). Furthermore, the perceived social support and received social support are distinguished, where the former describes the subjective feeling of being supported by the relationships and the latter focuses on actual support; indeed, perceived social support is commonly measured and more effective in buffering depression than received support (17).

Greater social support plays a protective role against depression, whereas less social support may be a risk factor for current depression or depression in later life (26, 53). Furthermore, social support can erase sex-specific effects on depression (26). The convoy model of social relations argues that individuals' interactions with essential people—defined as not only close relations but also those who have an effective impact on the individual—are stable and long-term; indeed, the accumulation of interactions can enhance individuals' spiritual health (31). Self-determination theory explains the transmission mechanism of social support, where extrinsic social contexts have transformed into intrinsic self-values and self-motivation and conversely facilitates the ability to cope with social contexts (54).

Family support is a robust protective factor against depression in the older people (33, 34). First, individuals prefer to have effective support rather than network size; the former includes matches between emotional demand and related support, and the quality of social relationships (17, 18). Older people's social networks are characteristically smaller but stronger in emotional closeness with network partners. Second, social-emotional selective theory argues that the perception of time influences individual motivation (55). Older people's perceived limited time left to live improves their selective preferences toward emotionally close social partners (26, 52, 56). People in the United States and European countries prioritize friend networks; however, people in Asian countries regard family networks as important (3, 17, 57). Much social support is drawn from kin, and with age, the effects of relatives are more essential than non-kin relationships (58). Therefore, when addressing depression in the Asian context, families should be included in the plan for support and interventions.

Family support from adult children can improve older people's life quality and strengthen their life satisfaction, especially for the positive effects on their mental health (59, 60). In particular, older parents who received financial support from their children had enhanced self-esteem and lower negative mental outcomes. In this aspect, older people show similarities across genders with regard to positive effects from financial support (33, 34). Furthermore, family support from relatives can significantly alleviate the death anxiety of older people, which supplies a useful resource to help older people to relieve negative emotions and contain better psychological condition (61). Finally, older adults with strong family support can deal with stressful issues more effectively than those without (16, 26, 52).

Social activity is highly associated with good self-rated health and lower depressive symptoms (62, 63). Indeed, although social

participation occurrence decreases with age, the influence of social participation on health status will increase with age (62). Therefore, social activity is a key to healthy aging (21). Older people participating in social activities can decrease the risk of depressive symptoms; indeed, more frequent and more diverse participation can further reduce the risk (64). Further, diverse activities rather than single activity can be more protective against depressive symptoms (65).

Stressful Life Events, Social Support, and Depression

Social support plays a protective role against depression and acts as a moderator between stressful life events and depression (20, 28, 35, 36). Through social support, individuals enhance their resilience to cope with stressful life events, and consequently, depression decreases (36). Indeed, the older people have different responses toward social support stress-buffering effects, with the oldest older people showing the greatest response (16).

Therefore, the study proposes the following hypotheses:

Hypothesis 1: Chinese older people who experience stressful life events will show an increase in depression.
Hypothesis 2: When Chinese older people experience stressful life events, social activities may buffer its effect on their depression.
Hypothesis 3: When Chinese older people experience stressful life events, family support may moderate its effect on their depression.
Hypothesis 4: When Chinese older people experience stressful life events, social support may lessen its effect on their depression.

DATA AND METHODOLOGY

Methodology

Multiple Regression Analysis

The study used multiple regression of the ordinary least square estimates to present the linear relationship between stressful life events and depression, and the moderating effects of social support on the relationship. Additionally, social support and its components, social activities and family support, were considered separately.

The multiple regression equations are:

$$Y_1 = \alpha + \beta_1 MX + \beta_2 CX + \varepsilon \quad (1)$$

$$Y_2 = \alpha + \beta_1 MX + \beta_2 CX + \beta_3 SA + \beta_4 MX \times SA + \varepsilon \quad (2)$$

$$Y_3 = \alpha + \beta_1 MX + \beta_2 CX + \beta_5 FS + \beta_6 MX \times FS + \varepsilon \quad (3)$$

$$Y_4 = \alpha + \beta_1 MX + \beta_2 CX + \beta_3 SA + \beta_4 MX \times SA + \beta_5 FS + \beta_6 MX \times FS + \varepsilon \quad (4)$$

where Y is depression, and the subscripts from 1 to 4 represent separate models: stressful life event model, social activity model, family support model, and social support model. MX are main independent variables, CX are control variables, SA and FS are moderator variables of social activities and family support, and intersection variables between main independent variables and moderator variables are presented. α and β are coefficients; and ε is the error term.

Propensity Score Analysis

This study aims to discuss the association between stressful life events and depression and quantify the effects of stressful life events and social support on depression. The study's program evaluation is based on counterfactual inferences; the treatment group comprises older people who have experienced stressful life events, and those who have not, comprise the control group.

Whether older people experience stressful life events is the outcome of self-selection. First, stressful life events are sorted into independent events (e.g., bereavement) and dependent events (e.g., divorce), where dependent stressful events result from individuals' behaviors (42, 66). Second, age is a trigger for stressful life events (16), and explains the fact that older people are a high-risk cohort to the problems of health adversities and bereavement. However, seniors of different age groups present diversified risks; for example, the young-old and older-old are exposed differently. Therefore, the initial limits of the treatment and control groups are different, and selection biases exist.

The effects of stressful life events on depression are measured as follows:

$$y_i = \begin{cases} y_{1i} & D_i = 1 \\ y_{0i} & D_i = 0 \end{cases} \quad (5)$$

where D_i is a dummy variable that takes 1 if the respondent has experienced a stressful life event, and 0 otherwise; and y_i is the outcome of interest that represents depression in this study, with y_{1i} denoting depression from stressful life events and y_{0i} denoting depression when the respondent did not experience stressful life events.

Because the treatment effect is a random variable, the average treatment effect (ATE) is measured as:

$$ATE \equiv E(y_{1i} - y_{0i}) \quad (6)$$

Average Treatment Effect on the Treated (ATT) is measured as:

$$ATT \equiv E(y_{1i} - y_{0i} | D_i = 1) \quad (7)$$

Given the observed covariate vector, the propensity score is the conditional probability that an observation case is assigned to a particular intervention (67). Based on the selection of observables, the ignorability assumption and matching assumption are satisfied.

The study uses PSM to identify older people who have not experienced stressful life events with similar characteristics to those who have, to further compare two-cohort differences in depression. The differences in depression result from the effects of experienced stressful life events. Social support and its components, social activities and family support, have been included separately as characteristics in models. PSM is conducted here in 3 steps: first, finding covariates that cause an imbalance between the treatment and control groups by logistic

regression; second, matching replacements in the common support region; and third, applying a data balancing check to appraise the match quality (67, 68). This study applied one-to-one neighbor, radius, and kernel matchings to measure the propensity score.

When considering covariates in detail, the equations are:

$$ATT_1 \equiv E(y_{1i} - y_{0i}|D_i = 1,\ x = CX) \quad (8)$$

$$ATT_2 \equiv E(y_{1i} - y_{0i}|D_i = 1, x = CX + SA) \quad (9)$$

$$ATT_3 \equiv E(y_{1i} - y_{0i}|D_i = 1, x = CX + FS) \quad (10)$$

$$ATT_4 \equiv E(y_{1i} - y_{0i}|D_i = 1, x = CX + SA + FS) \quad (11)$$

where ATT is average treatment effect on the treated, and the subscripts from 1 to 4 represent separate models: stressful life event model, social activity model, family support model, and social support model. Covariates include control variables (CX), moderator variables of social activities (SA) and family support (FS). Compared to stressful life event model, the change of differences in depression separately attributes to moderating effects from social activities, family support and social support.

PSM relies on a sufficient sample. However, when the number of matches increases, it increases the difficulty of precise matching between the treatment and control groups (67). Bias-corrected matching estimators proposed to solve the problems of conditional biases from simple matching estimators in inexact matching (68). Bias-corrected matching estimators use vector norms to measure the distance of every observable covariate, rather than a one-dimensional score, for the application of PSM. This study uses a bias-corrected matching estimator to further verify the effects of stressful life events on depression.

Robustness Check

For the main model, the study selected the total number of stressful life events experienced by older people to present a linear relationship with depression by means of multiple regression analysis. After PSM analysis, the study shrunk the sample to matched individuals and investigated whether experienced stressful life events can be used as the main independent variable to further check the robustness of the model

Data

The study uses 2015 panel data from the China Health and Retirement Longitudinal Study (CHARLS). CHARLS aims to collect a high-quality nationally representative sample of Chinese residents aged 45 years and older to serve the needs of scientific research on the older people. CHARLS was approved by the Institutional Review Board at Peking University. The IRB approval number for the main household survey, including anthropometrics, is IRB00001052-11015. Each interviewee who agreed to participate in the survey signed a written informed consent. The baseline national-level wave of data collection was in 2011, followed by 5 national waves in 2011, 2013, 2014, 2015, and 2018 (69). In order to be closer to reality, the study tends to select a recent panel; however, due to the time when the data was obtained, the study finally employs 2015 panel data from CHARLS.

First, based on individual ID, the study merged 8 data subsets into one to allow for the prerequisite of data washing, which included data on demographic background, family information, family transfer, healthcare, health status, individual income, and work, retirement, and pension. There were 21,069 observations in the sample (11,044 females and 10,025 males). Second, the study discarded observations beyond the specified age limits. The aim of this study was to discuss the association between stressful life events and depression among the older people. Therefore, the study retained data from individuals who are at least 60 years old, producing a sample of 9,785 individuals. However, individuals do not experience stressful life events randomly, and a personal history of depression exacerbates lifetime adversity and is a risk factor for experiencing stressful life events and depression in later life (20, 42, 43). Therefore, this study discarded individuals with clinically diagnosed depression to avoid endogeneity problems. Finally, 9,619 interviewees were included in the final sample.

In this study, stressful life events are conceptualized as exposure to bereavement and divorce, health adversities, accidents, and defrauded financial losses. Events of bereavement of spouse, child, and relatives and severe accidents fulfill the criteria of a traumatic event as described by the American Psychiatric Association (70): "Directly experiencing the exposure to actual or threatened death, serious injury, or sexual violence; or witnessing, in person, the event(s) as it occurred to others; or learning that the traumatic event(s) occurred to a close family member or close friend; or experiencing repeated or extreme exposure to aversive details of the traumatic event(s)" (page 182). Events of divorce and defrauded financial losses fulfill the criteria of an adjustment disorder, where the stressor can be of any severity or type rather than that required by traumatic events (page 187).

Event selections should consider the independence of events, that is, whether events are the outcomes of problems (41). Health is discarded in the selection, in that health is reflected as an individual's wellbeing but not a specific event (20). However, it is possible to cover this in the selection if a health comparison is included. Furthermore, including health events as the main independent variables rather than control variables will show a strong association with depression (28). Indeed, poor self-rated health is highly associated with depression (5, 19). Events of health adversities in this study cover poor self-rated health, hospitalization in the previous year due to illness, and functional disability. Due to health and memory problems, when the older people have at least one of these six difficulties, are unable to function independently without help, and when such a situation has not been resolved within 6 months, the study regards the older people as those who experienced stressful life events of functional disability. These difficulties include using the toilet, including getting up and down; getting into or out of bed; eating, such as cutting up food; bathing or showering; dressing; and controlling urination and defecation.

Measures

Dependent Variable

Depression

This is a cumulative variable that is measuring by adding up the scores for responses to the question of how the respondent felt and behaved during the preceding week. The responses were: (1) I was bothered by things that do not usually bother me; (2) I had trouble keeping my mind on what I was doing, (3) I felt depressed, (4) I felt everything I did was in vain, (5) I felt hopeful about the future, (6) I felt fearful, (7) My sleep was restless, (8) I was happy, (9) I felt lonely, and (10) I could not continue my life. Negative items are assigned a value of 1, for responses of "rarely" or "none of the time;" a value of 2 for "some or a little of the time;" a value of 3 for "occasionally" or "a moderate amount of the time;" and a value of 4 for "most or all of the time." Responses for positive items are conversely assigned from 1 for "most or all of the time" to 4 for "rarely or none of the time." The value of Cronbach's alpha for these 10 items is 0.7950, which denotes a good credential of scales (71). The responses were summed up to measure depression in the older people.

Main Independent Variables

Number of Stressful Life Events Experienced

This variable is added to stressful life events experienced by the older people. There are eight stressful life events: widowhood and divorce, bereavement of child, bereavement of relatives in the past 12 months, being financially defrauded, limited daily activities due to earlier accident, poor self-rated health, functional disabilities, and hospitalization due to illness in the past 12 months.

Experienced Stressful Life Events

This is assigned a value of 1 for individuals who have experienced at least one of the stressful life events mentioned above, and 0 otherwise.

Moderator Variable of Social Activities

Social Activities

Social activity is defined as being involved in communities and engaging in productive activities, which presents the association between the social activities of the older people and depression (7, 18, 72). This is a cumulative variable based on the social activities of the older people once done in the last month. Social activities include (1) interactions with friends; (2) playing Mahjong, chess, or cards, or going to a community club; (3) helping friends or neighbors who do not live with you; (4) going to a sport, social, or other kinds of club; (5) taking part in a community-related organization; (6) voluntary or charity work; (7) caring for a sick or disabled adult who does not live with you; (8) attending an educational or training course; (9) online stock investment; and (10) other social activities. The study intersects variable of social activities with the number of experienced stressful life events and whether they experienced stressful life events. These two intersection variables represent the buffering effects of social activity between stressful life events and depression.

Moderator Variable of Family Support

Living Children

The variable of living children is a cumulative variable that measures how many living children the older people have. The quality of life of older people was negatively associated with the number of children. The proportion of older people with many children who believe that their children are not filial is significantly higher than that of older people with fewer children (73). Furthermore, too many children could shirk their responsibilities when caring for their parents, leading to a free-rider problem (74). Therefore, the study set a quadratic term for the number of living children to test the linear relationship between the number of living children and depression in older people.

Satisfaction With Relationships With Children

Responses to the question "How satisfied are you with your relationship with your children?" were ranked on a 5-point scale, with 1 standing for completely satisfied, 5 not at all satisfied. Furthermore, this variable intersects with main independent variables to present the moderating effects between stressful life events and depression.

Financial Support by Children

The variable is a binary, measured by the response to "In the past year, did you or your spouse receive economic supports at least 500 yuan (including money support and in-kind support) from your children?" that takes a value of one for an affirmative response and 0 otherwise. Furthermore, two intersection variables were set.

Financial Support by Relatives

This variable is a binary response to "In the past year, did you or your spouse receive economic supports from your non-coresident other relatives, excluding cash gift?" that takes a value of 1 to an affirmative response, and 0 otherwise. Furthermore, two intersection variables were established.

Average Frequency of Meeting With Living Children

First, responses to the question "How often do you meet your child?" are ranked as follows: 1 (almost never), 2 (once a year), 3 (once every 6 months),4 (once every 3 months), 5 (once a month), 6 (every 2 weeks), 7 (once a week), 8 (2-3 times a week), and 9 (almost every day). First, all responses for living children were summed up to measure the total frequency scores of meetings. If no living children exist, a value of 0 is assigned to the variable. Second, the average frequency of meeting with living children is calculated as the total frequency divided by the total number of living children. Higher frequency scores indicate that older people meet their children more frequently. Finally, this variable intersects with main independent variables to measure the moderating effects.

Average Frequency of Contact With Living Children

Responses to the question "How often do you have contact with your child either by phone, text message, mail, or email, when you didn't live with him/her?" are rated as follows: 1 (almost never), 2 (once a year), 3 (once every 6 months),4 (once every

3 months), 5 (once a month), 6 (every 2 weeks), 7 (once a week), 8 (2-3 times a week), and 9 (almost every day). Indeed, the total frequency scores were added up and divided by living children to obtain the average frequency of contact with living children. Higher scores represent a higher frequency of contact with living children. The average frequency of contact with living children intersects with main independent variables separately to measure the moderating effects of family support.

Control Variables

Age

This is a cumulative variable. Age is a moderator between widowhood and senior loneliness (33). Indeed, stress-buffering of social support is more effective toward the oldest-old than the young-old (16).

Gender

This is assigned a value of 1 for female individuals, and 0 for male individuals.

Marriage

An individual's marital status is a binary variable that takes the value of 1 for married individuals, including married but not living with spouse temporarily and cohabitated, and 0 for separated, divorced, widowed, and never married.

Urban

Studies have found that the mental health of Chinese older people in urban and rural areas is different. The scores of depression and anxiety of urban older people are higher than those of rural older people (75). In contrast, mental health level of rural older people is generally lower than that of urban older people (76). Therefore, the study merged individuals who lived in the main city zone, a combination zone between urban and rural areas, and town center. Otherwise, the study merged individuals who live in special areas, township centers, and villages. Therefore, variable of urban is a binary variable with a value of 0 for country living and 1 for urban living.

Education

The responses to the highest level of education attained by the individual are ranked at 11 levels: 1 (illiterate), 2 (did not finish primary school), 3 (home school), 4 (elementary school), 5 (middle school), 6 (high school), 7 (vocational school), 8 (2-/3-year college/associate degree), 9 (4-year college/Bachelor's degree), 10 (Master's degree), and 11 (Doctoral degree/Ph.D.).

Pension

Having financial difficulties and being unable to pay bills for medicine can deteriorate the mental health of the older people (50). Pension income improves mental wellbeing in the older people and moderates the effects of depression as it helps secure their financial resources (77, 78). Although the basic pension cannot support the daily expenses of most rural elderly people, its spiritual effect on the older people is much higher than its economic effect (61). Therefore, pension is a binary variable that takes 1 if the individual was included in at least one pension program, and 0 otherwise. Pension programs cover pensions and supplemental pensions from the government, institutions, and firms; new cooperative pension programs; urban and rural resident pension programs; land expropriation pension insurance; old age pension allowance; life insurance; commercial pension insurance; and other pension programs.

Medical Insurance

Economic factors are an essential factor in access to medical services; indeed, expansion of healthcare insurance coverage has reduced the medical costs of those patients with low socioeconomic status (79). Therefore, this is a binary variable that takes 1 if it includes at least one medical insurance, and 0 otherwise. Medical insurances covered 10 different programs: urban employee medical insurance, urban resident medical insurance, new cooperative medical insurance, urban and rural resident medical insurance, government medical insurance, medical aid, private medical insurance purchased by work unit, private medical insurance purchased by individual, urban non-employed health insurance, and other medical insurance.

RESULTS

Table 1 presents the descriptive analysis. The mean value of depression among the 7,986 Chinese older adults included in the study was 18.36. In total, 66.5% of older people once experienced at least one stressful life event, and on average, 2.81 stressful life events were experienced. The average social activity was 0.754, which was <1 activity, and 53.4% of the 9619 Chinese older adults did not participate in social activities. In total, 45.2% and 55.2% of respondents received financial support from their relatives and children. The mean of the average frequency of meeting and contact with living children were 2.449 and 1.722, respectively, which was considered relatively infrequently connected. The sample was nearly equally distributed by gender, with 50.4% females and 49.6% males. However, living in urban or rural areas was not distributed equally, with 28.2% of the Chinese older people living in urban areas. A total of 78.9% reported being in the relationships, and 79.6% and 97.7% had pension and medical insurance, respectively.

As shown in **Table 2**, experiencing more stressful life events significantly increased depression in the Chinese older people. When considering the variable of social activities, although the Chinese older people have experienced cumulative stressful life events, more social activities can decrease the risk of depression. As for variable of family support, the number of children has an inverted- U shape effect on depression. When the older people experienced more stressful life events, financial support from relatives and children can decrease depression. When the average frequency of meeting and contact is higher, older people who have experienced cumulative stressful life events report lower depression. However, if the older people are not satisfied with their children, the negative effects from stressful life events accumulate and significantly increase their depression. As for control variables, cohort with older old, male, living in the urban areas, higher levels of education can decrease risk of depression. As 97.7% of older people owned medical insurance, where

TABLE 1 | Descriptive statistics of the variables.

Variable	Obs.	Mean	Std.Dev.	Range
Depression	7,986	18.36	6.541	[10,40]
Number of stressful life events experienced	9,619	2.810	1.399	[0,8]
Experienced stressful life events	9,619	0.665	0.472	[0,1]
Social activity	9,619	0.754	1.036	[0,9]
Living children	6,008	3.145	1.673	[0,15]
Financial support by relatives	9,619	0.452	0.498	[0,1]
Financial support by children	9,619	0.552	0.497	[0,1]
Satisfaction with relationship with children	8,712	2.391	0.753	[1,5]
Average frequency of meeting with living children	9,619	2.449	2.760	[0,9]
Average frequency of contact with living children	9,619	1.722	2.475	[0,9]
Age	9,619	68.58	7.076	[60,105]
Gender	9,619	0.504	0.500	[0,1]
Marriage	9,617	0.789	0.408	[0,1]
Education	8,269	2.885	1.879	[1,10]
Urban	9,587	0.282	0.450	[0,1]
Pension	9,547	0.796	0.403	[0,1]
Medical insurance	9,619	0.977	0.151	[0,1]

TABLE 2 | Results from multiple regression model of risk factors and social support when experienced multiple stressful life events predicting depression.

Model	Stressful life event	Social activity	Family support	Social support
Number of stressful life events experienced (NE)	1.556***(0.078)	1.727***(0.094)	1.595***(0.427)	1.810***(0.435)
Moderator variable of social activities				
Social activities		0.262(0.182)		0.300(0.232)
Social activities with NE		−0.244***(0.060)		−0.225***(0.069)
Moderator variable of family support				
Living children			0.527***(0.183)	0.504***(0.182)
Quadratic form of living children			−0.028(0.020)	−0.027(0.020)
Financial support by relatives			1.548(0.966)	1.604*(0.967)
Financial support by children			1.308(1.156)	1.321(1.155)
Satisfaction with relationship with children			1.315***(0.356)	1.380***(0.355)
Average frequency of meeting with living children			0.096(0.106)	0.085(0.105)
Average frequency of contact with living children			0.142(0.105)	0.138(0.104)
Financial support by relatives with NE			−0.363(0.252)	−0.344(0.253)
Financial support by children with NE			−0.305(0.308)	−0.315(0.307)
Satisfaction with relationship with children with NE			0.160(0.098)	0.133(0.098)
Average frequency of meeting with NE			−0.060*(0.033)	−0.056*(0.032)
Average frequency of contact with NE			−0.034(0.032)	−0.031(0.031)
Control variables				
Age	−0.048***(0.012)	−0.055***(0.012)	−0.088***(0.016)	−0.094***(0.016)
Gender	1.718***(0.159)	1.757***(0.159)	1.788***(0.207)	1.825***(0.206)
Marriage	0.603**(0.241)	0.512**(0.240)	0.420(0.257)	0.355(0.256)
Education	−0.408***(0.043)	−0.353***(0.044)	−0.379***(0.054)	−0.330***(0.054)
Urban	−1.129***(0.177)	−1.048***(0.177)	−1.006***(0.227)	−0.909***(0.228)
Pension	−0.056(0.187)	−0.015(0.186)	0.050(0.232)	0.082(0.231)
Medical insurance	1.269**(0.504)	1.155**(0.500)	0.629(0.672)	0.612(0.664)
Constant	16.058***(1.098)	16.287***(1.103)	13.262***(1.987)	13.213***(1.996)
Observations	6868	6868	4248	4248
R-squared	0.134	0.141	0.190	0.197

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. *Robust standard errors are in parentheses.*

medical insurance variable has an extremely skewed distribution, this variable must be omitted in further analyses.

Therefore, in order to find covariates to apply PSM analysis, based on multiple regression outcomes, the study selected the variables of age, gender, marital status, educational levels, urban, and pension to measure the factors related to whether the Chinese older people experienced stressful life events by means of logistic regression. Furthermore, variables of total number of social activities in social activity model and the number of children, financial support from relatives and children, satisfaction with children, the average frequency of meeting and contact with children in family support model are selected. The study applied nearest neighbor matching, radius matching, and kernel matching to measure the propensity score of the four models.

In **Table 3**, one-to-one nearest neighbor matching shows that the stressful life events experienced significantly increased the risk of depression in 2.929. In the model of social activity, after one-to-one matching, the risk of depression increases to 2.982, which presents no clear buffering effects from social activity. The models, including family support and social support, were insignificant. For radius matching, a quarter of the standard deviation of the estimated propensity value of the sample may be used as the caliper size (67). Therefore, the study set 0.01 as the caliper size. Matching similar resources between treated and control groups, the stressful life events experienced significantly increased the risk of depression by 2.969. When engaging in social activity, the risk is enhanced to 2.981. However, the risk of depression significantly decreases to 1.938 and 1.962 when considering models of family support and social support, respectively, which explains the buffering effects of family support. Kernel matching presents the same trend as radius matching but a much stronger buffering effect from family support on depression. The moderating effects from stressful life events on depression on radius matching are 1.031 in the family support model (2.969 vs. 1.938) and 1.007 in the social support model (2.969 vs.1.962); however, the values are 1.150 (2.942 vs. 1.792) and 1.080 (2.942 vs. 1.862), respectively in kernel matching.

Furthermore, in bias-corrected matching, stressful life events experienced significantly increased the risk of depression in 3.029; however, it decreased to 2.021 with the help of family support. Indeed, estimators of bias-corrected matching strengthen social activity buffering effects, which decrease the effects of experienced stressful life events on depression to 1.932 under the condition of social support.

To check match quality, the study conducted a data balancing test. The results are listed in **Table 4**. Based on the significance of the models, the study selected radius matching and kernel matching to make comparisons for better application of PSM. The pseudo R-square decreased for both matches of the model of stressful life event. The mean bias decreased strongly in radius matching from 26.2% to 5.1%. In the social activity model, the pseudo R-square and mean bias decreased significantly from 0.144 to 0.008 and from 22.6 to 5.3%, respectively, in radius matching. It shows the same trend in the family support model and social support model, which indicates that radius matching is a much more effective method. Therefore, in the robustness check, the study uses the outcomes of radius matching to further check the models' robustness and shrink the sample to the matched ones.

In the model of robustness check (**Table 5**), whether the Chinese older people experienced stressful life events was selected as the main independent variable, which presents positive effects on depression. Social activities can buffer the effects of stressful life events and depression in the negative direction of the intersection. As for variables of family support, children's contribution still has an inverted-U shape effect on depression. Indeed, greater dissatisfaction with children increases depression levels in the older people. Furthermore, more frequent meeting and contact with children can moderate the effects of stressful life events on depression. However, considering whether experienced stressful life events affect depression, variables of financial support by relatives and children do not contribute to the effects on depression as effectively as the relationship between the total number of stressful life events experienced and depression. In this qualitative model, variable of financial support by children has negative effects on depression, but the intersection variable between stressful life events and financial support by children does not present similar effects.

CONCLUSIONS AND DISCUSSIONS

Chinese older people who experience stressful life events are likely to experience an increase in their depression, which is supported by both linear multiple regression analysis and propensity matching analysis. Hypothesis 1 is thus supported.

Stressful life events, especially bereavement, leading to depression in Chinese older people are affected by Chinese cultural contexts. As a Confucian country, China is a family-concentrated society, which is tightly related to the bonds of kin and marriage. Social networks of older people decrease as age increases (33, 34); consequently, emotional closeness with family members is stronger. Besides, due to the stigmatization of mental disorders, the negative stereotypes by the inadequate understanding of depression from community and individual, older people may be hesitant to express their feelings and refuse to receive professional treatments of symptoms, when they experienced stressful life events.

In detail, first, bereavement refers to the losses of close network partners, which gives rise to short-term negative emotional shocks and even long-term psychological trauma; for example, widowhood implies that older people have lost stable emotional support and resources of functional support (31). Indeed, Chinese inter-generational connections between parents and children are close, and children have become a factor affecting parents' self-efficacy and happiness. Adult children are the main family caregivers toward Chinese older people to supply monetary, instrumental and emotional support under the traditional perspective (59). Therefore, bereavement of children may give rise to destructive effects on older people. Second, most studies have certified high correlation between physical health and mental health (27, 28). For example, functional impairment

TABLE 3 | Results from propensity score matching (PSM) and bias-corrected matching from stressful life events and social support predicting depression.

Model	Stressful life event	Social activity	Family support	Social support
One-to-one nearest neighbor matching	2.929***(0.480)	2.982***(0.503)	1.466(1.050)	1.271(1.108)
Radius matching with caliper size 0.01	2.969***(0.348)	2.981***(0.344)	1.938**(0.944)	1.962**(0.939)
Kernel matching	2.942***(0.347)	2.956***(0.344)	1.792**(0.887)	1.862**(0.894)
Bias-corrected matching	3.029***(0.368)	3.049***(0.361)	2.021***(0.260)	1.932***(0.245)

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. Standard errors are in parentheses.

TABLE 4 | Result comparisons of data balancing test under the method of radius and kernel matching in propensity score matching (PSM).

Method	Radius matching			Kernel matching		
Sample	Pseudo R^2	LR chi2	Mean bias	Pseudo R^2	LR chi2	Mean bias
Model of stressful life event						
Unmatched	0.144	1266.7	26.2	0.144	1266.7	26.2
Matched	0.008	88.94	5.1	0.008	90.91	5.4
Model of social activity						
Unmatched	0.144	1267.98	22.6	0.144	1267.98	22.6
Matched	0.008	93.01	5.3	0.009	97.58	5.9
Model of family support						
Unmatched	0.182	750.46	27.3	0.182	750.46	27.3
Matched	0.078	667.45	18.7	0.079	683.75	18.8
Model of social support						
Unmatched	0.182	751.10	25.7	0.182	751.10	25.7
Matched	0.083	709.03	18.6	0.084	722.64	18.7

may lead to depression, and conversely, depression may result in functional impairment. Third, due to decline of cognitive ability, older people are likely to be frauded online (80) and being frauded has made older people feel frustrated, experience financial losses and lose their trust in society, consequently leading to decline of life quality.

Social activity, as a moderator between stressful life events and depression, is supported by linear regression; however, it is not clearly measured by propensity matching analysis, which is partly supported by Hypothesis 2. Under Chinese cultural contexts, Chinese prefer to actively participate in social activities and frequently connect with their neighbors and partners in the community. Furthermore, older people perceive the boundaries of time and prefer to select emotionally meaningful activities through the process of maximizing their experiences of positive emotions and avoiding negative emotions (15, 52). Therefore, social activities give older people an efficient way to relieve the pressure and acquire network support from partners in the community. However, it is essential to consider reverse causality problems, in that health problems and increasing age may prevent the participation of activities (7). Indeed, social activity effects will reverse from positive to negative in very late life (72). In this study, nearly 53.4% of the 9,619 respondents did not participate in social activities.

When the respondents experienced stressful life events, family support significantly buffered its negative effects on depression, which supports Hypothesis 3.

When older people experienced stressful life events, with the perception of limited time, they instinctively value close social ties and loved ones as main supporters. Emotional support in the family alleviates older people's shocks from stressful life events and helps older people remain positive psychological condition. An adaptation cycle toward trauma exposure is described as follows: in the early phase, grief rises and individuals tend to withdraw social relations; as the grief loses over time, individuals are likely to resume their life and resolve what has happened (14, 34). Therefore, emotional support suited with adaptation cycle presents the following status: first, family support as an effective way has helped older people decrease their intensity of grief in the early phase of exposure to stressful life events; second, duration of grief will be consequently shortened by family support. Economic support, as a form of family support, helps older people secure their financial resources to keep stable life. For example, depression outpatient treatment and psychotherapy are out of the scope of medical insurance in most cities (81, 82). With the economic support, old people are likely to lessen their financial burdens and be willing to have treatments. Therefore, when older people, as recipients, perceive the received social support as being sufficient to meet their emotional needs, their efficacy, confidence, and self-esteem are enhanced, which consequently increases their appraisal of their own ability to deal with stress. Indeed, close contact and meeting between older people and their adult children decrease the risk of older people being financially frauded.

TABLE 5 | Results from multiple regression model of risk factors and social support when experienced stressful life events after propensity score matching (PSM) analysis predicting depression (Robustness check).

Model	Stressful life event	Social activity	Family support	Social support
Experienced stressful life events (QE)	3.342***(0.156)	3.714***(0.195)	1.091(1.276)	1.549(1.291)
Moderator variable of social activities				
Social activities		−0.199**(0.094)		−0.085(0.145)
Social activities with QE		−0.443***(0.126)		−0.457***(0.168)
Moderator variable of family support				
Living children			0.654***(0.202)	0.616***(0.202)
Quadratic form of living children			−0.040*(0.023)	−0.039*(0.023)
Financial support by relatives			0.142(0.770)	0.200(0.766)
Financial support by children			−0.166(0.894)	−0.181(0.887)
Satisfaction with relationship with children			1.146***(0.237)	1.136***(0.237)
Average frequency of meeting with living children			−0.007(0.061)	−0.008(0.061)
Average frequency of contact with living children			0.061(0.060)	0.070(0.060)
Financial support by relatives with QE			0.098(0.854)	0.135(0.851)
Financial support by children with QE			0.219(1.013)	0.230(1.006)
Satisfaction with relationship with children with QE			0.831***(0.284)	0.791***(0.283)
Average frequency of meeting with QE			−0.096(0.076)	−0.084(0.076)
Average frequency of contact with QE			−0.040(0.074)	−0.039(0.073)
Control variables				
Age	−0.027*(0.014)	−0.034**(0.014)	−0.075***(0.018)	−0.080***(0.018)
Gender	1.858***(0.164)	1.899***(0.164)	1.876***(0.217)	1.915***(0.217)
Marriage	−0.175(0.267)	−0.208(0.268)	−0.108(0.267)	−0.140(0.268)
Education	−0.442***(0.044)	−0.378***(0.045)	−0.427***(0.055)	−0.372***(0.056)
Urban	−1.192***(0.182)	−1.106***(0.182)	−1.059***(0.234)	−0.957***(0.236)
Pension	−0.054(0.195)	−0.001(0.194)	0.104(0.244)	0.155(0.244)
Medical insurance	1.477***(0.553)	1.264**(0.548)	0.454(0.799)	0.410(0.796)
Constant	17.562***(1.153)	18.140***(1.151)	17.408***(1.846)	17.737***(1.848)
Observations	6426	6416	3903	3887
R-squared	0.128	0.135	0.161	0.166

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. *Robust standard errors are in parentheses.*

As for Hypothesis 4, the effects of social support, as a moderator between stressful life events and depression, are supported by linear regression analysis and propensity matching of bias-corrected estimators. Under social support, which covers family support and social activities as a whole, the buffering effects of stressful life events on depression are more decreasing, which also reflects the effects of social activities. Social activity and family support are guided by policies and specific measurements to take effects. For one thing, family policy encourages Chinese to carry forward the traditional virtues of supporting the older people to strengthen inter-generational close relationship. For another, policies and specific measures support the construction of the platforms to facilitate social activities of older people, such as the universities for the aged, senior care centers, and sports parks equipped with smart fitness facilities. Currently, policies mainly focus on public service issues such as activities and care toward Chinese older people. However, policies and specific measurements are not sufficient toward depression in Chinese older people; and services for the prevention and treatment of mental disorders are inadequate either.

Therefore, the negative effects of stressful life events on depression can be partly erased, when older people perceive support from family and social activities. Indeed, the negative effects will be minimal, if older people receive sufficient family support and take part in diverse social activities, such as complete satisfaction with relationship with children, daily or weekly contact and meeting with children.

The intervention for and prevention of mental disorders in Chinese older people are based on four aspects. First, Chinese still regard kinship and filial piety as an essential value in life. Family members should consciously pay attention to older people's mental condition and provide effective support that meets their needs, especially when older people experienced stressful life events. Second, older people and their neighbors and community partners mutually support each other in the close partnership. When older people experience stressful life events, network partners should frequently communicate with older people and encourage them to social activities. Third, public policy should support community health service centers financially and professionally to make it capable of mental health services. For example,

early detection of mental disorders by means of incorporating emotional assessment into the daily physical examination of older people; continuous attention to risky groups; and psychotherapy to the patients. Fourth, the public should improve awareness of mental disorders by publicizing the knowledge of depression through community lectures, bulletin boards and other various ways to erase its stigmatization, enlarge the public covers of medical insurance, and encourage business medical insurance to supply diverse plans to help mitigate patients' burdens.

Due to interviewees' recall accuracy and different willingness to disclose, this study has certain limitations. First, the seniors retrospectively self-reported the stressful life events may lead to recall bias. Second, the study makes use of the 2015 CHARLS panel data to discuss the effects of the previously experienced stressful life events on depression and downplays the limits of time when stressful life events occurred. Although bereavement effects on depression have time differences between the short and long terms (33), bereavement also causes life-course pain (51). Therefore, the bereavement of spouse and children, financial problems, and some health adversities throughout the lifetime are discussed in this study. Third, the selected stressful life events have been regarded as a whole in the study, and each event has been assumed to have same psychological impacts on the interviewee, both of which lack event heterogeneity. For example, the bereavement, by an accident or peaceful death after suffering severe illness over several years, can bring about great differences in the traumatic effects on individuals. To eliminate recall bias, future research can make use of a third party to recall the stressful life event that the individual once experienced and measure individuals' depressive feelings and behaviors. Differentiating stressful life events can help measure individuals' responses in greater detail.

DATA AVAILABILITY STATEMENT

Publicly available datasets were analyzed in this study. This data can be found here: China Health and Retirement Longitudinal Study (CHARLS), http://charls.pku.edu.cn/en.

AUTHOR CONTRIBUTIONS

XY and SL: Conceptualization and methodology. SL: Writing—original draft preparation. XY: writing—review and editing. All authors have read and agreed to the published version of the manuscript.

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Trends of Healthy Life Expectancy of the Elderly in China in 1994–2015: Revisiting From the Perspective of Morbidity Transition

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Research on healthy life expectancy (HLE) in China has been fueled by a spate of new data sources and studies, yet no consensus is reached on the pattern of HLE changes and the underlying mechanism. This study examined the change of HLE in China over 20 years with long term national data. Health status, measured by activities of daily living, is combined with mortality to calculate the disability-free life expectancy by the Sullivan method. The results show that the HLE rose slower than life expectancy (LE) in 1994–2004, indicating morbidity expansion. However, in 2010–2015, the proportion of HLE to LE increased, manifesting morbidity compression. A counterfactual analysis further shows that health improvement has been increasingly important in increasing HLE in 2010–2015, despite the dominance of mortality decline. The findings suggest that morbidity can transition between compression, expansion and dynamic equilibrium over a long period due to different combinations of mortality and health improvements. Given the limited data in this study, whether and how morbidity transitions unfold in the future remains open and requires further research.

Keywords: health life expectancy, life expectancy, disability-free life expectancy, activities of daily living, morbidity transition, older people, China

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INTRODUCTION

China's population is aging fast, due largely to fertility decline and modestly to mortality decline (1). The proportion of people aged 60 and over is forecast to rise from 18.7 to 34.6% in 2020–2050, far faster than Europe, the oldest continent, where the proportion of older people will rise from 25.7 to 34.95% (2, 3). During the same period, Meanwhile, remaining life expectancy at age 60 will rise from 19.1 to 23.1 years for men and from 22.5 to 25.6 years for women (2). The rapid growth of the older population accompanied by the steadily lengthening of lifespan implies a great demand for health care and social support, posing a huge challenge to China in the future. The health status of older people and its trends is crucial for China's successfully dealing with population aging.

Increased longevity is not simply equivalent to increased quality of life. Healthy life expectancy (HLE) was thus developed to account for mortality and morbidity into a single indicator (4). Because of its desirable properties, HLE is widely used to address whether observed increases in life expectancy are accompanied by decreases in morbidity (5, 6). By now, three hypotheses

have been developed on health trends in aging population: (1) Compression of morbidity (7), which states that the period of morbidity would compress with the increase of life expectancy (LE) (2). Expansion of morbidity, Gruenberg (8) and Kramer (9) argued that the improvement of medical technology helped to reduce the mortality rate of certain diseases and increase the survival probability of unhealthy people, and therefore, as the life expectancy of the elderly increases, the period of illness and the period of disability are expanded (3). In the middle was the hypotheses "Dynamic equilibrium" proposed by Manton (10), suggesting that the prevalence of disability may increase, but the severity of disability would decrease, which leads to balanced changes in healthy and unhealthy life.

The above three hypotheses have their empirical supports, probably due to different research designs, such as longitudinal or cross-sectional data, countries, ages under study, social groups and health measurements (5, 6, 11–16). In China, evidence is mixed. While some studies support the compression of morbidity [e.g., Guo and Gu (17); Zeng et al. (18)], others reported evidence for the expansion of morbidity (19, 20).

To date, great efforts have been made to gain insight into the mechanism underlying the inconsistency of HLE trends. One effective approach has been to examine changes in HLE and LE in as many countries as possible, thereby drawing out general patterns of morbidity change. For example, the Global Burden Disease study (GBD) collected data on mortality and morbidity from around the world and found that most of 178 countries showed morbidity expansion from 1990 to 2010 (5). The current accumulation of empirical findings allows us to rethink the dynamics of morbidity.

Implicitly or explicitly, older people are assumed to follow a similar pattern of morbidity change, either expansion or compression. Efforts have been made in the pursuit of consistent evidence of change in disability and morbidity, but the lack of consensus on the trends in changes is disturbing [e.g., Robine and Michel (12)]. Nevertheless, different populations may be at different stages of the mortality and health transition (21) and, thus, exhibit different characteristics of morbidity trends. Health transition is a process that is assumed to occur in stages, with important causative factors shifting from one stage to another. As such, the health transition lacks singularity or simplicity in the means by which it was achieved (22), and understandably so does morbidity transition. For instance, an earlier study based on the GBD project found that morbidity, indicated by health-adjusted life expectancy, tended to increase as life expectancy rose to around 70 years, after which morbidity flattened for men and appeared to decrease for women (23). Yong and Saito (24) investigated the trend in healthy life expectancy in Japan using self-rated health to measure health status and reported that from 1986 to 2004, Japanese men and women experienced morbidity compression until 1995, when LE was 76 years for men and 83 years for women, respectively, followed by morbidity expansion.

Even in the same country, different factors usually lead to the health transition at different times. Various interventions that may reduce mortality or improve health statuses, such as public health policies or medical advances, are rarely introduced simultaneously. The resulting transition in mortality and morbidity will unfold at different rates over time. Therefore, different patterns of morbidity trends may be observed over a long period of time. For instance, using a longitudinal dataset in 2002–2014 and the measurement of Activities of Daily Living, Song et al. (25) found that China's elderly people first experienced morbidity compression, followed by the dynamic equilibrium. Li et al. (26) reported that the disability-free life expectancy of older people in Shanghai switched from compression to expansion in 1998–2013. Based on 23-year multi-wave data, Deeg et al. (27) calculated physically healthy life expectancy using self-reports of major chronic diseases and Instrument Activity of Daily living and reported fluctuations across the study period. All of these findings, including the two studies by Mathers et al. (23) and Yong and Saito (24) mentioned above, suggest that the pattern of change in morbidity may not be fixed over time, even for the same population, and that instead, morbidity can transition between different states.

According to the morbidity transition perspective, a longer observation period would be desirable as it would cover multiple stages of morbidity transition. However, given some limitations of survey data (e.g., poor representativeness, small size and low reliability), it remains unclear whether conclusions drawn from survey data can be applied to national trends in healthy aging. Therefore, to fill this knowledge gap, this study examined health trends from 1994 to 2015 based on data from nationally representative large-scale surveys in 1994 and 2004 and the population censuses in 2010 and 2015, thus constructing a complete picture of the evolution of healthy aging in China.

DATA AND METHODS

Data and Measurement

Health data of the elderly were obtained from the National Sample Survey of Population Changes (NSSPC) in 1994 and 2004, the 2010 census and the 2015 National 1% Population Sample Survey (micro-census).

