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# Household Environments and Functional Decline Among Middle-Aged and Older Adults in China

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# HOUSEHOLD ENVIRONMENTS AND FUNCTIONAL DECLINE AMONG MIDDLE-AGED AND OLDER ADULTS IN CHINA

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# ABSTRACT

This thesis investigates the associations between household social, economic, and physical environment conditions and the trajectory of self-reported functional limitations over time among middle-aged and older adults in China. Despite the increasing interest in the impact of household environments on functional decline, most existing studies are cross-sectional or concern changes in functioning observed in two waves of surveys, and they primarily focus on the influence of one condition. This thesis explores how the trajectory of functional decline is influenced jointly by multiple household factors, including living arrangement, annual living expenditure per capita, indoor air pollution resulting from solid fuels, and housing quality. To analyze the data, a linear growth curve model is applied to four waves of surveys of 13,564 respondents aged 45 years and older from the China Health and Retirement Longitudinal Study (CHARLS) conducted between 2011 and 2018. The study finds that female and older respondents experience faster functional decline compared to male and younger respondents, but there is no significant urban-rural difference in the rate of decline. Living alone, particularly for rural, female, and older respondents, is associated with a faster functional decline when compared to living with a spouse and without children. Improved housing quality is linked to a slower functional decline. Living with young descendants and without adult children for urban residents, and living with a lower expenditure per capita for younger respondents, are associated with a faster functional decline. Discussions are given for expected and unexpected results, the limitations and implications of this study.

# DEDICATION

This thesis is dedicated to my beloved parents, who have been my source of inspiration, conviction, and strength as I sail through peaceful and tough times. With deep gratitude, I dedicate this work to them.

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# INTRODUCTION

Functional ability or capacity is conceptualized as an individual's inherent capability to perform fundamental physical, emotional, or mental actions (Verbrugge & Jette, 1994; World Health Organization, 2001 & 2019). The concept of functional ability comprises five key domains: (i) meeting basic life needs, (ii) mobility, (iii) learning, personal growth, and decision-making, (iv) building and maintaining relationships, and (v) contributing to society (World Health Organization, 2019). These domains align with Lawton's (1983) concept of behavioral competence, which encompasses a crucial domain known as "the good life", including psychological well-being, perceived quality of life, and the objective environment. Functional limitations refer to restrictions in performing these activities (Waite & Hughes, 1999), while disability represents the manifestation of functional limitations within a social context, highlighting the discrepancy between an individual's capabilities and the demands of their environment (Pope & Tarlov, 1991). It is a commission for the society to understand individual and environmental factors that impact functional limitations to enact policies and practices to promote the well-being of older adults (Stuck et al., 1999; Luppa et al., 2010).

Functional decline among middle-aged and older adults in China is an important issue that deserves careful study due to its sweeping public health, social, and economic implications. With birth rate becoming increasingly low in recent years and population aging accelerating (Rossi & Xiao, 2023; CSIS, 2023), China's population declined for the first time in decades in 2022 and was recently surpassed by India in 2023. Such a significant population structure change leads to shrinking of the workforce, increased pension and health care expenditure, and shortage of active persons to support dependent older adults (Lai, 1999). This ongoing change can be compounded by rapid functional decline and disablement among older adults. To mitigate the impact of these challenges,

there is a pressing need for improved understanding of the causes that may accelerate functional decline, which could help society develop targeted measures to extend relatively healthy and disability-free years lived among older adults.

The present study concerns the associations between household environments and the trajectory of self-reported functional limitation in mobility over time among middle-aged and older adults in China. The primary objective is to examine the significant roles played by household socio-economic and physical conditions, including living arrangement, living expenditure, indoor air pollution resulting from solid fuel usage, and housing quality, in influencing the acceleration or deceleration of functional decline in mobility among this population. The study utilizes data from the China Health and Retirement Longitudinal Study (CHARLS), a nationally representative longitudinal survey of persons in China aged 45 years or older and their spouses, including assessments of socio-economic and health circumstances of community-residents (Zhao et al., 2014). Existing literature on functional decline or impairment in mobility among older adults has predominantly focused on a single household environment, with limited exploration of the impact of solid fuel usage and housing quality. Also, many studies are cross-sectional in nature or examine changes in functional capacity over only two consecutive waves of assessments, lacking sufficient evidence regarding the influence of household conditions on the rate of functional decline over multiple years. To address these research gaps, the present study aims to enhance our understanding of the combined impact of multiple household conditions on the trajectory of functional limitations using data from four waves of the CHARLS survey. A linear growth curve model is employed to examine the effect of each household environment on the rate of functional decline among different gender, residence, and age groups within the target population.