NBS conducted the NSSPC surveys in 1994 and 2004. Respondents to the survey were randomly selected from 31 provinces in mainland China, 124,114 older people aged 60 years or older were included in the 1994 sample and 152,055 in 2004. Health status was measured by a question on activities of daily living [ADL: (28)]. "Are you able to perform the following activities of daily living: eating, dressing, bathing and going to the toilet?" The answer could be "Yes, I am" or "No, I am not." Older people who chose the second answer were considered unable to look after themselves. The 2010 and 2015 censuses collected health data by using a question." Your health status is ____." Answers can be one of "healthy," "mostly healthy," "unhealthy but able to take care of yourself" and "disabled." We have combined the first three responses into one category for older people who can look after themselves, leaving the fourth response for older people who cannot look after themselves.

As the daily ability measures in 1994 and 2004 differ from those in 2010 and 2015, it is difficult to directly compare the estimated health indicators between these two periods. Therefore, this study first investigated changes in HLE from 1994–2004 to 2010–2015, respectively. The relative rates of change between the

two periods were then compared after removing the effect of different scales in the morbidity question.

The life tables were calculated from mortality data collected in censuses and micro-censuses from 1982 onwards. Taking into account the errors in mortality data, we reassessed mortality rates for census and micro-census years with reference to the most recent estimates of mortality from national statistical offices, the United Nations (2) and other scholars (29, 30).

We start our estimations with mortality data from 1982, assuming that age-specific mortality follows an exponential change (decline), as it usually does (31). The assumption of exponential change is reasonable given that no extreme events occurred from 1982 to 2015. The age pattern of mortality decline is similar to the general pattern noted by Tuljapurka et al. (32), whereby the major declines in mortality occur first in infants and children, followed by young adults, the young elderly and the elderly in that order. We modeled age-specific death rates for 1994, 2004, 2010, and 2015 by targeting LE in 1994 and 2004 estimated by the UN and LE in 2010 and 2015 by the NBS and other scholars (29, 30). Based on the resulting age-specific mortality, abridged life tables were constructed for 5-year age groups ending with 85 years and over. See **Supplementary Material** for detailed tables.

Methods

Sullivan (33) proposed estimating HLE by combining health status prevalence in cross-sectional survey data with period life tables. With the removal of the effect of age structure, the estimated HLE can be compared across populations or the same population at different points in time. The method applies to the case without transition probabilities (34). Because of its straightforward and succinctness, the Sullivan method is commonly used in the estimation of HLE. Besides, multistate life tables can be used to calculate the HLE. This method considers the dynamic changes between functional states and mortality in different health states (18). However, it is more demanding on data that are required to obtain multistate data of different individuals. In recent years, microsimulation and Bayesian methods have been increasingly applied to estimate HLE (34, 35).

In this study we used the classic Sullivan method, which is based on life tables and disability data collected in censuses and national level sample surveys. The prevalence of disability for each age group person-years into years with and without disability. The number of surviving person-years in the life table is multiplied by the proportion of people able to care for themselves to give the number of surviving person-years without disability, which is then divided by the number of survivors to obtain an estimate of HLE.

As mentioned earlier, the HLE contains information on mortality and morbidity, so it derives its change from changes in mortality and health status. Therefore, counterfactual analysis is used to assess the contribution of mortality and health status improvements to changes in the HLE over time. For example, we will estimate a counterfactual HLE with the same health status as in 1994 but with a mortality rate of 2004. The difference between this HLE and the actual HLE can therefore indicate how much of the change in the HLE from 1994 to 2004 is due to a reduction in mortality. The contribution of health improvement is estimated by subtracting

TABLE 1 | Disability-free life expectancy of the elderly, 1994 and 2004.

Male

	LE			HLE			HLE/LE (%)		
Age	1994	2004	Δ	1994	2004	Δ	1994	2004	Δ
60	16.18	17.23	+1.05	14.99	15.69	+0.71	92.64	91.09	−1.55
65	12.63	13.48	+0.85	11.42	11.96	+0.55	90.42	88.79	−1.63
70	9.61	10.18	+0.57	8.38	8.69	+0.31	87.15	85.32	−1.83
75	7.30	7.63	+0.33	6.03	6.13	+0.10	82.69	80.41	−2.28
80	5.50	5.81	+0.31	4.23	4.28	+0.05	76.86	73.60	−3.26
85+	4.05	4.24	+0.19	2.91	2.84	−0.06	71.82	67.05	−4.78

Female

	LE			HLE			HLE/LE (%)		
Age	1994	2004	Δ	1994	2004	Δ	1994	2004	Δ
60	19.04	19.69	+0.65	16.97	17.25	+0.29	89.13	87.63	−1.50
65	15.21	15.73	+0.51	13.13	13.32	+0.19	86.29	84.72	−1.57
70	11.71	12.13	+0.41	9.63	9.76	+0.13	82.19	80.50	−1.69
75	8.83	9.14	+0.31	6.77	6.84	+0.07	76.63	74.79	−1.83
80	6.44	6.70	+0.26	4.46	4.40	−0.07	69.38	65.66	−3.72
85+	4.66	4.91	+0.26	2.88	2.78	−0.10	61.86	56.59	−5.26

Δ, *the change in the indicator in 1994–2004.*

TABLE 2 | The effect of changes of the mortality and disability-free rate of the elderly on HLE from 1994 to 2014.

Male						
Age	**1994 (1)**	**2004 (2)**	**Counterfactual (3)**	**Δ (4) = (2)–(1)**	**Due to mortality (5) = (3)–(1)**	**Due to DFR (6) = (4)–(5)**
60	14.99	15.69	15.90	0.71	0.91	−0.20
65	11.42	11.96	12.14	0.55	0.72	−0.17
70	8.38	8.69	8.84	0.31	0.47	−0.16
75	6.03	6.13	6.29	0.10	0.25	−0.16
80	4.23	4.28	4.46	0.05	0.23	−0.18
85+	2.91	2.84	3.05	−0.06	0.14	−0.20
Female						
Age	**1994 (1)**	**2004 (2)**	**Counterfactual (3)**	**Δ (4) = (2) – (1)**	**Due to mortality (5) = (3) – (1)**	**Due to DFR (6) =(4) – (5)**
60	16.97	17.25	17.48	0.29	0.52	−0.23
65	13.13	13.32	13.52	0.19	0.39	−0.19
70	9.63	9.76	9.93	0.13	0.30	−0.16
75	6.77	6.84	6.98	0.07	0.21	−0.14
80	4.46	4.40	4.63	−0.07	0.17	−0.24
85+	2.88	2.78	3.04	−0.10	0.16	−0.26

Δ, *the change in the indicator in 1994–2004.*

the change due to mortality decline from the actual change in HLE.

The results of the counterfactual analysis allow a comparison of changes in morbidity over time and the contribution of its components. This comparison can help determine whether morbidity is compressing or expanding, or whether a shift in morbidity is occurring.

RESULTS

The 1994–2004 Period

The Trajectory of Healthy Life Expectancy of the Elderly in China

From 1994–2004, older people in China enjoyed an increase in life expectancy (**Table 1**). The LE for men rose by 0.20–1.05 years and for women by 0.26–0.70 years. For both men and women, the increase in LE decreases with age. The gender gap in gains in LE becomes smaller at higher ages, indicating a converging trend in mortality improvement.

Over the same period, HLE increased in the younger elderly, but decreased in the oldest old. Gender differences were evident, with the increase in HLE for men at 60–74 years roughly twice that of HLE for women. For men aged 85+ and women aged 80+, the change in HLE ranged from an increase to a decrease due to poor performance in improving the health of the oldest people.

Women had higher LE and HLE than men, except for age 85+, though with a decreasing gap with age. But the ratio of HLE to LE is higher for men than for women, indicating that women had relatively poor health despite their longevity. Importantly, in 1994–2004, HLE rose less than LE or even decreased above age 80, and consequently, the ratio of HLE to LE declined, implying an expansion of morbidity. Noteworthy, for younger old, men experienced a greater decrease in the ratio of HLE to LE than women. However, for the oldest old, the ratio of HLE to LE for women declined by 1.4 percentage points more compared with men, suggesting that women are becoming less healthy at advanced ages.

The Effect of Mortality and Disability-Free Rate on the Changes in HLE

To determine the impact of mortality and disability-free rate, we conducted a counterfactual analysis. We calculated a hypothetical HLE using the 2004 life table and the 1994 disability-free rate (DFR) and compared it to the actual HLE in 1994. As the two HLEs share the same DFR, their differences indicate the effect of mortality changes.

The results of the counterfactual analysis are presented in **Table 2**, where columns (1), (2) and (4) are the same as the three columns in the middle of **Table 1**. Here column (5) is obtained by subtracting column (3) from column (1) and represents the counterfactual change in HLE that would have occurred if the DFR had remained the same as in 1994 and only the mortality rate had changed. For example, the 0.91 in column (5) represents the 0.91-year increase in male HLE that would have occurred if the DFR had remained at the 1994 level because of a decrease in mortality.

The difference between the actual change and the counterfactual change in column (4) is usually smaller for the former than for the latter, indicating that HLE may be much higher if the health status of older people remains the same as

TABLE 3 | Disability–free life expectancy of the elderly in 2010 and 2015.

Male									
	LE			**HLE**			**HLE/LE (%)**		
Age	2010	2015	Δ	2010	2015	Δ	2010	2015	Δ
60	17.79	18.17	+0.38	17.27	17.67	+0.40	97.05	97.22	+0.17
65	14.04	14.36	+0.32	13.52	13.86	+0.34	96.27	96.53	+0.26
70	10.78	11.03	+0.25	10.26	10.54	+0.28	95.14	95.53	+0.39
75	8.17	8.37	+0.20	7.64	7.87	+0.23	93.53	94.02	+0.49
80	6.01	6.16	+0.15	5.47	5.65	+0.18	90.95	91.71	+0.76
85+	4.51	4.61	+0.10	3.96	4.07	+0.12	87.72	88.27	+0.55
Female									
	LE			**HLE**			**HLE/LE (%)**		
Age	2010	2015	Δ	2010	2015	Δ	2010	2015	Δ
60	21.45	22.02	+0.56	20.51	21.12	+0.60	95.63	95.93	+0.30
65	17.32	17.81	+0.49	16.38	16.91	+0.53	94.60	94.97	+0.37
70	13.55	13.96	+0.42	12.61	13.06	+0.45	93.12	93.56	+0.44
75	10.36	10.70	+0.34	9.42	9.78	+0.36	90.96	91.46	+0.50
80	7.64	7.90	+0.26	6.69	6.97	+0.27	87.61	88.18	+0.57
85+	5.62	5.80	+0.18	4.69	4.84	+0.16	83.39	83.55	+0.16

in 1994. For example, if there had been no change in DFR, HLE would have risen by 0.91 years for women, compared to an actual rise of 0.71 years. Thus, the difference between 0.91 and 0.71 years indicates the effect of deteriorating health status.

The rise in mortality-induced HLE decreases with age, showing a similar age pattern to LE, HLE and its changes. Even so, almost all age groups experienced mortality improvements from 1994 to 2004, except for women over 80 years of age. DFR-induced HLE loss is usually high at age 60 and then declines. Although there are clear gender differences in longevity and health status, the benefits of declining mortality are much greater for men than for women. In addition, as shown in column (6), women suffered more health deterioration than men.

The 2010–2015 Period

The Trajectory of Healthy Life Expectancy of the Elderly in China

From 2010 to 2015, both LE and HLE increased among older people in China. As shown in **Table 3**, the rise in LE ranged from 0.10 to 0.56 years. In addition, HLE increased by 0.12 to 0.60 years for all age groups. Even for the oldest old, the HLE increased by about 0.12–0.16 years.

The increase in HLE exceeded the increase in LE, except for women over 85 years of age. It is also clear that women have an advantage over their male counterparts in terms of growth in both HLE and LE at all ages. Thus, the ratio of HLE to LE increased from 2010 to 2015, indicating morbidity compression.

The Effect of Mortality and Disability-Free Rate on the Changes in HLE

We applied the counterfactual analysis to the change in HLE from 2010 to 2015. Again, we calculated a hypothetical HLE using the 2010 DFR, but with two actual life tables in 2010 and 2015, and compared this to the actual change in HLE in 2010. The results are presented in **Table 4**.

Unlike the period 1994–2004, when deteriorating health partially offset the positive impact of declining mortality, the period 2010–2015 witnessed a reversal of the DFR contributing to an increase in HLE, albeit of a modest magnitude. This reversal strongly suggests that older people have made considerable progress in improving their health since 2010. For example, the 0.40-year rise in HLE was due to 0.36 years from mortality improvements and 0.04 years from health improvements.

From 2010–2015, declines in mortality dominated the rise in HLE, although this was accompanied by an increase in the importance of health improvements. For example, declines in mortality accounted for 90% of the rise in HLE at age 60 and improvements of activities of daily life contributed to the rest 10% of the rise in HLE.

Comparison Between 1994–2004 and 2010–2015

Due to the different lengths of the two periods studied, the annual rate of exponential changes in the proportion of HLE to LE should be calculated for comparison purposes. As shown in **Figure 1**, blue represents males, indicating that the annual rate of change in the ratio of HLE to

TABLE 4 | The effect of changes of the mortality and disability-free rate of the elderly on HLE from 2010 to 2015.

Male						
Age	**2010 (1)**	**2015 (2)**	**Counterfactual (3)**	**Δ (4) = (2)–(1)**	**Due to mortality (5) = (3)–(1)**	**Due to DFR (6) = (4)–(5)**
60	17.27	17.67	17.63	0.40	0.36	0.04
65	13.52	13.86	13.81	0.34	0.29	0.05
70	10.26	10.54	10.49	0.28	0.23	0.05
75	7.64	7.87	7.82	0.23	0.18	0.05
80	5.47	5.65	5.60	0.18	0.13	0.05
85+	3.96	4.07	4.05	0.12	0.09	0.03
Female						
Age	**2010 (1)**	**2015 (2)**	**Counterfactual (3)**	**Δ (4) = (2) – (1)**	**Due to mortality (5) = (3)–(1)**	**Due to DFR (6) = (4)–(5)**
60	20.51	21.12	21.02	0.60	0.51	0.10
65	16.38	16.91	16.82	0.53	0.44	0.09
70	12.61	13.06	12.98	0.45	0.37	0.08
75	9.42	9.78	9.72	0.36	0.29	0.07
80	6.69	6.97	6.91	0.27	0.22	0.05
85+	4.69	4.84	4.83	0.16	0.15	0.01

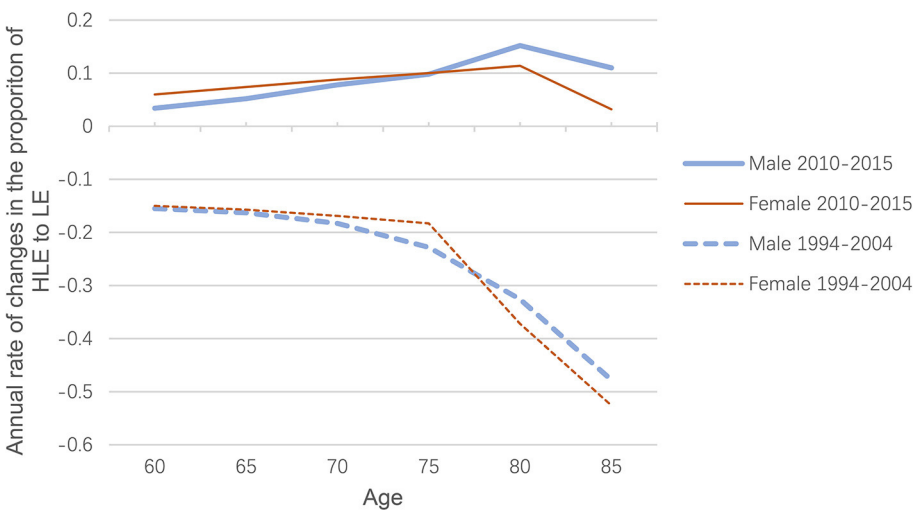

FIGURE 1 | Age-specific rate of annual change in the proportion of HLE to LE for both sexes, 1994-2004 and 2010-2015.

LE from 2010 to 2015 is much higher than the ratio from 1994 to 2004. The ratio of HLE to LE for females is the same case (red). In both periods, both sexes show similar rates of improvement in HLE relative to LE, as shown by the solid and dashed lines almost overlapping each other.

There is clearly a transition from expansion to compression in morbidity, with the underlying factors changing over time. As shown in **Figure 2**, from 1994 to 2004, the increase in HLE was driven only by a decline in mortality, particularly in the early years, with the decline in DFR (disability-free rate) even offsetting the positive impact of mortality changes. However, in 2010–2015, the change in DFR has become positive and increasingly important, contributing to the rise in HLE. That is, the impact of the DFR component reversed between the 1994–2004 period and the 2010–2015 period. This reversal has brought about a shift in morbidity, although improvements in mortality have been dominating changes in HLE.

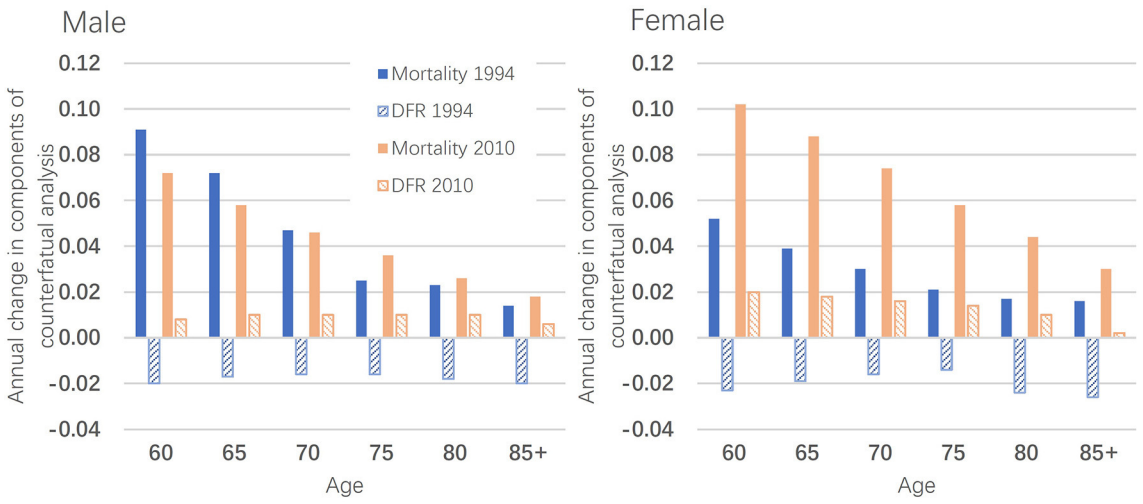

FIGURE 2 | Annual change in components of counterfactual analysis.

DISCUSSION

We examined national trends in HLE among older people in China since the mid-1990s. Based on national-level data, this study found that LE and HLE in older Chinese have steadily increased, but that the changes in HLE have created different morbidity trends. From 1994 to 2004, the proportion of HLE to LE declined, supporting morbidity expansion. However, from 2010 to 2015, the proportion increased, indicating morbidity compression. Between these two periods, a transition from expansion to compression of morbidity occurred.

A counterfactual analysis was used to explore the mechanisms underlying the morbidity transition. The increase in HLE was dominated by a decline in mortality, particularly from 1994 to 2004, with the decline in DFR even offsetting the positive impact of mortality reductions. As a result, a typical morbidity expansion occurred during this period. However, in 2010–2015, the DFR turned positive, contributing to an increase in HLE, which led to morbidity compression. The significant improvement in HLE is partly attributable to intensive tools that can reduce the demands on dependent living. With the help of these tools, some dependent older adults can regain their independence (29).

In the absence of mortality and morbidity data for the period 2004–2010, we cannot directly examine the trajectory of HLE in the period, which should mark the transition from expansion to compression of morbidity. Even so, it is reasonable to speculate that there must have been some important progress in health improvement around 2004.

China's major health reform from 2003 may be one notable development that has helped improve the health of older people. Since the launch of market-based economic reforms in 1978, the Cooperative Medical Scheme (CMS)—a community-based health care financing system that operated in the 1970s—is dismantling due to a lack of financial support from the rural collective economy (36). As a result, nearly 80 per cent of the rural population (∼640 million) did not have any health insurance in 2003 (37), and health care costs have risen sharply in tandem with market-oriented health care reforms since the 1990s (38, 39). It is estimated that ∼44.4% of rural older people did not have access to adequate health care in 2003 (37). Although some health care coverage is available to older people in urban areas, the vast majority of older people in urban areas still have to pay a significant amount of their own health care costs. Older people are less likely to receive adequate treatment due to limited income or lack of access to adequate health resources due to lack of health coverage (17, 20, 40). Consequently, life expectancy increases while overall health declines (16, 25, 26), leading to expanded morbidity.

In response to popular dissatisfaction with the health system, China launched a nationwide programme in rural China in 2003 known as the New Cooperative Medical Scheme (NCMS), a voluntary government-run insurance scheme that focuses on coverage for catastrophic illnesses (41). Studies have found that NCMS increases the use of resources (42). Although NCMS did not significantly impact mortality, NCMS significantly improved activities of daily living and cognitive function among older enrollees (43). In addition, participation in NCMS promotes self-rated quality and health changes in older adults (44). Importantly, the cumulative impact of health reform on older people's health implies that the positive effects of NCMS can sustain health promotion. Thus, the positive effects of health system reform can partially explain the health improvements and morbidity compression from 2010 to 2015.

There are some limitations to this study that require further research. Firstly, the 1994 and 2004 data are from large-scale surveys, which, while having nationally representative samples, are not fully comparable with the 2010 census and 2015 micro-census data. In addition, there are some differences between the survey and census questions on health status. Recognizing the

issue of comparability, we focused our analysis on the relative change in morbidity indicators and limited the comparison to the relative rate of change. In general, survey participants are likely to be in better health than the population as a whole, partly because surveys do not usually include older people living in institutions and hospitals, who tend to be in poorer health than those living in communities. In addition, healthy older people are more likely to participate in surveys, producing a selective sample. Even so, the transition from expansion to compression in morbidity observed between 1994–2004 and 2010–2015 may confirm the transition in China during this period. Secondly, a long-term time series of mortality and morbidity data is desirable for studying morbidity transitions, as it can cover possible multi-stage transitions and identify their turning points. However, such data are not currently available. Furthermore, the lack of data for 2004–2010 prevents us from examining how morbidity transitioned from expansion to compression during this period. In the future, we can apply new methods to reconstruct historical data to create a complete picture of the morbidity transition in China.

DATA AVAILABILITY STATEMENT

Publicly available datasets were analyzed in this study. This data can be found here: http://www.stats.gov.cn/tjsj/pcsj/.

AUTHOR CONTRIBUTIONS

ZZ and QL: designed the study. ZZ, QL, JD, and CZ: revised the report, did the analysis, and interpreted the data. ZZ and QL: wrote the first draft. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2021.774205/full#supplementary-material

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Forecasting the Health Transition and Medical Expenditure of the Future Elderly in China: A Longitudinal Study Based on Markov Chain and Two Part Model

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Set in the rapid development of population aging, this study focuses on the relationship between health and medical expenditure of the elderly population. Taking the health and medical expenditure of the elderly as the research object, this study analyzes the characteristics and the intrinsic relationship between them. Based on the future elderly model, this study calculates the transition probability of the elderly's self-assessment health state using the Health Transition Model and estimates the medical expenditure of the elderly by the Two-Part Model. Based on the above, this study predicts the trend of the population size and medical expenditure of the elderly in the next 15 years (2020–2035). Based on the results, the policy suggestions are put forward. To begin with, strengthening health management and health services for the elderly in the construction of healthy China. Next, building a comprehensive system of health care for the elderly in government, society, family, and individual. Then, establishing a long-term care service system as soon as possible. In addition, it is better to establish lifelong health consciousness and cultivate healthy accomplishment behavior. Finally, it is necessary to promote gender mainstreaming in the health field.

Keywords: population aging, health status of the elderly, medical expenditure of the elderly, health transition probability, healthy aging

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INTRODUCTION

Population aging is the irreversible normal social phenomenon, the common future of mankind, and also the fundamental reality of China. Recently, the Political Bureau of the Communist Party of China Central Committee held a meeting to hear a report on major policies and measures to actively respond to an aging population during the 14th Five-Year Plan period. The report pointed out the need to steadily increase the legal retirement age, accelerate the construction of an elderly care service system that integrates family and community institutions and medical care and health care, and implement the three-child policy to actively respond to the aging of the population to provide the necessary guarantee.

According to the seventh national census, there are 260 million people aged 60 or above in China, accounting for 18.7% of the total population. On the basis of the program forecast in the

national strategy research on coping with population aging, the aging level will exceed 20% in 2024, reach 30% in 2039, and increase to 34.9% in 2053, when the number of elderly population will reach a peak of 487 million (1). It is a natural rule that the physical function of the elderly will weaken with the increase of age. With the deepening of aging, the scale of the unhealthy elderly population will expand rapidly. According to the Survey on the Living Conditions of the Elderly in Urban and Rural China (2015), the proportion of disabled and semidisabled elderly population in China is 18.3%. Assuming this ratio stays the same, the number of disabled and semidisabled elderly people will approach 100 million by mid-century. There is no doubt that the scale of demand and expenditure for geriatric medical and health services will rise sharply, causing unprecedented pressure on medical and health supply. It is urgent to comprehensively, deeply, and systematically analyze the health status of the elderly and predict the changing trend, so as to provide timely and scientific theoretical basis and information support for the planning and decision-making of the health and economic and social development of the elderly.

At present, the focus of geriatric health research is mainly to explore the influencing factors of geriatric health and the changing trend of geriatric health state. The main factors affecting the health of the elderly can be classified into four categories: First, demographic factors. The elderly in different countries, races, or ethnicities have different evaluations of their own health status. There are significant age and gender differences in the health of the elderly. When using cohort analysis to study the self-assessment of health, it is found that the self-assessment of the health of the elderly decreases with the increase of age (2). Second, social and economic factors. The relationship between health disparities and the socioeconomic status of the elderly is usually discussed using variables such as income (family income and personal income), education level, occupation, and wealth (3–5). Third, health behavior factors. Moderate drinking and exercise are beneficial to health, but heavy drinking and risky drinking increase morbidity and mortality (6). Smoking harms the health of the elderly, and cancer, cardiovascular diseases, and respiratory diseases are highly correlated with smoking (7). BMI is closely related to health, and the higher the BMI, the more prone to coronary heart disease, stroke, ischemic stroke, dyslipidemia, and other diseases (8). The fourth factor is social relations. A good marriage relationship can slow down the decline of health status and reduce the risk of death in the elderly (9). Social participation in the elderly can significantly reduce the risk of death and improve cognitive function in the elderly (10, 11). As for the dynamic research on the health status of the elderly, the current prediction methods of the health status of the elderly include the multistate life table method, the non-covariate method, and the covariate effect method (12–14). Rickayzen and Walsh (2002) were the first to use the Markov method to predict long-term care needs (15).

On the whole, these studies have laid a rich theoretical and methodological foundation for the study of health transfer and future health needs of the elderly. This study focuses on the overall scale analysis of the health state transfer of the elderly and the measurement of the future medical expenditure of the elderly. The main contents include: first, the main research objects of the study are defined, including the health status of the elderly and medical expenses; second, the Health Transition Model (HTM) and the Two-Part Model (TPM) are constructed by using the cohort analysis method; third, quantitative research was conducted on the health status and medical expenditure of the elderly respectively, and the transfer probability of the health status of the elderly and the fitting value of medical expenditure under different health status were estimated; fourth, based on the prediction of the future trend of the number of the elderly population in China, the health probability of different periods is calculated by Markov Chain (MC) to predict the size of the elderly population in different health states. On the basis of this, the total demand and its changing trend of medical and health expenses of the elderly in different health states in the future are judged.

METHODS

Data Sources

Using the data of China Health and Retirement Longitudinal Study (CHARLS) provided by the National School of Development of Peking University in 2011 and 2013, the elderly people born before 1951 (that is, aged 60 and above) in 2011 were selected as the research object. The sample size of 2011 and 2013 was 17,596 and 18,416, respectively. Based on the longitudinal data, this study matched the sample size of two periods, and finally, 5,487 effective samples were obtained after eliminating the missing and new samples. Considering that the CHARLS data of 2015 does not contain death related data, and in the research framework of this study, the death status of the elderly population needs to be processed as the absorption state, so the latest data of 2015 is not adopted.

Concept Definition

Definition of the Health Status of the Elderly

When evaluating the health of the elderly, the elderly health self-rated was used to calculate the probability of health transition of the elderly. Self-rated health status can not only reflect the individual's health status from both subjective and objective aspects but also evaluate the health status comprehensively. Although self-rated health is essentially an indicator of subjective judgment and has its limitations, its information not only contains the past and future health status of the interviewees but also can be stable and effective for a considerable period of time, with high effectiveness, credibility, and stability. In the CHARLS data, self-rated health questions were divided into two parts, and respondents were randomly assigned to answer questions DA001 or DA002. The questions were: DA001 "How would you say your health?" The answers to this question were "excellent, very good, good, fair, or poor." DA002 "What do you think of your health?" The answers to this question were "excellent, very good, good, fair, or poor." Since the respondents were randomly divided into two groups, the two groups of data were combined in this study when dealing with this problem and the data results are relatively robust. Therefore, when dealing with self-rated health variables, two groups of questions related to self-rated health in

TABLE 1 | Estimated value of self-rated health elderly transition probabilities (including death).

	Percentage (2011)	Percentage (2013)
State 1 (healthy)	12.15	12.96
State 2 (basic heathy)	29.82	30.22
State 3 (unhealthy)	38.49	34.86
State 4 (very unhealthy)	19.54	17.92
State 5 (death)	—	4.05

Unit: %.

the CHARLS data were combined and death status was added to obtain six predictable health status indicators, namely, "excellent, very good, good, fair, poor or death," wherein, "excellent" and "very good" are denoted as health and are represented as state 1. The remaining "good, fair, and poor" were successively expressed as status 2: basic healthy, status 3: unhealthy, status 4: very unhealthy, and status 5: death. Among them, statuses 1, 2, 3, and 4 belong to the transfer state, and 5 is the absorption state. According to the statistics, the distribution of those states is shown in **Table 1**.

Definition of Medical Expenditure

The data of medical expenditure used in the model are mainly from the microsurvey data of medical expenditure in CHARLS data, including the average medical expenditure of families per year and the average medical expenditure of the elderly individual per month. From the perspective of families, family medical expenditure refers to the total annual medical expenditure (including the part that can be reimbursed by medical insurance) of families with elderly people aged 60 or above, including direct medical expenditure and indirect medical expenditure, excluding health care expenses. Direct medical expenses refer to outpatient, hospitalization, and daily medical expenses of family members; indirect medical expenses refer to the indirect expenses incurred at the time of medical treatment, such as transportation expenses, nutrition expenses, and expenses for accompanying family members.

From the perspective of the individual, the elderly individual medical total expenditure (including medical insurance that can be reimbursed) refers to the medical and health care costs of the elderly, including to go to medical institutions to see outpatient services or accept doorstep medical services (excluding to go to the hospital to do physical examination) costs; the total cost of hospitalization (including the cost paid to the hospital and the cost of the hospital room, excluding the salary of the escort, the cost of transportation for oneself or family members); and the cost of self-treatment (including the cost of purchasing prescription drugs, over-the-counter drugs, traditional Chinese herbal medicines or traditional methods of treatment, taking health supplements such as vitamins and using health equipment). The measurement of the individual medical expenditure of the elderly includes only the direct medical expenditure related to the individual elderly and excludes other expenses related to treatment.

Model Construction and Methods

Model Construction of Health State Transition Probability

Based on the health transition model, logistic regression was used to estimate the health transition probability of the elderly population. The model took the health status of the elderly in 2011 as the basic sample box and analyzed the health status of the same birth cohort in 2013 according to the health status of the elderly aged 60 and above in 2011 with basic demographic characteristic variables, such as economic status variables, health behavior variables, and social relationship variables.

Taking 2011 health state i as the independent variable, the model calculates the probability of current health state j as follows:

$$P_{i,j,t+2}\left(H_{i,j,t+2}=1\middle|H_{i,t},\ X_{i,t}\right)=\frac{1}{1+e^{-[\alpha_{it}+\beta H_{i,t}+\gamma X_{i,t}+\varepsilon_{it})]}} \quad (1)$$

the odds of the healthy state:

$$\frac{P_{i,j,t+2}(H_{i,j,t+2}=1|H_{i,t},\ X_{i,t})}{P_{i,j,t+2}(H_{i,j,t+2}=0|H_{i,t},\ X_{i,t})}=\frac{p_{i,j,t+2}}{1-p_{i,j,t+2}} \quad (2)$$

$$=e^{\alpha_{it}+\beta H_{i,t},+\gamma X_{i,t}+\varepsilon_{it}} \quad (3)$$

The logarithm of odds is taken to obtain the regression model:

$$\ln\left(\frac{p_{i,j,t+2}}{1-p_{i,j,t+2}}\right)=\alpha_{it}+\beta H_{i,t}+\gamma X_{i,t}+\varepsilon_{it}, \quad (4)$$

$$i,j=1,2,3,4;\quad t=2011,t+2=2013 \quad (5)$$

where, $p_{i,j,t+2}$ is the probability that the individual is in the healthy state i in t period and changes to healthy state j in t+2 period. $H_{i,t}$ is health state, and covariant variable $X_{i,t}$ includes demographic characteristics variables (age, gender, and household registration), social and economic status variables (education, medical insurance, and pension), health and behavioral variables (chronic diseases, drinking, smoking, and BMI), and the social relations variables (marital status and social activities).

Model Construction of Medical Expenditures Under Different Health Conditions

Whether medical expenditure occurs or not is the optimal decision of self-selection. Therefore, some samples are zero or missing in medical expenditure. If these samples are ignored, the results will be selection bias. To correct the selectivity bias, TPM was used to estimate the medical expenditure of the elderly (16, 17).

The first part of TPM adopts the Probit model to locate whether there is medical expenditure:

$$I_i=x_i\delta_1+\mu_{1i},\quad \mu_{1i}\sim N(0,\ 1), \quad (6)$$

when I $\geq$ 0, medical expenditure ME occurs.

TABLE 2 | Estimated value of self-rated health elderly transition probabilities (including death).

	State 1	State 2	State 3	State 4	State 5
State 1	0.3211	0.3561	0.2342	0.0544	0.0342
State 2	0.1459	0.3707	0.3492	0.1054	0.0288
State 3	0.1007	0.2933	0.3674	0.1973	0.0413
State 4	0.0441	0.1826	0.3745	0.3352	0.0636
State 5	0	0	0	0	1

The second part is the linear expenditure equation of medical expenditure ME_i:

$$\mathrm{Y}\left(ME_i|I_i > 0\right) = x_i\,\delta_2 + \mu_{2i}, \quad \mu_{2i} \sim N\left(0,\ \sigma_\mu^2\right), \tag{7}$$

The likelihood function of this model is:

$$L\left(\delta_1, \delta_2, \sigma^2\right) = \Pi L_i\left(\delta_1, \delta_2, \sigma^2\right), \tag{8}$$

where, L_i is the likelihood function of i th observation value.

In the empirical analysis, this study established a model equation by predisposing factors, enabling factors, and needing factors for medical services (18, 19).

EMPIRICAL RESULTS AND DISCUSSION

Self-Rated Health Transition Probability of the Elderly

Overall

Based on HTM, the health status transition probability matrix of the elderly cohort with different initial health statuses was calculated from 2011 to 2013 (**Table 2**). The results showed that When the base period is in a healthy state (state 1), the probability of remaining healthy is 0.3211, and the probability of being basic healthy is 0.3561. The probability of deterioration in physical health is 0.2886, of which the probability of transition to unhealthy is 0.2342, the probability of very unhealthy is 0.0544, and the risk of transition to death is 0.0342. When the elderly are in basic health (state 2), the probability of their current health status recovering to health is 0.1459, the probability of maintaining basic health is 0.3707, and the probability of transition to unhealthy or very unhealthy is significantly increased; however, the risk of death is decreased. The probability of returning to the basic health of the elderly who were in an unhealthy state (state 3) is 0.2933. Most of the elderly are still in the original unhealthy state during the current period, and the probability of dying in the current period increases slightly to 0.0413 compared with the previous state. For the elderly who are very unhealthy at the base stage, there is only 0.0441 probability of recovering to health status and 0.3745 probability of recovering to unhealthy status, 1/3 of the elderly continue to maintain very unhealthy status, and the risk of death is 0.0636 at this time.

The elderly's self-rated health status showed the following transition characteristics: first, no matter what the basic health status of the elderly is, the elderly will mainly keep their original health status until the next period, and the probability of each health status of the elderly to maintain their current status is more than 30%; second, the better the basic health status of the elderly, the lower the probability of the transition to unhealthy or very unhealthy in the next period; third, the worse the basic health status of the elderly, the lower the probability of transition to health and basic health in the next period, and the probability of cross-state physical improvement of the elderly is lower as well. It can be seen that the basal health status of the elderly has an important effect on the health status of the later period.

TABLE 3 | Estimated value of self-rated health elderly transition probabilities by age (including death).

	State 1	State 2	State 3	State 4	State 5
			60∼64		
State 1	0.3552	0.3271	0.2526	0.0421	0.0230
State 2	0.1552	0.3841	0.3610	0.0909	0.0088
State 3	0.1002	0.3155	0.3662	0.1976	0.0205
State 4	0.04	0.1507	0.4141	0.3603	0.0349
State 5	0	0	0	0	1
			65∼69		
State 1	0.2757	0.3964	0.2073	0.0657	0.0649
State 2	0.1323	0.3853	0.3667	0.0971	0.0186
State 3	0.0883	0.3212	0.3681	0.2001	0.0223
State 4	0.0546	0.1921	0.3751	0.3334	0.0448
State 5	0	0	0	0	1
			70∼74		
State 1	0.3124	0.3048	0.2015	0.1302	0.0511
State 2	0.1328	0.3346	0.3706	0.1209	0.0411
State 3	0.0917	0.2711	0.3815	0.2093	0.0464
State 4	0.0561	0.1931	0.3207	0.3412	0.0889
State 5	0	0	0	0	1
			75∼79		
State 1	0.2683	0.3293	0.2317	0.0976	0.0731
State 2	0.1409	0.3264	0.3149	0.1340	0.0838
State 3	0.1011	0.2523	0.3685	0.1721	0.1060
State 4	0.036	0.2432	0.3333	0.3063	0.0812
State 5	0	0	0	0	1
			Aged 80 and over		
State 1	0.2947	0.2549	0.3197	0.0717	0.0588
State 2	0.1405	0.3841	0.2222	0.1316	0.1218
State 3	0.1419	0.1768	0.3416	0.1707	0.1689
State 4	0.0752	0.1821	0.2875	0.237	0.2183
State 5	0	0	0	0	1

The Age-Specific Transition Probability of the Elderly Self-Rated Health

According to the estimation (**Table 3**), among the elderly aged 60–64, when they are in a health state (state 1) at the base stage, the probability of remaining healthy at the current stage is 0.3552, the probability of being basic healthy is 0.3271, the probability of being transferred to unhealthy state is 0.2526, the probability of being very unhealthy is 0.0421, and the probability of having died at the current stage is 0.0230. Compared with state 1, elderly

in basic health (state 2) at baseline were significantly more likely to transition to poor health and very poor health; however, less likely to die. The probability of returning to basic health is 0.3155 for the elderly in an unhealthy base period (state 3), and the probability of death by the current period is 0.0205, which is similar to state 1. For very unhealthy (state 4) of the elderly, the probability of recovery to health and basic health in the current period is relatively low. The probability of recovery to unhealthy is 0.4141, which is greater than to maintain the original state probability. These results indicate that for people who have just entered the old age, the self-health recovery ability is stronger, and the health status of the young elderly is better on the whole.

There was no significant difference between the elderly aged 65–69 years and the elderly aged 60–64 years from the overall health transfer status, but the probability of transition to the basic health of the healthy elderly in the current period increased significantly, and the risk of death of the elderly in each health state also increased slightly.

For the middle aged people aged 70–74 and 75–79, when the base phase is in a healthy state, 1/3 of the elderly will be transferred to basic health. The base period is basic healthy, the probability of recovery to health is low, and most of the elderly maintain the original state or transfer to the next state. When the base stage of the elderly was unhealthy, the probability of the elderly still being unhealthy was 0.3815 and 0.3685, respectively. However, compared with those aged 70–74 years, the risk of overall death was significantly increased in those aged 75–79 years, especially those in basic health and those in poor health.

The elderly aged 80 and above have a lower probability of recovering to a better health state, and the probability of transferring to unhealthy health is higher than that of other age groups.

In conclusion, older people of all ages have a higher probability of maintaining their original health status. The younger elderly are more likely to maintain their current health status or recover to better health status than the older elderly, and the probability of death is slightly lower. In contrast, older adults were slightly less likely to have their baseline health status transitioned to unhealthy or very unhealthy health than younger adults, showing a higher risk of death than other age groups.

Analysis of Influencing Factors of Medical Expenditure

Table 4 is the regression of the influence of self-rated health of the elderly on the average annual medical expenditure of the family and the average monthly medical expenditure of the elderly according to the two-part model. Model 1 and Model 3 estimate whether the elderly choose to go to hospitals, clinics, or self-care; Model 2 and Model 4 are medical expenditure equations.

The elderly family and personal medical participation present the following features: Model 1 and Model 3 show that both family and individual participation in health diagnosis and treatment of the elderly is significant at the level of 10%. The worse the self-rated health status of the elderly is, the more families and individuals choose medical treatment, and the probability of personal medical treatment is higher than that of family medical treatment. When the elderly have a health crisis, family perception lags behind individual perception, and individuals actively respond to health changes through hospitals, clinics, or self-diagnosis. Among the controlling factors that determine whether families and individuals participate in health care, household registration and social security items have the greatest influence. Specifically, first, the older the elderly are, the less likely they are to choose medical treatment, and the more likely families are to provide medical treatment for the elderly than individuals. Second, there are no gender differences in the provision of medical care to older persons by families and individuals. Third, agricultural (rural) families have a higher proportion of family medical diagnosis and treatment probability than nonagricultural (urban) families. Fourth, whether the family provides medical treatment is not related to the education level of the elderly, but the higher the education level of the elderly, the more likely they will choose medical treatment, which is directly related to health awareness, occupation distribution, insurance status, personal income, and other factors. Fifth, the level of family income contributes to the timely provision of medical treatment by both families and individuals, and the level of family income has the same influence on the medical treatment behavior of both families and individuals. Sixth, the elderly participate in endowment insurance and medical insurance to help families to take medical treatment, endowment insurance with regular fixed supplies becomes a part of the individual and family income, the higher the income, the greater the possibility of providing medical treatment.

Family and individual medical expenditures are directly related to the health status of the elderly. Model 2 and Model 4 show that the impact of the self-rated health status of the elderly on both family and individual medical expenditures is significantly correlated at the level of 1%. The worse the self-rated health status of the elderly is, the more family and individual medical expenditures are. The most important individual characteristic that affects the family and individual medical expenditure is the nature of household registration. The influence of the age, gender, and education level of the elderly on the family and individual medical expenditure are not significant at 1, 5, and 10%.

In conclusion, the self-rated health status of the elderly is directly related to whether they receive medical treatment or not and medical expenditure, indicating that the worse the self-rated health status of the elderly, the more they will receive medical treatment, and the higher the amount of family medical expenditure and personal medical expenditure. Differences in individual characteristics of older persons lead to differences in family and individual medical treatment and expenditure. It is worth paying attention to the difference in medical treatment and expenditure caused by the nature of household registration. Nonagricultural household registration has a comparative advantage in the right to enjoy medical resources. In addition, both endowment insurance and medical insurance significantly improve the enthusiasm of the elderly for medical treatment, but the security function of endowment insurance is more direct and timely, and the security of medical insurance has a certain lag, and the advance of medical expenses

TABLE 4 | Regression of self-rated health and medical expenditure.

	Average medical expenditure of families per year		Average medical expenditure of the elderly individual per month	
	Model 1	**Model 2**	**Model 3**	**Model 4**
Self-rated health	0.192***	1,571***	0.261***	218.8***
	(0.0202)	(185.1)	(0.0151)	(31.96)
Demographic characteristics variables				
Age	−0.0306**	−104.5	−0.0253**	17.09
	(0.0156)	(145.9)	(0.0113)	(24.21)
Gender (Female = 0)	0.0181	−88.64	−0.0400	−22.38
	(0.0390)	(356.8)	(0.0292)	(60.46)
Household registration (Non-agricultural = 0)	0.139***	−1,401***	−0. 149***	−256.7***
	(0.0523)	(481.4)	(0.0396)	(80.54)
Social and economic status variables				
Education (Under Middle School = 0)	−0.00160	129.1	0.0687*	36.81
	(0.0531)	(479.7)	(0.0402)	(81.61)
Family income	0.0448***	1,185***	0.0483***	60.50**
	(0.0166)	(155.1)	(0.0122)	(26.14)
Pension (No Pension = 0)	0.203***	−1,096*	0.0420	−199.1**
	(0.0577)	(578.0)	(0.0450)	(95.29)
Medical insurance (No Medical Insurance = 0)	0.386***	938.3	0.115*	263.9*
	(0.0834)	(939.1)	(0.0673)	(146.6)
Social relations variables				
Marital status (Without Spouse = 0)	0.252***	712.7	0.0662*	18.01
	(0.0499)	(493.3)	(0.0377)	(79.89)
Social activities (No Attend = 0)	0.0619	−585.9*	0.151***	−107.9*
	(0.0385)	(352.0)	(0.0287)	(60.12)
Constant	−0.341*	−8,431***	−0.608***	−423.8
	(0.204)	(1,984)	(0.151)	(329.4)

*, **, *and* ***represent significant at 10, 5 and 1% levels, respectively. The values in brackets are standard deviations.

may reduce the possibility of timely medical treatment of the elderly.

Calculation of Medical Expenditure for the Elderly

According to the estimated results of the self-rated health status of the elderly, this study estimated the family and individual medical expenditure of the elderly with different self-rated health statuses. The results showed that the average medical expenditure of families with self-rated health was ¥ 3,171.16 per year, the average medical expenditure of families with self-rated basic health was ¥ 3,851.09 per year, and the average medical expenditure of families with self-rated unhealthy increased to more than ¥ 4,000, reaching ¥ 4,579.76 per year (**Table 5**). The average medical expenditure of families who rated themselves as very unhealthy surged to RMB 7,200.96 per year, which was 1.27 times higher than that of the elderly families who rated themselves as healthy.

TABLE 5 | Estimation of medical expenditure for self-rated health elderly.

	State 1	State 2	State 3	State 4
Average medical expenditure of families per year (Yuan)	3171.16	3851.09	4579.76	7200.96
Average medical expenditure of the elderly individual per month (Yuan)	177.81	175.73	315.99	647.86

The average medical expenditure of the elderly individual with the self-rated healthy elderly was ¥ 177.81 per month, whereas the average medical expenditure of the elderly individual with the self-rated basic healthy elderly declined to ¥ 175.73 per month, the average medical expenditure of the elderly individual with the self-rated unhealthy elderly was ¥ 315.99

per month, and the average medical expenditure of the elderly individual with the self-rated very unhealthy elderly surged to ¥ 647.86 per month. It is 2.64 times higher than the average medical expenditure of the elderly individual who is self-rated as healthy.

Under the rigid health status of the elderly, assuming that the average monthly personal medical expenditure is stable, according to the estimation results in **Table 5**, the average annual personal medical expenditure of the elderly who self-rated as very unhealthy, unhealthy, basically healthy, and healthy is ¥ 7774.32, ¥ 3791.88, ¥ 2108.76, and ¥ 2133.72, respectively. The increase in personal health expenditure was higher than that of family health expenditure, and the better the self-rated health status was, the greater the gap between personal health expenditure and family health expenditure was. This reflects that the worse the health status of the elderly is, the more the family medical expenditure for the elderly is, and the medical expenditure for the elderly accounts for more than 50% of the family medical expenditure.

Age Difference of Medical Expenditure of the Elderly Under Different Self-Rated Health States

The medical expenditure of the elderly in different age groups is measured according to the family, and the individual medical expenditure of the elderly with different self-rated health status output is shown in **Table 6**. Family and individual medical expenditures of the elderly in different age groups basically support the conclusion that the better the self-rated health status is, the lower the family and individual medical expenditures are. The special feature is that the family expenditure of the 65–69-year-old group is lower than that of the elderly group, and the individual medical expenditure of the 80-year-old and above group is lower than that of the elderly group. The two states of self-rated health and self-rated basic health basically indicate that the physical condition of the elderly may not affect the occurrence of functional conditions, so the contrary decrease in expenditure is consistent with the general understanding.

In terms of health status, the elderly aged 65–69 who self-rated as healthy had the highest family medical expenditure of ¥ 4,451.52 per year, followed by the elderly aged 70–74 with an average annual medical expenditure of ¥ 3,232.45. The age group aged 80 and above had the highest individual medical expenditure of ¥ 355.69 per month, followed by the elderly aged 65–69. The average monthly medical expenditure was ¥ 125.01; the family and individual medical expenditure of the elderly showed a "V" shape, and the medical expenditure of the elderly aged 70–74 was less. The elderly aged between 70 and 74 who self-rated as unhealthy had the highest family medical expenditure of ¥ 4925.58 per year, whereas the elderly aged between 70 and 74 had the lowest family medical expenditure of ¥ 3,855.74 per year. The elderly aged between 70 and 74 had the highest individual medical expenditure, and the elderly aged between 70 and 74 had the lowest medical expenditure. The trend of family and individual medical expenditure of the elderly with unhealthy self-evaluation is opposite, which reflects the different attitudes of families and individuals to cope with the unhealthy physical condition of the elderly, and the family medical expenditure lags behind the individual. The family and individual medical expenditure of the elderly who self-rated very unhealthy kept the same trend; the medical expenditure of the elderly aged 60–64 was the highest, and the medical expenditure of the elderly aged 65–74 was the least.

TABLE 6 | Estimation of medical expenditure for self-rated health elderly by age.

	State 1	State 2	State 3	State 4
			60~64	
Average medical expenditure of families per year (Yuan)	3010.94	4247.63	4673.69	8801.67
Average medical expenditure of the elderly individual per month (Yuan)	92.21	162.76	308.49	738.63
			65~69	
Average medical expenditure of families per year (Yuan)	4451.52	3728.46	4740.35	6600.16
Average medical expenditure of the elderly individual per month (Yuan)	125.01	152.19	367.76	636.52
			70~74	
Average medical expenditure of families per year (Yuan)	3232.45	3419.31	4925.58	6848.63
Average medical expenditure of the elderly individual per month (Yuan)	88.63	153.79	269.03	618.45
			75~79	
Average medical expenditure of families per year (Yuan)	1662.97	3763.87	4104.32	7135.99
Average medical expenditure of the elderly individual per month (Yuan)	84.36	241.65	354.14	729.68
			Aged 80 and over	
Average medical expenditure of families per year (Yuan)	2125.19	3720.39	3855.74	5144.09
Average medical expenditure of the elderly individual per month (Yuan)	355.69	263.43	449.04	589.11

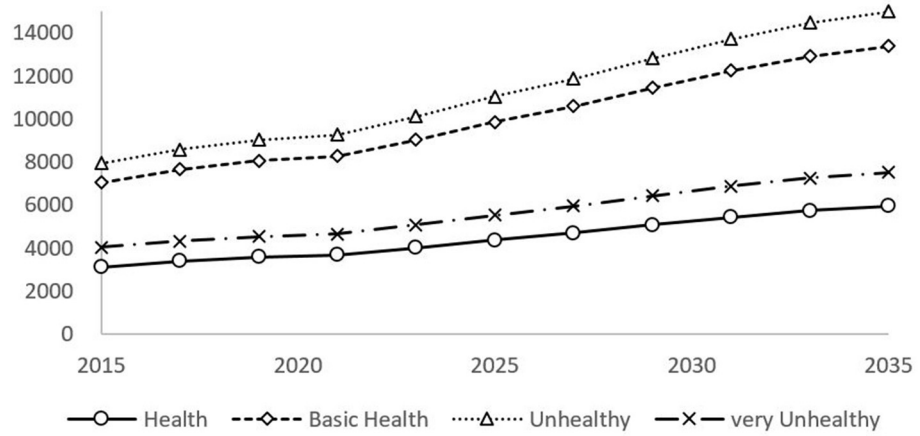

FIGURE 1 | Forecast of the overall health status for SAH elderly in China.

FORECAST OF THE HEALTH STATUS OF THE ELDERLY AND THE TOTAL DEMAND FOR MEDICAL EXPENDITURE

Theoretical Basis of Forecast

If $X_t = i$, this process represents the state at time t as i. Now, assuming that every process is in state i, then the probability of getting to the next state j is fixed. Therefore, it is assumed that there exists a fixed probability independent of time for:

$$P\left\{X_{t+1} = j \,\middle|\, X_t = i,\, X_{t-1} = i_{t-1}, \ldots,\, X_1 = i_1,\, X_0 = i_0\right\} = P_{ij}, t \geq 0 \quad (9)(10)$$

while $j, i, i_0, i_1, \ldots, i_{t-1} \in M$, and this random process is called Markov Chain.

Probability represents the probability of moving from a given current state I to state J, which obviously has:

$$P_{ij} \geq 0,\ \ i,j \geq 0;\ \sum_{j=0}^{\infty} P_{ij} = 1,\ i = 0, 1, \ldots \quad (11)$$

A matrix of transition probabilities:

$$P_{ij} = \begin{Vmatrix} P_{00} & P_{01} & \cdots & P_{0j} \\ P_{10} & P_{11} & \cdots & P_{1j} \\ \vdots & \vdots & \ddots & \vdots \\ P_{i0} & P_{i1} & \cdots & P_{ij} \end{Vmatrix} \quad (12)$$

P_{ij} represents a one-step transfer matrix, or a first-order matrix of a Markov Chain.

Then Chapman-Kolmogorov equation is used to calculate Markov n-step transition probability P_{ij}^{n}.

Based on the basic principle and the empirical results of the health transition model, the MC first-order matrix of the self-rated health of the elderly was obtained as follows:

$$P_{ij}(SAH) = \begin{Vmatrix} 0.3211 & 0.3561 & 0.2342 & 0.0544 & 0.0342 \\ 0.1459 & 0.3707 & 0.3492 & 0.1054 & 0.0288 \\ 0.1007 & 0.2933 & 0.3674 & 0.1973 & 0.0413 \\ 0.0441 & 0.1826 & 0.3745 & 0.3352 & 0.0636 \\ 0 & 0 & 0 & 0 & 1 \end{Vmatrix} \quad (13)$$

Each element in the matrix represents the probability of the elderly person moving from their initial state of health in the base period to their current state of health. The sum of each row in the matrix is 1.

According to the estimated first-order transition probability matrix of MC, Chapman–Kolmogorov equation was used to simulate the n-order transition probability of MC[1], that is, the health transition probability of the elderly in different cohorts in each t+2 period over time was obtained. Based on the data of the elderly population size predicted by the National Plan of the National Strategy Research Group for Coping with population Aging (2014), 2015 was taken as the starting point for the prediction, and the health self-assessment status of the elderly was analyzed to simulate the annual distribution of disability status of the elderly population from 2015 to 2035.

Forecast of the Overall Health Status of the Elderly

The size of the elderly population with different self-rated health statuses from 2015 to 2035 is shown in **Figure 1**. The elderly population with an unhealthy state and basic health status is the largest, while the healthy elderly population is the smallest. In addition, the change rate of the unhealthy elderly population is faster than that of other elderly populations, and the change rate of the healthy elderly population is

[1]If more information of Markov process and Chapman-Kolmogorov equation are needed, please contact the author for details.

TABLE 7 | Forecast of health status for SAH elderly in China by age.

	Healthy	Basic healthy	Unhealthy	Very unhealthy
			60∼64	
2015	1184	2489	2836	1334
2025	1464	3136	3595	1704
2035	1628	3489	3999	1896
			65∼69	
2015	686	1853	1968	984
2025	838	2332	2540	1267
2035	1275	3707	4076	1994
			70∼74	
2015	477	1070	1318	762
2025	771	1927	2370	1394
2035	1032	2503	3279	1811
			75∼79	
2015	361	822	943	506
2025	542	1144	1529	771
2035	711	1434	1977	1112
			Aged 80 and over	
2015	446	745	863	465
2025	615	988	1141	596
2035	1102	1791	2024	1067

Unit: 10,000.

relatively stable. By 2035, the number of healthy, basically healthy, unhealthy, and very unhealthy elderly population will be 59.38 million, 133.78 million, 149.83 million, and 75.09 million, respectively. Compared with 2015, the number of healthy and basically healthy elderly population will increase the most.

Self-Rated Health Status Prediction of the Elderly in the Different Age Groups

In different age groups (**Table 7**), from 2015 to 2035, the scale of the healthy, basic healthy, and the unhealthy elderly population has the same consistent trend with age whereas the scale of the very unhealthy elderly population has an inverted V shape with age. In 2015, the number of healthy, basic healthy, unhealthy, and very unhealthy people aged 60–64 is 11.84 million, 24.89 million, 28.36 million, and 13.34 million, respectively. The number of elderly people aged 75–79 in every self-rated health status is the smallest. The scale of the elderly population aged 80 and above who self-rated their health status has rebounded, which confirms the grim trend of the aging population in the future.

Toward the middle of the century, the size of the elderly population in every healthy state will rise. By 2035, the number of healthy, basically healthy, unhealthy, and very unhealthy elderly population aged 60–64 will be 16.28 million, 34.89 million, 39.99 million, and 18.96 million, respectively. The number of healthy, basically healthy, and unhealthy elderly population aged 80 and above will all increase compared with the number of elderly population aged 75–79. The number of unhealthy elderly decreased by 4,50,000 from 75 to 79 to 11.02 million, 17.91 million, and 20.24 million, respectively.

Forecast of Medical Expenditure Demand of the Elderly Under Different Health States

The actuarial model is used to forecast the medical expenditure of the elderly. When forecasting the medical expenditure, it is decomposed into the function of the number of the elderly population in different health states and the per capita medical expenditure in different health states, taking into account the difference of the medical demand of the elderly under different health states. When an individual is in the state j at time $t + 2$, the average monthly medical expenditure is $ME_j(t + 2)$, $N(t + 2)$ is the number of the elderly population in various health states, and ME is the average monthly medical expenditure of the elderly. Assuming that the medical needs and behaviors of the elderly remain unchanged in the next 20 years, the present value of the medical expenditure of the elderly population aged 60 and above is denoted as:

$$ME_j(t+2) = \sum N(t+2) \cdot ME \tag{14}$$

Based on the estimate of the health size of the elderly population, we forecast the medical expenditure of the elderly population under various health conditions (**Figure 2**). According to the forecast results, the very unhealthy elderly population has the highest level of medical expenditure, and the gap with the unhealthy medical expenditure is small. Relatively speaking, the health and basic health elderly population have a relatively low level of medical expenditure. In 2015, the medical expenditure level of the very unhealthy elderly population was ¥ 26.112 billion, whereas that of the healthy elderly population was only ¥ 5.542 billion, with a difference of ¥ 20.57 billion between the two. In 2035, the gap will reach ¥ 38.088 billion. In 2035, the expenditure on medical care for the elderly in good health, basic health, unhealthy and very unhealthy will be ¥ 10.558 billion, ¥ 23.510 billion, ¥ 47.344 billion, and ¥ 48.645 billion, respectively.

With the rapid development of the aging population in China, the total elderly population is increasing rapidly, and the scale of the disabled elderly population is gradually expanding, which directly leads to the rapid expansion of medical security fund demand. In 2000, the medical expenditure of the elderly population in China accounted for 0.48% of GDP, and in 2015, it accounted for 1.24%, and it is estimated that this proportion will continue to expand. The pressure on the scale of medical expenses for the elderly concerns the health and quality of life of all citizens, the people's livelihood and the health of the people. It has fundamentally changed the intergenerational distribution pattern of medical and health resources, caused potential social intergenerational conflicts and conflicts of interest, and profoundly affected the realization of the strategic goal of Healthy China.

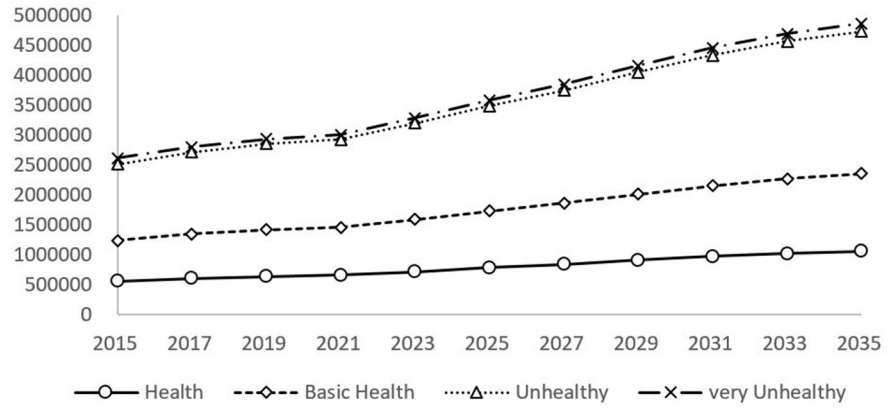

FIGURE 2 | Forecast of annual medical expenditure for SAH elderly in China.

The elderly population aged 60–64, 70–74, and 75–79 years old had the largest scale of unhealthy medical expenditure, the elderly population aged 65–69 and 80 years and above had the largest scale of unhealthy medical expenditure, and the elderly population in different age groups had the least health medical expenditure (**Figure 3**). In 2015, the medical expenditure of the elderly population aged 60–64, 65–69, 70–74, 75–79, 80 and above were ¥ 1.092 billion, ¥ 857 million, ¥ 423 million, ¥ 304 million, and ¥ 1.585 billion, respectively. The elderly population and the young elderly population had the highest medical expenditure. The underage elderly population is a potential human capital resource, and large-scale medical expenditure can effectively improve their health status, which provides conditions for delaying the retirement age. In 2015, the medical expenditure of the elderly population aged 60–64, 65–69, 70–74, 75–79, 80 and above in very unhealthy state was ¥ 9.853 billion, ¥ 6.262 billion, ¥ 4.713 billion, ¥ 3.695 billion, and ¥ 2.738 billion, respectively, showing that the older the population is, spending on health care to deal with very unhealthy conditions is less but still higher than spending on health care for the healthy elderly population. In 2035, the medical expenditure of the elderly population of all ages to deal with very unhealthy physical conditions will be ¥ 14.07 billion, ¥ 12.373 billion, ¥ 11.20 billion,¥ 7.387 billion, and ¥ 6.288 billion, respectively. Compared with 2015, medical expenditure increased by ¥ 4.154 billion, ¥ 6.111 billion, ¥ 6.487 billion, ¥ 3.692 billion, and ¥ 3.55 billion, respectively. The elderly population aged 70–74 and 65–69 had the largest increase in medical expenditure.

CONCLUSION

Population aging is an irreversible normal social phenomenon, the common future of mankind, and also the fundamental reality of our country. The physical function of the elderly weakens with age and the dependence on health resources and services is natural. With the rapid development of population aging, the scale of unhealthy elderly people in China is expanding, the demand for health services is increasing rapidly, and the expenditure of medical and health care is increasing markedly. The aging population has exacerbated the challenge and pressure of health and medical expenditure inflation in the elderly population. Paying attention to the health of the elderly and realizing healthy aging is the key to alleviating the pressure of population aging, and also the basic intention of China's active response to population aging strategy in the new era.

Set in the rapid development of population aging, this study focuses on the relationship between health and medical expenditure of the elderly population. Taking the health and medical expenditure of the elderly as the research object, this study analyzes the characteristics and the intrinsic relationship between them. Based on the future elderly model, this study calculates the transition probability of the elderly's self-assessment health state using the health transition model and estimates the medical expenditure of the elderly by the two-part model. Based on the above, this study predicts the trend of the population size and medical expenditure of the elderly in the next 15 years (2020–2035). The main conclusions are as follows:

First, due to the rigid "ratchet effect" of the health status of the elderly population and the characteristics of the marginal decline of medical expenditure, it is decided that the basal period medical expenditure has a significant negative correlation with the health status of the elderly population.

Second, based on the health transition model, it is found that the health changes of the elderly population are mainly affected by initial health, age, and gender. In different initial states, regardless of the health status of the elderly in the base period, continuing to the next stage, the elderly population is primarily in keeping with the original health status, and the probability of maintaining the status quo in the next phase of the elderly population is above 30% percent for each health condition. Among the elderly population, the probability of maintaining an existing state of health or recovering to a better level of health at a younger age is higher than that at an older age, and with a slightly lower death rate. When the elderly are in a state of health in the basal line, in the next period, the health transition probability of women is significantly greater than that of men, whereas the

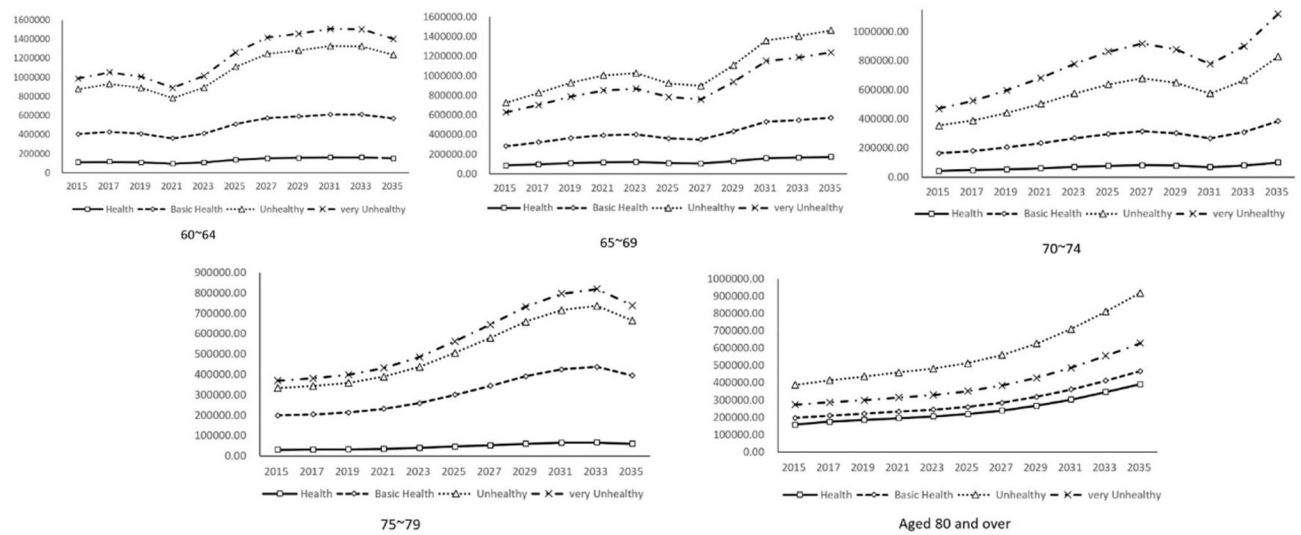

FIGURE 3 | Forecast of annual medical expenditure for SAH elderly in China by age.

older men have a stronger ability to improve their health status than women.

Third, the health status of the elderly population is directly related to family, personal medical treatment, and medical expenditure. On the one hand, the poorer the health status of the elderly, the higher the rate of medical treatment and medical expenditure. On the other hand, differences in individual characteristics of the elderly population lead to differences in medical treatment and medical expenditure between families and individuals. The poorer the health of the elderly, the more family and personal medical expenses, and personal medical expenditure accounts for more than 50% of the family's medical expenditure. In addition, the medical treatment and medical expenditure of the elderly population of different age groups basically support that the better the self-rated health status, the lower the family and personal medical expenditure.

Fourth, based on the Markov chain and Chapman-Kolmogorov equation, this study forecasts the health status and corresponding medical expenditure of the elderly population in the whole group and the age group during 2020 and 2035. It turns out that in terms of quantity, unhealthy status and basic health status of the elderly population is the largest, and relatively, the size of health status is smallest. In terms of age, the growth trend of the elderly population with healthy, basic health, and unhealthy status is the same with an increase in age, and the growth trend of the unhealthy elderly population is an "inverted V" with age change. In terms of gender, there is no obvious gender difference in the trend of health change among the elderly. In terms of medical expenditure, the elderly population with a very unhealthy status has the highest level of medical expenditure, whereas the mild disability elderly population has the highest medical expenditure.

Based on all the above, the policy suggestions are put forward. To begin with, to strengthen health management and health services for the elderly in the construction of healthy China. Next, building a comprehensive system of health care for the elderly in government, society, family, and individual. Then, establishing a long-term care service system as soon as possible. In addition, it is better to establish lifelong health consciousness and cultivate healthy accomplishment behavior. Finally, it is necessary to promote gender mainstreaming in the health field.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

YG specialism is Aging Population and Population Economics and Health Economics. JL specialism is Population Economics and Labor Economics. XY specialism is Aging Population and Population Economics. All authors contributed to the article and approved the submitted version.

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Son or Daughter Care in Relation to Self-Reported Health Outcomes for Older Adults in China

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Objectives: Parental care in China is traditionally provided by sons. In recent decades—partly due to the One-Child Policy but also economic development and urbanization—significant changes have occurred with more and more parents receiving care from daughters. We investigate the disparities in outcomes of eldercare provided by son(s) and daughter(s).

Methods: Our study compares the self-reported health (SRH) status of parents who receive eldercare from daughters and sons in China, analyzing the harmonized 2013, 2015, and 2018 waves of CHARLS with random-effects logistic estimates.

Results: Our results show that the SRH status of parents who receive care from their sons is greater than those cared for by their daughters. This disparity is greater in rural areas, for mothers, and poorer families.

Discussion: The One-Child Policy was more effective in urban areas, reducing both the availability of sons and cultural son preference. Higher levels of education received by girls in urban settings increases their employability and thus their ability to materially care for their parents. However, traditional norms and gender differences in social economic statuses still persist in rural areas, leading to higher SRH status of those cared for by sons, especially amongst those who are heavily dependent on their children: mothers or parents with less wealth.

Keywords: eldercare, health inequality, gender difference, self-reported health, CHARLS

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INTRODUCTION

In traditionally patrilineal societies such as China—influenced by the Confucian cultural norm—filial piety is valued as a core virtue, and married sons and daughters-in-law act as the primary caregivers to parents, while married daughters are expected to care for their husband's parents. Despite moves by the Chinese government to include daughters within the legal framework of care obligations, filial obligations remain most strongly with sons. Yet while traditional practices exclude married daughters from the filial discourse surrounding their own parents, they often have the most intimate relationship with their parents (1). Over recent decades, in part due to the One-Child Policy, but also arising from economic development and urbanization, significant changes have occurred in practice with daughters providing more and more support to their natal parents (2–5). Anthropological studies have suggested that the growing importance of parent-daughter relationships is specifically related to female independence and economic

empowerment and the increased emphasis on affection and care replacing filial piety in parent-child relationships (6).

This has given rise to a particular interest in the contrasting provision of care (financial, emotional, or instrumental support for elderly parents) between daughters and sons (7–12). Changes in the gendered norm of sons providing care for elderly parents have been highlighted (13–15). As Lei (16) points out, there is a growing rural-urban divide in this respect as daughters provide more instrumental and emotional support to parents in urban China, whereas sons and daughters do not differ in rural China.

The literature on comparing the outcome of support provided by daughters and sons is limited. Zeng et al. (17) disclose that older parents whose primary emotional carer is a daughter (or son-in-law) are associated with a lower level of mortality rate and higher cognitive capacity than those with a son (or daughter-in-law) as primary carer. Zeng et al. (18) provide evidence that older parents are more likely to be satisfied with the support for activities of daily living (ADLs) provided by a daughter (or son-in-law) compared with the care given by a son (or daughter-in-law). Another study estimates that the likelihood of reporting an unmet need in ADLs support is lower among urban parents whose primary carer is a daughter than a son (19). Co-residence with a daughter was found to be associated with a higher level of mental wellbeing than co-residence with a son (20). The daughter advantage in providing care might be explained by the stereotyped gender norm that women are better at caring and the common conflicts between a daughter-in-law and a mother-in-law lowering parents' wellbeing (21).

However, there is also evidence showing the son advantage in providing instrumental care and affecting subjective well-being and mental health (5, 22). Cong and Silverstein (23) found a stronger positive wellbeing impact of care provided by daughters-in-law (son's family) than by daughters in rural Anhui, conditional on cultural prescribed expectation. The authors argued that whether the source of care is culturally appropriate or not may be more influential to older parents' wellbeing compared to the support itself. Additionally, some other work investigates the association between gender composition of children and the mortality rate of parents to explore the son preference in patrilineal societies (such as mainland China, Taiwan, and Bangladesh), finding mixed results (24, 25).

RESEARCH AIMS AND HYPOTHESES

Due to shrinking family sizes, increasing female empowerment, and weakening traditional patrilineal kinship in China, it has become increasingly common for daughters to provide eldercare to their natal parents (3, 4), and there is growing evidence of a closer relationship between adult daughters and their natal parents (10–12). However, the possible disparity in health outcomes of eldercare provided by daughters and sons has limited attention. This study investigates the difference in the self-reported health of parents who receive eldercare from daughters and sons in China, analyzing the 2013, 2015, and 2018 waves of China Health and Retirement Longitudinal Study (CHARLS). We consider four linked hypotheses.

The first is around the cultural norm and gender difference in socio-economic statuses. In a patrilineal family, sons are expected to fulfill the Confucian ethic of filial piety and undertake the role of primary carers for their old parents (26, 27). In contrast, daughters are considered to be temporary family members. They become a permanent member of the husbands' family after marriage, responsible for taking care of their parents-in-law. In exchange for eldercare, parents invest more in their sons and traditionally would even only leave an inheritance to their sons. Therefore, we expect that sons have a stronger incentive to provide better eldercare (high-quality nutrition, clothing, healthcare services, and living environments). In addition, care from the culturally appropriate source is found to be beneficial for older parents' wellbeing (23). Gender disparities in socio-economic statuses (e.g., income and education) contribute to the difference in the financial capability to provide eldercare between sons and daughters. Older adults' health will be improved with high-quality care, noting that sons are more financially capable and have a stronger incentive to support their parents. Although a number of studies report the decline of these gender-based norms of filial piety and a strengthening of ties between married daughters and their natal parents (4, 6), we still expect the self-reported health of parents who receive care from their sons to be better than those cared for by their daughters (Hypothesis 1).

The second concerns regional disparities which may cause a difference in health outcomes of care provided by sons and daughters. For example, the One-Child Policy was stricter in urban areas. Residents are more likely to have a son in rural areas, as rural couples were allowed to have a second child if the first was a daughter. Compared with urban areas, son preference is much stronger, and economic development is much lower (28). The implementation of nine-year compulsory education in China from 1986 and economic development managed to dramatically close the gender inequality in education and income, especially across urban areas (29, 30). The differences in education between boys and girls mainly exist among poor residents living in rural areas (31). In addition, there are well-known regional inequalities in infrastructure, benefit levels in terms of social welfare, and access to healthcare and social care services where residents living in the rural area are disadvantaged (32, 33). Those inequalities may lead to a higher level of dependence on adult children amongst older parents in rural areas. Thus, we expect that the difference in the outcomes of care provided by sons and daughters is stronger in rural areas (Hypothesis 2).

The third hypothesis draws on the literature around the gendered experience of care. The gender gap in life expectancy from birth (LE) continues at 74.5 for men and 79 for women (34). Combining the gender gap in LE with the gender ideology that women are expected to undertake domestic work, including providing care for families, men are more likely to receive companion and support from their partners (35). In contrast, mothers are more dependent on their children, especially when their partners pass away. Ha et al. (36) supply evidence in favor of the fact that widowed mothers rely on their children for financial and legal advice and instrumental support to a greater extent compared to widowed fathers. Gender norms prescribe men to typically take care of the financial matters of the household

(37). Additionally, the literature shows that mothers' wellbeing is more sensitive to the support provided by their adult children (38, 39). Therefore, we expect differences in the outcome of care provided by sons and daughters to be stronger among mothers (Hypothesis 3).

The fourth considers the moderating effect of wealth. Parents with a high level of wealth are able to purchase food and healthcare services and products independent of their children. They can also afford extra care to supplement any insufficient unpaid care provided by their children or spouse. Li et al. (40) analyse data from residents in Shanghai to show that older adults with a higher level of income are more likely to receive formal care. Congruently, Zhu (19) find that older adults with financial independence are less likely to report an unmet need in long-term care. For this reason, wealthier parents' health is less dependent on their children's financial ability and filial piety, and we expect differences in the health outcomes of care provided by daughters and sons to be weaker amongst them (Hypothesis 4).

Our resulting hypotheses are thus

1. The self-reported health of parents who receive care from their sons will be better than those cared for by their daughters.
2. The difference in the health outcomes of care provided by sons and daughters is stronger in rural areas.
3. The difference in the health outcomes of care provided by sons and daughters is expected to be stronger with mothers.
4. The difference in the health outcomes of care provided by sons and daughters is expected to be weaker amongst wealthier parents.

METHODS

Data and Sample

The nationally representative China Health and Retirement Longitudinal Study (CHARLS) was first conducted in 2011 (41). It collects information on family structure, health, employment, and financial status among those aged 45 and over. Our analysis used waves 2013, 2015, and 2018 of CHARLS with 18,605, 21,095, and 19,816 respondents, respectively. Wave 2011 provides information on whether the respondents received any care from a child's spouse but did not disclose which child the spouse referred to. Without this information, we couldn't tell if the care provided by a child-in-law is from a son's family or a daughter's. For this reason, we exclude Wave 2011 from our analysis.

As there is a fundamental difference in health status between people who need support for daily activities and those who do not, we restrict our sample to those currently receiving instrumental assistances (n = 10,936). The health status between parents and their childless peers is also divergent, as people with a lower health status are less likely to have a child (42). We exclude childless adults from our sample, and this process leaves 10,769 observations. Then we cut out the individuals with missing observations of the key variables and drop outliers for household income: the top and bottom 1% of the income. Finally, our sample includes 9,159 observations for 6,594 individuals aged 45 and over who had at least one child and were receiving care during the survey period.

Dependent Variables

To measure health outcomes, we utilize self-reported health status to create a dummy variable, *SRH_Poor*, following Yiengprugsawan et al. (43): this is equal to one if the respondent reports poor or very poor health and zero if fair, good, very good or excellent health. We refer to it as poor self-reported overall health in the following context if *SRH_Poor* equals 1. For robustness checks, we applied two different measurements for health. The first is a categorical variable for the self-reported health status, *SRH_CA*, consisting of four values: 1 for poor health (poor and very poor health), 2 for fair health, 3 for good health, and 4 for great health (very good and excellent health). Self-reported health has been found to be a reliable physical health measure in multiple studies (44, 45). The second is *Chronic*, capturing the incidence of chronic disease: 1 for no chronic disease, 2 for having chronic disease before, 3 for the onset of new chronic disease since the previous interview.

Key Independent Variables

CHARLS asked respondents for the information on their primary carers with the following question:

> *Who most often help you with dressing, bathing, eating, getting out of bed, using the toilet, controlling for urination and defecation, doing chores, preparing hot meals, shopping, managing money, making phone calls, taking medications?*

Participants were allowed to report up to three persons, and the care structure is displayed in **Figure 1**. We categorize respondents (n = 9,159) into four groups based on the relationship between participants and their primary carers: (a) parents cared for by their son (n = 2,470); the participants' primary carers include at least one son (or daughter-in-law) but no daughter (or son-in-law); (b) parents cared for by their daughter (n = 895); the participants' primary carers include at least one daughter (or son-in-law) but no son (or daughter-in-law); (c) parents cared for by both their daughter and son (n = 849); the participants receive regular care from at least one son (or daughter-in-law) and one daughter (or son-in-law); and (d) parents cared for by others (4,945); the participants obtain regular support from their spouse, siblings, and other relatives or friends rather than their children. We generate a dummy variable for each group: *CaredbySon*, *CaredbyDaughter*, *CaredbyBoth* and *CaredbyOther*.

It should be noted that respondents in the above categories a-c may receive care from other people in addition to their children. Among those who receive care from sons but not daughters, 51.38% of them are only cared for by their son(s) (*OnlySonCare*, n = 1,269), and the remaining receive additional support from their spouse or other relatives. For the people who receive care from their daughter(s) but not their son, 47.71% of them are looked after only by their daughter(s) (*OnlyDaughterCare*, n = 427). As

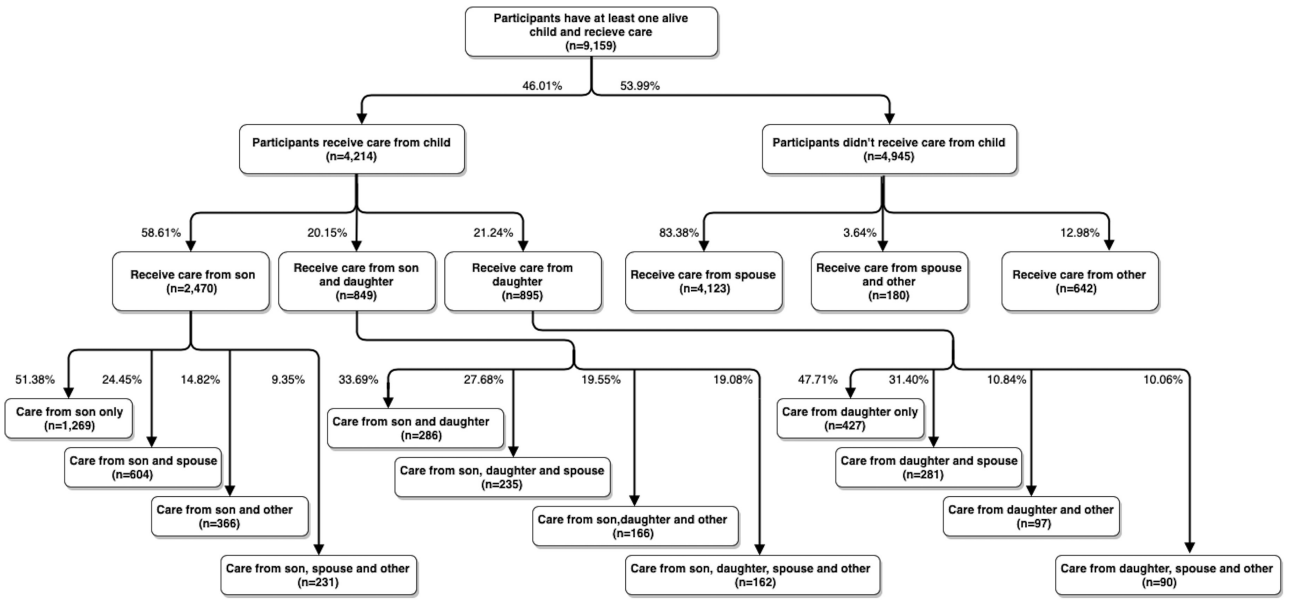

FIGURE 1 | Care structure for people aged 45 and over in China.

a cursory robustness check, we restrict our sample to those cared for only by their son(s) or only by their daughter(s).

Baseline Model

To investigate whether parents who are receiving care from their son(s) have a better self-reported health status than those who obtain care from their daughter(s), we estimate the following model:

$$\begin{aligned} SRH\_Poor_{i,t} &= \beta_0 + \beta_1 CaredbySon_{i,t} \\ &+ \beta_2 CaredbyDaughter_{i,t} + \beta_3 CaredbyBoth_{i,t} \\ &+ \beta_4 * Controls_{i,t} + u_i + u_t + \epsilon_{i,t} \end{aligned} \quad (1)$$

$SRH\_Poor_{(i,t)}$ is the self-reported health status for individual i in year t. $CaredbySon_{i,t}$, $CaredbyDaughter_{i,t}$, and $CaredbyBoth_{i,t}$ are the dummy variables indicating the care structure as described above. The reference group in the model is those who didn't receive any care from their children ($CaredbyOhter_{i,t} = 1$). If the care provided by a son outperforms that by a daughter (Hypothesis 1), we would expect β_1 to be significant and smaller than β_2. $Controls_{i,t}$ are other factors identified in the literature as essential determinants of health status: gender, age, marital status, education attainment, financial status, employment status, and family structure (17). The definitions of all variables are listed in Appendix (**Supplementary Table A1**). u_i *and* u_t represent the individual-specific time-invariant effects and the business cycle effects, respectively. $\epsilon_{i,t}$ is an idiosyncratic error term.

Restricting our sample to those who only receive care from sons or daughters, we estimate the following equation:

$$\begin{aligned} SRH\_Poor_{i,t} &= \beta_0 + \beta_1 OnlySonCare_{i,t} \\ &+ \beta_2 * Controls_{i,t} + u_i + u_t + \epsilon_{i,t} \end{aligned} \quad (2)$$

$OnlySonCare_{i,t}$ is equal to one if individual i is only looked after by their son(s) in year t and zero otherwise. In this model, the reference group is parents who only receive care from their daughter(s). If Hypothesis 1 cannot be rejected, the random-effects logistic estimator, β_1(odds ratio), would be significantly smaller than 1. To examine Hypotheses 2–4, we estimate Equations 1 and 2 with subsamples of urban and rural, mothers and fathers and participants with a high and lower wealth level.

RESULTS

Descriptive Statistics

Table 1 shows our sample characteristics. Among those who receive care and have at least one child ($N = 9{,}195$), 36.47% of them are male ($N = 3{,}340$), and 31.63% live in urban areas. This group's average age is about 66, 77.55% of the whole sample are married, and 18.47% are widowed. Among those looked after by their daughter but not by their son, 44.02% of them do not have an alive son. Compared with parents who receive care from a son but not their daughter, they are more likely to be married (67.82% vs. 58.54%), complete primary education (33.97% vs. 25.02%), live in the urban areas (39.66% vs. 28.99%) and engage in non-agriculture working (6.70% vs. 4.78%). They also tend to be younger (mean age 65.63 vs. 68.60) and have a higher household

TABLE 1 | Sample characteristics.

	Full sample	Care providers			
		Son	Daughter[a]	Both	Other
	N = 9,195	*N* = 2,470	*N* = 895	*N* = 849	*N* = 4,945
	M (SD)	*M* (SD)	*M* (SD)	*M* (SD)	*M* (SD)
Male	0.3647	0.2980	0.2793	0.3004	0.4245
	(0.4814)	(0.4575)	(0.4489)	(0.4587)	(0.4943)
Age	65.9388	68.5951	65.6257***	67.6231	64.3794
	(10.4904)	(10.7649)	(11.1680)	(11.3744)	(9.7350)
Married	0.7755	0.5854	0.6782***	0.6337	0.9124
	(0.4173)	(0.4927)	(0.4674)	(0.4821)	(0.2827)
Widowed	0.1847	0.3640	0.2726***	0.2980	0.0599
	(0.3881)	(0.4812)	(0.4456)	(0.4576)	(0.2372)
Primary education	0.335	0.2502	0.3397***	0.3039	0.3824
	(0.4721)	(0.4332)	(0.4739)	(0.4602)	(0.4860)
Urban	0.3163	0.2899	0.3966***	0.3663	0.3064
	(0.4651)	(0.4538)	(0.4895)	(0.4821)	(0.4610)
Real household income	23500.89	22421.43	26180.88**	23357.36	23579.66
	(35196.50)	(33737.13)	(37558.93)	(34445.84)	(35577.79)
Logarithm of real household income	8.5679	8.5026	8.5130	8.4619	8.6286
	(2.6505)	(2.6507)	(2.9540)	(2.8132)	(2.5613)
Real household wealth	23427.43	21806.02	24811.71	25821.83	23559.21
	(53558.87)	(50209.44)	(57142.19)	(62545.43)	(52864.62)
Logarithm of real household wealth	8.7928	8.6800	8.8360*	8.7165	8.8497
	(1.7076)	(1.7652)	(1.7252)	(1.8362)	(1.6529)
Farming	0.3924	0.3506	0.3263	0.3475	0.4330
	(0.4883)	(0.4773)	(0.4691)	(0.4764)	(0.4955)
Non-agriculture working	0.0701	0.0478	0.0670*	0.0766	0.0807
	(0.2553)	(0.2133)	(0.2502)	(0.2660)	(0.2724)
Number of sons	1.6747	2.0688	0.9140***	1.8339	1.5883
	(1.0952)	(1.0968)	(1.0408)	(0.9625)	(1.0354)
Number of daughters	1.5517	1.4628	2.1654***	1.8257	1.4380
	(1.2039)	(1.3117)	(1.1200)	(0.9883)	(1.1546)
No son	0.0976	0.0008	0.4402***	0.0000	0.1007
	(0.2968)	(0.0284)	(0.4967)	(0.0000)	(0.3010)
No daughter	0.1783	0.2660	0.0000***	0.0012	0.1972
	(0.3828)	(0.4419)	(0.0000)	(0.0343)	(0.3979)

[a]*We have conducted mean-comparison tests between the care provider groups of Son and Daughter.*
$^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

income (RMB 26,181 vs. RMB 22,421) and are less likely to be widowed (27.26% vs. 36.40%). For those whose primary carers include their son but not their daughter, 26.60% of them do not have a daughter.