The remaining sections of the thesis are organized as follows. We begin with a comprehensive literature review that examines the associations between household conditions and the status or changes in functional capacity in mobility among older adults over time. Following the literature review, we reexamine a theoretical framework that elucidates the impact of household conditions on functioning from resources and demands perspective. Subsequently, two hypotheses are proposed to investigate how household environments influence the trajectory of self-reported functional limitations. The methods section introduces the data and sample used in the study, along with the measurement of functional limitations, household conditions, and control variables. The descriptive statistics of independent and dependent variables are presented, with *t*-tests and chi-squared tests to show if there are any significant differences across genders, residences, and ages. A linear growth curve model is proposed to study the relationships between household conditions and the trajectory of functional limitation over time. Inferential statistics are presented, and the results are discussed in terms of both expected and unexpected findings. The extent to which the hypotheses are supported is assessed, and the contributions, relevance and limitations of the study are discussed.

## LITERATURE REVIEW

Many studies have established the associations of personal mobility, chronical conditions, and lifestyle factors with the status or the trajectory of functional capacity among older adults. As summarized in a few recent surveys (Stuck et al., 1999; Luppa et al., 2010; Jahan, 2017; Geyskens et al., 2022; Moreno-Martin et al., 2022), these factors commonly include multimorbidity, self-rated health status, cognition impairment and depression, vision and hearing impairment, handgrip strength and gait speed, smoking

and drinking frequency, history and fear of falls, physical exercises, and social activities. Cognitive performance, depression, mobility status, and multimorbidity (with certain specific conditions) have shown the most consistent evidence in relation to functional capacity (Stuck et al., 1999; Luppa et al., 2010; Moreno-Martin et al., 2022). Meanwhile, the associations between personal demographic factors and functional capacity have also been investigated, with mixed results regarding gender, education, marital status, and rural/urban residence. However, the majority of studies agree that older age (e.g., Li, 2005; Sun et al., 2009; Luppa et al., 2010; Payette et al., 2011; Liu et al., 2014; Chen et al., 2015a; St. John et al., 2015; Newman et al., 2016; Dong et al., 2017; Aggio et al., 2018; Monserud, 2019; Rundell et al., 2022; Zimmer et al., 2014) and widowhood (e.g., Unger, 1996; Wilcox et al., 2003; Monserud, 2019) are associated with lower functional capacity or a more rapid decline in functioning.

**Living Arrangement**

In addition to personal health, clinical, lifestyle, and demographic factors, the living environment plays a crucial role in shaping individuals' functional capacity. Living arrangement, a key household social condition, has been extensively studied, yielding both consistent and mixed results. For example, Weissman & Russel (2018) considered US older adults of age 65 and above and reported that those living with others (not spouse or children) have the most severe functional limitation compared to living with spouse and no children. Similarly, living with non-relatives was associated with an increased risk of functional decline among older adults aged 65 and older living in Taipei (Chen et al., 2015a). Li (2005) conducted a study on low-income frail elderly individuals living in the community in Michigan and found that respondents who lived with non-spouse individuals had higher levels of activities of daily living (ADL) disability at baseline and experienced more rapid ADL decline compared to those in other living

arrangements. Mahoney et al. (2000) observed that older patients who lived alone and receive home nursing after hospitalization were less likely to improve in function and more likely to be admitted to a nursing home, compared with those who lived with someone. In a study of Dutch women aged 60 to 70, Jonkman et al. (2018) discovered that those living alone had a higher risk of experiencing intermediate functional decline versus little/no decline. Hughes and Waite (2002) found that unmarried women living with children experienced disadvantages in terms of all health outcomes. They also observed that older married couples living together, by themselves or with children, exhibited the highest levels of functioning, while unmarried adults living alone or with others displayed the lowest levels. These relationships largely hold after demographic characteristics and household demands and resources have been considered (Waite & Hughes, 1999). Similar findings about ADL disability were reported by Wang et al. (2013) in a rural county population of older adults in China and by Li et al. (2009) based on the first two waves of the Chinese Longitudinal Healthy Longevity Survey (CLHLS).

Meanwhile, opposite findings regarding the impact of living alone have also been reported. A cross-sectional study conducted in China by Chen et al. (2015b) among older adults aged 60 and above found that living with family, as opposed to living alone, was significantly associated with ADL disability. St. John et al. (2015) surveyed a cohort of Canadian community-dwelling adults aged 65 and above and reported that individuals living with others at the baseline had a higher risk of functional impairment compared to those living alone, both at the baseline and five years later. In Taiwan, Liu et al. (2014) found in a cross-sectional analysis that individuals aged 65 and above who lived alone or only with their spouse had a lower risk of functional impairment or frailty compared to those living with others. Chen et al. (2022) also claimed that Taiwanese people of age 50 and above who lived with others were more likely to have a lower ADL performance

than those who lived alone. Sarwari et al. (1998) observed that unless severely physically impaired, white U.S. women living independently experienced less decline in functional health compared to peers in other living arrangements. Michael et al. (2001) conducted a study among U.S. women nurses aged 60 to 72 and found that those living independently were not at a higher risk of functional decline compared to those living with a spouse.