Table 2 displays the health status of participants by care structure, indicating a better health outcome of care provided by their son. A larger proportion of parents whose primary carers include their daughter(s) but not their son(s) report poor health (57.99% vs. 50.93%) and have had a new onset of chronic disease (42.37% vs. 35.81%) since the previous interview, compared with those whose primary carers include their son(s) but not their daughter(s).

Self-Reported Health Status and Care Structure

The random-effects logistic regression estimates for Equations 1 and 2 are reported in **Table 3**. In comparison to those who receive care from others rather than their own children, Column 1 shows that the odds ratio of having poor overall health vs. not poor health is similar amongst parents who receive care from their son (OR 0.985, 95% CI 0.839–1.158) and higher among parents who receive care from their daughter (1.453, 1.152–1.833). We have conducted an *F*-test to compare the self-reported health of parents who receive care from their sons with their daughters, and the result is reported at the end of the table. It confirms that the odds ratio of having poor health is statistically and significantly higher among parents who are cared for by their daughter(s) than those cared for by their son(s) ($p = 0.002$). The analysis shown in the second column restricts the sample to parents who only receive care from their sons or daughters. The odds ratio of having poor health for parents cared for only by their son(s) is 0.636 (0.439–0.919) times that of parents looked after only by their daughter(s).

TABLE 2 | Health status by care providers.

	Full sample	Care providers			
		Son	Daughter[a]	Both	Other
	N = 9,195	*N* = 2,470	*N* = 895	*N* = 849	*N* = 4,945
	M (SD)	*M* (SD)	*M* (SD)	*M* (SD)	*M* (SD)
Self-reported health					
1 poor	0.5275	0.5093	0.5799***	0.5253	0.5274
	(0.4993)	(0.5000)	(0.4939)	(0.4997)	(0.4993)
2 fair	0.3643	0.3664	0.3240*	0.3804	0.3678
	(0.4813)	(0.4819)	(0.4683)	(0.4858)	(0.4823)
3 good	0.0657	0.0826	0.0592*	0.0554	0.0603
	(0.2478)	(0.2753)	(0.2362)	(0.2288)	(0.2380)
4 great	0.0425	0.0417	0.0369	0.0389	0.0445
	(0.2017)	(0.1999)	(0.1886)	(0.1934)	(0.2062)
Chronic disease					
1 no chronic disease	0.2668	0.2569	0.2450	0.2534	0.2778
	(0.4423)	(0.4370)	(0.4303)	(0.4352)	(0.4480)
2 onset before	0.3518	0.3849	0.3314**	0.332	0.3424
	(0.4776)	(0.4867)	(0.4710)	(0.4713)	(0.4746)
3 new onset	0.3814	0.3581	0.4237***	0.4145	0.3797
	(0.4858)	(0.4796)	(0.4944)	(0.4929)	(0.4854)

[a]*We have conducted mean-comparison tests between the care provider groups of Son and Daughter.*
$^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

The Difference in Outcomes of Care Provided by Sons and Daughters by Region: Rural vs. Urban

We differentiate parents based on the regions in which they are living and compare the difference in the health outcome of care provided by daughters and sons between rural and urban areas, finding that this disparity mainly exists in rural areas (**Table 4**). In urban areas, there is no difference in the odds ratio of having poor health among parents who receive care from their children and those cared for by others. However, the parents cared for by their daughter(s) report a lower level of health status in rural areas (Column 2, OR 1.676, 95% CI 1.247–2.253). The difference in the odds ratio of having poor health among parents who receive care from daughters and from sons is statistically significant in rural areas ($p = 0.003$) but not in urban areas ($p = 0.195$). Consistently, Column 3 shows no significant difference in the health status of parents who receive care only from their daughter and those only from their son in urban areas (Column 3, OR = 0.877, 95% CI 0.454–1.693). The odds ratio of having poor health for parents cared for only by their son(s) is 0.620 (0.395–0.972) times that of people who receive care only from their daughter(s) in rural areas (Column 4).

The Difference in Outcomes of Care Provided by Sons and Daughters by Care Recipients: Mother vs. Father

Table 5 displays the results for mothers and fathers separately. Among fathers, there is no significant difference in the odds ratio of having poor health between those who receive care from children and those cared for by others (Column 1). Mothers looked after by others rather than children have a similar health status with those cared for by their son(s) (Column 2: OR = 0.960, 95% CI 0.782−1.178), while women cared for by their daughters(s) report a lower level of health status (Column 2: OR = 1.494, 95% CI 1.122−1.988). Focusing on the sample of people cared for only by sons or only by daughters, there is no difference in the health statuses between fathers who are looked after only by sons and by daughters (Column 3: OR = 0.502, 95% CI 0.242−1.042). However, the odds ratio for mothers cared for only by their son(s) is 0.644 (0.420−0.989) times that of those cared for only by their daughter(s).

The Difference in Outcomes of Care Provided by Sons and Daughters by Household Wealth

To investigate the moderating effect of wealth on the difference in health outcomes of care provided by sons and daughters, we differentiate participants based on their household wealth. We define participants whose wealth is in the top 25% of the distribution as wealthy parents, and the results are reported in **Table 6**. Care structure is not associated with wealthy parents' health: there is no difference in the odds ratio of having poor health among wealthy parents who receive care from their children and others (Column 1). Consistently, Column 3 shows that wealthy parents cared for only by their daughter have a similar health status with parents looked after solely by their son (0.290, 0.035–2.413). In contrast, less wealthy parents report a higher level of health status if they only receive care from their son (Column 4, OR = 0.681, 95% CI 0.471–0.985).

TABLE 3 | Random-effects logistic regression models for self-reported health and care provided by son and daughter.

	(1) Model 1	(2) Model 2
Male	1.0642 (0.9122–1.2416)	0.9145 (0.6471–1.2924)
Age	0.9977 (0.9894–1.0061)	0.9793* (0.9628–0.9962)
Marital status (ref. single or divorced)		
Married	1.1813 (0.8479–1.6458)	0.9095 (0.5081–1.6280)
Widowed	0.9430 (0.6514–1.3650)	1.0305 (0.5612–1.8923)
Primary education	1.3871*** (1.1814–1.6287)	1.0703 (0.7374–1.5535)
Household income	0.9663** (0.9427–0.9906)	0.9520 (0.9058–1.0005)
Working	0.4606*** (0.3556–0.5967)	0.9555 (0.4365–2.0917)
Number of sons	1.0472 (0.9737–1.1263)	1.1532 (0.9971–1.3338)
Number of daughters	1.0525 (0.9881–1.1211)	1.1247 (0.9953–1.2710)
Care structure (ref: CaredbyOther)		
CaredbyDaughter	1.4528** (1.1516–1.8326)	
CaredbySon	0.9854 (0.8389–1.1575)	
CaredbyBoth	1.0910 (0.8749–1.3605)	
Care structure (ref: OnlyDaughterCare)		
OnlySonCare		0.6356* (0.4394–0.9192)
Urban	0.7911** (0.6741–0.9284)	0.7313 (0.5222–1.0239)
Constant	0.9466 (0.4515–1.9844)	3.6458 (0.8219–16.1723)
Observations	9,159	1,694
Number of individuals	6,594	1,524
Wald chi2	162.88	45.25
AIC	12232	2323
p-value	0.0024	

We use a random-effects logistic model, and the odds ratios (ORs) are reported. The 95% confidence intervals are reported in parentheses. Year and province dummies are included in all models, but their coefficients are not reported for brevity. The P-value of F-test for the equality of coefficients on the 'CarebyDaughter' and 'CarebySon' is reported at the end of the table. See Appendix for the complete definitions of all variables.
$^*p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

Sensitivity Analysis

In addition to a dummy variable indicating overall poor health, we also use a category variable for self-reported health, and the incidences of chronic disease as additional measurements for health status. The results are displayed in the Appendix (**Supplementary Tables A2–A6**). The results consistently show that parents cared for by their son(s) have a higher odds ratio of having great health ($SRH\_CA = 4$) vs. the combined good ($SRH\_CA = 3$), fair ($SRH\_CA = 2$) and poor ($SRH\_CA = 1$) health and are less likely to have a new onset of chronic disease than those parents looked after by their daughters. The difference in health outcomes of care given by daughters and sons exists in rural areas for mothers and less wealthy parents.

DISCUSSION

The traditional eldercare system in China, where family members (and especially sons) are expected to look after their older parents, is challenged by low fertility rates and urbanization progress (46). In past decades, there has been an increasing number of parents receiving care from their daughters, triggered by the reduced availability of sons, women's empowerment, and modernization (2–4). We compared the health status of the parents who receive care from their daughters and their sons with nationally representative data.

Our results show that parents who receive eldercare from their son(s) report a higher level of self-reported health status than those cared for by their daughter(s), consistent with our first hypothesis. A pragmatic explanation might be the gender difference in the motivation and financial capability of providing eldercare. In a patrilineal society such as China, traditionally, all the family property will be divided solely among sons, and parents invest a larger amount in their son than their daughter. Sons are also expected to take care of their parents following the Confucian ethic of filial piety (26, 27). Therefore, sons have a stronger motivation to provide high-quality eldercare to their parents than daughters.

Along with social and economic changes, cultural necessities mandate the role that daughters typically play in the provision of eldercare for their natal parents (15, 17). In terms of a growing labor force participation, economic development increased women's empowerment and their subsequent household decision-making and financial capacity (47), which enable daughters to support their natal parents. However, the stratified gender differences in the social-economic status, income, and education, implies that sons can provide their parents with better food and healthcare service and products and more comfortable and convenient living arrangements, which improves their parents' health.

An alternative explanation concerns the influence of gendered expectations. In particular, parents with a strong prior son preference may report better health if they receive care from their son. We attempted to control for this factor through the inclusion of robustness tests where the diagnoses of new chronic diseases are applied as indicators of health outcomes. However, we also acknowledge that there may be a psycho-social element to these more objective variables. Older parents feeling less secure with daughter-care may experience stress leading to chronic disease, for example. Or they may perceive that their daughters are not able to physically support them and thus neglect to ask for assistance in moving around, leading to a worse wellbeing when daughters are the only carers.

TABLE 4 | Radom-effects logistic regression models for self-reported health and care provided by son and daughter: differentiating by region.

	Model 1		Model 2	
	(1) Urban	(2) Rural	(3) Urban	(4) Rural
Male	0.9736 (0.7442–1.2736)	1.1021 (0.9125–1.3310)	1.1129 (0.5713–2.1680)	0.8912 (0.5935–1.3382)
Age	0.9875 (0.9730–1.0022)	1.0017 (0.9914–1.0122)	0.9805 (0.9483–1.0138)	0.9801* (0.9606–1.0000)
Marital status (ref. single or divorced)				
Married	0.9650 (0.5212–1.7867)	1.2643 (0.8540–1.8718)	0.6428 (0.2166–1.9080)	1.0302 (0.5090–2.0849)
Widowed	0.7589 (0.3824–1.5062)	1.0057 (0.6488–1.5590)	0.6748 (0.2162–2.1062)	1.1679 (0.5596–2.4372)
Primary education	1.3133* (1.0033–1.7190)	1.3889** (1.1354–1.6991)	0.8481 (0.4486–1.6035)	1.1169 (0.6965–1.7912)
Household income	0.9828 (0.9434–1.0237)	0.9580** (0.9284–0.9885)	0.9836 (0.9075–1.0661)	0.9386 (0.8807–1.0002)
Working	0.3737*** (0.2411–0.5791)	0.5133*** (0.3706–0.7109)	0.8115 (0.2134–3.0865)	1.1045 (0.3957–3.0832)
Number of sons	0.9924 (0.8710–1.1307)	1.0729 (0.9815–1.1729)	0.9075 (0.6727–1.2243)	1.2131* (1.0184–1.4450)
Number of daughters	1.0101 (0.9022–1.1310)	1.0764 (0.9968–1.1624)	1.0357 (0.8207–1.3069)	1.1724* (1.0106–1.3601)
Care structure (ref: CaredbyOther)				
CaredbyDaughter	1.1510 (0.7851–1.6872)	1.6762*** (1.2473–2.2526)		
CaredbySon	0.8680 (0.6419–1.1738)	1.0411 (0.8594–1.2611)		
CaredbyBoth	1.3623 (0.9351–1.9847)	0.9806 (0.7455–1.2897)		
Care structure (ref: OnlyDaughterCare)				
OnlySonCare			0.8770 (0.4543–1.6931)	0.6196* (0.3950–0.9721)
Constant	2.6670 (0.6405–11.1048)	0.5837 (0.2391–1.4249)	1.5492 (0.0626–38.3305)	3.0146 (0.5304–17.1337)
Observations	2,897	6,262	557	1,134
Number of individuals	2,152	4,442	502	1,019
Wald chi2	71.89	113.42	18.27	33.06
AIC	3905.247	8358. 679	790.379	1563.392
p-value	0.1952	0.0030		

We use a random-effects logistic model, and the odds ratios (0Rs) are reported. The 95% confidence intervals are reported in parentheses. Year and province dummies are included in all models, but their coefficients are not reported for brevity. The P-values of F-tests for the equality of coefficients on the 'CarebyDaughter' and 'CarebySon' are reported at the end of the table.

$^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

The gender difference in the outcome of care provided by sons and daughters is greater in rural areas: our 2nd hypothesis was supported by the data. Indeed, the difference in the self-reported health outcome of care provided by sons and daughters was mainly exhibited by those living in rural areas. The One-Child Policy in China was more effective in urban areas, reducing both the availability of sons and also cultural son preference (48). In addition, the higher levels of education received by girls in urban settings have enabled them to increase their economic employment and thus the ability to provide care for their older parents (49). Higher education for both men and women also changes cultural norms and preferences and a greater acceptance by both of the necessity of daughters to provide care to their natal parents in the absence of sons (50). All of these factors enhance the daughter's incentive and capability to provide good eldercare to their parents in urban areas. However, many of these factors are not yet present in rural areas, so traditional cultural norms of behavior and expectations still exist.

Our third hypothesis was that the gender difference in the outcome of care provided by sons and daughters was expected to be stronger among mothers. This is also supported by the data as only mothers and not fathers experience this

TABLE 5 | Radom-effects logistic regression models for self-reported health and care provided by son and daughter: differentiating by gender.

	Model 1		Model 2	
	(1) Male	(2) Female	(3) Male	(4) Female
Age	0.9966 (0.9835–1.0100)	0.9981 (0.9873–1.0090)	0.9698 (0.9375–1.0032)	0.9829 (0.9640–1.0022)
Marital status (ref. single or divorced)				
Married	0.8942 (0.5023–1.5917)	1.2961 (0.8604–1.9523)	0.4906 (0.1784–1.3488)	1.2851 (0.6358–2.5977)
Widowed	0.6811 (0.3506–1.3230)	1.0514 (0.6675–1.6559)	0.5987 (0.2111–1.6976)	1.3853 (0.6667–2.8782)
Primary education	1.5337*** (1.2205–1.9274)	1.2612* (1.0059–1.5812)	1.3949 (0.7931–2.4534)	0.9074 (0.5632–1.4620)
Household income	0.9456** (0.9077–0.9851)	0.9817 (0.9511–1.0133)	0.9201 (0.8302–1.0199)	0.9731 (0.9195–1.0297)
Working	0.3480*** (0.2414–0.5019)	0.5621** (0.3901–0.8099)	0.5541 (0.1674–1.8339)	1.3191 (0.4957–3.5102)
Number of sons	0.9770 (0.8688–1.0986)	1.0895 (0.9923–1.1963)	1.0363 (0.8113–1.3237)	1.2170* (1.0213–1.4502)
Number of daughters	1.0467 (0.9499–1.1533)	1.0541 (0.9698–1.1457)	1.3065* (1.0239–1.6671)	1.0300 (0.8903–1.1916)
Care structure (ref: CaredbyOther)				
CaredbyDaughter	1.3853 (0.9162–2.0946)	1.4935** (1.1221–1.9880)		
CaredbySon	1.0032 (0.7693–1.3081)	0.9600 (0.7824–1.1779)		
CaredbyBoth	1.4225 (0.9668–2.0929)	0.9719 (0.7388–1.2787)		
Care structure (ref: OnlyDaughterCare)				
OnlySonCare			0.5023 (0.2422–1.0417)	0.6441* (0.4196–0.9887)
Urban	0.7756* (0.6049–0.9945)	0.8044* (0.6522–0.9921)	0.9099 (0.5099–1.6237)	0.6812 (0.4555–1.0186)
Constant	1.551 6 (0.4645–5.1825)	0.7902 (0.3036–2.0571)	11.9358 (0.4283–332.6507)	2.1821 (0.3962–12.0193)
Observations	3,340	5,819	423	1,270
Number of individuals	2,499	4,105	402	1,121
Wald chi2	98.45	97.28	11.91	37.55
AIC	4480.623	7782.467	610.048	1748.256
p-value	0.1593	0.0048		

We use a random-effects logistic model, and the odds ratios (0Rs) are reported. The 95% confidence intervals are reported in parentheses. Year and province dummies are included in all models, but their coefficients are not reported for brevity. The P-values of F-tests for the equality of coefficients on the 'CarebyDaughter' and 'CarebySon' are reported at the end of the table.

$^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

gender externality. Men are more likely to receive support and care from their spouse (51). The assistance given to men by female spouses will alleviate their dependency on their children, even in the case that the spouse is not the primary carer. Finally, we found that the differences in the health outcomes of care provided by daughters and sons were weaker amongst wealthy parents, Hypothesis 4. Wealthy parents could afford extra care to supplement the insufficient support offered by their children or other family members. They are also able to pay for high-quality healthcare services by themselves even if their children cannot provide it for them. A lower dependency on children contributes to a weaker gender difference in the health outcome of children's care amongst fathers and wealthy people.

Our results are inconsistent with some recent empirical studies which show daughter advantage in providing instrumental and emotional care (17–19), echoing Cong and Silverstein (23) and Liu and Harper (5). These differences are contributed to by divergent samples and various measurements for primary carer and outcomes. Three of the empirical studies analyzed the China Longitudinal Healthy Longevity Survey (CLHLS). Zhu (19) examined the older parents aged

TABLE 6 | Radom-effects logistic regression models for self-reported health and care provided by son and daughter: differentiating by wealth.

	Model 1		Model 2	
	(1)	(2)	(3)	(4)
	Wealthy	**Less wealthy**	**Wealthy**	**Less wealthy**
Male	1.0297 (0.7402–1.4325)	1.0446 (0.8802–1.2398)	2.5835 (0.4520–14.7680)	0.8210 (0.5722–1.1779)
Age	1.0106 (0.9938–1.0276)	0.9927 (0.9831–1.0024)	0.9596 (0.8861–1.0392)	0.9751** (0.9575–0.9930)
Marital status (ref. single or divorced)				
Married	0.6497 (0.2788–1.5143)	1.3374 (0.9326–1.9178)	0.4558 (0.0229–9.0787)	0.9341 (0.5229–1.6686)
Widowed	0.5109 (0.1998–1.3064)	1.1100 (0.7417–1.6610)	0.2689 (0.0100–7.1970)	1.1930 (0.6535–2.1778)
Primary education	1.4439* (1.0147–2.0546)	1.4311*** (1.1957–1.7129)	0.3025 (0.0413–2.2157)	1.2264 (0.8394–1.7919)
Household income	0.9424* (0.8932–0.9944)	0.9792 (0.9516–1.0076)	0.8215 (0.6312–1.0693)	0.9800 (0.9295–1.0331)
Working	0.3539*** (0.2010–0.6230)	0.5211*** (0.3872–0.7012)	0.0508 (0.0015–1.6731)	1.3173 (0.5745–3.0202)
Number of sons	0.9495 (0.8064–1.1180)	1.0754 (0.9920–1.1658)	1.0374 (0.5380–2.0003)	1.2274** (1.0522–1.4318)
Number of daughters	0.9405 (0.8203–1.0782)	1.0796* (1.0055–1.1591)	1.0907 (0.6192–1.9213)	1.1526* (1.0148–1.3092)
Care structure (ref: CaredbyOther)				
CaredbyDaughter	1.3965 (0.8464–2.3043)	1.4274** (1.1012–1.8504)		
CaredbySon	0.9275 (0.6345–1.3557)	1.0188 (0.8517–1.2188)		
CaredbyBoth	0.9345 (0.5545–1.5749)	1.1653 (0.9080–1.4953)		
Care structure (ref: OnlyDaughterCare)				
OnlySonCare			0.2897 (0.0348–2.4128)	0.6809* (0.4705–0.9853)
Urban	0.8907 (0.6367–1.2461)	0.8069* (0.6737–0.9663)	0.4626 (0.1000–2.1403)	0.8170 (0.5843–1.1425)
Constant	0.5996 (0.1149–3.1308)	1.2709 (0.5550–2.9105)	384.7024 (0.2765–535,247.4565)	5.9655* (1.2707–28.0061)
Observations	1,816	7,343	416	1,278
Number of individuals	1,626	5,400	403	1,168
Wald chi2	41.76	122.35	4.96	35.77
AIC	2487.810	9811.611	572.347	1769.196
p-value	0.1348	0.0189		

We use a random-effects logistic model, and the odds ratios (ORs) are reported. The 95% confidence intervals are reported in parentheses. Year and province dummies are included in all models, but their coefficients are not reported for brevity. The P-values of F-tests for the equality of coefficients on the 'CarebyDaughter' and 'CarebySon' are reported at the end of the table.

$^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

80 and over with the 2005–2011 waves of CLHLS, and Zeng et al. (17, 18) focused on the group aged 65 and over with 2002–2008 waves of CLHLS. It is very likely that the Family Plan Policy hadn't impacted those samples, and the average number of living children was 3.4 and 3.2 in urban and rural areas in Zhu (19) and 3.6 and 3.8 in Zeng et al. (18). The dataset asks the participant to report one primary carer, even though it is prevalent for multiple children to share caring responsibilities (52).

CHARLS, conversely, asked participants to report up to three primary carers if they receive regular care from multiple sources. **Figure 1** demonstrates that daughters usually care for their parents with their siblings. Of the 4,214 parents who receive care from their children, only 21.24% are cared for by daughters but not sons, 58.61% are looked after by their sons but not daughters, and the remaining are supported by both. Among those whose primary carers include a daughter but not a son, 44.02% of them do not have an alive son. Based on their

measurement of the carer, parents with a daughter as the primary carer are very likely to receive support from their sons as well. Their method largely underestimates the contributions made by the son.

Our study suffers from the following limitations. The primary measurement of health outcome in the study is self-reported health status, which could involve measurement error and be influenced by the respondent's mood or other factors during the interview. Future research could use other better measurements of health, such as biomarkers. There may also exist endogeneity between health status and care structure (e.g., preference of the primary carers). Therefore, our results cannot be interpreted as causal. However, we can use the association between health status and care structure to identify the people who are suffering from health inequality. When the data becomes available, it would be interesting to investigate the main mechanism behind the gender differences in health outcomes of care provided by children: gender difference in the motivation of providing care or the gender disparity in financial capability or gender expectations; and its heterogeneity among regions and cohorts.

Despite these limitations, our study contributes to the understanding of intergenerational support and health inequalities associated with the care system in China, with the following implications. As China modernizes, higher education for females will become more widespread, and women become more economically independent; their structural ability to provide high-quality care and the cultural acceptance of this care will increase. This is already the case in most urban areas of China, where higher education for both men and women has already changed cultural norms and preferences around daughter care. As these drivers spread to rural areas, so we would expect to see a great ability and acceptability of daughter care within all families. In order to support this transition in rural areas, our finding suggests that reducing dependency on children via seeking supplementary or substitution of care given by children may reduce this inequality.

Given the rapid aging speed in China, the accessibility of good quality of care is of great concern (53, 54). It becomes challenging for the only child to be the primary carer for their parents and parents-in-law (55). The current (formal) long-term care system in China is characterized by a growing provision of residential care with a decreasing bed occupancy rate, a low availability of home and community-based services and a lack of quality regulations and funding (33). One policy recommendation of our study is for governments to enhance the infrastructures for care services and promote the innovations of care products, for instance, care homes, nursing homes, and day-care centers, creating more choices for older parents to arrange their care. Our findings with respect to regional inequality encourage further policy attention and resource allocation, especially in rural areas.

Guiding older adults to arrange their care in order to help them understand the advantages of outsourcing care services is also important. It is still common in China for older adults to be reluctant to live in nursing homes, as they view it as stigma against the cultural norm (55). Actions are required to enhance the social acceptability of outsourced care products and services and encourage older adults to voluntarily seek the substitution of the care provided by their children. To increase older adults' independence, it remains crucial to improve their financial capability, which could be done through a reliable and comprehensive pension system.

Responding to population aging with a low fertility rate in China, the central government has gradually relaxed the Family Plan Policy since the 6th national population census in 2010 (56). At the time of writing, each couple is allowed to have up to three children (from May 2021 to date). It has already been argued that relaxing the Family Plan Policy alone has done little to improve the fertility rate, which appears due to a variety of complex interactions including new norms of child bearing, the high costs of rearing a child and the responsibility of eldercare (57). Therefore, developing the long-term care system may alleviate the family burden of adults of reproductive age and, in return, encourage them to have more children. However, it is worth noting that if the measure boosts fertility in the short term, the demand for childcare will further reduce the availability of family care for older adults within the currently underdeveloped long-term care and childcare system.

Collaboration across governments, the third sector, public bodies and the broader general public is needed to reduce health inequality among older adults as China transitions through economic development.

DATA AVAILABILITY STATEMENT

The original CHARLS survey data is publicly available (http://charls.pku.edu.cn/index/en.html).

AUTHOR CONTRIBUTIONS

SH planned the study, supervised the data analysis, and co-wrote the paper. YZ designed and undertook the statistical analyses and co-wrote the paper. Both authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2021.793873/full#supplementary-material

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Negative Life Events, Social Ties, and Depressive Symptoms for Older Adults in China

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Although it is widely acknowledged that older adults who have gone through negative life events are more likely to develop depression, there is limited evidence on whether and which type of social ties moderate this perceived relationship. Based on 2016 and 2018 waves of Chinese Longitudinal Aging Social Survey (4,466 individuals, 8,932 observations), we apply linear fixed effects models and confirm that negative life events are associated with depressive symptoms for older adults (Coef. = 0.35; 95% CIs 0.11–0.61), and social ties are negatively associated with depression (Coef. = −0.08; 95% CIs −0.10 to −0.07). Our study further suggests that the association between negative life events and depressive symptoms is significantly moderated by friendship ties (Coef. = −0.18, 95% CIs −0.30 to −0.07), rather than family ties (Coef. = −0.03, 95% CIs −0.09 to 0.15). Moreover, the buffering effects of friendship ties are more prominent for the less resilient and less privileged groups, namely male, rural, and less educated older adults. Our findings point to the importance of expanding and strengthening social networks for Chinese older adults in promoting their psychological health.

Keywords: negative life events, social ties, depressive symptoms, older adults, China

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INTRODUCTION

World Health Organization (WHO) names depression among older adults as a key global public health concern (1), which leads to heightened disease burden, poor life quality, and high risk of suicide (2, 3). Unipolar depression or major depressive disorder, characterized by a persistent feeling of sadness or a lack of interest in outside stimuli, affected about 7% of the older adults worldwide in 2017 (1). In China, the age-standardized prevalence rate of depression saw a modest decline from 1990 to 2017 according to the Global Burden of Disease Study, that was as opposed to the global trend. However, it is noteworthy that the prevalence rate of depression for older adults aged over 55 years showed a clear upward trend over the same period and was much higher than that for younger adults (4), which was quite consistent with the global pattern. Another study based on the nationally representative survey in China revealed that 37.4 and 6.6% of older adults aged 61–75 reported depressive symptoms and severe depression, respectively, and the corresponding rates for those aged 75+ were even higher, at 40 and 9.7% in 2012 (5). Against the backdrop of accelerated aging process in China, depression has placed great strains on China's health care system and old-age support.

At present, the pathogenesis of depression has not been clearly identified, with genetic, socioeconomic, environmental, and behavioral factors potentially acting jointly (6–8). Among

these factors, stress is acknowledged as an important risk factor for depression (9, 10). Negative life events, such as death of family members, severe illness, relationship crisis, and financial problems, pose tremendous stresses on older adults. A large amount of existing studies have demonstrated that experiencing negative life events are often associated with elevated risk of depression or increased depression severity for older adults in Western (11–13) and Asian contexts (14–16), and the magnitude of effects could vary by different types of life events and across various groups of population (13, 17). However, less attention has been paid to how to buffer the deteriorating impacts of negative life events (12, 18, 19). Social support, as a key coping resource, has been documented to improve an individual's resilience and adaptability, and thus contribute to maintaining mental health in psychological research (20). Therefore, it is essential to incorporate social support to examine its moderating impact on the relationship between adverse life events and depression for older adults.

Social support is normally obtained from interpersonal relationships, both within and outside family. In the context of China and other East Asian societies with strong family network, older adults traditionally resort to family members for assistance and comfort in case of difficulties (21, 22). However, along with radical social transformation and massive migration, China has seen prominent family changes in recent decades, such as decline in average household size from 3.1 persons in 2010 to 2.6 persons in 2020, and large increase in one-person and one-generation households at old ages (23, 24). In this circumstance, support from outside household gets increasingly important and critical. The relative importance of family support and friend support in moderating the adverse impacts of negative life events needs to be further explored.

In this paper, based on the biennial panel data from 2016 and 2018 waves of Chinese Longitudinal Aging Social Survey (CLASS), a nationally representative elderly survey, we examine the association between negative life events and depressive symptoms for older adults, and more importantly, differentiate the moderating roles of family ties and friendship ties in the perceived association.

LITERATURE REVIEW

Negative Life Events and Depression

The stress process model provides a guiding framework for understanding the association between negative life events and depression. Based on stress process model, stressors that appear either in the form of disruptive life events or the more persistent hardships are related both to people's social and economic status and then to their health (25). Moreover, exposure to one stressor, regardless of whether it is an event or more chronic hardship, may lead over time to exposure to other, secondary, stressors, a process named as stress proliferation (26). Stress proliferation can result in people's lives becoming mired in clusters of stressors, some of which may contribute to cumulative adversity (27). Indeed, negative life events, such as family upheavals, illness, and injury, have been the focus of aging studies in the past decades because older adults often experience them at an elevated level and face heightened risk of stress proliferation. As such, negative life events has been considered as one of the most important stressors of depression for older adults (12, 28).

A large body of empirical studies have demonstrated that experiencing negative life events are associated with elevated risk of depression at old ages. For example, studies have repeatedly shown that family bereavement is closely related to depression at later life (22, 29–32). Some other studies have also found a positive relationship between depression and other negative events such as incidence of severe illness (11), relationship crisis and financial/work problem (33), or the total number of negative life events (15, 34, 35). In 2002, a meta-analysis of 25 studies about negative life events and depression in 1980s and 1990s concluded that both the specific types of negative life events and total number of events is related to depression at a modest level ($r = 0.15$) for older adults (12). Another meta-analysis about 13 qualitative studies of depression in older ages also list negative life events as important risk factors of depression for older adults (36).

Similar results have been reported in Chinese context. One cross-sectional study with 385 community-dwelling older Chinse adults aged above 60 living in Singapore found that increased number of negative life events significantly increased older adults' depressive symptoms (16). Another two longitudinal studies in Hongkong about older adults aged 70 or above (260 older adults, 1992–1995) (14) and community-dwelling Chinese elderly aged 65 or above (2,630 older adults, 2001–2003) (17) also indicated that experiencing one or multiple events significantly increased the risk of depression for older adults.

In summary, a large amount of studies have demonstrated that negative life events are important risk factors of depression for older adults both in Western and Chinese context. However, less attention has been paid to whether and which type of social ties could moderate this perceived association.

The Buffering Effect of Social Ties: Family Ties vs. Friendship Ties

Social support is beneficial for mental health because it leads to "regular positive experience" and "a sense of predictability and stability in one's life situation, and a recognition of self-worth [(37), p. 311]." Moreover, social support has been documented as a key coping resource to buffer stresses from negative life events (20), but less is known about the structure or context of such support. It is essential to highlight the "contextual nature of social relation" in understanding the role of social support [(38), p. 84]. Social convoy model provides a theoretical framework to understand the dynamic contexts of social support for older adults. Based on social convoy model, individuals are "surrounded by supportive others who move with them throughout the life course" [(38), p. 84]. As for this study, social convoy model indicates that older adults are surrounded by social ties with dynamic function and of different types.

In East Asian context, with persistent Confucian culture, adult children have always been seen as the most important source of support for older adults (21, 22). Traditional family demographers have overwhelmingly emphasized the importance

of family ties (12, 35) and empirical studies also found that living with an adult child could lower older adults depressive symptoms both in China and other East Asian countries like South Korea (39, 40). Some studies also argued that family ties can promote health only if the family relationship is harmonious (41, 42).

However, in recent years, the traditional multi-generational living arrangement among older adults has been declining in China (43). In this context, more and more studies turned to emphasize the importance of social ties outside the household (e.g., support from relatives or friends) (44). Friendship ties have been shown to be positively associated with older adult's happiness (45, 46), emotional well-being (47), self-esteem (48), and lowered suicide attempt (49). In Mainland China, it was also found that strong friendship ties is associated with lower depressive symptoms for rural older adults living alone (44).

Although existing literature highlights the importance of family and friendship ties, they put more attention to their direct effects on mental health and less to how they moderate the association between stressful life events and depression. The only exception is the a study by Chou and Chi (15), which showed that the family network, friendship networks, and confident relationships could ameliorate the deleterious effect of negative life events based on a cross-sectional sample of 411 older adults aged 60+ in Hongkong. To the best of our knowledge, there is no study in Mainland China yet. Moreover, the study by Chou and Chi (15) did not compare the relative moderating roles of family networks and friendship networks. The differential buffering effects of family ties and friendship ties needs more rigorous examination.

Subgroup Differences in Social Ties' Buffering Effect

The meaning to and significance of social ties for different groups may be considerably different, and therefore, the buffering effects of social ties could vary by gender and socioeconomic status. For instance, studies suggest that the depressive symptoms among older adult is a little bit higher for women than men (50, 51), but male and female older adults use different coping strategies when facing stressful life events (52). Women are known as kin-keeper in the family (53) and have a wider and stronger social ties than men (54). In copying with negative life events in later life, women are more resilient (12), and on the contrary, men are more vulnerable in many situation.

Rural-urban differences have also been noted in China context (55). Numerous studies have examined the China's rural-urban divide in state policy, social and economic structure, health, and access to resources (43, 56–59). Rural older adults have higher depressive symptoms than those in urban area (55). But at the same time, rural older adults have less access to social security resources, which leads to more reliance on family and friend support in copying with stress (60). For example, one study in China found that the negative effect of disadvantaged living arrangement (e.g., living alone or living only with children) could be largely reduced by family and friendship ties in rural China, but this effect is less salient in urban China (44). The same logic can be applied to the educational difference in China. People with lower education often have higher level of depression (50, 51), but they are eligible to lower level of social security and have less access to coping resources (61), which make the less educated rely more on social ties when experiencing negative life events.

RESEARCH HYPOTHESIS

This paper focuses on the resilience of the older adults in China when experiencing negative life events and examines how social ties (including family ties and friendship ties) buffer the impacts of negative life events. Existing literature has documented that negative life events are important risk factors of depression in the later life (12). Therefore, we expect that experiencing negative life events would be detrimental to older adults' subjective well-being. In addition, we also expect that social ties (both family and friendship ties) are beneficial to older adults' subjective well-being.

Hypothesis 1: Experiencing negative life events will increase older adults' depressive symptoms.

Hypothesis 2: Social ties (including family ties and friendship ties) are negatively associated with older adults' depressive symptoms.

Based on the convoy model of social relations (38), we expect that social ties could buffer the association between negative life events and older adults' depressive symptoms:

Hypothesis 3: Older adults with stronger social ties have lower depressive symptoms than those with weaker social ties when experiencing negative life events.

In terms of the buffering effect of social ties, we will distinguish between the family ties and friendship ties. Previous studies have shown that family ties and friendship ties differ in the structure, quality, and function of relationship (44). But less is known about their relative importance in the contexts of negative life events for older adults in China. We expect that the buffering effect of family ties and friendship ties on the negative life events are different.

Hypothesis 4a: family ties play stronger roles in moderating the association between negative life events and depression than friendship ties.

Hypothesis 4b: friendship ties play stronger roles in moderating the association between negative life events and depression than family ties.

In addition, we also hypothesize the extent to which these ties ameliorate the perceived association differ across subpopulations. In general, we expect that the vulnerable and disadvantaged group benefits more from social ties. Considering older women are more resilient when facing negative life events, we expect that social ties may protect males more than females. We also expect social ties serve as more important protective barriers to the consequences of disruptive life events for rural and less educated older adults because they have less generous social security benefits and other coping repertoires.

Hypothesis 5a: The buffering effect of social ties on negative life events is stronger for the male than the female.

Hypothesis 5b: The buffering effect of social ties on negative life events is stronger for older adults in rural area than those in urban area.

Hypothesis 5c: The buffering effect of social ties on negative life events is stronger for less educated older adults than the better-educated.

DATA AND METHOD

Data

In this study, we use data from Chinese Longitudinal Aging Social Survey (CLASS) collected by the Institute of Aging Studies, Renmin University of China. The survey has been conducted for three waves in 2014, 2016, and 2018, respectively. It is a nationally representative survey of older adults in China, covering 28 provinces, 134 counties, and 462 villages/neighborhoods in China (with 34 provinces and around 2,800 counties in total). The survey uses a multi-stage stratified probability sampling method, with county as the primary sampling unit and village/neighborhood as the secondary. Within each village or neighborhood, a random sample of the households is selected, and within each household, one older adult aged 60 and over is randomly selected as the survey respondent. It collects information on their demographic and socioeconomic characteristics, access to health and services, pension/retirement planning, cognitive abilities, and attitudes toward aging.

In this study, we use the biennial panel data of 2016 and 2018 waves of CLASS, as the definition of cognitive impairment (which is used to check if the respondent is suited for answering questions regarding depressive symptoms) has been changed since 2016[1]. The 2016 wave interviewed 11,471 older adults. Among them, 9,642 respondents (84% of the total) were traced in 2018 wave, while the rest either died or lost to follow up. We only keep the participants who joined both waves and get a sample size of 19,284 person-year observations. In these two waves, each respondent needed to answer eight cognition-related questions and only those who answered five or more questions correctly would proceed to answer questions regarding depressive symptoms and attitudes. Otherwise, the respondents were regarded as cognitively impaired and not suited to answer questions regarding depressive symptoms. As a result, 8,170 person-year observations (42.37%) were excluded, and our sample reduced to 11,114 person-year observations (5,557 persons). We also drop the respondents with missing values in either wave (2,182 person-year observations, 11.3%), and most (84%) of the missing is due to missing values on our dependent variable, depressive symptom[2]. Missing data has been a common challenge in health surveys that use self-report instruments. For instance, among the 1,931 surgical patients surveyed in Canada, 351 (account for 18.2% of the total) did not fully complete the self-rated depression scale (62). The final sample size is 8,932 person-year observations (4,466 persons). We acknowledge that a missing rate of 11.3% is relatively high. But previous studies about depressive symptoms using CLASS data have shown similar (44) or even higher missing rate (63, 64), and their results were reasonable.

Measurement

Depressive Symptoms

Depressive symptoms were measured by using the Center for Epidemiologic Studies Depression (CES-D) scale (65). The scale involves the frequency of 9 items of symptoms which older adults have experienced in the past week: three items measuring feelings of positive affect (feeling happy, enjoying life, feeling pleasure), two items measuring feelings of negative affect (feeling lonely, feeling upset), two items measuring feelings of marginalization (feeling useless, having nothing to do), two items measured somatic symptoms having poor appetite, having trouble sleeping. The nine-item CES-D scale has been validated and widely used in assessing Chinese older adults' mental disorder (64, 66, 67). We code the frequency with which the response had experienced each symptom in the past week as 0 (rarely or never), 1 (sometimes), 2 (often). The 9 items were summed up and a depression symptom score was created, ranging from 0 to 18, with a higher score indicating more depressive symptoms.

Negative Life Events

It is a binary variable and is coded as 1 if the older adults experienced any of the following 9 items of negative experiences in the previous 12 months: (1) serious illnesses; (2) natural calamities; (3) death of spouse; (4) death of child/children; (5) death of other relatives or close friends; (6) serious financial loss; (7) serious illnesses of family members; (8) experiencing problems in a relationship with family members, relatives, or close friends; (9) experiencing accidents. It's to be noted that we also used different formats of coding of negative life events (e.g., the number of negative life events, or a 3 categorical variable of negative life events), and the results are consistent (results not shown)[3].

Social Ties

The Lubben Social Network Scale (LSNS) (68) is used in this paper to measure social ties for older adults. LSNS has been widely used in studies about social support for older adults in China (35, 44, 69). The scale is constructed from a set of three questions evaluating *family ties* and a comparable three questions for *friendship ties* (1) "How many relatives (including family members)/friends do you see or hear at least once a month?," (2)

[1]In 2014 wave of CLASS, they use five cognition-related questions and only those answered at least three questions correctly were invited to finish the mental health and attitudes questions, but since 2016 three more questions were added and those who answered at least 5 questions correctly were able to participate in the mental health and attitudes questions.

[2]1106 person-year observations were missing in the CES-D, and another 728 person-year observations were dropped in Fixed-effects model because only one wave of the data has record in CES-D.

[3]For example, we use the number of negative life events (range from 0 to 4) as the key independent variable and the result shows that one more negative life events will lead to 0.265 points of increase in CES-D score ($p = 0.010$); compared with those did not experience negative life events, those who experience one event will have 0.338 points higher CES-D score, and those who experienced multiple ($\geq$2) events will be 0.419 points higher. But considering that the sample size of those who experienced multiple events is quite small (only about 1.87% of the sample), we use the binary negative life events in our following analysis.

"How many relatives (including family members)/friends do you feel at ease with to talk about private matters?," and (3) "How many relatives (including family members)/friends do you feel close to such that you could call on them for help?." Response options range from none, one, two, three to four, five to eight, nine or more. We coded each item as 0 (none), 1 (one), 2 (two), 3 (three to four), 4 (five to eight), or 5 (nine or more). The three items were summed into a scale ranging from 0 to 15 for family ties and friendship ties, separately. Then the score of social ties, the sum of family and friendship ties, ranges from 0 to 30.

Demographic Variables

We also control the following demographic variables in the analyses, including age, age squared, marital status (currently married or not), presence of grandchild, coresidence with adult children, self-reported health (range from 1 to 5, the higher score, the better health), number of chronic diseases (range from 0 to 24, which is measured by a list of 24 kinds of chronic conditions such as hypertension, cardiovascular diseases, diabetes, etc.) and index of functional limitations (range from 0 to 30, which is measured by how well the respondents could conduct 15 activities, such as dressing, eating, bathing, using the toilet, doing housework, etc.; the higher, the worse).

Analytical Strategy

We use the linear fixed effects regression model to conduct analyses. Let y_{it} denotes the CES-D score for individual i in year t (i = 1,2…N; t = 1,2).

$$y_{it} = X_{it}\beta + u_i + \varepsilon_{it}, \;\; i = 1, 2, 3 \ldots N; t = 1, 2 \qquad (1)$$

Where X_{it} are the time variant variables including negative life events and social ties (the social ties, family ties, and friendship ties are included in the model as continuous variables), and control variables for individual i in year t. u_i is the unobserved time-invariant effects which represents the individual heterogeneity, ε_{it} is the idiosyncratic errors which varies by individual and time.

Fixed effects model could correct for the endogeneity bias using the within transformation to eliminate time-invariant unobservable characteristics (70). For instance, in this circumstance, older adult's early life experiences might jointly influence the risk of negative life events and depression at old ages. however, fixed effects model limits our analysis only to time variant variables in the analysis. All time-invariant variables like gender and education would be removed in the demeaning process and are thus not included as control variables.

Using the fixed effects model, we first examine the relationship between negative life events and depressive symptoms controlling for all of the covariates mentioned above. We then include social ties as the key moderating variables, and differentiate the impact of family ties and friendship ties. lastly, we will also examine subsample differences by gender, rural/urban and education level attainment.

RESULTS

Sample Description

Descriptive statistics of key variables for the whole sample and for three groups of subsamples are presented in **Table 1**. Depressive symptom as measured by CES-D score in the full sample is 6.98 on average. Female older adults suffer more severe depressive symptoms than male counterparts. There are also rural-urban and educational disparities in depressive symptoms, with rural older adults and those with less than secondary education having higher CES-D score.

Overall, 14.7% of older adults have experienced at least one negative life event during the previous 12 months. Among the nine items, the three adverse life events the older adults are most likely to go through are death of other relatives or close friends, serious illnesses, and serious financial loss[4]. Female, rural, and the less educated older adults have slightly higher exposure to negative life events than male, urban, and the better-educated older adults, respectively.

The average score of social ties is 14.5, and the strength of family ties is slightly stronger than the strength of friendship ties. The score of social ties is almost identical for males and females. Older adults living in rural area and having less than secondary education have weaker family ties and friendship ties than those living in urban area and having at least secondary education.

The average age of the older adults in our sample is about 69 years old, which is almost identical among all subgroups. 77% of older adults are currently married, 29.7% of them coreside with adult children, and 27% have grandchild presented in household, with these proportions varying a little among three groups of subsamples. The female, rural, and less educated older adults have worse health with higher number of chronic diseases and functional limitations.

Association Between Negative Life Events, Social Ties, and Depressive Symptoms

We examine the association between negative life events and depressive symptoms and address the moderating role of social ties on this perceived association. As shown in Model 1a in **Table 2**, after controlling for all the covariates, the CES-D score of those who have experienced at least one negative life events in the past 12 months is 0.350 higher than those who did not experience negative life events ($p = 0.005$). Moreover, the CES-D score decreases by 0.436 points with one standard deviation of increase in the score of social ties ($p < 0.001$), which means social ties are negatively associated with the severity of depression. These results are supportive of hypothesis 1 and 2.

In Model 1b, we add the interaction term of negative life events and social ties. We find that the deleterious effect of exposure to negative life events is significantly moderated by older adults' social ties (Coef. $= -0.081$, $p < 0.001$), which confirms hypothesis 3. To show the buffering effect of social ties more clearly, we present the predicted depressive symptoms by

[4]Due to space limitation, we do not present the detailed summary statistics of these nine negative life events.

TABLE 1 | Descriptive statistics in total and subsamples, CLASS 2016 and 2018.

Variable	Total	Male	Female	Rural	Urban	Less than Secondary	Secondary and above
Dependent Variable							
CESD (range from 0 to 18)	6.98	6.93	7.04	7.20	6.80	7.11	6.80
	[2.91]	[2.87]	[2.95]	[2.78]	[2.99]	[2.82]	[3.01]
Key independent variables							
Negative life events	0.15	0.14	0.15	0.16	0.14	0.15	0.14
	[0.35]	[0.35]	[0.36]	[0.36]	[0.35]	[0.36]	[0.35]
Social Ties (0–30)	14.50	14.50	14.49	14.42	14.56	14.21	14.89
	[5.25]	[5.39]	[5.08]	[5.45]	[5.07]	[5.29]	[5.15]
Family ties (0–15)	7.63	7.62	7.63	7.60	7.64	7.50	7.80
	[2.69]	[2.78]	[2.60]	[2.80]	[2.60]	[2.74]	[2.62]
Friendship ties (0–15)	6.87	6.88	6.87	6.81	6.92	6.71	7.10
	[3.06]	[3.13]	[2.98]	[3.16]	[2.98]	[3.09]	[3.01]
Covariates							
Age	69.16	69.23	69.08	68.69	69.54	69.94	68.08
	[6.56]	[6.43]	[6.71]	[6.17]	[6.85]	[6.63]	[6.32]
Married (%)	0.77	0.86	0.67	0.77	0.77	0.73	0.83
	[0.42]	[0.35]	[0.47]	[0.42]	[0.42]	[0.45]	[0.37]
Presence of grandchild (%)	0.28	0.26	0.30	0.33	0.24	0.30	0.25
	[0.45]	[0.44]	[0.46]	[0.47]	[0.43]	[0.46]	[0.43]
Number of chronic diseases (0–24)	1.30	1.20	1.41	1.32	1.28	1.34	1.24
	[1.47]	[1.42]	[1.52]	[1.45]	[1.49]	[1.51]	[1.42]
Index of functional limitations (0–30)	0.82	0.68	0.97	0.86	0.79	0.92	0.67
	[2.31]	[2.14]	[2.49]	[2.42]	[2.23]	[2.40]	[2.18]
Self-reported health [1–5]	3.44	3.50	3.38	3.37	3.50	3.36	3.56
	[0.88]	[0.87]	[0.89]	[0.91]	[0.85]	[0.90]	[0.84]
Coresidence (%)	0.30	0.28	0.32	0.33	0.27	0.31	0.28
	[0.46]	[0.45]	[0.47]	[0.47]	[0.44]	[0.46]	[0.45]
Person-year observations	8,932	4,732	4,200	3,997	4,935	5,182	3,750

The mean values (or percentage) are presented, with standard deviation in the parentheses.

social ties and negative life events in **Figure 1**, which delivers three key information. First, the increase in the strength of social ties is associated with reduced depressive symptoms (the slope is negative either for dotted or solid lines). Second, the negative association between social ties and depression is stronger for those exposed to negative life events than for those who did not (the slope of dotted line is steeper than the slope of solid line). Third, when the social ties are weak, older adults who have experienced negative life events show more severe depressive symptoms than those who did not (a CES-D score of 9 vs. 8 when social ties score is 0). But when social ties get stronger, the gap in depressive symptoms becomes smaller, and is closed when the social ties score is around 20.

The results from Model 1a and Model 1b indicate that social ties not only directly relate to lower depression severity, but also effectively moderate the shock from negative life events. But this does not tell us which type of social ties matters more. In model 2a and 2b, we distinguish the social ties into family ties and friendship ties to examine their differential impacts. In model 2a, both family ties and friendship ties are significantly related to lowered depression severity for older adults, and this association is stronger for family ties (coef. $= -0.093$, $p < 0.001$) than that of friendship ties (coef. $= -0.075$, $p < 0.001$). In model 2b, we further add the interaction terms of negative life events with family ties and friendship ties, separately. It turns out that only friendship ties could effectively moderate the deleterious health consequences of negative life events (coef. $= -0.186$, $p < 0.001$). This difference is clearly presented with the predicted depressive symptoms in **Figure 2**. In the left panel, regardless of the strength of family ties, the depressive symptom score for older adults exposed to negative life events is consistently higher than those who do not (the slopes of two lines are similar). But in the right panel of the graph, the gap in depressive symptoms between the groups with and without exposure to negative life events converges when friendship ties become stronger. These findings confirm hypothesis 4b which argues for the stronger moderating roles of friendship than family ties.

The covariates in the models behave in expected directions. For example, depressive symptoms increase by age. Older adults who are currently married, have less chronic diseases

TABLE 2 | The fixed effect models predicting depressive symptoms of chinese older adults, total sample, CLASS 2016 and 2018, $N = 8,932$.

	Model 1a	Model 1b	Model 2a	Model 2b
Neg. life events (yes = 1)	0.350***	1.598***	0.348***	1.482***
	[0.126]	[0.376]	[0.126]	[0.381]
Social ties (0–30)	−0.083***	−0.070***		
	[0.009]	[0.010]		
Neg. life events*Social ties		−0.081***		
		[0.023]		
Family ties (0–15)			−0.093***	−0.091***
			[0.023]	[0.025]
Friendship ties (0–15)			−0.075***	−0.052**
			[0.021]	[0.022]
Neg. life events*Family ties				0.028
				[0.063]
Neg. life events*Friendship ties				−0.186***
				[0.060]
Age	0.842***	0.814***	0.846***	0.815***
	[0.262]	[0.262]	[0.262]	[0.262]
Age–squared	0.001	0.001	0.001	0.001
	[0.002]	[0.002]	[0.002]	[0.002]
Married	−0.909***	−0.890***	−0.906***	−0.887***
	[0.329]	[0.329]	[0.329]	[0.329]
Presence of grandchild	−0.426***	−0.419***	−0.423***	−0.422***
	[0.141]	[0.140]	[0.141]	[0.141]
Number of chronic diseases	0.162***	0.154***	0.163***	0.155***
	[0.034]	[0.034]	[0.034]	[0.034]
Index of functional limitations	0.028	0.031	0.028	0.032
	[0.023]	[0.023]	[0.023]	[0.023]
Self-reported health (1–3, 5, 6)	−0.428***	−0.440***	−0.429***	−0.443***
	[0.059]	[0.060]	[0.060]	[0.060]
Coresidence	−0.286**	−0.290**	−0.284**	−0.292**
	[0.125]	[0.125]	[0.125]	[0.125]
Constant	−51.525***	−50.680***	−51.659***	−50.621***
	[9.151]	[9.142]	[9.157]	[9.146]
Person	4,466	4,466	4,466	4,466
N (Person–observation)	8,932	8,932	8,932	8,932

Note: The coefficient values included in the models are presented, standard errors in parentheses.
$^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.10$ (two–tailed tests).

and functional limitations, and report better health, have a lower score of depressive symptoms. Coresidence with an adult child and presence of grandchildren can lower the depressive symptoms.

Now we move to examine whether the buffering effect of social ties (family ties and friendship ties) differs by gender and socioeconomic status of the older adults. To do so, we split our data into three groups of subsamples: male vs. female, rural vs. urban, and less than secondary education vs. secondary education and above. We focus on the interaction effects of family/friendship ties with negative life events. As is shown in **Table 3**, for the total sample and each subsample, the association between negative life events and depressive symptoms is significantly moderated by friendship ties, rather than family ties, which further validates hypothesis 4b. More importantly, the moderating effect of friendship ties is stronger for male, rural, and less educated older adults. In other words, the coefficient of the interaction term of negative life events and friendship ties is significantly negative for male, rural and less-educated subsamples, but remains insignificant for female, urban and better educated subsamples. This finding confirms our hypothesis 5a, 5b, and 5c, which means friendship ties play a more important role in moderating the association between disruptive life events and depression for less resilient and disadvantaged groups who have less alternative coping resources.

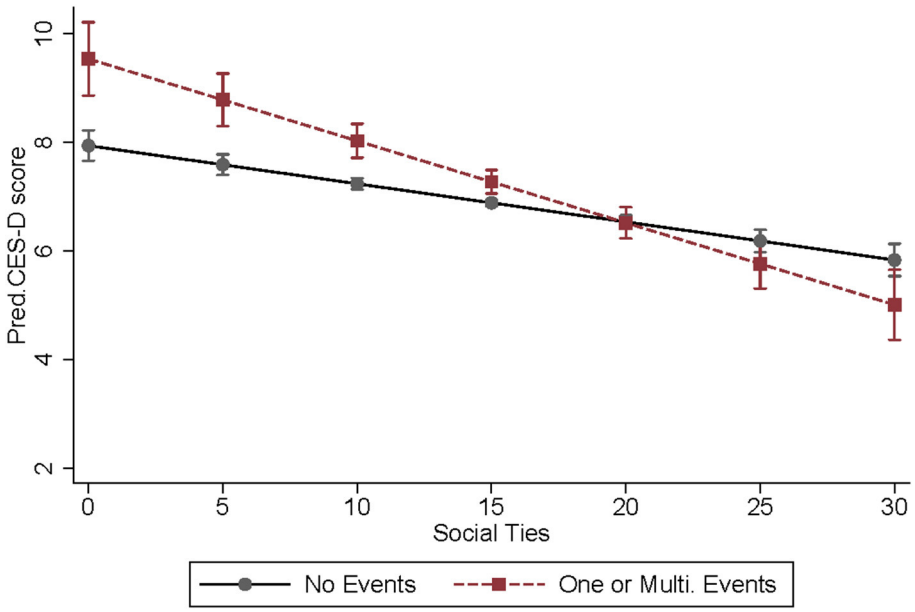

FIGURE 1 | Predicted depressive symptoms by social ties and negative life events (with 95% confidence intervals), CLASS 2016–2016, $N = 8,932$.

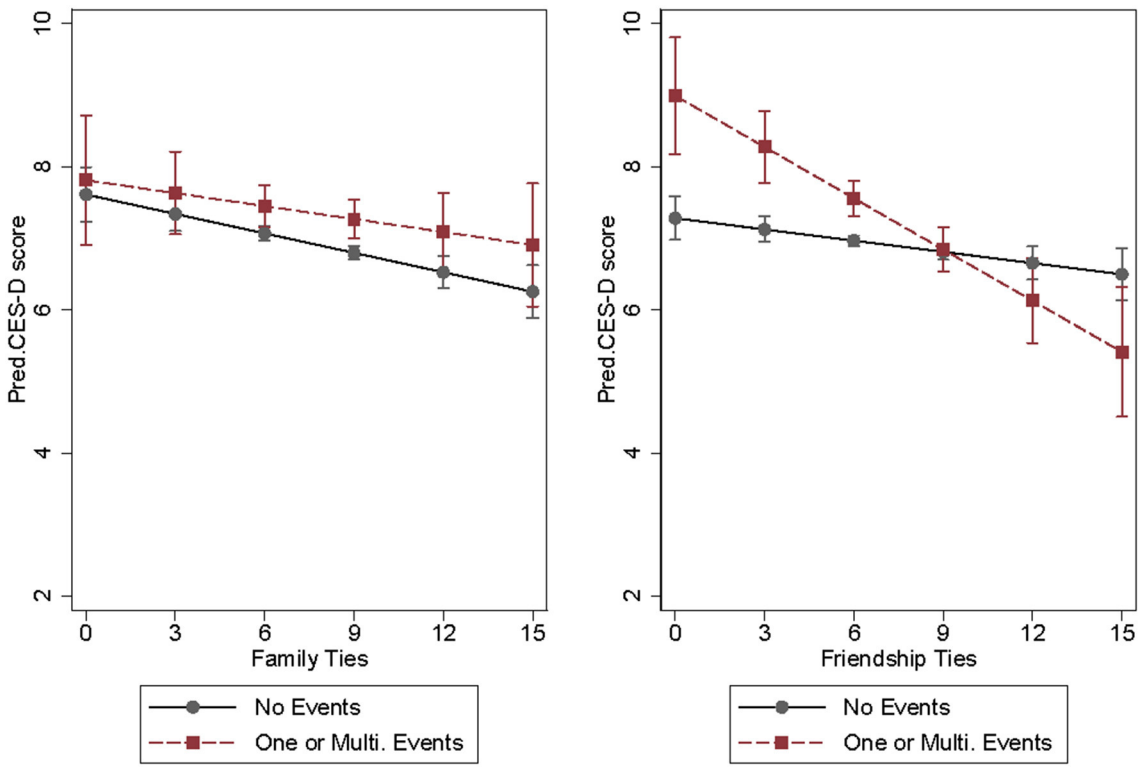

FIGURE 2 | Predicted depressive symptoms by family ties, friendship ties, and negative life events, CLASS 2016–2016, $N = 8,932$.

DISCUSSION AND CONCLUSION

Based on the nationally representative elderly survey in China, this paper examines the association between negative life events and depressive symptoms for older adults and explores how the perceived association is contingent on the strength of social ties. Our paper confirms that exposure to negative life events is an important risk factor of depression for older adults, echoing the

TABLE 3 | The fixed effects models predicting depressive symptoms of Chinese older adults, by subsamples, CLASS 2016 and 2018, $N = 8{,}932$.

	Male	Female	Rural	Urban	Less than secondary	Secondary and above
Neg. life events	1.426***	1.559***	1.791***	0.312	1.666***	1.251*
	[0.503]	[0.588]	[0.541]	[0.578]	[0.472]	[0.641]
Family ties (0–15)	−0.073**	−0.114***	−0.117***	−0.098***	−0.064**	−0.141***
	[0.034]	[0.038]	[0.037]	[0.037]	[0.032]	[0.040]
Friendship ties (0–15)	−0.035	−0.067**	−0.05	−0.066**	−0.086***	−0.007
	[0.030]	[0.033]	[0.032]	[0.033]	[0.028]	[0.035]
Neg. life events*Family ties	0.136	−0.093	−0.003	0.072	0.015	0.059
	[0.084]	[0.095]	[0.092]	[0.092]	[0.077]	[0.107]
Neg. life events*Friendship ties	−0.310***	−0.046	−0.209**	−0.087	−0.230***	−0.147
	[0.083]	[0.089]	[0.086]	[0.093]	[0.073]	[0.105]
Age	0.457	1.171***	0.196	1.385***	0.309	1.209***
	[0.366]	[0.377]	[0.390]	[0.357]	[0.329]	[0.440]
Age–squared	0.003	−0.001	0.004	−0.002	0.004*	−0.001
	[0.003]	[0.003]	[0.003]	[0.003]	[0.002]	[0.003]
Married	−1.224***	−0.521	−0.661	−1.476**	−0.840**	−1.009
	[0.458]	[0.476]	[0.418]	[0.616]	[0.367]	[0.683]
Presence of grandchild	−0.451**	−0.395*	−0.412**	−0.441**	−0.377**	−0.427*
	[0.192]	[0.207]	[0.194]	[0.218]	[0.176]	[0.230]
Number of chronic diseases	0.120**	0.189***	0.161***	0.097**	0.189***	0.117**
	[0.047]	[0.050]	[0.056]	[0.046]	[0.044]	[0.054]
Index of functional limitations	0.031	0.035	0.054*	0.006	0.021	0.045
	[0.031]	[0.033]	[0.033]	[0.032]	[0.028]	[0.039]
Self–reported health (1–3, 5, 6)	−0.514***	−0.378***	−0.157*	−0.730***	−0.461***	−0.419***
	[0.081]	[0.088]	[0.081]	[0.090]	[0.074]	[0.099]
Coresidence	−0.317*	−0.276	−0.03	−0.414**	−0.327**	−0.222
	[0.174]	[0.180]	[0.174]	[0.189]	[0.157]	[0.204]
Constant	−37.151***	−64.072***	−23.362*	−73.676***	−30.792***	−66.915***
	[12.752]	[13.159]	[13.517]	[12.521]	[11.597]	[15.111]
Person	2,366	2,100	2,143	2,612	2,591	1,875
N (Person–observation)	4,732	4,200	3,997	4,935	5,182	3,750

The coefficient values are presented, standard errors in parentheses.
****p < 0.01, **p <0.05, *p < 0.10 (two-tailed tests).*

previous findings for older adults in Singapore and Hong Kong of China (14, 16). Moreover, older adults with stronger social ties display less severe depressive symptoms than those with weaker social ties when experiencing negative life events. This finding in the context of mainland China enrich the evidence on the moderating roles of social ties, in support of the social convoy model ((38), p. 84).

More importantly, our paper expands on the current literature to compare the relative importance of family ties and friendship ties. On the one hand, both family ties and friendship ties are directly related to less severe depressive symptoms. On the other hand, the association between negative life events and depression is significantly moderated by friendship ties rather than family ties. Also, the moderating roles of friendship ties is more prominent for male, rural and less educated older adults, who are less resilient and have limited access to alternative coping resources. There might be two possible explanations for the stronger moderating roles of friendship ties as compared with family ties. First, the patriarchal culture strengthens family ties and intergenerational solidarity, but at the same time, it emphasizes the primary power and authority of male seniors and hinders intimate emotional interaction within household. Older adults might not be adapted to sharing painful and embarrassed feelings in case of stressful events with close family members (71, 72), thus friendship ties turn to be more important to cushion the shock. Second, the most common disruptive life event at old ages is death of family members. Family thus may become a pool where negative emotions and conflicts accumulate (73, 74), leading to a reduced buffering effect of family ties.

This paper also has several limitations. First, we code the exposure to negative life events as a dummy variable. Future studies could further differentiate the types of disruptive life events, such as family bereavement, severe illness, divorce, economic strains, and others. As such, they can figure out how social ties function to withstand the shock of various kinds of negative life events. Second, for each wave of the CLASS survey,

self-reported negative life events are measured cross-sectionally and might be subject to recall bias. For instance, older adults with depressive symptoms tend to perceive usual experience more negatively and report it as a negative life event, leading to an overestimation of the association between negative life events and depression. In order to evaluate the severity of such bias, we conduct a sensitivity test by restricting the scope of negative life events to these less prone to recall bias such as the death of spouse/children/relatives, natural calamities, and accidents. The results remain robust, but we still need to be mindful of potential bias[5]. Third, although we use fixed effects model to correct for the endogeneity bias resulting from time-invariant omitted variables, the endogeneity bias resulting from reversed causality might persist. For instance, severe depressive symptoms might lead to weakening friendship ties, such as, isolation from their friends, while have lesser impacts on family ties due to mutual obligations and commitments. Therefore, we should be cautious to attach a causal interpretation to our regression results. Future studies should use more rigorous design and longitudinal data to verify the time-varying effects of social ties on the association between negative life events and depression among the elderly.

Despite these limitations, our findings offer fresh evidence on the different roles of family and friendship support in moderating the association between stressful life events and depression in the context of mainland China, the society faced with accelerated aging process and intensified health concern. With heightened risk of encountering disruptive life events at old ages, the older adults are more susceptible to depression, which has become a major health challenge in China. Current policies often highlight the consolidation of family network to improve the well-being of older adults. For instance, the Central Committee of the Communist Party of China and the State Council jointly released a guideline addressing the issue of population aging in November 2021, that explicitly encourages adult children to co-reside or live close to their elderly parents. However, our study suggests a new and complementary perspective that highlights the importance of friendship ties for older adults' psychological health. Social ties outside the family, such as contact with and counseling from close friends, could act as a pivotal coping resource in relieving stresses from disruptive life events for older adults, in particular for those who are less resilient and have less access to alternative coping resources. Therefore, building and strengthening social network is as important as family network in promoting healthy aging in China.

[5]Due to space limitation, the results are not shown in the paper and are available upon request.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

HR and FC analyzed data and interpreted the results. HR and KS drafted and revised the paper. All authors have read and approved the final version of the manuscript.

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Association Between Self-Perceived Stigma and Quality of Life Among Urban Chinese Older Adults: The Moderating Role of Attitude Toward Own Aging and Traditionality

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Background: Ageism is a global challenge, which leads to a range of adverse outcomes for elderly people worldwide, which maybe more severe among urban older adults in a competitive society. However, how self-perceived ageism influences the quality of life in a sample of urban older adults remains inconclusive.

Objectives: The current study aims to assess the status of self-perceived stigma among urban Chinese older adults, identify its relationship with quality of life, and further explore whether both attitude toward own aging and traditionality moderate this relationship.

Materials and Methods: Primary data were collected through cross-sectional surveys among urban older adults in three provinces of China from October 2019 to December 2020. A total of 764 urban older adults were valid participants (effective response rate = 81.28%) and completed questionnaires via anonymous face-to-face interviews. Socio-demographic factors, self-perceived stigma, attitude toward own aging, traditionality, and quality of life were assessed using questionnaires that included the Self-perceived Stigma, Attitude Toward Own Aging, Traditionality, and SF-8 Scales.

Results: For urban Chinese older adults, the average score of self-perceived stigma was 2.041 ± 0.726. Self-perceived stigma ($\beta = -0.391$, $p < 0.05$) and attitude toward own aging ($\beta = -0.211$, $p < 0.05$) both influenced quality of life. Additionally, attitude toward own aging ($\beta = -0.530$, $p < 0.05$) and traditionality ($\beta = -0.525$, $p < 0.05$) moderated the association between self-perceived stigma and quality of life. Simple slope analysis revealed that when the level of negative attitude toward own aging and traditionality was higher, the strength of the influence of self-perceived stigma on quality of life was stronger.

Conclusion: Urban Chinese older adults were aware of the self-perceived stigma, which contributes to decreased quality of life. Attitude toward own aging and traditionality could moderate the association between self-perceived stigma and quality of life. When negative attitudes toward own aging and traditionality are higher, self-perceived

stigma has a greater effect on the quality of life. More interventions related to relieving self-perceived stigma, traditionality, and negative attitude toward own aging should be considered to build a new modern society that emphasizes health, friendliness, well-being, and dignity for all ages.

Keywords: self-perceived stigma, attitude toward own aging, traditionality, quality of life, aging

INTRODUCTION

In many modern "youth-centered" societies worldwide, discrimination against older people, regarded as ageism, is common. Ageism refers to stereotypes, prejudice, and discrimination against a particular age group, especially the elderly (1). A recent report showed that experiencing ageism is prone to lead to poorer health, social isolation, earlier deaths, and economic consequences worth billions; therefore, swift action implementing effective anti-ageism strategies is required (2). Older adults unavoidably encounter a period of biological and physical deterioration, including changes in body posture, hair color, voice, and ability to see and hear (3); these contribute to public stereotypes, prejudice, and discrimination toward older adults in daily life (4, 5). Especially in the digital age, there is a growing gap between older and younger individuals regarding values, thoughts, and lifestyles (6). Further, whereas social forces driven by the transformation of new media, social networking technology, and marketing strategies contribute to encouraging youth-centered lifestyle, they shape negative attitudes toward aging and elicit adverse depictions regarding older adults and the aging process (7, 8). Numerous older adults also struggle with multiple dilemmas and are often stereotyped as forgetful, useless, lonely, and unattractive (9). Ageism can not only change how older adults view themselves but can also erode solidarity between generations and devalue or limit public ability to benefit from younger and older populations, further increasing the threat to everybody's health, longevity, and well-being (10); there are also far-reaching impacts on economies and societies.

Self-perceived stigma and attitude toward own aging as two different patterns together make up one set of the ageism (11). Self-perceived stigma presents an age-based stereotype threat, meaning that older adults perceive age-based stigma from other social groups. Differently, the attitude toward own aging of elderly presents older adults' internal views on aging, as self-imposed ageism, meaning that it consists of subjective beliefs of older adult individual toward own cognitive abilities and physical capabilities. The difference of two concepts has been discussed in the previous literature (12) Since the concept of self-perceived stigma was proposed, there have been studies on different groups of people, such as people with mental illnesses (13), people with HIV (14), Chinese female sex workers and Chinese breast cancer survivors (15), and obesity-related perceived stigma (16).

Existing literature indicated that stigma was widespread, and its associated consequences were far-reaching, including lower quality of life, earlier death, poorer physical and mental health, and slower recovery from disability in older age (8, 17). Due to existing deterioration in physical function, appearance, and competence; lower ability to contribute to society; and social exit and retirement, it is difficult for older adults to keep lasting work and live happily or achieve a long-lasting, adequate quality of life (9), which refers to an individual's perception or evaluation toward self-position in the space of everyday social life.

Quality of life is nested inside the specific cultural context and value system one depends on for survival and is related to a set of goals, expectations, standards, and concerns (18); it is a multidimensional concept that consists of both objective and subjective domains, macro and micro-aspects, and positive and

TABLE 1 | Demographic information of participants.

Characteristics	*N*	%
Sex		
Male	346	45.29
Female	414	54.19
Age		
≤65	167	21.86
66–70	217	28.40
71–75	161	21.07
76–80	115	15.05
≥81	104	13.61
Pension		
Yes	339	44.37
No	384	50.26
Unsure	41	5.37
Register		
Migrated to a city	437	57.20
Urban-local	326	42.67
Education categories		
No school	176	23.04
Primary school	273	35.73
Middle school	157	20.55
High school	99	12.96
Higher education	56	7.33
Unsure	3	0.39
Marital status		
Married	611	80.1
Divorce	9	1.2
Loss of spouse	143	18.7
Monthly income-cost	21	2.75
Below average	73	9.55
Average	586	76.70
Above average	84	10.99
Unsure	176	23.04

negative components (19). Moreover, quality of life is a reliable and relevant indicator of older people's health and well-being (19), taking into account physical and psychological functions, body activity and participation, and environmental domains (20).

Relationship of Self-Perceived Stigma and Quality of Life

Several similar studies demonstrated that stigma caused psychological distress and social withdrawal, leading to decreased quality of life in different groups of patients, such as those with depressive disorders (21), Parkinson's disease (22), and HIV (23). Moreover, a meta-analysis showed that self-concept and social networks play a mediating role in the association between stigma and quality of life in patients with psychosis (24). Undoubtedly, age-based stereotypes or external discrimination increase the emergence of internal stigma and self-directed ageism (25) that also seriously threaten the well-being of older people. However, few studies have been conducted on stigma among general older adults, especially in China. Moreover, the potential mechanism of the association between perceived stigma and quality of life remains inconclusive. Previous studies confirmed that age-based stereotypes, prejudice, and discrimination harmed older adults, thus severely limiting opportunities to secure their health, well-being, and quality of life (8).

The Moderating Effect of Attitudes Toward Aging in the Relationship

A review study revealed that self-perceived stigma of older adults as an other-directed ageism has a negative impact on the physical and mental health (26). In fact, some older adults don't be affected although in the same social ecosystem in which stigmatization related to age (i.e., ageism) is a widespread phenomenon in the modern industrial societies (26). Now, we suspect that there is difference in individuals who present differentiated internal views on own aging. Several studies have established the associations between perceived stigma and aging attitudes and quality of life (17). Traditionally, understanding attitudes toward aging in various cultural contexts is crucial to foster the optimal quality of life for older adults (27). Existing studies have measured older adults' attitudes toward aging as stable and integrative judgments, summarizing their thoughts, feelings, and memories regarding aging or other situations; further, the subjective perception of aging, rather than the individual's chronological age and life, are emphasized (27). Generally, a significant association between elderly people's attitude toward own aging and the state of physical and mental health (28), as well as life satisfaction and well-being (29), has been found. Moreover, a previous study has revealed the negative impact of internalized stigma on the quality of life of people with serious mental (30) and chronic (31) illnesses. In addition, a recent study found that attitude toward own aging was a potential mediator in the relationship between personality factors and mental health and life satisfaction among older adults (32). Another study reported that attitude to aging moderated the relationship between subjective age and psychological well-being (33). A study regarding the COVID-19 pandemic showed that subjective age moderated the negative association between ageism and subjective health (10). In conclusion, attitude to aging likely moderates the association between self-perceptive stigma and quality of life among older adults. Integrating the evidence presented above regarding existing tendencies among older people, it can be surmised that attitude toward own aging can strengthen the correlation between self-perceived stigma and quality of life; this potentially contributes to providing a new clue for social governance to improve older adults' quality of life in the current aging society.

The Moderating Effect of Traditionality in the Relationship

Previous study suggested that the association varies across cultures shaped by a series of traditions, religious and sociocultural beliefs, and modern lifestyles (34). Further, traditionality can always be found in modern Chinese society; the ubiquity of traditionality may be related to Confucian teaching, which emphasizes interdependence and group harmony. However, whether traditionality potentially influences the strength of the associations discussed above remains unknown. Considering most past studies excluded cultural factors, the current study aims to provide meaningful insight regarding the interaction between culture and stigmatization and how this influences the quality of life of Chinese older adults. In China, due to the existing highly collective culture, traditionality is regarded as "an emphasis on expressive ties among people and values, such as respect for authority, filial piety, ancestor worship, male-domination, fatalism, and a general sense of powerlessness (35)." Chinese adults used to follow the five basic relations formed by Confucianism in traditional Chinese culture: emperor-subject, father-son, husband-wife, elder-younger, and friend-friend (35). Older adults, influenced by the existence of historical and human-cultural factors, used to exhibit high degrees of traditionality compared to younger individuals.

Yang defined Chinese traditionality as "the typical pattern of more or less related motivational, evaluative, attitudinal and temperamental traits that is most frequently observed in people in traditional Chinese society and can still be found in people in contemporary Chinese societies such as Taiwan, Hong Kong, and mainland China" (36). Generally, the traditionality refers to the extent to which individuals adhere to traditional cultural beliefs and values (37), which will deeply determinate person's mindset pattern and behavioral style, as well lifestyle. As such, older adults are likely prone to emphasize the extent to which individuals should fulfill the expectations defined by prescribed social roles based on the five basic relations (38). Conversely, older adults with low-degree traditionality are more likely to exhibit egalitarianism, self-reliance, and openness. Under the impact of the high level of traditionality, self-stigmatizing older adults are more likely to carry out limited resistance against ageism, resulting in an incapable adjustment from negative to positive emotions (35). Older adults with a high degree of traditionality are more likely to contribute to the limited quality of everyday communication with other community members in modern society, further restraining social interaction and positive support

from others, hinting that high-degree traditionality potentially leads to lower quality of life (38). An latest study in Italy revealed that the traditionalism was a determinant in the emergence of adolescents' ageism toward older adults (39). A cross-cultural meta-analysis suggested that the determinant of regional differences played an important role in shaping modern attitudes toward elders, further presenting that in modern, industrialized societies, easterners with collectivist traditions present negative attitude toward elders (40). Conversely, cultural individualism significantly predicted relative positivity-suggesting that, for generating elder respect within rapidly aging societies (40).

In general, the current study assumed that low degrees of traditionality can buffer the destructive effects of self-perceived stigma on quality of life. Moreover, existing research shows that traditionality plays a moderating role in a series of associations in the Chinese context (38, 41). Therefore, the current research attempted to explore the moderating effect of traditionality in the relationship between self-perceived stigma and quality of life among Chinese older adults.

Aim

This study aimed to enhance the understanding of self-perceived stigma among urban Chinese older adults and to further explore the moderating mechanism of its relation to the quality of life. Specially, the current study aimed to examine the prevalence of self-perceived stigma and attitude toward own aging, and to probe the moderating role in the relationship between them, including attitude toward own aging and traditionality.

MATERIALS AND METHODS

Sample and Data Collection

Primary data were collected using a cross-sectional survey from three provinces in China. A multistage stratified convenience sampling was used. Three provinces included northeast China' Heilongjiang province, east China's Zhejiang province and southeast China' Guangdong province, well-trained investigators randomly chooses communities and surveyed the encounter older adults at different times of the day. Participation to the current study was voluntary, informed consent was obtained from all participants on the front page of the self-administered questionnaires.

Considering the calculation method and standard requirements of the cross-sectional sample size from Zhou et al. (42), we identified 224 as the minimum sample size for this study. Of the 940 eligible patients, 176 were excluded. There were 764 urban older adults who were valid participants (effective response rate = 81.28%) and completed questionnaires via face-to-face interviews from October 2019 to December 2020. Face-to-face interviews were conducted by well-trained investigators among urban older adults. A brief interaction begins with an elucidation of research purpose or subject inclusion criteria, followed by inquiries or evaluation to address these criteria in increasingly precise ways on selecting participants. The eligibility criteria were being aged 60 years or older, having resided in the city for more than 6 months, being able to both listen and talk with others in Chinese, no diagnosis of Dementia, having clear cognition, having no serious hearing impairments, and having volunteered to participate in the research. In the current study, the basic demographic characteristics were consistent with the Chinese official data.

Measurement of Self-Perceived Stigma

The five-item Chinese version of the Self-perceived Stigma Scale was used to measure the self-perceived stigma of urban Chinese older adults (43); this scale has been proven to have good reliability and validity among Chinese subjects. Original questions have been subtly modified to suit this survey which assessed attitudes toward urban older adults in the Chinese context. Responses were graded on a five-point Likert scale (1 = not at all, 5 = very frequent). Sample items included "Because of my age, I felt emotionally distant from other people." The total score ranged from 5 to 25, with higher scores reflecting higher self-perceived stigma of urban older adults. In the current study, Cronbach's alpha coefficient was 0.791.

Measurement of Attitude Toward Own Aging

Attitude toward own aging was measured using a five-item questionnaire derived from the short version of the Attitudes to Aging Questionnaire (44), which has been widely used in the Chinese context (45, 46). Responses were graded on a five-point Likert scale (1 = completely disagree, 5 = completely agree). Sample items included "I think I am old"; "In my opinion, getting old is a process of constant loss"; "As I get older, I find it more difficult to make new friends"; and "Due to my age, I feel excluded." The total score ranged from 5 to 25, with higher scores reflecting higher negative attitude toward own aging among urban older adults. The scale had qualified internal consistency, with an overall Cronbach's alpha of 0.735 in this study.

Measurement of Traditionality

The Traditionality Scale was a five-item questionnaire originally developed by Yang et al. (35) and applied by Farh (41, 47), which has been widely used in the Chinese context (38, 48). Responses were evaluated using a five-point Likert scale (1 = strongly disagree, 5 = strongly agree). The total score ranged from 5 to 25, with higher scores reflecting higher traditionality. Sample items included "The chief government official is like the head of a household, the citizen should obey his decisions on all state matters"; "The best way to avoid mistakes is to follow the instructions of senior persons"; "When people are in dispute, they should ask the most senior person to decide who is right"; "Children should respect those people who are respected by their parents"; and "Before marriage, a woman should subordinate herself to her father, and after marriage, to her husband." The scale had acceptable internal consistency, with Cronbach's alpha of 0.782 for this study.

Measurement of Health-Related Quality of Life

Considering the cost-effectiveness and accessibility of the tool, the eight-item version of the SF Health Survey (SF-8) was used to evaluate the quality of life among urban older adults (49), including eight ordinal items: general health (GH), physical functioning (PF), role physical (RP), bodily pain (BP),

vitality (VT), social functioning (SF), mental health (MH), and emotional roles (RE). SF-8 has been proven to have good reliability and validity in a previous study (49). Responses were graded on a five-point Likert scale (1 = very poor, 5 = very good), indicating the minimum (5) and maximum (25) of possible SF-8 scores, and higher scores reflected a higher QoL. Sample items included "How would you describe your overall health?" A higher score reflected a lower quality of life among urban Chinese older adults The scale has an excellent internal consistency, with an overall Cronbach's alpha of 0.876 in this study.

Data Analysis Methods

Preliminary Analyses

Statistical significance was determined to have been achieved for a two-tailed $p < 0.05$. All analyses were conducted using SPSS version 22.0 (IBM, BM SPSS Statistics for Windows). Pearson's correlation coefficients were calculated to examine the correlations among the variables: self-perceived stigma, attitude toward own aging, traditionality, and quality of life. Descriptive statistics of the demographic information and variables were indicated using the mean, standard deviation (SD), number (N), and percentage (%).

Moderator Analysis

In the present study, a series of associations among the variables were tested as well as to examine the moderating effects using Multiple Linear Regression Models (MLRM) and the predictive value of self-perceived stigma on the quality of life at different conditions. Two moderation analyses were performed by testing the significance of the interactions of self-perceived stigma and attitude toward own aging and the interactions of self-perceived stigma and traditionality. Statistical significance was also considered (50), then a simple slope analysis was conducted to visualize the interaction term.

RESULTS

Demographic Information for Participants

Participants' demographic characteristics are shown in **Table 1**. The mean age of participants was 71.83 years (SD = 7.45, range = 60–96), and 54.19% were female. About 80.1, 9, and 18.7% were married, divorced, and had lost a spouse, respectively. In terms of education, 23.04% of participants had less than a full primary school education; 35.73% finished full primary school; 20.55% finished middle school; 12.96% finished high school; and 7.33% had higher education. In total, 44.37% of participants had a pension. About 76.70, 10.99, and 9.55% of participants defined their economic status as average, above average, and below average, respectively; 23.04% had an unsure status. Register refers to a person's origin or origins, and living conditions of their parents, which is divided into two group, namely a group of older adults migrated to current city and urban-local older adults.

TABLE 2 | Means, standard deviation (SD), and correlations of continuous variables ($N = 764$).

Variables	M	SD	1	2	3	4
1 Self-perceived stigma	2.041	0.726	1			
2 Attitude toward own aging	2.955	0.559	0.405**	1		
3 Traditionality	3.201	0.755	0.118**	−0.073*	1	
4 Quality of life	4.205	0.580	−0.498**	−0.418**	−0.031	1

*$p < 0.05$; **$p < 0.01$.

Correlations Among Study Variables in the Total Sample ($N = 764$)

Pearson's correlation coefficients for continuous variables are shown in **Table 2**. Self-perceived stigma was positively correlated with attitude toward own aging ($r = 0.405$, $p < 0.01$) and traditionality ($r = 0.118$, $P < 0.01$) and negatively correlated with quality of life ($r = -0.498$, $p < 0.01$). Moreover, attitude toward own aging was negatively correlated with the traditionality ($r = -0.073$, $p < 0.05$) and quality of life ($r = -0.418$, $p < 0.01$).

Hierarchical Regression Analyses

Table 3 displays the results of a series of hierarchical regression analyses. The first step examined the influence of control variables, including sex, age, marital status, migrating status, retirement, and education level. In the second step, self-perceived stigma was found to be significantly and negatively related to the quality of life ($\beta = -0.391$, $p < 0.01$). Similarly, attitude toward own aging was significantly and negatively associated with the quality of life ($\beta = -0.211$, $p < 0.01$). Self-perceived stigma and attitude toward own aging improved the model fits of quality of life ($R^2 = 0.334$ and adjusted $R^2 = 0.237$, $p < 0.01$). The Self-perceived stigma × Attitude toward own aging interaction term was significantly and negatively associated with quality of life ($\beta = -0.530$, $p < 0.01$). Simple slope analysis revealed that when the attitude toward own aging was higher, the association between self-perceived stigma and quality of life became stronger. In other words, the strength of the impact of self-perceived stigma on quality of life was different in groups with negative (1 SD below the mean, $p < 0.001$) and positive (1 SD above the mean, $p < 0.001$) attitudes toward own aging. For more legible and direct visualization of the results, the interaction is presented in **Figure 1**. Self-perceived stigma and traditionality improved the model fits of quality of life ($R^2 = 0.292$ and *adjusted* $R^2 = 0.192$, $p < 0.01$). The Self-perceived stigma × Traditionality interaction term was also significantly and negatively associated with the quality of life ($\beta = -0.525$, $p < 0.01$). Simple slope analysis revealed that when traditionality was higher, the association between self-perceived stigma and quality of life became stronger. In other words, the strength of the impact of self-perceived stigma on quality of life was different in groups with low (1 SD below the mean, $p < 0.001$) and high (1 SD above the mean, $p < 0.001$) traditionality. The interaction is visualized in **Figure 2**.

TABLE 3 | Hierarchical linear regression models.