**Economic Conditions**

The impact of economic conditions on the functioning of older adults has been extensively studied, with a variety of different findings. Many studies report certain positive associations. A cross-sectional study conducted in the District of Columbia and two counties in Maryland by Kahn and Pearlin (2006) found that current financial strain and lower household income were significantly associated with higher functional impairment. Financial difficulties that occurred more recently had a stronger negative impact on functional capabilities, with persistent hardship being the most damaging. Harttgen et al. (2013) analyzed two multi-country data collections SHARE (Börsch-Supan et al., 2013) and SAGE (Kowal et al., 2012) and found that individuals with lower education and income or wealth showed a higher level of frailty in most countries. Interestingly, the level of frailty was higher in higher income countries compared to lower income countries. Dong et al. (2017) studied U.S. Chinese older adults and showed that those who have lower income had lower functional performance at the baseline, but income was not associated with the rate of functional decline. Rundell et al. (2022) showed that U.S. community-dwelling adults aged 65 and above with a lower income have a higher relative risk associated with belonging to each of the lower self-reported physical capacity trajectory groups versus the higher trajectory group. Payne & Xu (2022) used principal component analysis to combine six socioeconomic status (SES) measures including household income and life expenditure into a single SES index, and

claimed that the largest disparities in ADL disability-free life expectancy among Chinese older adults were found between those with persistently low SES and those with consistently high SES throughout life. Haas (2008) claimed that both childhood and adult health and SES factors influence the baseline functional limitation, but only childhood status are associated with the rate of change in functional limitations over time.

On the other hand, lack of or negative associations between variables of interest have also been discovered. For example, Arber and Ginn (1993) conducted a study in the United Kingdom and found that older adults living in advantaged material circumstances reported better overall health. However, they also noted that the level of functional disability was influenced more by previous professional position than by current material circumstances. Semaan (1990, 1996) conducted a national survey in the U.S. and discovered that income explained only a very low level of variance in the severity of functional impairment among older adults, whether they self-responded or had a proxy respondent. In fact, higher income was associated with a slight increase in functional impairment. Liu et al. (2014) examined a national survey of adults aged 65 and above in Taiwan and found that higher income did not necessarily correlate with a reduced risk of belonging to worse functional categories. Zimmer et al. (2017) studied data of women in Philippine through midlife into early old age and reported that coming from a higher wealth household is a detrimental factor to functional performance; they argued that the type of labor that is typically undertaken by rural lower income women may be more physically intensive and benefit their longer-term functional health outcomes.

**Indoor Air Pollution from Solid Fuels**

The impact of indoor air pollution due to solid fuel use on health, particularly in developing countries, is a significant concern. Hundreds of millions of people in rural

China are still using solid fuel to meet their household energy needs (Yu et al., 2018), and hundreds of thousands of deaths annually in China are attributed to indoor air pollution from solid fuel use (Yin et al., 2020). The use of solid fuel has been convincingly connected to several disabling chronic conditions such as arthritis, cardiovascular, and respiratory diseases (Jin et al., 2023).

Several cross-sectional studies have explored the association between using solid fuel and functional capacity. A cross-sectional study (Liu et al., 2020) based on the 3rd wave of China Health and Retirement Longitudinal Study (CHARLS) (Zhao et al., 2014) found a strong and positive effect of using clean cooking fuels on an individual's ability to cope with daily activities, with substantially greater effects on female and older respondents. Another cross-sectional study (Cao et al., 2021) explored the data from the baseline CHARLS survey and confirmed that using solid fuels for cooking is associated with a higher level of ADL/IADL disability. Similarly, a cross-sectional study based on the 4th wave of CHARLS (Jia et al., 2022) pointed out that solid fuel usage increases the risks of depression and chronic pain, which may act as a mediator to impact the ADL/IADL disability. Jin et al. (2023) reported that respondents who used solid fuels in the baseline CHARLS survey had a higher composite frailty index in the 2015 follow-up survey. These studies are cross-sectional or are based on the change in functional capacity in two consecutive waves of survey.