Variables	Quality of life				
	$M_1(\beta)$	$M_2(\beta)$	$M_3(\beta)$	$M_4(\beta)$	$M_5(\beta)$
Control variables					
Sex	−0.083*	−0.095**	−0.087**	−0.087**	−0.082**
Age	−0.240**	−0.153**	−0.158**	−0.206**	−0.201**
Marital status	−0.068	−0.038	−0.037	−0.043	−0.047
Migrating status	0.085*	0.061	0.062	0.062	0.061
Retirement	−0.042	−0.012	−0.021	−0.056	−0.052
Education level	0.058	−0.027	−0.024	0.002	0.007
Independent variable					
Self-perceived stigma		−0.391**	0.025	−0.450**	−0.047
Moderator variable 1					
Attitude toward own aging		−0.211**	−0.013		
Interaction 1					
Self-perceived stigma× Attitude toward own aging			−0.530**		
Moderator variable 2					
Traditionality				−0.038	0.318**
Interaction 2					
Self-perceived stigma × Traditionality					−0.525**
F	14.155**	47.154**	43.218**	38.605**	35.914**
R^2	0.097**	0.334**	0.341**	0.292**	0.301**
ΔR^2	0.104**	0.237**	0.245**	0.192**	0.202**

M1: control variables, including Sex, Age, Marital status, Migrating status, Retirement, and Education level.
M2: explains the influence of self-perceived stigma and attitude and toward own aging on Quality of Life.
M3: explains the influence of self-perceived stigma× attitude toward own aging on Quality of Life.
M4: explains the influence of self-perceived stigma and traditionality on Quality of Life.
M5: explains the influence of self-perceived stigma traditionality on Quality of Life.
**P < 0.05; **P < 0.01 (two-tailed).*

DISCUSSIONS

Current Situation of Self-Perceived Stigma and Attitude Toward Own Aging Among Urban Chinese Older Adults

The results of this study showed that the self-perceived stigma ($M = 2.041 \pm 0.726$) and attitude toward own aging ($M = 2.955 \pm 0.559$) of urban Chinese older adults were lower than the median score, consistent with previous studies that suggested a less favorable perception of emotion experiences of older adults due to negative stereotypes about aging (51). Stigmatization related to age (i.e., ageism) is a widespread phenomenon in the modern industrial societies (26), as a self-concept threat, then which results in age-based stereotype threat about cognitive decline (52), further leading to a detrimental influence on older adults on their cognitive performance and self-perceived stigma, final generalizing negative attitude toward own aging (52).

Importantly, the current study indicates that self-perceived stigma and attitude toward own aging among urban Chinese older adults were very noticeable issues. It is common for urban Chinese older adults to endure with their own stigma and to keep a negative attitude toward their own aging, thus older adults are forced to embody socially acceptable labels to face the process of getting older. Theories such as stereotype embodiment (53) and social identity (54) theories have sought to provide a rationale for explaining the phenomena of self-perceived stigma, inferring that external stigma contributes to reinforcing internalized self-stereotypes. That is, aging self-stereotypes are more likely to increase negative expectations and attitudes toward older adults, which is prone to contribute to reduced daily activities frequency; this may result in decreased physical and emotional health (55). With the further assumption that a vicious cycle can develop as a potential possibility, wherein weakened cognitive and physical functioning of urban older adults likely leads to the formation of negative attitudes toward aging and self-perceived stigma (56). Further, social forces—driven by a series of media reports, mainstream culture, and marketing strategies—covertly shape public attitudes to aging by presenting implied negative narrative depictions toward urban older adults and the aging process. In turn, this further contributes to the formation of negative aging attitudes—such as uselessness, dependence, and hopelessness—and self-perceived stigma toward older individuals. As such, the current findings emphasize that targeted interventions alleviating urban older adults' self-perceived stigma and negative attitude toward own aging should be implemented to guard their quality of life.

The Relationship Between Self-Perceived Stigma and Quality of Life

This study found that greater self-perceived stigma was related to lower quality of life among urban older adults in China, which is consistent with previous studies (57). Existing studies indicated that self-perceived stigma and prejudice were prone to lead to reduced cognitive and physical functioning (58), increased risk of depression and anxiety (59), and limited will to survive and quality of life among older adults (60).

Attitudes Toward Own Aging Moderated the Relationship Between Self-Perceived Stigma and Quality of Life

This study found that negative attitudes toward own aging moderated the association between self-perceived stigma and quality of life. Results of the simple slope analysis showed that the stronger effect of self-perceived stigma on the quality of life among older adults exists along with more negative attitudes toward own aging, which refers to negative attitudes and beliefs toward older adults or toward the aging process itself (32). Older adults with a positive attitude toward their own aging are more likely to combat external stigma better, regulate their negative emotions openly, maintain health-promoting behaviors and lifestyles, and more easily make efforts to integrate into modern society (61). Older adults with negative attitudes toward their own aging tend to be more vulnerable facing stigma, leading to a further impairment in quality of life (62). Moreover, older adults with negative attitudes toward components of aging—such as disability or infirmity, which result in objective physical decline and social segregation—may also experience declines in their quality of life (63). In interpreting the interaction between self-perceived stigma and negative attitude toward own aging found in the present study, it can be speculated that older adults who recognize themselves as aging faster are more vulnerable to suffering negative concomitants of external stigma. In a "youth-centered" era, medical industries emphasize older age as a risk factor for health; this serves as both suggestion and autosuggestion for older adults regarding the process of aging. In turn, a cyclic establishment of self-perceived stigma is established, further destroying older adults' quality of life. Therefore, negative attitudes toward own aging are also potential threats that can render ones less immune to the harm of stigma. The findings from this study thus suggest that building positive attitudes among older adults toward aging may be a valid approach to minimize the degree of the negative impact of self-perceived stigma on the quality of life. Governments should initiate projects cultivating positive attitudes toward aging to better the quality of life of elderly people. Only when ageism is eliminated at all levels can a better age-friendly society exist.

Traditionality Strengthened Moderated the Relationship Between Self-Perceived Stigma and Quality of Life

The present study highlighted that traditionality moderated the association between self-perceived stigma and quality of life, which confirmed the third hypothesis of this study. Traditionality seeps into all aspects of individual role definition in Chinese society (64) and contributes to affecting older adults' responses facing external stigma. Self-Determination Theory, which explains the results of this study (65), points out that people are willing to cultivate relationships with those who value their opinions and who are sensitive to their needs and wants (65), hinting that traditionalists are prone to experience decreased satisfaction of basic psychological needs rapidly (66) when they encounter negative external evaluation and stigmatization. This further results in reduced health-related and social-related quality of life (67). Influenced by Chinese cultural heritage, older adults with a high degree of traditionality often believe that younger individuals should show deference, be obedient, and be loyal to older groups (38). Often, older adults are used to maintaining their authority, thinking styles, and top-down communication, thus hindering fair and open interactions with younger individuals and leading to the increased probability of stigma from younger groups (35). Several organizational behavior studies confirmed that traditionality was conducive to organizational operation, personal satisfaction, and career success by increasing individual perceptions of procedural justice and job insecurity (68); further, this implies that traditionality is more likely to be suitable for a bureaucratic system that is characterized by a culture of hierarchy and compliance (41). However, traditionality does not always play a positive role for older adults in an aging society, especially in everyday life that emphasizes freedom and equality of communication. Conversely, in farming societies, getting older leads to a loss of power, authority, and autonomy. Older adults who are traditionalists are more likely to receive less psychological support and less likely to have positive relationships with others when facing stigma (38), resulting in decreased quality of life more than those with low degrees of traditionality. Moreover, older adults with modern characteristics, tendencies, or values are prone to deal with stigma with levity and openness; this contributes to one's flexible adjustment of their attitudes and behavioral responses, further buffering the self-inflicted damage of stigma on quality of life (64). Therefore, the current study posits that older adults who have traditionalist tendencies may hesitate to adjust their emotions and may enter a relatively negative psychological and social state, further strengthening the negative effect of self-perceived stigma on quality of life. Influenced by Confucian cultural tenets, traditionalism is deeply rooted in Chinese older adults and is not always conducive to positive outcomes, especially in modern eras (64). Therefore, this study's findings also suggest that an aging society must build a more open, inclusive, and diverse culture to alleviate the damage of stigma on the quality of life of older adults.

Implications and Contributions

At last, implications for practitioners working with older adults are discussed as follow. This study contributes to some insights on the implications and contributions for formulating policies to deal with the Chins' aging tendency. Relatively low-cost, feasible strategies should serve as the basis of effective interventions to reduce ageism in the whole scope of society (1). Formal intervention programs regarding promoting and

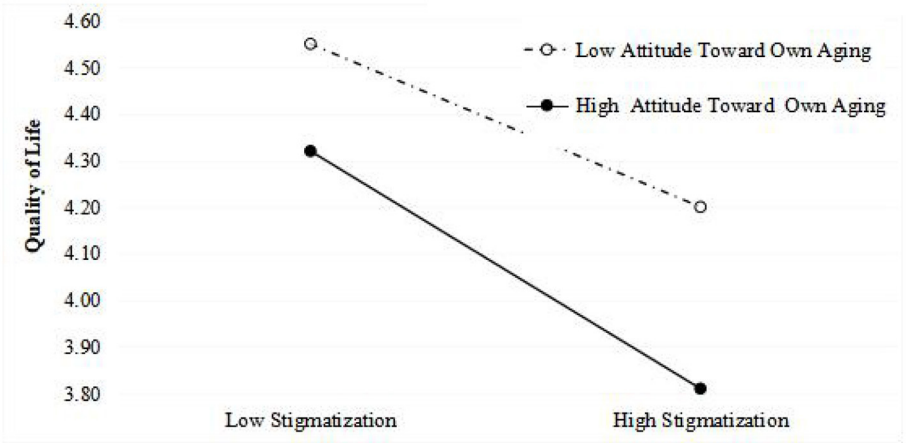

FIGURE 1 | Simple slope diagram of the influence of the interaction between self-perceived stigma and attitude toward own aging on the quality of life.

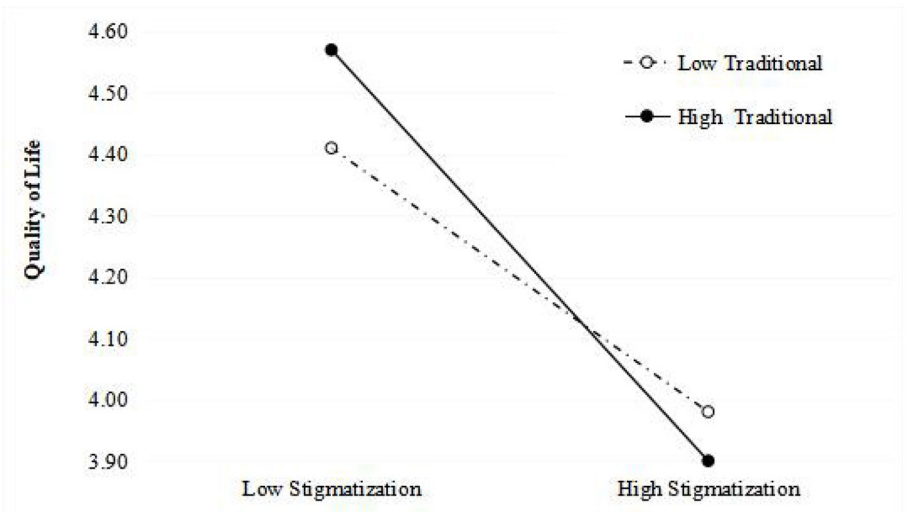

FIGURE 2 | Simple slope diagram of the influence of the interaction between self-perceived stigma and traditionality on the quality of life.

supporting self-management and self-care for elderly should be adopted to raise self-efficacy, then reducing their self-directed ageism (69). Moreover, modern lifestyle activities should be encouraged to foster the modern values of older adults (69). This study contributes to a new finding that individual cognition and cultural belief as the moderators determinate the strength of influence self-perceived stigma on the quality of life, which should facilitate establishing a public health and welfare policy for the most older adults, a group that has been increasing in China. Significantly, Chinese, Japanese, and Korean mostly rooted in Confucian values and ethics that are the central philosophic background for much of the culture in East Asia, particularly for understanding older adults' cognitive behavior (70).

A study in the Korean elderly revealed that there is the cultural characterization explanation of ageism and related coping processes among Korean elderly (71). However, a study conducting an international comparison found that the overall ageism score was lowest in Japan where favorable conditions for economic status, health status, and social participation are provided for older adults (72). From this, professional interventions and organizational interventions also be considered through teaching modern culture and beliefs in the community college to cultivate positive attitude toward aging for the elderly. Moreover, favorable conditions as a characterization of modernize city potentially protect older adults' self-efficacy for direct raising quality of life and indirect reducing their self-directed ageism.

Fortunately, the central government of China is already launching a comprehensive, in-depth reform to modernize the national governance system and capabilities to promote the quality of life and well-being of the elderly.

Limitations

This study provided a new understanding regarding the association between self-perceived stigma and quality of life among urban Chinese older adults. However, the following limitations of this study must be emphasized. First, the data was collected through convenience sampling outdoors; this is prone to response bias, and unhealthy older adults, such as those with disabilities, may have been inadvertently omitted. Second, although much effort has been implemented to ensure a representative sample, it must be acknowledged that the effective response rate was not ideal. Third, a cross-sectional design cannot ascertain a causal relationship between self-perceived stigma and quality of life, suggesting that a longitudinal study is needed. Fourth, except for QOL (SF-8), other surveys had low Cronbach's alpha (<0.8) in the current study, indicating that more suitable or appropriate measuring instrument should be selected in future. Finally, considering that traditionality is a unique cultural phenomenon in China, further research should be conducted to test whether results from the current study are observable across different cultural contexts.

CONCLUSION

In summary, the current study found that self-perceived stigma and attitude toward own aging of urban Chinese older adults were at a lower level. Moreover, both self-perceived stigma and attitude toward own aging were associated with a reduced quality of life, and both attitude toward own aging and traditionality can moderate the association between self-perceived stigma and quality of life. When negative attitudes toward own aging and traditionality were higher, self-perceived stigma had a greater effect on the quality of life. More importantly, older adults should be given more care and attention in daily life, and attitudes toward own aging and traditionality should be jointly intervened with to enhance the quality of life of older adults.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary files, further inquiries can be directed to the corresponding author/s.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Ethics Committee of Harbin Medical University (ECHMU). However, owing to the anonymous survey approach, written informed consent could not be obtained. Verbal informed consent to participates in this study was approved by the Institutional Review Board of Harbin Medical University and obtained from each of the participants on the front page of the questionnaire. Therefore, once a questionnaire was submitted successfully, we believed the consent of the nurse to participate in our study. Informed consent was obtained from all participants on the front page of self-administered questionnaires.

AUTHOR CONTRIBUTIONS

TS and S-EZ: conceptualization and software. TS, S-EZ, and X-hW: methodology. XC, K-yJ, and S-yC: formal analysis. S-EZ, M-yY, T-hL, and Y-qY: investigation. TS: resources and writing—original draft preparation. H-yY, C-xZ, and Y-pW: data curation. TS, S-EZ, X-hW, X-hH, and D-pC: writing—review and editing. X-hH and D-pC: visualization, supervision, and project administration. All authors have read and agreed to the published version of the manuscript.

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Association Between Functional Limitations and Incident Cardiovascular Diseases and All-Cause Mortality Among the Middle-Aged and Older Adults in China: A Population-Based Prospective Cohort Study

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Background: The prevalence of functional limitations is relatively high among the middle-aged and older adults. However, the contribution of functional limitations to subsequent incident cardiovascular diseases (CVD) and death is unclear. This study aims to examine the association between functional limitations and incident CVD and all-cause mortality among the middle-aged and older adults.

Methods: This is a nationally representative prospective cohort study. Participants were middle-aged and older Chinese adults from The China Health and Retirement Longitudinal Study. Functional limitations were measured using activities of daily living (ADL) scale and instrumental activities of daily living (IADL) scale. Incident CVD and death were recorded at followed-up from June 1, 2011, up until August 31, 2018. Cox proportional hazards model was used to assess the association between functional limitations and incident CVD and all-cause mortality.

Results: A total of 11,013 participants were included in this study. During the 7 years of follow-up, 1,914 incident CVD and 1,182 incident deaths were identified. Participants with functional limitations were associated with a 23% increased risk of incident CVD (HR, 1.23, 95% CI:1.08,1.39) after adjusting for age, gender, residential area, marital status, education, smoking, alcohol drinking, sleep duration, nap duration, depression symptoms, social participation, history of hypertension, diabetes, dyslipidemia, use of hypertension medications, diabetes medications, and lipid-lowering therapy. Moreover, participants with functional limitations were associated with a 63% increased risk of all-cause mortality (HR,1.63, 95%CI: 1.41,1.89) after adjusting for potential confounders.

Conclusions: Functional limitations were significantly associated with subsequent incident CVD and death among the middle-aged and older Chinese adults.

Keywords: functional limitation, cardiovascular diseases, elderly, cohort study, all-cause mortality

INTRODUCTION

Functional ability is an important indicator that reflects the quality of life and health status. With the population of middle-aged and older adults is increasing in China, the prevalence and incidence of functional limitations among this group is relatively high and posing significant medical challenges to the nation and care-givers (1, 2). A recent longitudinal study reported that 15.3 and 19.2% of the Chinese adults aged 45 and over developed functional limitations during 4 years of follow-up according to the definition of activities of daily living (ADL) scale and instrument activities of daily living (IADL) scale, respectively (3). Previous epidemiological studies demonstrated that cognitive function impairment, depression, unhealthy lifestyle behaviors, chronic conditions and multimorbidity were potential predictors of functional limitations (4–6). Furthermore, several studies found that functional limitations were associated with a range of adverse health outcomes and higher mortality risk (7, 8).

The incident cardiovascular diseases (CVD), well known for their heavy economic and social burden (9), seriously endanger health and quality of life (10). The prevalence of and mortality due to CVD in China is continuously rising (9, 11, 12). Specifically, CVD has been the leading cause of death in China, ahead of oncology and other diseases, accounting for 45.91 and 43.56% of deaths in Chinese rural and urban areas, respectively (12). Previous studies found that incident CVD and its mortality were associated with unhealthy lifestyle behaviors (13–15), overweight and obesity (16), emotional problem (17), cardiorespiratory fitness (18) and insomnia or poor sleep (19). In this regard, the progression of CVD may involve multiple risk factors acting together over a long-term period of time, suggesting that the underlying mechanisms of CVD, its risk factors and improved treatment remain a hot field of further research.

The contribution of chronic diseases to functional disabilities has been widely examined in previous studies. For example, a study conducted in seven countries with low and middle incomes showed that dementia made the largest contribution to functional disability, other substantial contributors were stroke, limb impairment, arthritis and so on (20). Similarly, a cross-sectional study conducted among community-dwelling oldest-old in Israel reported that stroke and heart attack were associated with functional limitations according to both ADL and IADL scales (21). Also, in a Chinese Longitudinal Healthy Longevity Survey, stroke or cerebrovascular disease and cognitive impairment were the strongest risk factors of functional disability among the elderly aged 80 years and over (22). However, the contribution of functional limitations to incident CVD among community-dwelling middle-aged and older adults is ambiguous. In addition, the association between functional disability and all-cause mortality has not been adequately explored among the Chinese population.

Therefore, this population-based prospective cohort study aimed to examine the association between functional limitations and incidence of CVD and all-cause mortality among the middle-aged and older adults in China. We hoped that this study could provide more valuable information for the prevention of incident CVD and death.

METHODS

Study Population

Participants in this cohort study were from the China Health and Retirement Longitudinal Study (CHARLS), which is an ongoing nationally representative longitudinal study by the National School of Development at the Peking University. Details of the study design have been described elsewhere (23). In brief, a total of 17,708 participants were recruited by a multistage probability sampling procedure involving 150 counties or districts and 450 communities within 28 provinces of China at baseline in 2011 with a response rate of 80.5%. Data on sociodemographic and lifestyle behaviors factors and health-related information were collected by about 500 professional interviewers who worked in this field, using a face-to-face computer-assisted personal interview (CAPI) system. All participants were followed up biennially after the baseline survey. In this study, participants aged 50 years and more were included, those with CVD and have missing values on functional status at baseline were excluded, and those having no response regarding their CVD status during the follow-up period were also excluded. The CHARLS was approved by the Biomedical Ethics Review Committee of Peking University (IRB00001052-11015; IRB00001052-11014) and written informed consent was obtained from all participants.

Measures

Assessment of Functional Limitations

Functional limitations at baseline were assessed by the Katz activities of daily living (ADL) scale (24) and the Lawton instrumental activities of daily living (IADL) scale (25). CHARLS asked respondents if they required assistance with any of the six ADLs (dressing, bathing, eating, getting into and out of bed, toileting and controlling urination and defecation) and with any of the five IADLs (preparing a hot meal, shopping for groceries, doing housework, taking medicines and managing money). Each item was divided into four responses as follows: (1) No, I do not have any difficulty, (2) I have difficulty but still can do it, (3) Yes, I have difficulty and need help, and (4) I cannot do it. Participants were scored 0 for responding "no difficulty", (1) for responding "have difficulty but still can do it", (2) for responding "have difficulty and need help", and (3) for responding "cannot do it". The summed score over the six ADL items served as the total score of the ADL scale for a subject, and this ranged from 0 to 18. The summed score over the five IADL items served as the total score of the IADL scale for a subject, and this ranged from 0 to 15. Participants who reported needing any help in any item (score of 2 or 3 in any item) were classified as having ADL or/and IADL limitations, thereafter called functional limitations (26).

Ascertainment of Incident CVD Events and Deaths

The study outcome was incident CVD and death. In accordance with previous studies (27, 28), incident CVD was assessed by asking the following standardized questions based on a self-reported physician's diagnosis: "Have you been diagnosed with

a heart attack, coronary heart disease, angina, congestive heart failure, or other heart problems by a doctor?" or "Have you been diagnosed with a stroke by a doctor?". Participants who reported heart disease or stroke during the follow-up period were defined as having incident CVD. The date of CVD diagnosis was recorded as between the date of last interview and the date of interview when an incident CVD was reported (27). The mortality status from all causes and death date were ascertained by interviewers in each visit. Furthermore, at every interview wave, interviews with earlier respondents were sought. If a respondent's death was reported, the CHARLS team identified a knowledgeable informant (typically a family member) and conducted exit interviews to obtain information about the death (29).

Covariates

Information related to sociodemographic characteristics, health-related factors, depressive symptoms and social participation were collected by trained interviewers using a structured questionnaire at baseline. Precisely, sociodemographic information included age, gender, residential area (urban/rural), marital status and education level. Marital status was classified as married and unmarried (including separated, divorced, widowed and never married). Education level was classified as no formal education, primary school, middle or high school, and college or above. Health-related factors included self-reported smoking status (current/former/never), drinking status (current/former/never), sleep duration (<7h;7–7.9h and ≥8h) and nap duration (<30 min; 30–59 min and ≥60 min).Sleep duration was assessed using a single item, "During the past month, how many hours of actual sleep did you get at night (average hours for one night) (This may be shorter than the number of hours you spend in bed)?". Nap duration was assessed by a single item, "During the past month, how long did you take a nap after lunch?". Self-reported physician-diagnosed medical conditions included diabetes, hypertension and dyslipidemia. Use of medication for hypertension, diabetes and dyslipidemia was also assessed. Depressive symptoms in the past week were assessed at baseline using the 10-items Center for Epidemiologic Studies Depression Scale short form (CESD-10), participants with total score of 12 or higher were defined as having depressive symptoms (30). Participants not participating in any social activities over the last month (e.g. interacting with friends; playing chess or cards; attending a community sports, social or other club; participating in a community-related organization; participating in voluntary or charity work; and attending any educational or training courses) were classified as having low social participation (31). Moreover, anthropometric measurements including height, weight, and blood pressure (diastolic blood pressure and systolic blood pressure) were measured by a trained nurse following standard tools and procedures in CHARLS. Body mass index (BMI) was calculated according to the formula of kg/m^2. Additionally, venous blood sample was collected in CHARLS participants and assayed for fasting plasma glucose (FPG), total cholesterol (TC), triglycerides (TG), high-density lipoprotein cholesterol (HDL-C), low-density lipoprotein cholesterol (LDL-C-), high-sensitivity C-reactive protein and glycated hemoglobin (HbA1c) (32).

Statistical Analysis

Characteristics of the overall sample at baseline were summarized using mean and standard deviation (SD) for normally distributed continuous data, or median and interquartile range for skewed continuous data. Categorical data were summarized as counts and percentages. The chi-square test, student's *t*-test or Mann-Whitney U test were used to compare study sample characteristics at baseline between participants with and without functional limitations. Missing data items, 14.8% (1,631 of 11,013) in the baseline covariates were imputed using the multiple imputation of chained equations. Pooled results were reported based on five imputed data sets, which were created using command "mi estimate" in Stata statistical software version 16.0.

Person-time of follow-up for each participant was calculated from the date of the 2011 baseline survey to the dates of CVD diagnosis, death, loss to follow-up [820 of 11,013 (7.4%)], or end of follow-up (August 31, 2018), whichever came first. Incidence rate of CVD and death per 1,000 person-years were computed according to different functional status. The Cox proportional hazards model was used to assess the association between functional limitations and incident CVD and all-cause mortality. The effect size of this association was computed as the adjusted hazards ratios (HR) with 95% confidence interval (CI) in three models. That is, the association was adjusted for age and gender in model 1, and it was adjusted for age, gender, residential area, marital status, education, smoking, drinking, sleep duration, nap duration and depression symptoms in model 2. Finally, the variables adjusted for in model 2 plus history of diabetes, hypertension, dyslipidemia, use of medication for hypertension, dyslipidemia, diabetes and social participation were adjusted for the association in model 3. In addition, three-knotted restricted cubic spline regression was used to explore the potential non-linear association between functional limitation and CVD as well as all-cause mortality. To examine the possible interaction between functional status and other factors for incident CVD and deaths, subgroup analyses were conducted by stratification according to following factors: age (<60 or ≥60 years), gender, marital status, residential area, educational level, smoking, drinking, sleep duration, nap duration, depressive symptoms, social participation, diabetes (defined as FPG ≥ 126 mg/dL and/or HbA1c ≥ 6.5%, current use of antidiabetic medication, or self-reported history of diabetes), dyslipidemia (defined as TC ≥ 240 mg/dL, TG ≥ 150 mg/dL, LDL-C ≥ 160 mg/dL, HDL-C < 40 mg/dL, current use of lipid-lowering medication, or self-reported history of dyslipidemia) and hypertension (defined as systolic blood pressure ≥ 140 mm Hg, diastolic blood pressure ≥ 90 mm Hg, current use of antihypertensive medication, or self-reported history of hypertension). The *P* values for interactions were calculated using interaction terms and likelihood ratio tests.

We conducted three sensitivity analyses as follows: (1) repeating all analysis using the complete data set (9,382 participants) without multiple imputations; (2) reporting the results after adjusting for BMI, blood pressure, TC, TG, HDL-C, LDL-C, HbA1c and C-reactive protein based on model 3 in the subpopulation of 5,388 participants; (3) using the Fine and Gray competing risk model to account for competing

risks due to mortality when examining the association between functional limitation and incidence of CVD and death (33); and (4) repeating all analysis after excluding participants who had a CVD event within 3 years. Two-sided $P < 0.05$ was considered as statistically significant. All analyses were performed using Stata statistical software version 16.0 (Stata Corp, College Station, Texas, USA) and R statistical software version 4.0.3 (R Foundation).

RESULTS

A total of 17,708 CHARLS participants were available at baseline for sample selection. Of these, 3,730 were excluded for being younger than 50 years, 1,841 for having a heart disease at baseline, 425 for having stroke at baseline, 267 for having missing values on functional status, and 432 were excluded for having no response regarding their CVD during the follow-up period. Finally, 11,013 participants were included in this study for analysis. A comparison of baseline characteristics between the included participants and those not included in the analysis is shown in **Supplementary Table S1**.

Considering the sample included in this study for analysis, the mean (SD) age at baseline was 62.1 (8.6) years, proportion of men was 5,604 (50.9%) and the proportion of those living in rural areas was 6,997 (63.5%). Furthermore, 2,458 (22.4%) participants self-reported that they had hypertension and 17.6% of them had been using antihypertension medication. The prevalence of functional limitations was 14.8% (1630/11013) at baseline. **Table 1** shows the characteristics of participants at baseline according to functional status. Univariate analysis showed that participants who reported functional limitations were more likely to be older, be female, be living in rural areas, have no formal education, have self-reported hypertension, have self-reported diabetes or dyslipidemia, use antihypertension medications, use antidiabetic or lower-lipid medication, never smoke and drink, have depressive symptoms, have low social participation, have shorter sleep duration and higher BMI.

During the follow-up period (mean follow-up period of 6.7 (1.2) years), 1,914 individuals reported incident CVD (heart disease: 1,377; and stroke: 695) and 1,182 individuals died. The incidence rate of CVD was 36.04 per 1000 person-years among the participants with functional limitations, and 25.97 per 1000 person-years among the participants without functional limitations. The incidence of death was 6.33 per 1,000 person-years among the participants without functional limitations, and 14.04 per 1,000 person-years among the participant with functional limitations. After adjusting for potential confounders, participants with functional limitations were associated with a 23% increased risk of incident CVD (HR, 1.23, 95%CI: 1.08, 1.39). Moreover, individuals with functional limitations were associated with a 44% increased risk of incident stroke (HR, 1.44, 95%CI: 1.17, 1.77). However, there was no significant association between functional limitations at baseline and incident heart disease (HR, 1.06, 95%CI: 0.91, 1.24). Also, participants with functional limitations were associated with a 63% increased risk of all-cause mortality after adjusting for potential confounders (HR, 1.63, 95%CI: 1.41, 1.89). The results were shown in **Table 2**.

Similar results were obtained when subgroup analyses were conducted between ADL or IADL limitations and incident CVD and all-cause mortality (**Supplementary Table S2**). In this regard, participants with ADL limitations were associated with a 25 and 105% increased risk of CVD (HR, 1.25, 95%CI: 1.04, 1.50) and all-cause mortality (HR, 2.05, 95%CI: 1.72, 2.46), respectively. On the other hand, individuals with IADL limitations were associated with a 23 and 66% increased risk of CVD (HR, 1.23, 95%CI: 1.08, 1.41) and all-cause mortality (HR, 1.66, 95%CI: 1.43, 1.93), respectively. Further, results of the 3-knotted restricted cubic spline regression model indicated a linear association between ADL and CVD ($P = 0.474$) as well as between IADL and CVD ($P = 0.751$). Similarly, there was a linear association between IADL and all-cause mortality ($P = 0.494$), but there was a positive nonlinear association between ADL and all-cause mortality ($P = 0.044$). The results are presented in **Figure 1**.

Also, results on the possible interaction between functional status and other factors for incident CVD and all-cause mortality showed that there was no significant interaction between functional limitations and potential risk factors for incident CVD and all-cause mortality (**Figure 2** shows the details). Similarly, complete data analyses for a subpopulation of 9,382 participants (**Supplementary Table S3**) did not change the earlier found results on the association between functional limitations and incident CVD and all-cause mortality. Likewise, these results did not significantly change after adjusting for BMI, blood pressure, FPG, TG, TC, HDL-C, LDL-C, HbA1c and C-recreative protein in a subpopulation of 5,388 participants (**Supplementary Table S4**). Sensitivity analysis excluding participants who had a CVD event within 3 years of follow-up showed that the associations between functional limitations and the risk of CVD and all-cause mortality were unchanged (**Supplementary Table S5**). In addition, people with functional limitations were associated with a 20% increased risk for incident CVD, after adjusting for potential confounders, when using the Fine and Gray model with death as competing risk event (**Supplementary Table S6**).

DISCUSSIONS

Based on a nationally representative sample, we longitudinally examined the association between functional limitations and incident CVD and all-cause mortality, among the Chinese adults aged at least 50 in China, during 7 years of follow-up. The prevalence of functional limitations was 14.80% at baseline. Moreover, functional limitations were associated with a 23 and 63% increased risk of CVD and all-cause mortality, respectively.

There has been growing evidence suggesting that the presence of functional limitations is associated with increased risk of CVD and mortality. For example, the Cardiovascular Health Study demonstrated that limitations in ADL modified the association of blood pressure with CVDs and deaths. That is, among people with ADL limitations, a high systolic blood pressure remained associated with higher risk of incident CVD, whereas the association of diastolic blood pressure with CVD was inverted (34). A prospective cohort study conducted by Tsuji et al. demonstrated that the Japanese adults aged at least 65 with

TABLE 1 | Characteristics of participants at baseline according to functional status.

Characteristics	Total sample (n = 11,013)	functional limitations		P value[a]
		Yes (n = 1,630)	No (n = 9,383)	
Age, years	62.1 (8.6)	67.2 (10.3)	61.2 (7.9)	<0.001
Male	5,604 (50.9)	668 (41.0)	4,936 (52.6)	<0.001
Rural residence	6,997 (63.5)	1,184 (72.6)	5,813 (62.0)	<0.001
Married	9,408 (85.4)	1,231 (75.5)	8,177 (87.1)	<0.001
Education level[b]				
No formal education	5,687 (51.7)	1,190 (73.1)	4,497 (48.0)	<0.001
Primary school	2,326 (21.1)	239 (14.7)	2,087 (22.3)	
Middle or high school	2,801 (25.5)	189 (11.6)	2,612 (27.9)	
College and above	184 (1.7)	10 (0.6)	174 (1.9)	
Self-reported chronic conditions[b]				
Hypertension	2,458 (22.4)	462 (28.6)	1,996 (21.3)	<0.001
Diabetes	536 (4.9)	118 (7.3)	418 (4.5)	<0.001
Dyslipidemia	812 (7.5)	141 (8.9)	671 (7.3)	0.020
Use of medication[b]				
Antihypertension	1,925 (17.6)	381 (23.6)	1,544 (16.5)	<0.001
Antidiabetic	380 (3.5)	83 (5.1)	297 (3.2)	<0.001
Lipid-lowering medication	448 (4.1)	90 (5.7)	358 (3.9)	0.001
Smoking				
Never	6,717 (61.0)	1,087 (66.7)	5,630 (60.0)	<0.001
Former	929 (8.4)	153 (9.4)	776 (8.3)	
Current	3,367 (30.6)	390 (23.9)	2,977 (31.7)	
Drinking				
Never	7,396 (67.2)	1,185 (72.7)	6,211 (66.2)	<0.001
Former	705 (6.4)	151 (9.3)	554 (5.9)	
Current	2,912 (26.4)	294 (18.0)	2,618 (27.9)	
Depression symptoms[b]	2,684 (27.9)	682 (52.9)	2,002 (24.0)	<0.001
Low social participation[b]	5,310 (51.8)	918 (63.2)	4,392 (49.9)	<0.001
Sleep duration [b]				
<7 h	5,247 (51.6)	832 (58.3)	4,415 (50.5)	<0.001
7–7.9 h	1,879 (18.5)	178 (12.5)	1,701 (19.5)	
≥8 h	3,043 (29.9)	418 (29.3)	2,625 (30.0)	
Nap duration[b]				
<30 min	4,994 (48.8)	696 (48.2)	4,298 (48.9)	0.119
30–59 min	895 (8.7)	109 (7.5)	786 (8.9)	
≥60 min	4,344 (42.5)	640 (44.3)	3,704 (42.1)	
Body mass index (kg/m^2)[c]	22.96 (3.55)	22.64 (3.42)	23.00 (3.57)	0.010
Blood pressure, mm Hg[c]				
SBP	132.36 (22.67)	132.00 (21.55)	132.41 (22.83)	0.648
DBP	75.91 (11.89)	75.84 (11.85)	75.91 (11.90)	0.076
Metabolic biomarkers[c]				
FPG, mg/dL	110.35 (35.10)	110.55 (36.65)	110.33 (34.86)	0.876
TC, mg/dL	194.26 (38.56)	193.87 (39.58)	194.32 (38.41)	0.773
TG, mg/dL	129.92 (94.07)	126.55 (84.97)	130.43 (95.36)	0.307
HDL-C, mg/dL	51.71 (15.55)	52.44 (16.34)	51.60 (15.43)	0.200
LDL-C, mg/dL	117.06 (35.44)	116.24 (35.43)	117.18 (35.45)	0.511
HbA1c, %	5.28 (0.81)	5.28 (0.83)	5.27 (0.81)	0.928
C-reactive protein, mg/L	1.08 (1.68)	1.08 (1.65)	1.14 (2.13)	0.156

Data were presented as n (%) or mean (standard deviation) or median (interquartile range). [a]P values were obtained according to the chi-square test, student's t-test or Mann-Whitney U-test. [b]Missing values: 15 for education; 47 for hypertension; 82 for diabetes; 194 for dyslipidemia; 47 for antihypertension medication; 82 for antidiabetic medication; 194 for lipid-lowering medication; 1,365 for depressive symptoms; 753 for social participation; 844 for sleep duration; and 780 for nap duration. [c]Measured in subgroups of 5,388 participants. SBP, systolic blood pressure; DBP, diastolic blood pressure; FPG, fasting plasma glucose; TC, total cholesterol; TG, triglycerides; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; HbA1c, glycated hemoglobin.

TABLE 2 | Incidence rate of CVD and all-cause mortality according to functional status.

Outcome	Cases, No.	Incidence rate, per 1,000 person-years	HR (95%CI)		
			Model 1[a]	Model 2[b]	Model 3[c]
CVD (n = 1,914)					
Functional limitation					
No	1,570	25.97	1.00 [Reference]	1.00 [Reference]	1.00 [Reference]
Yes	344	36.04	1.30 (1.15,1.47)	1.29 (1.14,1.47)	1.23 (1.08,1.39)
Heart disease (n = 1,377)					
Functional limitation					
No	1,153	18.23	1.00 [Reference]	1.00 [Reference]	1.00 [Reference]
Yes	224	33.34	1.13 (0.97,1.31)	1.12 (0.96,1.31)	1.06 (0.91,1.24)
Stroke (n = 695)					
Functional limitation					
No	553	8.83	1.00 [Reference]	1.00 [Reference]	1.00 [Reference]
Yes	142	14.29	1.56 (1.29,1.89)	1.54 (1.26,1.89)	1.44 (1.17,1.77)
All-cause mortality (n = 1,182)					
Functional limitation					
No	408	6.33	1.00 [Reference]	1.00 [Reference]	1.00 [Reference]
Yes	774	14.04	2.06 (1.81,2.34)	1.68 (1.45,1.94)	1.63 (1.41,1.89)

HR, hazards ratio; CI, confidence interval; CVD, cardiovascular disease. [a]adjusted for age and gender. [b]adjusted for age, gender, residential area, marital status, education level, smoking, drinking, sleep duration, nap duration and depression symptoms. [c]adjusted for variables adjusted for in model 2 plus history of diabetes, hypertension, dyslipidemia, use of medication for hypertension, use of medication for dyslipidemia, use of medication for diabetes and social participation.

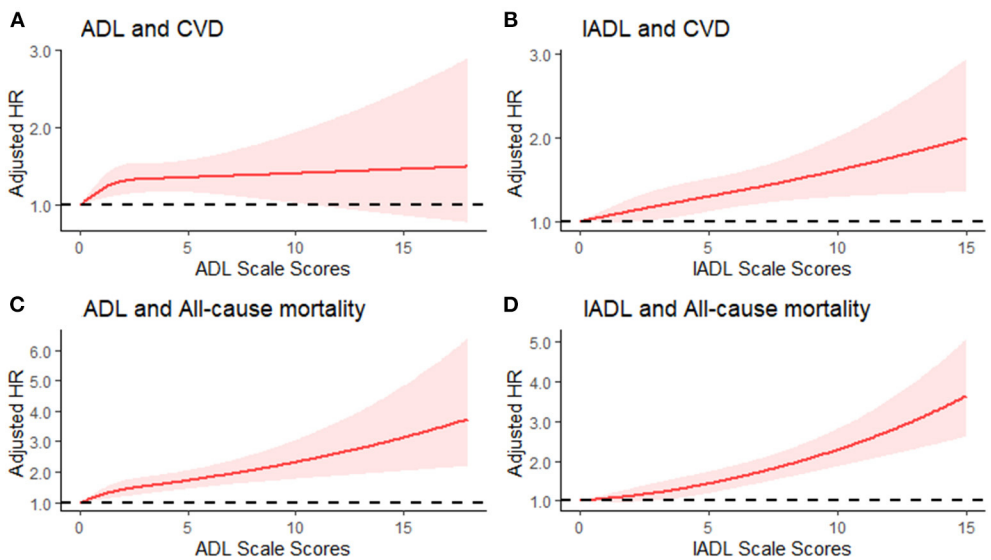

FIGURE 1 | Adjusted Hazard Ratio (HRs) of cardiovascular disease and all-cause mortality according to ADL and IADL scale score. **(A)** Adjusted HRs for association between ADL score and CVD; **(B)** Adjusted HRs for association between IADL score and CVD; **(C)** Adjusted HRs for association between ADL score and all-cause mortality; **(D)** Adjusted HRs for association between IADL score and all-cause mortality.

ADL limitations were significantly associated with increased risk of stroke and its mortality, and their limitation in ambulatory activity was significantly associated with increased risk of heart disease mortality (35). Similarly, a large cohort study conducted in the United States demonstrated that functional limitations were powerful independent predictors of mortality among older participants aged at least 80 (36). Moreover, in the older Dutch population, a 15-year follow-up cohort study showed that functional limitations were significant predictors of all-cause mortality (37).

Although the association between functional limitations and incidence of CVD and all-cause mortality was statistically significant in this study, the hazards ratio continuously declined from model 1 to model 3, suggesting that lifestyle behaviors,

	A. Cardiovascular disease		B. All-cause mortality	
Factor	HR(95%CI)	*P* value for interaction	HR(95%CI)	*P* value for interaction
Age		0.796		0.200
<60 years	1.24(0.99,1.56)		2.32(1.59,3.39)	
⩾60 years	1.23(1.05,1.43)		1.53(1.31,1.79)	
Gender		0.861		0.614
Male	1.20(0.97,1.49)		1.67(1.37,2.02)	
Female	1.23(1.04,1.44)		1.56(1.24,1.95)	
Living residence		0.251		0.687
Rural	1.15(0.98,1.35)		1.59(1.34,1.89)	
Urban	1.40(1.12,1.76)		1.73(1.30,2.30)	
Marital status		0.876		0.262
Married	1.22(1.06,1.40)		1.72(1.44,2.04)	
Unmarried	1.26(0.93,1.69)		1.47(1.13,1.92)	
Education level		0.091		0.069
Primary school and below	1.17(1.02,1.35)		1.34(1.10,1.62)	
Middle school and above	1.49(1.11,2.01)		2.04(1.52,2.72)	
Smoking		0.804		0.763
Never	1.21(1.03,1.43)		1.69(1.37,2.08)	
Former	1.19(0.80,1.77)		1.78(1.22,2.59)	
Current	1.24(0.96,1.61)		1.46(1.13,1.87)	
Drinking		0.421		0.268
Never	1.27(1.09,1.47)		1.53(1.27,1.84)	
Former	1.13(0.83,1.55)		1.44(1.05,1.98)	
Current	1.03(0.67,1.65)		2.85(1.85,4.39)	
Depression symptoms		0.982		0.488
Yes	1.22(1.02,1.46)		1.74(1.39,2.18)	
No	1.21(1.00,1.46)		1.54(1.24,1.92)	
Social participation		0.496		0.052
Low	1.32(1.08,1.60)		1.56(1.26,1.94)	
High	1.17(0.99,1.39)		1.77(1.41,2.21)	
Sleep duration		0.373		0.687
<7 h	1.32(1.12,1.56)		1.93(1.24,2.99)	
7-7.9 h	1.07(0.74,1.57)		1.55(1.27,1.89)	
⩾8 h	1.12(0.87,1.44)		1.72(1.33,2.22)	
Nap duration		0.130		0.487
<30 min	1.26(1.04,1.52)		1.65(1.31,2.07)	
30-59 min	1.40(0.89,2.21)		1.54(1.25,1.90)	
⩾60 min	1.13(0.93,1.37)		2.52(1.50,4.23)	
Diabetes		0.191		0.570
Yes	1.28(1.11,1.47)		1.99(1.40,2.82)	
No	1.03(0.76,1.43)		1.56(1.33,1.84)	
Hypertension		0.825		0.258
Yes	1.24(1.04,1.46)		1.73(1.40,2.14)	
No	1.23(1.01,1.50)		1.56(1.27,1.91)	
Dyslipidemia		0.391		0.842
Yes	1.25(1.04,1.49)		1.65(1.38,1.96)	
No	1.19(0.98,1.45)		1.58(1.19,2.08)	

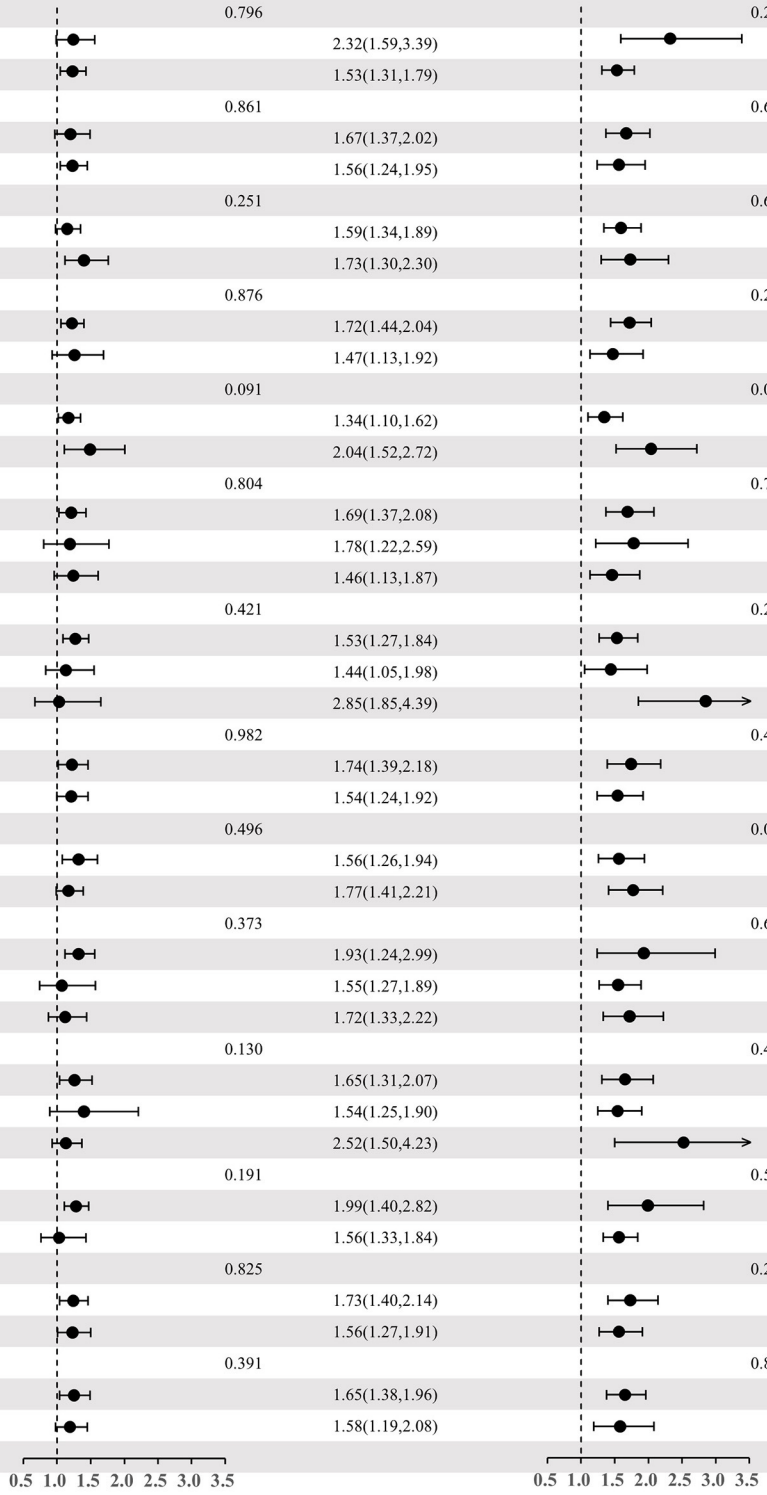

FIGURE 2 | Association between functional limitation and risk of cardiovascular disease and all-cause mortality stratified by different factors. **(A)** Adjusted HRs for association between functional limitation and CVD; **(B)** Adjusted HRs for association between functional limitation and all-cause mortality.

emotional problems, chronic conditions, and social participation might have played a significant role in mediating the association between functional limitations and the risk of CVD and all-cause mortality. However, the underlying mechanisms in such a "black box" are complex and multifactorial. In terms of biological mechanisms, the functional limitations tended to be the consequence of physiological changes associated with aging (38). Using three clinical-biomarker-algorithm methods, older adults with more advanced biological aging reported dependence in more ADLs and IADLs, and were at increased risk of death (39). Growing evidence has also supported the hypothesis that aging is accompanied by impairments in heart (40), vascular structure and functioning (41), which may further lead to increase in the risk of CVD and mortality (42). Thus, functional limitations and CVD are highly interconnected and may share common biological pathways. Furthermore, from a social psychological point of view, disability in late life has been associated with increased dependence and loss of autonomy. Functional limitations among the elderly have also often been accompanied with reduced likelihood of social activities and social contact (43, 44). Additionally, functional limitations may be associated with worse relationship with offspring due to the fact that increased dependence of parents with functional limitations on help may go beyond the routine support; hence may cause more friction between them and their children or caregivers (45). Also, older adults with physical functional limitations were at higher risk of depressive symptoms, anxiety symptoms and suicidal ideation (46, 47). Functional limitations are often accompanied with depression and may evoke inflammation, platelet activation and thrombosis, and autonomic nerve dysfunction (48). All of these were potential risk factors for stroke (49) and myocardial ischemia (50), hence may increase the risk of mortality (51). Undoubtedly this is an important pathway to the delay or development of CVD and death. As regards behavioral factors, people with functional limitations in ADLs or IADLs were more likely to report smoking (52), lower level of physical activity (53), and lower sleep efficiency or irregular sleep (54), which in turn are risk factors for CVD and all-cause mortality (55, 56).

Further, the substantial prevalence of functional limitations, among the middle-aged and older adults in this study, underscores the importance of interventions aimed at prevention and control of CVD incidences in this group. These may include physical therapy or physical activity interventions for improving underlying impairments in physical abilities (57).

The main strength of this study is that it used a representative sample, and examined the outcome variables of interest in a considerably longer period of followed-up time (7 years). Therefore, adequate information was collected for the purpose of this study. Besides, a wide range of potential confounders were taken into account to control confounding bias and clearly understand the association between functional limitations and incident CVD and all-cause mortality. Also, the application of sensitivity analyses presented a more complete picture of the association between functional limitations and incident CVD and death. Specifically, sensitivity analyses showed that the result were stable and hence more reliable. Despite the foregoing strengths of this study, several potential limitations need to be acknowledged. First, the occurrence of CVD and death were self-reported because medical records were not available in the CHARLS. However, there has been a high agreement between self-reports and medical records of the elderly with cardiovascular diseases (58). Second, functional limitations were self-reported, which could exaggerate its prevalence in the sample. However, the ADL scale and IADL scale are the most frequently used self-reported questionnaires in the measurement of disability in the elderly (59). Third, there may be a bidirectional effect between functional limitations and CVD, but the subsequent impact of CVD on the functional limitations was not clarified in this study. Fourth, some potential covariates of the association between functional limitations and CVD and all-cause mortality, such as income (60), social isolation (61) and physical activity (62) were not considered in this study due to dataset limitations. Finally, only participants from China were involved in this study, thus the findings may not apply to populations of other countries.

CONCLUSIONS

This study found that functional limitations among the Chinese middle-aged and older adults were significantly associated with incident CVD and all-cause mortality. Prevention and control of functional limitations maybe a potential way to reduce the risk of CVD and death.

DATA AVAILABILITY STATEMENT

CHARLS data are available at http://charls.pku.edu.cn/pages/data/111/zh-cn.html. The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author/s.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Biomedical Ethics Review Committee of Peking University. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

ZH and HX designed the study. ZH and BZ wrote and revised the manuscript. FZ conducted the analyses and prepared **Figure 2**. AK edited the manuscript. All authors reviewed the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2022.751985/full#supplementary-material

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How Has the Nationwide Public Health Emergency of the COVID-19 Pandemic Affected Older Chinese Adults' Health Literacy, Health Behaviors and Practices, and Social Connectedness? Qualitative Evidence From Urban China

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Older Chinese adults' daily lives have been affected significantly during the outbreak phase of the COVID-19 pandemic since January 2020. They were confronted with activity restrictions due to strict pandemic prevention. The older population also had to get accustomed to widely-used modern technologies in community management, such as health codes and WeChat groups. By late 2021, mainland China had reduced the prevalence of COVID-19, and people's daily lives had primarily returned to pre-pandemic normality. Under China's systematic health management during the pandemic, older Chinese adults' responses to this nationwide public health emergency may have influenced their health in the long run. However, it remains unclear what specific health changes or improvements have occurred. Such a void in the literature is worrying, given that older adults are at high health risks due to the pandemic which, might still be with humankind for a while. Thus, it is of necessity to explore and report their health changes after this official, large-scale health intervention. In this study, 17 adults aged 55 and above were recruited as interviewees. All interviewees reside in a community located in Q district, N city of the People's Republic of China. According to the findings, many interviewees now have better literacy in health risk prevention. Information and Communication Technologies (ICTs) play a significant role in getting access to health information. Specifically, television, WeChat chatting groups, and TikTok could be valuable information sources for older adults. As for the understanding and evaluation of health information, although older participants can distinguish COVID-19 rumors, they may sometimes feel confused about the underlying scientific logic. Regarding changes in health behaviors and practices, many older adults can integrate health information and

knowledge into their daily lives. Additionally, although interviewees can keep important social connections, not all of them are familiar with using new ICTs, such as online chatting group, for social participation and engagement. The empirical evidence suggests that both the communities and the local governments can offer specific training programs to older residents for the sake of enhancing their health literacy, health behaviors and practices, and social connectedness during and after the pandemic.

Keywords: COVID-19, older Chinese adults, health literacy, health behaviors and practices, social connectedness, semi-structural interviews

BACKGROUND

Older adults are particularly vulnerable during the COVID-19 pandemic (1, 2). Even though the virus has affected all age groups, recent data show that the senior population has the highest mortality rates. In the initial stages of the pandemic, older adults' mortality rates in China, Western Europe, the United Kingdom, Canada, and the United States were eight to 62 times higher than adults 55 years and younger. Those aged 65 and above were found to have the highest mortality rate (3). Data show that, in the United States, COVID-19 deaths in 2020 totalled around 380,000, with approximately 80% aged 65 and above (4). Accordingly, Americans' life expectancy at age 65 drops by 0.75–0.94 years in the best and worst scenarios, respectively (5). These indicate glaring mortality disparities due to age. Besides fatalities, health challenges facing the aged have been well documented. Although there is some disagreement in the literature–a few experts found, for instance, that older adults were not negatively affected in terms of some specific health outcomes such as anxiety, stress, and depression [see (6, 7)]–plenty of other studies have demonstrated the opposite. A systematic research review found that mental health issues such as anxiety and depression commonly affected older adults during the COVID-19 lockdown (8). A certain proportion of older adults reported worse health behaviors compared to the pre-pandemic period (9). Other worrying global trends have been reported, including less exercising or inactivity (10, 11) and malnutritional behaviors (12–14). The COVID-19 crisis thus calls for urgent academic attention to underlying pathological and social factors contributing to the ways that older adults are confronted with possible health issues due to the pandemic. Additionally, in the Chinese context, existing studies have explored people's coping strategies toward pandemic risks, such as doing exercises at home and contacting community workers via online services (15, 16). However, more comprehensive research is needed to detect how older Chinese responded to the pandemic, and whether and how the pandemic has affected older Chinese's health literacy, health behaviors and practices, as well as social connectedness. Relevant explorations are crucial to understanding health situations facing older Chinese under COVID-19 and are thus essential to policymaking.

Abbreviations: CCTV, China Central Television; ICTs, Information and Communication Technologies; NHC, National Health Commission of the People's Republic of China; WHO, World Health Organization.

Underlying Pathological Causes Leading to Older Adults' High Mortality Due to COVID-19

Existing pathological investigations have identified both immunosenescence and comorbidity as underlying reasons that can lead to older adults having higher likelihoods of being affected by COVID-19. Immunosenescence is defined as a functional decline in an individual's immune system due to aging (17). Napoli et al. (18) reported that the destructive effect of COVID-19 on older adults could be exacerbated by immunosenescence. Similarly, Sun et al. (19) researched older Chinese residing in Wuhan and identified that immunosenescence is a significant cause of their pneumonia. Accordingly, Brooke and Fahy (20) have proposed reversing immunosenescence as a means of COVID-19 prevention.

Comorbidity is another core mechanism that results in disproportionally high mortality within the older population (21). Sanyaolu et al. (22) reviewed related research and found that hypertension and diabetes aggravate the severity of COVID-19. Likewise, Sharma (23) modeled COVID-19 mortality among Americans and found that obesity and hypertension are both potential triggers accelerated by age. Additionally, a meta-analysis conducted by Wang and associates (24) supports the notion that comorbidity is an underlying cause of COVID-19 mortality; therefore, diagnosed patients should pay attention to comorbidities, including "hypertension, diabetes, chronic obstructive pulmonary disease, cardiovascular disease, and cerebrovascular disease" (p. 6056).

Social Factors Contributing to Health Problems Facing Older Adults During the COVID-19 Pandemic

Besides pathological causes, social factors that contribute to older adults' health problems during the pandemic have also been well investigated. Although social distancing and quarantining have been implemented for pandemic prevention in many countries and regions, these required regulations may lead to social disconnectedness and isolation, especially for older adults (7, 25, 26). Under the pandemic context, existing research has shown that many older adults develop mental health issues as indicated by the co-occurrence of depressive symptoms (27, 28), affective disorder and suicide intentions (26), and other psychological concerns (29–31). Mata et al. (32) explored longitudinal data focusing on the daily lives of Germans

during the pandemic; results indicate that health-promoting behaviors including less screen time, healthier food intake, and more exercising can improve people's mental health, including older adults.

Lack of financial support (33, 34) and health and medical resources (35) have been argued to be critical contributors to health risks and problems facing older adults during the pandemic. Many older adults have been economically challenged due to job market shrink. They are confronted with a reduced income or a shortage of other financial support. Scholars, therefore, warned of the urgency to focus on older adults living under disadvantaged economic conditions, such as poverty and food insecurity (29, 34). Unequal access to health resources due to geographic divides may also lead to disparities in health outcomes among the aged. For example, Henning-Smith (36) indicated that older adults residing in rural areas have fewer healthcare facilities compared to their urban counterparts. From a global perspective, scholars have also emphasized older adults living in less developed countries and regions because they lack necessary medical and life resources (37–39).

Older Adults' Coping Strategies in Daily Health Practices Toward the Pandemic

Although older adults are at high risks of being negatively affected by the COVID-19 pandemic, mainly due to pathological and social factors (19, 33, 35), they may have the agency to develop resilience and coping strategies against the public health crisis (40). Chen and associates (15) interviewed 15 close contacts of diagnosed COVID-19 patients about their feelings and coping mechanisms at different stages of quarantine. Their interviewees actively used a couple of coping strategies, such as distraction strategies and keeping optimistic, throughout quarantine. Despite these crucial findings, interviewees recruited were aged between 18 and 60; there was no focus on the older population. Another important study was done by Yang and associates (16). The researchers interviewed 18 older adults aged 65 and above to investigate their experiences during the lockdown in 2020 in Wuhan. They found that older adults developed coping strategies, such as doing exercises at home and actively followed community management and government governance. Also, social support from families, communities, and the local government were crucial resources for older adults. Another remarkable finding is that older adults were able to use online chat groups or online platforms to order food and drugs and use online doctor services for health consultations. Despite these vital findings, further explorations are needed. Specifically, for instance, although the authors indicated that older adults used the internet to get updated pandemic information, no more details have been detected regarding the role of Information and Communication Technologies' (ICTs) use in this regard. Also, the research did not explore whether older adults were able to understand and evaluate key health information which is, however, important for making health decisions. Additionally, changes and improvements in older adults' health behaviors and practices after the first-wave pandemic remain unclear.

The Chinese Context of Pandemic Governance

China has a clear timeline regarding the outbreak and development of the COVID-19 pandemic. As He, Shi and Liu (41) reported, China's domestic outbreak can be traced to December 2019 in Wuhan, Hubei Province. The human-to-human transmission was confirmed 11 days after the first death occurred on January 9, 2020; Wuhan was timely locked down three days after this confirmation. On April 8, 2020, China ended Wuhan's lockdown.

China has been exerting a "tough model" (42) targeting pandemic prevention at a macro level. Community mobilization during the pandemic was strictly regulated. Notably, China implemented rapid and concrete measures, including carrying out strict community mobilization registration, advocating mask-wearing and other effective preventive measures as crucial health information, building field hospitals (41), and promoting vaccine research (43). Some policies were implemented on the national scale during and after the Wuhan lockdown, such as using health QR codes for mobility identification[1] and vaccine immunization. China's grid-style social management[2] in every community assisted in community governance (41, 46, 47). Firm government control and concrete policy implementation have efficiently controlled the first-wave pandemic in China (48).

The Current Study

The current study fills two literature gaps. First, under China's strict pandemic management, on the individual level, little is known about how the Chinese have waded through the pandemic and whether this public crisis has brought any changes to their health. Accordingly, this work uses the conceptual tool of "health literacy" for further explorations. In the 1970s, Simonds (49) put forward the concept of "health literacy," highlighting the importance of health education as social policy for America's K-12 system. In 1998, the World Health Organization (WHO) defined health literacy as "the cognitive and social skills which determine the motivation and ability of individuals to gain access, understand and use information in ways which promote and maintain good health." [See (50), p.264]. Health literacy can thus be seen as an individual's asset (51). Sørensen et al. (52) further put forward four dimensions of health literacy: access, understanding, appraisal, and application of health information. Getting access to health information and adjusting health behaviors have been argued as effective coping strategies during the pandemic quarantine (15, 16). Additionally, more comprehensive dimensions of older adults' access to health

[1]Health QR codes are used for identifying people's daily routine and health status. A colored code is attached to widely-used apps, such as Alipay. Green refers to (1) not a close contact, (2) no travelling to medium or high-risk areas, (3) no COVID-19 symptoms, and thus (4) health.

[2]Grid-style social management is a way of social management in China. According to Cai (44), an administrative district is normally divided into several segments (grids), and each segment is assigned to a "designated person" (para. 2), aka grid manager, whose working contents and responsibilities mainly concentrate on collecting information of their assigned segment and regularly submitting information to the "next higher level of authority." (para. 3). Grid-style social management works efficiently in disease prevention and control during the pandemic (45).

information, their understanding and evaluation of health information, as well as using health information as primarily indicated by any changes and improvements in health behaviors, yet remain unknown. It is also unclear how the pandemic has affected older adults' social connectedness. However, keeping socially connected is crucial for older adults' health maintenance through obtaining necessary health information and achieving a wide range of support from families, friends, and neighbors (53). Hence, the current study aims to contribute to related literature by addressing the research concerns of whether and how the COVID-19 pandemic has affected older adults' health literacy, health behaviors and practices, and their social connectedness. The roles of national and community policies have also been taken into account as macro- and meso-level contexts.

The other literature gap is that not many academic efforts focusing on the Chinese context are qualitative. Two of the very few qualitative studies exploring Chinese people's involvement, experiences, and coping strategies under the pandemic were conducted by Chen and associates (15) and Yang and colleagues (16). This dearth in the literature results in little known about older Chinese adults' actual life experiences and feelings related to the pandemic. Accordingly, this work uses semi-structured interviews to detect older adults' lives during the pandemic through a qualitative lens.

METHODS

Data Collection

This study uses semi-structural interviews. The research team collected data in a demolition and resettlement community located in Q District, N city, the People's Republic of China. The author held training sessions for six research assistants who helped collect data. The interviews were done in April 2021. In total, 17 adults who have lived in the community for years and aged 55 and above were recruited with the assistance of a community leader.

The interview outline includes six sections. The first and last sections have questions on interviewees' essential demographic and socioeconomic background, including age, gender, educational attainment, employment, and living arrangements. Also, as previous studies explored, older adults with health problems may have been affected more severely compared to their healthy counterparts (22, 24). Therefore, the second section is about health status, including interviewees' self-rated health and diagnosed chronic diseases. In the third section, interviewees were asked about their perceptions of this pandemic, including their feelings about daily governance by communities and governments. In the fourth and fifth sections, interviewees were asked about their health literacy, including access to essential health information, how they understand and evaluate pandemic rumors, and their application of health information. Interviewees' health behaviors and practices before and after the first-wave pandemic, including daily exercising, smoking, drinking, handwashing, mask-wearing, and ventilation, were considered important aspects of applying health information. Interviewers also asked about whether and how older adults' social connections have changed since maintaining social connectedness helps the aged in health management (54).

Although the interview outline is somewhat structured, interviewees were encouraged to recall and tell their authentic experiences and feelings. Interview questions consider participants' demographic and socioeconomic backgrounds, individual experiences, and community management; this aims to provide relatively panoramic life experiences of older participants under the pandemic and ensure the validity of research findings (55). All participants were interviewed based on the same interview guide.

Data Analysis

The author rigorously conducted data analysis by taking the following steps. First, all interview records were transcribed into text files. The author then read transcripts several times to get familiar with the data. A Microsoft Word keyword search was used search during the reading process. Notably, because the accuracy of automatic transcription was affected by dialects, the author carefully compared interview audios and transcripts to avoid any possible misinterpretations. Because this study has specific research topics, the interview outline is to a degree structured; thus, interview transcripts can be categorized into themes regarding older adults' health literacy, health behaviors and practices, and their social connections. Further, the author reread transcripts and then used a word search and MAXQDA software program to generate subthemes through coding line by line, including "getting access to health information using traditional ICTs," "getting access to health information using new ICTs," "health practices that are relatively easy to develop," "health behaviors that are difficult to change," and "using new ICTs to maintain social connections." These subthemes are closely related to the research concerns and were widely reported by the interviewees so that they can sufficiently cover the qualitative data that have been collected. Finally, a research assistant separately read all transcripts and checked themes and subthemes generated by the author and interviewees' quotes that are featured in this paper. The author and the assistant reached a consensus after discussions.

Research Ethics

This study highlights the application of research ethics. The Psychology Department at the School of Social and Behavioral Sciences of Nanjing University gave ethical approval for the current research, and the approval code is NJUPSY202106001. The interview began with clarifying interviewees' rights, including quitting the interview whenever they wanted. All interviews and discussions are reported anonymously to protect interviewees' privacy and other personal interests. Also, the author paid all interviewees for their participation and contributions.

RESULTS

Table 1 presents the demographic characteristics and self-rated health of the interviewees. In the interviews, 17 older adults aged between 55 and 74 years were recruited. Their average age is

TABLE 1 | Demographic characteristics, self-rated health, and diagnosed chronic diseases of interviewees aged 55 and above, $N = 17$.

	N	Mean or %
Age		63.59 years
Below 60	4	23.53%
60–69 years	11	64.71%
70 years and above	2	11.76%
Gender		
Female	8	47.06%
Male	9	52.94%
Educational attainment		
Below middle school	3	17.65%
Middle school	6	35.29%
High School	8	47.06%
Employment		
Retired	10	58.82%
Part-time	2	11.76%
Employed	5	29.41%
Living arrangements		
Living with partners	16	94.12%
Living with partners, children, and grandchildren	1	5.88%
Self-rated health		
Average	1	5.88%
Good	11	64.71%
Very good to excellent	5	29.41%
Diagnosed chronic diseases[a]		
Yes	15	88.24%
No	2	11.76%

[a]*Diagnosed chronic diseases, such as hypertension, cardiac diseases, hyperglycemia, and osteoporosis, are common among older Chinese people (56).*

63.59 years, and most interviewees (64.71%) are between 60 and 69. Nine of the interviewees are male. As for their educational attainment, three (17.65%) are below middle school, and the rest have middle school or high school degrees. Interviewees' educational backgrounds may help facilitate their use of ICTs, such as televisions and the internet, to access helpful health information during the pandemic. More than half (58.82%) of the interviewees are retired; two of the rest are doing part-time jobs, and five are formally employed. All of the interviewees live with their partners, one of whom live with her adult children and grandchildren. None of them live alone. Regarding self-rated health, most reported that they were currently in good health status (64.71%), and none of them reported poor health. As stated, 88.24% of the interviewees have chronic diseases. But as rated and reported by the interviewees, these diseases do not heavily affect their daily lives. **Appendix 1** presents detailed information on each interviewee's demographic background and self-rated health.

This study mainly focuses on older adults' health literacy, health behaviors and practices, and social connectedness. Health literacy includes their access to, and understanding, evaluation, and use of health information. The use of health information is reflected by changes and improvements in health behaviors and practices in daily life. Social connections are also important sources for gaining essential health support, such as health information and emotional support. To preface research findings, results first indicate that ICTs have become an efficient method for their access to health information. Also, interviewees were able to evaluate pandemic rumors as false information, but they may not understand the underpinning scientific logic. Notably, some older participants strategically applied related information to daily life practices, as indicated by some clear improvements in health behaviors and practices. But some participants showed no differences in their health literacy, health behaviors, and health practices after the major wave of the pandemic compared to their pre-pandemic statuses. Moreover, interviewees maintained social connectedness to receive emotional and social support and kept themselves updated on health information and pandemic news.

The Access to Crucial Health Information: The Role of Traditional and New ICTs

Access to key health information is one significant dimension of health literacy (50–52). The research results show that ICTs play a crucial role in helping older participants obtain health information, improving their health literacy. Traditional media, such as broadcast and television, still plays a crucial role in information access. "*We got to know [pandemic] information through radio broadcast and community advocation. We wore masks when we went outside, and we didn't go to crowded places.*" (N5, male). Compared to the radio broadcast, television is more widely reported as a way of getting health information. "*I [created] my WeChat [account] recently, but I don't know how to use it. … I watched television and got to know the pandemic information.*" (N1, female). Likewise, as another interviewee said, "*We got to know health information via television. For instance, television channels often broadcasted pandemic news, so we were able to know what was going on and what to do.*" (N3, female). This interviewee trusts China Central Television (CCTV), China's state television channel, and the provincial television channels as primary information sources. Similarly, official television news represents authority to some older adults who do not trust new media platforms but wish to know factual pandemic news. For example, a male interview (N16) said, "*Television is the best way to get access to health information. I watch television every day. Cellphone [news] is another way, but it is sometimes correct and sometimes incorrect. [But] news on television channels, CCTV or local official channels must be correct.*"

The internet and some new communication methods, such as WeChat instant chatting group, have emerged as another powerful method for many but not all older adults. "*I watch online news via the channel of Tou'tiao (Headline, a Chinese e-news platform) every day. I also got to know pandemic information via community WeChat groups.*" (N14, female). Also, according to interview transcripts, WeChat instant chatting group is widely accepted and welcomed by many interviewees. The main reason is that, in this way, older residents can get to know about pandemic news and community policies concerning pandemic governance in a timely manner. Some older adults have also used some other new media platforms, such as TikTok, showing a

consistency with prior research, which indicates that many older Chinese have begun to use new ICTs (57, 58). An interviewee said that she has gotten used to learning body mechanics and accessing pandemic prevention information on TikTok (N6, female). Similarly, another interviewee (N3, female) reported that she sometimes watched short videos regarding pandemic prevention (e.g., mask-wearing and handwashing related) on TikTok. Moreover, one interviewee (N17, male) reported that, besides television channels and WeChat groups, he has also begun using smart speakers to get health information. As the interviewee said, "*I ask the smart speaker to give me the current pandemic situation, and it can respond to me immediately.*"

Understanding and Evaluating Health Information: How Did Older Participants Treat COVID-19 Rumors?

Two interview questions about prevalent COVID-19 rumors were included in the outline to detect how older adults understand and evaluate health information. The first question is, "whether you have heard the news that shuang'huang'lian oral liquid (a traditional Chinese patent medicine[3]) can prevent or cure COVID-19, and whether you believe it or not." Some interviewees said that they do not trust such statements, "*[Although] I've heard about this statement, I think it is not reliable. I don't trust it.*" (N13, male). Some expressed that scientific or medical authorities should be the only trustable source when understanding and evaluating health information. An interviewee said that "*No, I don't trust this [rumor]. If you got affected, you should go to the hospital.*" (N14, female). Likewise, a male interviewee (N11) said that "*I don't think it [the rumor] is reliable. It is probably a type of advertisement. For example, Hong'mao medicinal wine (note: a type of wine and a Chinese healthcare product). … I heard that my daughter-in-law and aunt who had used the medicinal wine said it is not that useful. It is not as effective as what they said [in the advertisement]. Therefore, I don't think I would believe such statements. You should keep optimistic to maintain your own health.*"

Notably, to some interviewees, evaluating health information depends on whether the information comes from the government. For example, an interviewee demonstrated that he only trusted what the government said about the pandemic, "*I kind of heard this [statement]. We generally don't trust it. It's better to follow local pandemic reality to decide which [piece of information] to trust or distrust. There are so many rumors outside, but we normally don't believe them. The government can [and would] transfer [pandemic] information to 'Red Posthouse' (note: a newly emerged type of activity center for community residents and Party members) through Party branches to [further transfer pandemic information] to community residents.*" (N5, male).

[3]Existing research indicates that traditional Chinese medicines may have "good therapeutic efficacy in the treatment of COVID-19" [see (59), Abstract, para.4]. Nonetheless, that shuang'huang'lian oral liquid can prevent or cure COVID-19 is a pandemic rumor.

The interview outline includes another question, "whether you have heard drinking alcohol can prevent or cure COVID-19, and whether you believe it or not," because drinking is common among older Chinese adults. Similarly, although some participants or their partners have developed the alcohol drinking habit for years, most do not believe that drinking would cure COVID-19. As an interviewee (N7, male) explained, "*I drink a little bit of wine every day…but it is just a personal habit. I don't trust that drinking could prevent COVID-19.*" Another male interviewee (N11) said, "*I haven't heard statements about drinking, but I've heard similar things about smoking. I didn't get to know the information from the television news or newspapers but from neighbors. They said that those infected patients are nonsmokers; the likelihood of smokers getting infected is lower. I think such a statement is without scientific evidence. Infection is due to an individual's low immune system.*"

To briefly conclude, according to the transcripts, most participants are able to evaluate and distinguish these two pandemic-related rumors correctly. As some expressed, these rumors do not make sense, and they trust health information offered by medical doctors and advocated by the government. However, older adults may find it difficult to clearly understand the underlying scientific logic why the Chinese patent drug or alcohol could not prevent or cure COVID-19. For example, an interviewee said, *"I don't take [these] medicines. I don't understand it, and I also don't need [shuang'huang'lian oral liquid]. I have never heard of this information; I am healthy, so my family never has these things. My husband is healthy too. We don't really need it.*" (N9, female). Another interviewee (N2, female) said that "*My cousin relayed the information regarding shuang'huang'lian oral liquid to our WeChat group. I don't trust it could cure COVID-19. But I know that another drug named tu'mei'su (oxytetracycline) could be useful. Tu'mei'su was widely accepted in rural areas during my childhood. I heard that it would work, but I am not sure.*"

The Application of Health Information: Observed Modes of Changes in Health Behaviors and Practices

The application of health information is another critical dimension of health literacy, which can be indicated by changes in people's daily health practices and behaviors (52). A couple of modes have been observed based on data analysis.

For many interviewees, the pandemic has brought some changes in their daily lives in that they have paid more attention to daily health practices and have developed healthier behaviors. For example, many reported that "thanks to" the COVID-19 crisis, they got to know the efficiency of hand washing and mask-wearing, which WHO highly recommends as efficient pandemic preventive methods (60). "*I learned the seven-stage hands washing method during the pandemic.*" (N2, female). "*Now, I know the importance of improving immunity. I am aware of the irreplaceable importance of my health. I've developed habits of wearing masks when necessary (such as for cough prevention) and washing hands.*" (N16, male). Similarly, after the first wave of the COVID-19 pandemic, some interviewees reported that

they have been exercising more often since last January. A female interviewee said that, "*I do daily exercise more often after the [first-wave] pandemic than before. I didn't care this much about exercising before the pandemic.*" (N8, female). Likewise, another interviewee said, "*I now pay more attention to exercising for to health [improvement]. Some people [at my place of work] do fitness. I also do fitness sometimes. I participate in jogging activities when available.*" (N7, male).

Some interviewees have practiced these beneficial health behaviors for a long time, so the pandemic rarely affects them. For instance, one interviewee is a public health expert, so she knows much health knowledge and emphasizes family health. The pandemic thus has a minimal impact on her daily health practices (N3, female). Similarly, another participant said, "*For years I do exercise 3 hours per day [on average], basically walking in the park: 1 hour in the morning; 1 hour in the afternoon, and 1 hour in the night.*" (N5, male). A female interviewee (N6) reported paying a lot of attention to maintaining health and usually walked in the community part 1 hour per day. The pandemic did not stop her from doing this exercise. From this perspective, the findings align with prior studies that older Chinese pay much attention to health management or improvement through physical activities (61, 62).

Even though the pandemic has brought positive changes in older adults' health practices and behaviors, some more destructive health behaviors are not easy to change even under the pressure of COVID-19. For example, some older men have been smoking and drinking for a long time, so they feel that making positive changes will not make a big difference. A female interviewee said that "*The pandemic didn't change my husband's smoking habit, as he told me that quitting smoking for him is impossible.*" (N1). Similarly, another interviewee reported that her husband "*Continues to drink and smoke. But he has the self-awareness not to go to crowded places such as parks.*" (N2, female). As a male interviewee (N16) demonstrated, he has now reduced smoking frequency compared to his pre-pandemic volume, but he continues to smoke nevertheless.

Keeping Socially Connected as a Method for Health Maintenance

This research lastly investigated older adults' social connectedness during the pandemic. No evidence suggests that interviewees were confronted with disconnectedness or isolation issues during this public health crisis. This may be due partially to the fact that all interviewees live with their partners, and many live close to their children and grandchildren. Many interviewees took on daily caregiving tasks if their grandchildren were young; such intergenerational interactions enrich their daily lives, which may help them to avoid social isolation and loneliness.

Results indicate that ICTs also helped interviewees to maintain connection during the pandemic. This is in line with existing studies, which document that ICTs have become common among older Chinese for social connections (57, 63). As reported, all interviewees have used feature phones or smartphones to stay in touch with siblings, other relatives, and friends. For example, one interviewee (N5, male) said that "*Basically we called them (note: his daughter's family) and told them not to come back [during the pandemic] because it was unsafe for them on the way back… We called them every once for a while to ask how things were going.*" Additionally, some (but not all) interviewees are familiar with the most widely-used Chinese smartphone apps, such as WeChat. These new media platforms provide older adults with a convenient online community where maintaining timely connections is attainable. "*I truly like using WeChat. I often talk with friends and relatives using WeChat instant video calls.*" (N2, female). Similarly, "*WeChat typing or video chatting makes [communication] more convenient than before. I think it is truly good.*" (N15, male). Hence, using new ICTs during the quarantine may have prevented older adults from being forced into social disconnectedness or isolation, which helps them avoid being negatively affected in terms of their health. Older adults can interact with each other online during the pandemic, reducing possible risks due to face-to-face interactions. They can get timely pandemic news and health information from their social connections. For example, WeChat groups have been used widely to share news efficiently. "*Householders are in the WeChat group. If community workers need to announce anything, they do that through WeChat group chatting.*" (N3, female). Likewise, an interviewee said, "*We have a big WeChat group with [more than] three hundred community residents. Our neighbors remind each other about safety and security during the pandemic. We also relayed [pandemic news and community announcements] to the chatting group.*" (N4, male).

DISCUSSION

The current study is based on a specific context in which older adults worldwide face health risks due to the COVID-19 pandemic (3, 38). This study focuses on health literacy, health behaviors and practices, and social connectedness of older Chinese adults due to the COVID-19 pandemic. It is among the limited qualitative endeavors to explore pandemic experiences among older Chinese specifically. Findings show effective self-adjustment of older adults to avoid possible physical and mental problems. Many older Chinese can maintain or improve their health during and after the pandemic with the efficient assistance of scientific and systematic community governance and wide use of ICTs.

Findings first shed light on the remarkable role of ICTs–both traditional and new ones–in access to health information among older Chinese; however, new ICTs deserve closer attention because not all older participants are familiar with them. Television is the primary type of traditional ICTs that the interviewees said that they watched televisions for gaining health information during the pandemic. New ICTs include the internet, WeChat chatting groups, TikTok, and so forth. Worth noting is that some interviewees know little about these new digital technologies. For example, an interviewee (N10, female) said, "*What does TikTok mean? We older people don't quite understand these [apps]. It's probably because we are old and unable to keep pace with these [new things].*" Moreover, not all older

adults have positive experiences of using new ICTs, and that is also noteworthy. Some interviewees (N = 4) do not have smartphones; their in-use phones have limited functions. They also reported inconvenient experiences due to the prevailing application of digital technologies in pandemic prevention. An example is that when these older adults were required to use new ICTs for community entrance, they felt inexperienced and thus depressed. "*Those technologies don't work very conveniently for older people. I feel a bit annoyed about the health QR code, but it works well for young people and the entire community governance.*" (N11, male). Hence, one related policy suggestion is that communities where older adults dwell should set age-friendly training programs on ICT use to increase access to key health information and social engagement and involvement (25).

Findings regarding observed modes of conduct indicate the complexity of changes in health behaviors and practices among older participants. It is not difficult for older participants to improve some health behaviors and practices, such as exercising, washing hands, and mask-wearing. These changes are primarily driven and impacted by health-promoting community advocation and changes in collective health patterns. But some longstanding, unhealthy behaviors, such as smoking, are not as easy to quit. One interviewee reported that he has been working on quitting smoking and drinking (N5, male), but the underlying motivation is not related to the pandemic. A policy suggestion in this vein is that community advocation should take into consideration both health practices that are relatively easy to develop and some long-lasting destructive behaviors that are prevalent among older Chinese adults.

Regarding older adults' understanding and their evaluation of health information (pandemic rumors), findings reveal an inconsistency between interviewees' understandings and evaluations of pandemic health information. Older adults' evaluations are primarily affected by news from authoritative sources and their own life experiences, but they may not completely understand the scientific mechanisms behind them. Such inconsistency may lead to incorrect evaluations of more puzzling pandemic rumors, making it essential for older adults' families and communities to offer necessary consulting services on this subject.

Findings also indicate that interviewees lived with families and could maintain social connectedness during the pandemic. Older adults can and do avoid isolation and loneliness and reduce health anxiety during the pandemic through receiving necessary emotional, financial, or other support from important social connections with families, friends, and neighbors (28, 64, 65). Moreover, these findings are consistent with existing ones that demonstrate that, with the assistance of ICTs, older adults can get timely health information and other health-promoting resources from robust connections (16, 54).

Further, although many efforts have been used to detect mechanisms linking older age and negative health consequences, the fact that some older adults have their agency, autonomy, and resilience for pandemic prevention and self-protection should not be ignored. As one interviewee said, "*I am not afraid of this pandemic at all. I had never developed the sense of fear. I even wished to be a volunteer when the virus hit Wuhan. I volunteered for community affairs last year.*" (N2, female). This interviewee is 61 years old and can be seen as a 'young-old' that can be defined as older adults aged below 70 (66, 67). She now works as a caregiver for the 'middle-old' and 'oldest-old' in a community institution. She is self-perceived as a "*retired person*" but who wishes to continue to "*make contributions [to the society].*" Some other interviewees also worked as community volunteers during the first-wave pandemic. "*We took temperatures for [the community residents]. We worked as volunteers during the pandemic.*" (N4, male).

Policy implementations regarding pandemic governance at the macro- and meso-levels also have exerted influences on older Chinese adults' health. When China underwent the first-wave of COVID-19, both the national and local governments took strict measures for pandemic prevention (41, 42, 46, 47). China's solid and effective governance and considerate community management aim to create a secure and friendly living environment for older adults. The interviewees hold positive attitudes toward the strict community governance during the first wave of the pandemic. Interview transcripts of this study show that the community applied multiple means, including measuring temperatures, personal information registration and management, and public sphere disinfection. During the crisis, community leaders, workers, and volunteers provided services for all dwelling residents. As some interviewees reflected, "*[Our] community leader, other [community] workers, and volunteers worked hard for the pandemic prevention. You could see them everywhere, especially when there were public health emergencies.*" (N11, male). Likewise, "*The community workers took care of every aspect of our community well during the pandemic.*" (N12, male). China's community management and service systems have been designed to cover all dwelling residents (41). Therefore, health inequalities due to age gaps may have been reduced due to these beneficial regulations based on national and community-level policies. Improvements in collective health patterns may also have positively impacted older Chinese.

Limitations and Future Studies

This study is not without limitations. One limitation is that research findings cannot represent the older Chinese population at a national level. Interviewees are from urban areas in East China. Most interviewees share relatively similar demographic and socioeconomic backgrounds. None of them live in poverty or live alone, and none of them have urgent financial or healthcare needs. However, disparities in household income, organization membership, participation in city activities, and social capital have been shown to be contributors that lead to stratified health outcomes among older Chinese (27, 68). Thus, findings of this study can only laterally reflect pandemic experiences of older Chinese adults. It has been argued that understanding and meeting the care needs of older adults is essential for policymaking (69, 70). I thus call for more qualitative explorations and large-scale quantitative measures to help give us a panoramic picture regarding changes in health literacy, health behaviors and practices, and social connections among older adults due to the COVID-19 pandemic, and underlying reasons contributing to possible health inequalities that exist among the aged.

Another limitation is that this study did not pay close attention to the COVID-19 vaccine, which has been promoted nationwide in China. "More than 2.12 billion doses of COVID-19 vaccines had been administered" as of September 9, 2021 (71), benefiting approximately 970 million Chinese as of September 6, 2021, or about 77% of the country's total population (72). Hence, the next step is to investigate how the vaccine has affected older Chinese's daily health practices and health outcomes. Vaccinations may have long-term physiological and sociological meaning, especially considering that the pandemic has become recurrent as a consequence of new variants of COVID-19.

The third limitation is that this study uses retrospective data. Some interview questions on health change before and after the first-wave pandemic are retrospective, which may decrease the accuracy of the data. Timely data collection and explorations are thus required under new pandemic situations. A most recent pandemic condition is that new COVID-19 variants, such as Delta and Omicron, have meant that the local epidemic now rebounds back and forth. For example, N city had experienced a new city-level wave of the Delta variant pandemic in July and August 2021. Now, Omicron has emerged as a predominant variant in some countries and regions (73). As a response, China now implements regular pandemic prevention and control policies (74). While this policy benefits public disease prevention, it may bring new challenges and health risks facing older adults. For example, an individual's updated health QR code is required for public area entrance, which may become an obstacle and a new psychological stressor to the life of those older adults who are not familiar with digital technologies. These new pandemic facts therefore warrant further timely explorations into older Chinese's daily lives to understand their health challenges and needs, such as the need for expedient psychological services due to self-stigmatization and victimization under the pandemic (75–78).

The final limitation is due to the fact that interviews were conducted within a limited time. The temporary and formal interactions may have made it difficult for the author to profoundly capture more dimensions, details, and realities regarding older adults' daily health practices and social engagement. Considering that older Chinese have developed and practiced own life logic over their life courses, longitudinal and more comprehensive fieldworks through the author's participation and observation are thus further needed.

CONCLUSION

This study uses semi-structural interviews to collect qualitative data among older Chinese residents living in N city, an east-coast city with a developed economy. Findings show that interviewees were able to handle the COVID-19 public health crisis strategically. Specifically, older Chinese adults were able to maintain or improve health literacy as well as health behaviors and practices to stay healthy. Also, older Chinese have autonomy and agency to keep themselves socially connected, thus avoiding loneliness and isolation and gaining health information and news. Remarkably, ICTs play a significant role in obtaining health information and keeping themselves connected with families, friends, and the community they dwell in. ICTs include traditional ones, such as television, and newly emerged technologies, such as WeChat instant chatting group and TikTok. But not all older adults were familiar with new technologies, especially those who do not have smartphones. This digital gap may have created obstacles for this segment of older Chinese because new ICTs have been widely used in pandemic management and governance. There also exists a gap between older adults' understanding and evaluation of health information. Specifically, although older adults were able to evaluate pandemic rumors correctly, they may not wholly understand underlying scientific logic. Policy recommendations were developed based on these findings.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Psychology Department at the School of Social and Behavioral Sciences of Nanjing University (NJUPSY202106001). The patients/participants provided their oral informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

XC proposed and developed the research idea, organized and participated in data collection, conducted data analysis, and wrote this manuscript.

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APPENDIX

Appendix 1 | Demographic background and self-rated health of each interviewee, $N = 17$.

	Gender	Age	Education	Employment	Living arrangements	SRH[a]
N1	Female	68	Primary school incompletion	Retired	Living with partner, son, daughter-in-law, and grandchildren	Good
N2	Female	61	High school	Employed	Living with partner, close to son	Average
N3	Female	74	Middle school	Part-time	Living with partner, close to children	Very good
N4	Male	63	Middle school	Retired	Living with partner, close to children	Excellent
N5	Male	68	Primary school	Retired	Living with partner, close to son	Excellent
N6	Female	58	Middle school	Retired	Living with partner, close to daughter	Good
N7	Male	55	Middle school	Employed	Living with partner	Very good
N8	Female	62	High school	Retired	Living with partner, close to daughter	Good
N9	Female	63	High school	Part-time	Living with partner	Good
N10	Female	66	Middle school	Retired	Living with partner, close to son	Good
N11	Male	66	High school	Employed	Living with partner	Good
N12	Male	56	High school	Employed	Living with partner	Good
N13	Male	70	Middle school incompletion	Retired	Living with partner	Good
N14	Female	64	High school	Retired	Living with partner	Good
N15	Male	57	Middle school	Employed	Living with partner	Very good
N16	Male	65	High school	Retired	Living with partner	Good
N17	Male	65	High school	Retired	Living with partner, close to children	Good

[a]*SRH refers to respondents' self-rated health. Although most of the interviewees have chronic diseases, their self-rated health statuses are in general at a relatively good level or above. This may indicate that the chronic diseases affect older interviewees' daily lives only slightly or remotely.*

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The multidimensional relative poverty of rural older adults in China and the effect of the health poverty alleviation policy

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Introduction: Although, especially in the past decade, poverty measurement approaches have been duly developed in two paths (from unidimensional to multidimensional poverty and from absolute to relative poverty), merely a few studies have focused on the combination of both perspectives. However, with global aging, poverty among older adults simultaneously presents multidimensionality and relativity characteristics. This paper explores a multidimensional relative poverty index (MRPI) relative to the aged group in four dimensions, namely, health, social, mental, and material, and then empirically evaluates the specific effects on the MRPI of one of the key targeted anti-poverty policies, that is, the health poverty alleviation policy (HPAP), which includes public health service, medical expense reimbursement, rewarding assistance, basic medical insurance, and so on.

Methods: Using pooled cross-sectional data of poverty alleviation from 2014 to 2020 with a total of 83,521 observations aged 60+ in County J, Shaanxi Province in China, we calculate the MRPI for the older adults *via* a fuzzy set approach. Statistical difference testing is used to analyze the characteristics and trends of the MRPI. In policy evaluation, to address endogenous problems, the treatment effect model based on Heckman's two-stage regression and finite distributed lag model are used with a controlled township cluster structure.

Results: From 2014 to 2020, the MRPI shows a significant upward trend for older adults in rural China, and the health component takes the dominant MRPI position. Empirically, we find that the HPAP can significantly alleviate the MRPI of older adults. Furthermore, among the health poverty alleviation measures, basic medical insurance is the most effective anti-poverty policy to support older adults. Specifically, empirical evidence shows that there is a more statistically significant reduction in the MRPI with the HPAP for the sub-group of older adults with chronic diseases or disabilities.

Conclusion: Both relativity and multidimensionality should be emphasized when analyzing poverty *vis-à-vis* the aging society, and for this, the MRPI is one of the effective tools. Comparing the relativity with the aged group engenders a more accurate understanding of their poverty situation. Moreover, the importance of the health component among all the four dimensions is

more conducive to the detailed analysis of their poverty. The empirical analysis results show that regarding poverty reduction approaches in China, developing integrated health promotion systems is necessary and imminent, especially in the long run, such as long-term care insurance that covers typical disabled older adults with chronic diseases.

KEYWORDS

relative poverty, multidimensional poverty, health poverty alleviation policy, older adults, treatment effect model

Introduction

In the past decade, several theoretical analyses on the nature of poverty have been conducted, and a vast empirical literature has been produced in two branches. One is developed from unidimensional to multidimensional poverty (1–7), while the other is expanded from absolute to relative poverty (8–11). Only a few studies conceptually touch topics bordering on combining both perspectives (12, 13). This paper presents an attempt at this combination by constructing a multidimensional relative poverty index (MRPI) to measure the poverty levels among older adults.

From a life cycle perspective, poverty at old age is an important component that affects people's life-long wellbeing, which cannot be ignored (14). Compared with others, older adults are a special and vulnerable group because they can easily fall into poverty and find it challenging to extricate themselves from penury through their individual efforts, such as employment (15, 16). Along with age, it is inevitable for older adults to face the increasing health risks of functional limitation and medical expenditure for chronic diseases. Meanwhile, their ability to learn, adapt, and participate in society gradually decreases (17, 18).

On the one hand, poverty measured by income or consumption as a unidimensional standard is likely to overestimate the poverty ratio for the aged group (18–20). Generally, the standard is determined by the average level of the entire population, although the income or consumption of seniors hovers around the lower level relative to the entire population. According to Sen's "capability approach," low-monetary income cannot wholly explain poverty, while deprivation in other dimensions is what causes it (1, 21–24). Based on the extensive literature (16, 25–27), poverty among older adults emerges in four dimensions. Materially, they are mainly supported by fixed pensions and intergenerational support, which make resisting the impact of external risks challenging (28–30). Regarding the health dimension, chronic, sudden, or serious diseases are generally accompanied, and their physical health is generally lower than that of other groups (31). Mentally, "empty nest" older adults are dramatically increasing, especially with the population transformation of less children and family structure change, and the mental health problem among older people is becoming increasingly prominent (16). Socially, with the rapid development of social media and digital economics, the social networks of the old adults are further compressed, and the seniors are said to be "digital refugees" (32, 33).

On the other hand, differing from those of the younger age groups, the use of the absolute poverty line neither reflects the true situation of older people nor is it indicative of the vulnerability and depth of poverty (2, 23, 34–36). Rather than absolute poverty, relative poverty refers to the poverty state of a reference object. It is generally expressed by the relative deprivation of a certain situation of an individual from the highest one. And it is dynamic from a life cycle standpoint. However, there is no consensus on how to determine the relative poverty standard (37). In general, the understanding of relativity entails to two terms: relative to the entire population and relative to the older population. Relevant studies only focus on the former rather than the latter. However, as mentioned above, older adults have evident vulnerabilities compared to other populations, mainly in terms of material, mental, social, and health. When comparing older adults to the entire population, it is clear that older adults are poor in many dimensions. Considering the similar cohort characteristics, we believe the study of individual relative poverty compared with the old group itself will provide a better understanding of the poverty level and characteristics of older adults.

Thus, in the second part of this paper, we construct the MRPI for older adults, combined with the four dimensions of material, health, mental, and social, and use the population aged 60+ as a frame of reference. Thereafter, we decompose the index to determine the importance of the different dimensions.

Over the past decade, the Chinese government has made great efforts to reduce poverty on a large scale. One of the anti-poverty policy innovations entails that different policies are designed for various causes of poverty, an approach that is referred to as the targeted poverty alleviation policy. To minimize the risk and cost associated with the health problem, a complete security system was established to ensure

accessibility to basic medical and health services in 2016. This strategy includes new rural cooperative medicine, serious illness insurance, medical assistance, and supplementary medical insurance (38). Subsequently, in 2017, the categorization and treatment of poor people suffering from serious illnesses and chronic diseases further facilitated the implementation of health assistance packages for poor people. Additionally, targeting the poor due to their health problems specifically, a wide range of preferential policies, institutional arrangements, and support measures, including public health services, reimbursement of medical expenses, and incentive assistance was implemented. From the current practice results, these targeted poverty alleviation policies have indeed played a role in poverty alleviation (39, 40). In 2020, absolute income poverty was eliminated based on the World Bank's current standard of US$ 1.9 per person per day. According to the National Bureau of Statistics, 98.99 million rural poor people have been lifted out of absolute income poverty (41).

However, from the perspective of multidimensional relative poverty (MRP), the evaluation of these targeted policies to determine the effects for the specific dimension of relative poverty is significant, especially for older adults, who face much higher health risks and potential medical expenses in the long term as they age. Therefore, in the third part of this paper, we evaluate the poverty alleviation policy implemented for rural older adults.

The remainder of this paper proceeds as follows: Section 2 describes the measurement of the MRPI for older adults in China. Section 3 details the empirical evaluation of the health poverty alleviation policy (HPAP) on the MPRI. Section 4 discusses the results. Section 5 presents the conclusion and policy suggestions.

Measurement of the MRPI for rural older adults

Data source

The data are obtained from the "Poverty Alleviation Database" in County J in Shaanxi Province, which has been constructed by the Chinese government for all poverty households since 2014. The identification of poverty households is based on multidimensional poverty indicators. Specifically, the whole household is identified based on the household income, housing, education, health, and other conditions. Once the application meets the identification criteria, the household's information is entered into the database, and the data are reviewed and updated regularly. The database structurally covers the individual demographic information, household structure, health status, living standard, income level, and poverty intervention policy involved.

TABLE 1 The total sample and the older adults' sample size from 2014 to 2020.

Year	Total sample	Older adult sample	%
2014	41,365	9,877	23.88%
2015	40,934	10,335	25.25%
2016	48,168	9,931	20.62%
2017	48,379	10,306	21.30%
2018	47,290	14,180	29.99%
2019	46,402	14,341	30.91%
2020	45,682	14,551	31.85%
Total	318,220	83,521	26.25%

County J in Shaanxi Province is a typical poverty-stricken county in Northwest China. In 2014, 15.52% of the population was living under the absolute income poverty line in County J. After the poverty alleviation intervention, up to February 2020, County J successfully achieved the exit criteria for the poor.[1] County J comprises 13 townships, each of which has a different population size and economic status. The distribution of the total sample and older adults' sample in County J from 2014 to 2020 is shown in Table 1. The total sample population in the database is 318,220, including 83,521 old adults aged 60+, accounting for more than one-quarter of the total sample.

Selection of dimensions

As mentioned above, we construct the MRPI in four dimensions: health, social, mental, and material (16, 25–27). Table 2 presents the detailed dimensions and indicators with the selected variable descriptions.

Health dimension

This includes health status and health insurance. Health status is measured by whether the older adult is disabled or with at least one type of disease (42). Owing to the full coverage of basic public medical insurance available now, health insurance here refers to commercial supplementary health insurance (43).

Social dimension

This includes social participation, social security, information sources, and political participation (44–46).

1 Poverty-stricken counties exit criteria: First, the combined poverty incidence rate is reduced to <2%. Second, all poor villages are out of poverty. Third, the growth rate of per capita disposable income of rural residents is higher than the average level of the province. Fourth, the level of basic public services reached or got close to the provincial average.

TABLE 2 Compositions of multidimensional poverty dimensions and indicators for older adults.

Dimensions	Primary indicators	Secondary indicators
Dim_1: Health	Health Status	Disability: Presents at least one disability = 1, otherwise 0.
		Disease: Suffers from at least one disease = 1, otherwise 0.
	Health Insurance	No commercial health insurance = 1, otherwise 0.
Dim_2: Social	Social Participation	No work: No work = 1, otherwise 0.
	Social Security	No basic pension = 1, otherwise 0.
	Sources of Information	No radio/TV at home = 1, otherwise 0.
	Political Participation	Not a party member = 1, otherwise 0.
Dim_3: Mental	Adapt Ability	Education level: 0 illiteracy; 1 primary school; 2 junior high school; 3 high school; 4 professional training college; 5 bachelor's degree and above.
	Sense of Loneliness	Live alone: living alone = 1, otherwise 0.
Dim_4: Material	Income	Per capita income of the old adults in RMB yuan.
	Living standards	Housing area per capita in squared meters.
		Non-clean fuel: Non-clean fuels at home= 1, otherwise 0.
		No electricity at home = 1, otherwise 0.
		No safe drinking water at home = 1, otherwise 0.
		No sanitary toilet at home = 1, otherwise 0.

Social participation is measured by still outworking or not; social security is measured by holding a basic pension or not; the information sources in rural areas for older adults are mainly radio or TV, so we measure information accessibility by possessing a radio/TV or not; political participation is also an important aspect of the social dimension, and we measure the political participation of the seniors by being party members or not.

Mental dimension

This includes learning, adaptive ability, and loneliness (30). Because of the unavailability of the learning and adaptive ability information in the data set, the proxy indicator of educational attainment is chosen. The higher the educational level of the older adult, the higher his or her learning and adaptive abilities (47). Additionally, living alone is used to measure the loneliness of the older adults.

Material dimension

This includes income level and living standard. Income level is a continuous variable measured as per capita income. The living standard refers to the basic living condition with housing area per capita, clean energy, electricity, safe drinking water, and sanitary toilet. Housing area per capita is a continuous variable measured in squared meters. If clean fuel, electricity, safe drinking water, or sanitary toilet are not available to the older people, the indicator value is 1. This means that they have a poor standard of living conditions, otherwise it is 0.

Appendix A presents the statistics of all the indicators for the four dimensions by year. It can be seen that in the health dimension, ∼13.6% (46.5%) of the older adults are disabled (suffer from diseases). Very few seniors have medical supplemental insurance except public health insurance. All the social dimension indicators show an upward trend. In 2014, only 1.5% of seniors are employed, 95% have pension insurance, 1.7% are party members, and 20.8% have a radio/TV at home. Moreover, up to 2020, the ratios rise to 15.4, 100, 5.1, and 73.1%, respectively. For the mental dimension, an upward education level trend of the older adults is also shown. The rate of living alone in the older people decreases from 30.7% in 2014 to 23.3% in 2020. With the rapid aging phenomenon in rural areas in recent years, the oldest-old group of seniors is increasing, the cases of living with informal caregivers are slightly increased, thereby elucidating why the case of living alone decreases. Materially, the housing area of the older adults changed a little overall, but the income increased significantly. Notwithstanding the full coverage of electricity in 2016 and safe drinking water in 2018, only a few older adults started to use clean energy in 2020, and approximately half of them had sanitary toilets in their houses.

Construction of the MRPI

Owing to the emphasis on the relativity of multidimensional poverty with a large sample size in our study, we apply the fuzzy set approach in calculating the MRPI. Compared with the popular AF method developed by Alkire and Foster (4, 5, 48, 49), which is widely used in studies on absolute multidimensional

poverty, the fuzzy set approach can not only measure relative deprivation but also raise the data-driven endogenous weight, which reflects the relative importance of certain indicators (50–54).

The fuzzy set approach replaces the criterion of poverty line with poverty under a range of segments (7). Cerioli and Zani (55) constructed a fuzzy theoretical model for the multidimensional analysis of poverty, which was later developed and improved by Cheli and Lemmi (50), resulting in the totally fuzzy and relative method. It is based on the membership degree functions to obtain the indicators of deprivation given sample variables, and the values obtained from it are used to reflect the relative degree of deprivation of individuals. Thus far, the fuzzy set approach has been widely applied in measuring multidimensional poverty (50–54). Meanwhile, another advantage of this method is that the calculation of weight depends on the intensity of the relative deprivation in different dimensions, which overcomes the deficiency of equal weight in the calculation of multidimensional indicators.

The MPRI calculation and its decomposition are based on the following four steps.

Step 1: Determining the membership degree function

We classify the above-mentioned indicators into three types, namely, binary, discrete, or continuous variables. Thereafter, we determine their membership degree functions (56).

1. *Binary variables.* For binary indicators, if the membership degree function μ_p is defined to have a value of 1, the possession of the item is assumed to be more prone to poverty for the older adult. Otherwise, it is 0.

$$\mu_p = \begin{cases} 1, & x_{ij} = 1 \\ 0, & x_{ij} = 0 \end{cases}$$

where, x_{ij} represents the value of the ith person on the jth indicator, $i = 1,2,\ldots. n; j = 1,2,\ldots k$. As shown in Table 2, we define the values of Disability, Disease, No health insurance, No work, No pension, No radio or TV, Not a party member, Non-clean fuel, No electricity, No safe drinking water, No sanitary toilet, and Live alone, as the indicators of membership, as 1.

2. *Discrete or continuous variables.* Discrete or continuous variables can only have one possible value within a certain range, such as Education level, Income, and Housing area indicators. We define the membership degree function μ_p as (50):

$$\mu_p = \begin{cases} 0 & x_{ij} \geq x_{\max,j} \\ \frac{x_{\max,j} - x_{ij}}{x_{\max,j} - x_{\min,j}} & x_{\min,j} < x_{ij} < x_{\max,j} \\ 1 & x_{ij} \leq x_{\min,j} \end{cases}$$

where $x_{\min,j}$ and $x_{\max,j}$ denote the minimum and maximum values of the jth indicator except the outliers, respectively. The further away the value of x_{ij} is from $x_{\max,j}$, the more likely the individual is to be relatively poor. For instance, for the education level, $x_{\min,j}$ represents illiteracy, and if the education level of an older adult typifies illiteracy, the individual is considered to be extremely poor based on this indicator, that is 1. Similarly, for income and house area, when the indicator value is equal to $x_{\max,j}$, the membership degree is 0, which means that the older people are exempt from any risk of poor on this indicator.

Step 2: Determination of weights

Based on Cheli and Lemmi's (50) method, higher weights should be given to indicators that can easily lead to relative poverty. For example, if the indicator "no safe drinking water" is equal to 1, then give it a higher weight. This is an endogenous weighting method. Using endogenous weights with one particular dataset can reflect the importance of the different indicators in the composite measure (57, 58). Endogenous weight overcomes the shortcomings of the traditional equal weight method, which is arbitrary and varies with the number of indicators (49).

The weight for the indicators is calculated as:

$$w_j = \ln\left[\frac{1}{\frac{1}{n}\sum_1^n \mu_p(x_{ij})}\right]$$

where $\mu_p(x_{ij})$ denotes the membership value of the ith older adults on the jth indicator, and n is the sample size. The endogenous weight calculated for each indicator over the years is shown in Appendix A.

Step 3: Calculating the MRPI

Combining the membership degree function and the weight, the MRPI for each old adult is calculated as

$$MRPI_i = \frac{\sum_{j=1}^k \mu_p\left(x_{ij}\right)^* w_j}{\sum_{j=1}^k w_j}$$

where $\mu_p(x_{ij})$ denotes the membership value of the ith individual on the jth indicator, w_j is the weight of the jth indicator, and κ is the number of the indicators.

Table 3 shows the average MRPI for older adults over the years and the group difference. It can be seen that MRPI showed an upward trend from 2014 to 2019, except for the sudden decline in 2020 to achieve the poverty eradication goal. Compared to 2014, the MRPI jumped from 0.124 to 0.350 in

TABLE 3 The MRPI for rural older adults from 2014 to 2020 and group difference.

Year	MRPI	Gender		Adjusted	Age Groups			Adjusted	Household		Adjusted
		Female	Male	Wald test	Group 1 Aged 60+	Group 2 Aged 70+	Group 3 Aged 80+	Wald test	Non-poor	Poor	Wald test
2014	0.124	0.126	0.123	*	0.119	0.127	0.146	***	0.085	0.126	***
2015	0.159	0.161	0.157	**	0.151	0.163	0.185	***	0.134	0.166	***
2016	0.190	0.193	0.187	**	0.175	0.199	0.236	***	0.150	0.206	***
2017	0.166	0.168	0.165		0.154	0.173	0.201	***	0.136	0.181	***
2018	0.201	0.203	0.200		0.187	0.210	0.236	***	0.185	0.243	***
2019	0.350	0.357	0.343	***	0.324	0.375	0.392	***	0.338	0.489	***
2020	0.141	0.144	0.138	***	0.130	0.151	0.160	***	0.141	-	-

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

2019. This result is contrary to the absolute multidimensional poverty trend among older adults: it shows a decreased trend from 0.394 in 2014 to 0.289 in 2016 (59). A possible reason for the significant rise in relative poverty among the older adults in 2019 is the time lag of other poverty alleviation policies. For example, albeit the industrial poverty alleviation policy intervened heavily in 2018, the effect of poverty alleviation can be realized only after a year, such as planting and farming. Additionally, the industrial poverty alleviation policy mainly targets young older people who have the ability to work, and the data show that 56.68% of the older people who participate in industrial poverty alleviation are under 70 years old, which further divides the relative poverty of the older adults.

Gender difference exists, showing that the MRPI is significantly higher for females than for males. This is because female elderly health is at a disadvantage compared to male health, both in terms of physical and mental health (60, 61). Rural poor older females lack resources and opportunities, both socially and economically, and are a vulnerable group with a low-survival capacity (62).

The MRPI of the older age group 3 aged 80+ is higher than that of younger age group 1 aged 60+. The MRPI of the older adults in the poor household group is higher than that of the non-poor, and this maintains its statistical significance over the years. This suggests an identification divergence between unidimensional and multidimensional poverty, a situation that can be explained by the fact that while income is important, multidimensional poverty measures (including this relative standard) reveal dimensions of poverty that cannot be reached by increasing household income (11).

Thus, we can conclude that females in the oldest age group and living in poor households will be the most likely to experience MRP.

Step 4: Decomposition of the MRPI

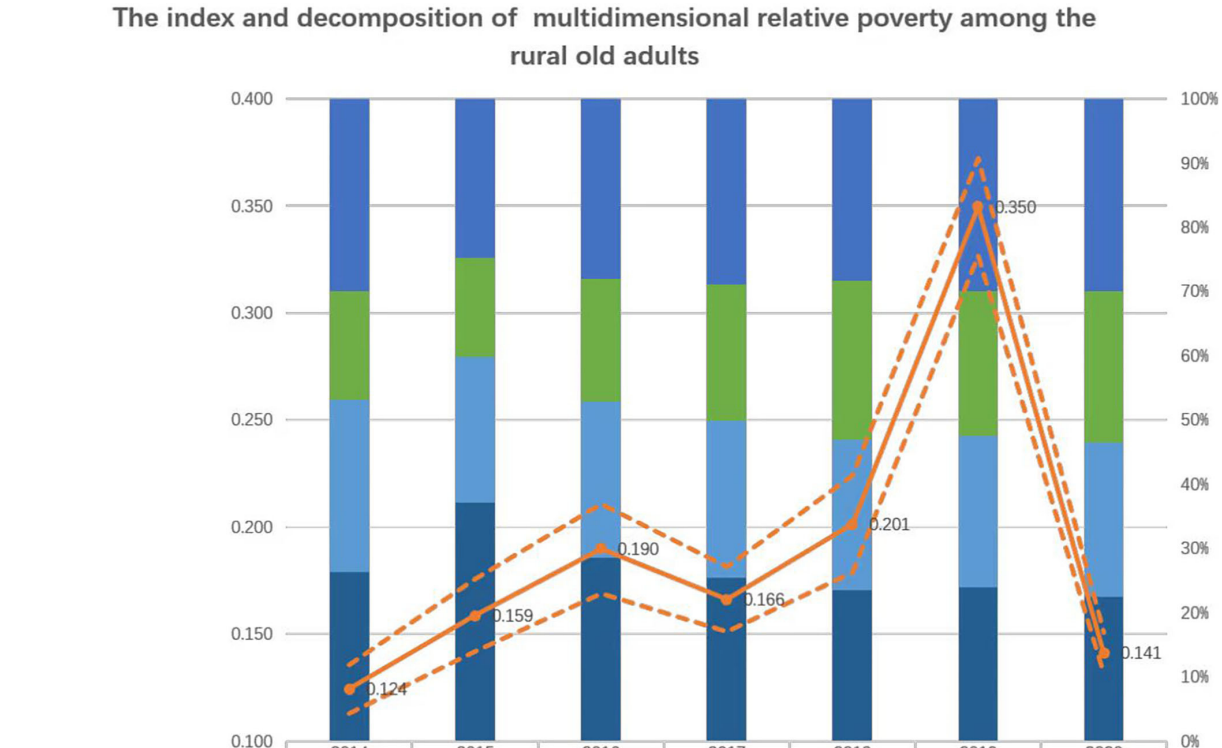
To appraise its relative importance based on the contribution rate for different dimensions, we decompose the MRPI. Take the first health dimension as an example, it is calculated as:

$$Contribution\_Rate_{Dim_1} = \frac{\sum_{j=1}^{3} \mu_p \left(x_{ij}\right)^* w_j}{\sum_{j=1}^{k} w_j}$$

Figure 1 shows the MRPI and the contribution rate for the four dimensions. It shows that among the four dimensions, the health component has the highest contribution rate to the MRPI for older adults. It maintains a stability of 29.9% in 2014 and 30.0% by 2020. That is, approximately one-third of the MRPI determinants for older adults is the health dimension. Conversely, the contribution rate of the material dimension showed an overall decreasing trend, and in 2020, it was the lowest, accounting for only 22.4%. This is consistent with the declining facts of material demand relative to other dimensions under the condition of rapid economic development, especially for older adults.

Therefore, the health dimension is the most important composition that cannot be ignored when analyzing poverty among older adults (42). In 2014, 49% of the older adults were under the poverty line owing to diseases, and the proportion increased to 55.3% in 2016. In 2016, an important targeted poverty alleviation policy, named the HPAP, began to be implemented, and, consequently, the proportion of the poor older adults caused by diseases fell from 45.7% in 2017 to 37.1% in 2020.

Does this targeted policy intervention effectively affect the MRPI for older adults? In the following part, we check the determinants of the MRPI *via* ordinary least squares (OLS) as a benchmark model and then evaluate the effect of the HPAP on the MRPI. Furthermore, for the analysis of heterogeneity, this paper examines which health poverty alleviation measure is



	2014	2015	2016	2017	2018	2019	2020
Health	29.9%	24.7%	28.0%	28.9%	28.3%	30.0%	30.0%
Social	17.0%	15.5%	19.1%	21.3%	24.8%	22.5%	23.5%
Mental	26.8%	22.6%	24.4%	24.4%	23.4%	23.6%	24.1%
Material	26.3%	37.2%	28.5%	25.5%	23.6%	23.9%	22.4%
MRPI	0.124	0.159	0.190	0.166	0.201	0.350	0.141
LL(95% confidence interval)	0.113	0.142	0.169	0.151	0.179	0.327	0.132
UL(95% confidence interval)	0.136	0.176	0.211	0.181	0.224	0.372	0.151

FIGURE 1
The index and decomposition of multi-dimensional relative poverty among the rural old adults.

the most effective, as well as which subgroup of people benefits the most.

Determinants of the MRPI and evaluation of the HPAP on the MRPI

Benchmark model for the determinants of the MRPI

We apply OLS for analyzing the determinants of the MRPI as a benchmark model[2]:

$$Y_{it} = a_{it} + \alpha X_{it} + \delta_i + \mu_{it}$$

where,

Y_{it}: MRPI for older adult i at time t.

X_{it}: the control variables, including the demographic characteristics of an individual: gender, age, and ability to work; family characteristics: if in a poor household or not, family size, the number of patients, the number of children, and the number of students in the family; and the natural assets: the area of cultivated land per person and the area of fruit land per person.

δ_i: the township and year fixed effects.

μ_{it}: error term.

Although the process of identifying poor households is based on certain criteria, the poverty status varies widely across townships. Therefore, in the following analyses, we control the township cluster for the survey data.

Treatment effect model for the evaluation of the HPAP on the MRPI

Owing to the voluntary nature of applying for the support of the HPAP among the poor old adults, self-selection bias

2 Stata command: svyset town [pweight = finalwgt]; svy: reg MRPI X_{it} i.year i.town.

occurs. To investigate the possible effects of participating in health poverty alleviation on the MRPI of the old adults, we use Heckman's two-stage regression with the treatment effect model to evaluate the policy effect (63–66).

Regression model (second stage):

$$Y_{it} = a_{it} + \beta I_{it} + \alpha X_{it} + \delta_i + \epsilon_{it}$$

Selection model (first stage):

$$I_{it} = \gamma Z_{it} + \rho X_{it}^{'} + \nu_{it}$$
$$Prob\,(I_{it} = 1|Z_{it}) = \Phi(\gamma Z_{it})$$

where in the first- and second-stage regression model:

I_{it}: dummy variable, HPAP = 1 indicates that the old adult involved in the intervention of the health poverty alleviation policy, otherwise, it is 0;

$X_{it}^{'}$: Except for the control variables in the benchmark model, we add the policy intervention variables, including social security guarantees, farmers' cooperatives, industrial poverty alleviation, and relocation of migrants, to control for the policy binding effect. To control the endogeneity of self-participation of these policies, the lag phases of the policy are controlled.

In the selection model for the first stage:

Z_{it} : instrumental variables (IVs). Based on the research of Schultz and Yang (67–69), we evaluate health care access for older adults by the distance away from the main road as instruments. It is reasonable to assume that the farther the distance from the main road is, the higher the cost of participating in the health poverty policy is, such as information and transportation cost. Therefore, it lowers the probability of HPAP participation. In addition, poor villages have poor medical facilities and poorer medical standards compared to non-poor villages; thus, their demand for HPAP participation is higher. We selected if the old people live in a poor village as an IV.

Variable statistics

Table 4 provides the description and summary statistics of the selected variables.

A total of 83,350 older people are observed, and 54.26% of them are involved in health poverty alleviation program. The statistical difference in the MRPI is noted between the older adults who do not participate in the HPAP (MRPI = 0.148) and those who do (MRPI = 0.232), suggesting that the older adults who participate have a worse poverty situation. It is found that the average age of the older adults in the panel sample is 70.5 years old, only 14% of them are able to work, and 45.3% of the old adults are in poor households. Statistical MRPI differences exist between the older adults who participate in the HPAP and those who do not participate in any variable except labor ability. Moreover, 49.0% of the old adults participate in the farmers' cooperative programs, which is the highest participation rate compared with other programs. The IV of distance indicates that the majority of the older adults who participate in the HPAP live close to the national road.

Regression results

Table 5 shows the OLS regression result for the determinants of the MRPI and the treatment effect model regression for the policy evaluation for the second stage.

In the OLS result of the MRPI for pooled cross-sectional data from 2014 to 2020, we find no evidence for gender and age differences, but the statistical significance is shown for all the other control variables, including demographic, family characteristics, and township and year effect. Especially, older adults without work ability are more likely to experience MRP, and the human resources, such as family size, and natural assets, such as cultivated land, contribute to the downward trend of the MRPI. However, family burdens, including the presence of patients, children, and students in the family, definitely increase the possibility of MRP among older adults. Although from 2014 to 2020, absolute income poverty has been eliminated, the positive year dummy coefficients show the increasing effect on the MRPI compared to the base year by controlling for other independent variables.

In the second-stage treatment effect model, the HPAP coefficient is significantly negative, indicating that participation in the HPAP can significantly reduce the MRPI of the old adults. Among the other policy control variables, only farmers' cooperatives have the expected poverty alleviation effect, but it is not significant. We control for the MRPI determinants and also the year and township, and this shows an identical result with the benchmark model. The first-stage F-statistic and the over-identification test of the J-statistics are also shown in Table 5.

Analysis of heterogeneity

In J County, the HPAP includes seven types of measures: public health service, reimbursement of treatment expenses, incentive assistance, basic medical insurance, serious illness insurance, medical aid, and treatment of serious and endemic diseases. Have all of these measures been effective in reducing the MRPI? Which one is more effective? We introduce dummy variables for seven HPAP measures to explore these issues and control for endogeneity through the lag phase method. The results are shown in Panel A in Table 6. The regression results show evidence that basic health insurance and treatment of serious and endemic illnesses are effective in mitigating MRP in older adults, while the other measures

TABLE 4 Descriptive statistics for selected variables, 2014–2020.

Variable	Total sample				HPAP = 0	HPAP = 1	Difference
	Mean	Std. Err	Min	Max	Mean	Mean	*t*-test
MRPI	0.194	0.006	0.011	0.996	0.148	0.232	***
Characteristics of the older adults							
Gender (Male = 1)	0.509	0.007	0	1	0.52	0.499	***
Age	70.561	0.227	60	106	70.271	70.806	***
Ability to work	0.141	0.015	0	1	0.141	0.141	
Family characteristics							
Poor household	0.453	0.032	0	1	0.648	0.289	***
Family size	2.141	0.063	1	9	2.035	2.23	***
Number of patients	1.075	0.035	0	8	0.996	1.141	***
Number of children	0.097	0.012	0	5	0.082	0.11	***
Number of students	0.147	0.017	0	5	0.118	0.172	***
Cultivated land	1.540	0.084	0	4.852	1.328	1.718	***
Fruit land	0.093	0.034	0	3.892	0.112	0.077	***
Intervention policies							
HPAP	0.543	0.018	0	1	-	-	-
Social security guarantees	0.341	0.039	0	1	0.328	0.352	***
Farmers' cooperatives	0.490	0.020	0	1	0.196	0.738	***
Industrial poverty alleviation	0.216	0.012	0	1	0.026	0.376	***
Relocation of migrants	0.004	0.001	0	1	0.002	0.005	***
Instrumental variables							
Distance	0.411	0.046	0	50	0.436	0.39	***
Poor village	0.191	0.022	0	1	0.166	0.212	***
Sample size		83,350			37,814	45,536	

***$p < 0.01$.

are not. The three measures, public health service, incentive assistance, and medical aid, were not statistically significant. Serious illness insurance and medical expense reimbursement widened the MRPI gap in older adults to varying degrees. The result is expected since, although it is understandable that all anti-poverty programs reduce absolute poverty or minimize capability deprivations, it is possible to find that some of them increase relative poverty because they tend to help relatively the better-off more. In the case of health insurance, for example, basic health insurance covers the entire population and therefore reduces relative poverty, while serious illness insurance is affordable only to wealthier seniors and therefore increases relative poverty. The HPAP alleviates MRP in older adults by improving their health status. Will its effects differ for older adults with different levels of health? We introduce the dummy variables of serious disease, chronic disease, and disability, as well as their intersection with the HPAP to test this hypothesis. The results are shown in Panels B to D in Table 6.

In Panel B, the partial effect on the MRPI for older adults with serious illness who participated in the HPAP was −0.157 (=-0.159+0.002), which was lower than that of the seriously ill older adults who did not participate (−0.001). Similarly, as shown in Panels C and D, the coefficients for older adults with chronic illness and disability who participated in the HPAP were −0.162 and −0.011, respectively, which were lower than those older adults with chronic illness and disability who did not participate in the HPAP (−0.012 and 0.098). In conclusion, older adults with chronic illnesses or disabilities can benefit from the HPAP.

Among all the poor older adults, those who are poor due to illness account for the largest share of the total poor population, ∼39.89%. We further explore the effect of the policy on those who are poor due to illness. The results are presented in Panel E in Table 6. We can find that the coefficient for the people who were poor due to illness and participated in the HPAP was −0.175, which was lower than that of the seriously ill older adults who did not participate (−0.02). This result is consistent with those presented in Panels B to D in Table 6.

Discussion

Our current research provides new evidence for MRP in older adults. Although poverty research has been well-developed

TABLE 5 Determinants of the MRPI and the impact of the HPAP on the MRPI.

Variables	The OLS result for MRPI		The second stage for MRPI	
	Coef.	Std. Err.	Coef.	Std. Err.
HPAP			−0.159***	(0.004)
Characteristics of the older adults				
Gender	0.002	(0.001)	−0.003	(0.002)
Age	0.000	(0.000)	0.000*	(0.000)
Ability to work	−0.033***	(0.003)	−0.023***	(0.004)
Family characteristics				
Poor household	0.028***	(0.004)	0.001	(0.008)
Family size	−0.054***	(0.003)	−0.060***	(0.003)
Number of patients	0.037***	(0.002)	0.045***	(0.002)
Number of children	0.017***	(0.005)	0.017**	(0.007)
Number of students	0.041***	(0.003)	0.050***	(0.005)
Cultivated land	−0.014***	(0.002)	−0.010***	(0.002)
Fruit land	−0.003	(0.003)	−0.008	(0.005)
Year effects				
2015	0.041***	(0.007)		
2016	0.079***	(0.006)	0.039***	(0.004)
2017	0.070***	(0.005)	0.025***	(0.005)
2018	0.126***	(0.010)	0.077***	(0.007)
2019	0.272***	(0.011)	0.208***	(0.012)
2020	0.061***	(0.006)	0.024**	(0.009)
Other poverty alleviation policies				
Social security guarantees			0.025***	(0.005)
Farmers' cooperatives			−0.011	(0.008)
Industrial poverty alleviation			0.071***	(0.014)
Relocation of migrants			0.017	(0.012)
Constant	0.189***	(0.017)	0.302***	(0.015)
Town	Fixed		Fixed	
Observations	83,350		65,787	
R Square	0.465			
Instrumental variables			Distance and poor village	
First-stage *F*-statistic			8.78	
Overidentifying restrictions *J*-test and *p*-value			44 (0.000)	

To control the endogeneity of the policy variables, we use the lag term of the policy variables, so the sample size is reduced to 65,787. The robust standard errors are presented in parentheses. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

in two paths, this study examines poverty among older adults from both multidimensional and relative perspectives for the first time. On the one hand, a single income or consumption cannot capture the poverty of the old adults accurately (70), and the poverty among older adults can be summarized into four dimensions: health, social, mental, and material dimensions. On the other hand, older adults are disadvantaged in income, health, and cognition, making them relatively poor (59), and the vulnerability of the older people compared with the whole population is obvious, instead, the study of individual relative poverty compared with the seniors group itself is of more theoretical and practical significance.

Our study found that the MRPI of rural older adults increased from 2014 to 2020, although all of them were lifted out of absolute income poverty by the end of this period. The health dimension accounts for about 30% of the MRPI among older adults (42). As they age, the health of older adults deteriorates (59). This reduces their source of income and increases their health care burden, pushing them into poverty. To alleviate the MRP faced by the older people, it is necessary to improve the health security system as well as pensions and health insurance for rural older adults.

We empirically examined the determinants of the MRP among older adults in the benchmark model. We find that

TABLE 6 Analysis of heterogeneity.

Variables	Coef.	Std. Err.
Panel A: Basic regression model + Health poverty alleviation measures		
HPAP	−0.160***	(0.004)
L.Public health service	0.005	(0.005)
L.Medical expense reimbursement	0.007***	(0.002)
L.Incentive assistance	0.004	(0.003)
L.Basic medical insurance	−0.053**	(0.018)
L.Serious illness insurance	0.056**	(0.020)
L.Medical aid	0.003	(0.004)
L.Treatment of serious and endemic diseases	−0.013*	(0.006)
Panel B: Basic regression model + Serious ill +Interaction term (serious ill*HPAP)		
HPAP	−0.159***	(0.004)
L.serious ill	−0.001	(0.008)
L.serious ill * HPAP	0.002	(0.011)
Panel C: Basic regression model + Chronic ill +Interaction term (chronic ill*HPAP)		
HPAP	−0.163***	(0.005)
L.chronic ill	−0.012***	(0.003)
L.chronic ill * HPAP	0.013***	(0.004)
Panel D: Basic regression model + Disability +Interaction term (disability*HPAP)		
HPAP	−0.145***	(0.004)
L.disability	0.098***	(0.004)
L.disability * HPAP	0.036***	(0.002)
Panel E: Basic regression model + Poverty caused by illness +Interaction term (Poverty caused by illness*HPAP)		
HPAP	−0.159***	(0.006)
Poverty caused by illness	−0.02***	(0.004)
Poverty caused by illness*HPAP	0.004	(0.005)

All the model samples were 65,787 and passed the Wald Test. The other control variables and the regression results of the selection model are as the same as the benchmark model in Table 5. The meanings of MRPI and HPAP are the same as those in Table 5. The robust standard errors are in parentheses. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

older adults without work ability are more likely to experience MRP, while natural assets like cultivated land help lower the MRP situation. This is because, in rural areas, the main occupation for older people is agricultural work. If a senior loses the ability to work because of a disability, he or she loses his or her main economic income and increases his or her corresponding financial burden of health care. Conversely, if there are more natural assets, more agricultural income can be earned. The larger the family size of rural older adults, the less likely they are to fall into poverty. A larger family size means a higher proportion of the workforce, which indicates that rural older adults are able to receive more intergeneration financial support from family members. The corresponding family burdens, including patients, children, and students in the family, definitely increase the possibility of MRP among older adults. The positive year dummy coefficients show the increasing effect on MRP by controlling for other independent variables. This indicates that the MRP among older adults keeps increasing compared with the base year of 2014.

We further investigated the impact of the HPAP on the MRP among older adults. The results show that the HPAP can significantly alleviate MRP in older adults. In particular, basic health insurance has the most obvious effect on poverty reduction, and these two measures (medical expense reimbursement and serious illness insurance) will widen MRP. This may be because of the following reasons: first, in the social security system, basic medical insurance is the program that benefits the widest range of people, and it requires a substantial amount of funds. Moreover, there are additional financial subsidies for family members in special hardship conditions, such as minimum living security recipients. This measure has a greater impact on the overall effect of income redistribution in the social security system, while other health poverty alleviation measures do not have redistributive characteristics. In addition, according to the samples, it is found that non-poor older adults are the majority of the beneficiaries of these measures. For example, 9,885 non-poor older adults receive public health services, while only 404

poor older adults benefit from this poverty alleviation policy, which also further increases the overall inequality among older adults.

The HPAP can effectively alleviate MRP among older adults with chronic diseases or disabilities. Poverty due to illness and return to poverty due to illness are more common in rural areas. In the sample of this study, for example, ∼39.89% of the older adults were poor due to illness and 47.56% returned to poverty due to illness. The HPAP can alleviate MRP among older adults, especially for those whose poverty is caused by chronic diseases and disablement. This finding shows the significant contribution of the HPAP to help to support rural older adults in the long run.

Conclusion and policy implication

By constructing the MRPI of older adults, this study finds that relative poverty still persists for rural older adults, showing an upward trend. In addition, among the four MRPI dimensions, the health component plays the most important role rather than mental, social, and material factors for older adults. Using the Poverty Alleviation Database of J County in Shaanxi Province from 2014 to 2020, we empirically show the determinants of the MRPI, and we find that the HPAP can significantly alleviate MRP among older adults. In particular, basic health insurance has the most evident effect on poverty reduction. The HPAP can effectively alleviate MRP among older adults with chronic diseases or disabilities. Therefore, it is important to emphasize that the focus should be on vulnerable populations when implementing pro-poor policies. Improving the quality of health management and services is an effective way to block the occurrence of MRP in rural older adults. Presently, in China, constructing an integrated health promotion system is necessary and imminent. Specifically, popularizing health knowledge for all ages, establishing hierarchical diagnosis and treatment systems, conceptualizing medical insurance systems, such as long-term care insurance, and providing medical integration will efficiently reduce relative poverty in the future.

Strength and limitations

Our study has various strengths and limitations. A significant strength is that we try to construct the MRPI by combining the multidimensional and relative issues to analyze poverty among older adults. This provides an essential reference point for further studies on relative poverty among older adults.

Although the fuzzy set approach can avoid the disadvantages of arbitrary equal weights and the inability to measure the relativity better than the AF method, it has apparent drawbacks, for example, the weights cannot be fixed in different years. Recent solutions regarding data-driven endogenous weights for calculating the MRPI are provided by Dutta et al. (71), but the application of panel data or pooled cross-sectional data as well as selecting the base period or full period data will still ensue different weights, resulting in cross-period incompatibility. Therefore, the possibility of potential expansion still exists.

Additionally, limited to the availability of data, we focus only on older adults at the edge of the poverty line. This might underestimate the MRP incidence among the entire aged population. There is also a lack of subjective indicators in the mental dimension (72), instead, we choose proxy variables which can cause the possibility of imprecision. This article may also suffer from the problem of omitting variables (e.g., the ability, personality, and preferences of the elderly).

Data availability statement

The dataset is administrative data, not open to public use so far. Requests to access these datasets should be directed to zengwh@mail.xjtu.edu.cn.

Author contributions

WZ conceived the idea. PZ and YZ participated in data collection and statistical analysis. WZ and PZ drafted the manuscript and edited the paper. RS gave many valuable comments on the draft and polished it. All the authors contributed toward revising the manuscript and have read and approved the final manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2022.793673/full#supplementary-material

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