In a most recent longitudinal study based on the first four waves of CHARLS surveys, Ren et al. (2022) employed a Cox proportional-hazards model and revealed that solid fuel usage for cooking and heating is associated with increased risks of developing new ADL/IADL disabilities across age, gender, and residence groups. Interestingly, the study also found that individuals who switched from solid fuels to clean fuels for heating had a lower likelihood of developing new functional disabilities compared to those who

continued using solid fuels. These results provide further evidence of the detrimental effects of solid fuel usage on functional capacity and highlight the importance of transitioning to cleaner energy sources to mitigate such risks.

**Housing Quality**

The research on the associations between housing quality and functional capacity among older adults is relatively limited and predominantly conducted in developed countries. Existing studies mostly focus on factors such as housing accessibility, satisfaction with the residence (including housing and neighborhood), and environmental challenges. Byrnes et al. (2006) conducted a cross-sectional study near Detroit in Michigan, which revealed that individuals reporting lower levels of mental and physical functioning also reported lower satisfaction with their residence and faced significant environmental challenges. In a cross-sectional study in eight European cities, Braubach & Power (2011) showed that houses that were poorly accessible imposed significant difficulties for older residents to use normal house functionalities in daily living and increased the risks of accidents and injuries. Iwarsson & Wilson (2006) highlighted that as functional limitations increased among older adults over time, the magnitude of housing accessibility problems also escalated. However, modifications made to improve housing accessibility can alleviate the need for relocation. Moreover, Gefenaite et al. (2020) found that housing accessibility predicted ADL difficulty among older adults with Parkinson's disease in Sweden, with general self-efficacy and house-related control beliefs moderating generic ADL and disease-specific ADL performances, respectively.

Overall, these studies underscore the importance of housing quality, particularly accessibility, in relation to physical functioning, accidents and injuries, and environmental challenges among older adults. Enhancing housing accessibility not only

improves daily living and reduces functional limitations but also promotes independence and enhances the overall well-being of older individuals. Despite the limited research in this area, these findings highlight the significance of housing quality in supporting functional capacity and improving the quality of life for older adults.

**Rate of Functional Decline**

The studies reviewed above explored the associations between various household environmental variables and functional capacity, impairment, or decline among older adults. Most studies on these relationships are either cross sectional or focus on the change in functional capacity between the baseline and a follow-up survey. To better understand the determinants of the rate of functional decline among older adults, it is crucial to employ longitudinal data that spans multiple waves of assessments. Longitudinal studies provide stronger evidence of causal relationships and enable more robust statistical modeling of functional trajectories over time. Several longitudinal studies have been conducted to investigate the factors influencing the rate of change in functional capacity over time among older adults.

These studies have explored the impact of various factors, including widowhood (Monserud, 2019), cognitive performance (McConnel et al., 2002; Haas, 2008), self-efficacy and outcome expectations (McAuley et al., 2009), physical effort at work (Pebley et al., 2021), neuropsychiatric and cardiovascular multimorbidity (Vetrano et al., 2018), working status (Stenholm et al., 2014), indoor solid fuel usage in cooking and heating (Ren et al., 2022), as well as multiple variables encompassing socio-demographic, mobility, health/morbidity, and lifestyle factors (Botoseneanu et al., 2016; Aggio et al., 2018; Rundell et al., 2022). These studies commonly employ linear mixed-

effects or growth curve models to analyze the rate of functional change over time. Such a statistical model will also be utilized in the present study.

**Analysis of Joint Effects**

To our knowledge, there is currently a gap in the literature regarding the comprehensive examination of the combined effects of multiple household conditions on the trajectory of functional limitation among middle-aged and older adults in China. While individual household factors have been studied independently and shown significant associations with functional outcomes, their interrelationships and combined impact have not been extensively explored. By considering multiple household conditions simultaneously, we aim to address this gap and gain a more comprehensive understanding of their joint influence on the trajectory of functional limitation. For instance, household factors such as income and life expenditure per capita may be interconnected with the use of clean fuel and housing quality. Examining these factors together in a model allows us to identify the most significant contributors to functional trajectory, which might be underestimated or overshadowed when analyzed individually. By incorporating multiple household conditions and assessing their combined effects, our study aims to provide a more nuanced and accurate understanding of how these factors collectively shape the functional outcomes of middle-aged and older adults in China. This comprehensive approach will contribute to a more robust analysis of the complex relationships between household conditions and functional limitation over time.

## THEORETICAL PERSPECTIVES

The general relationship between the environment and the functional capacity could be understood through the ecological change model (Lawton & Nahemow, 1973;

Lawton, 1974). This framework suggests that desirable behavior of an individual may be engendered or elevated in quality by the provision of a favorable environment, and an increase in the competence of the individual gives him a greater control over his environment. There is a large body of literature on the impact of neighborhood and home environments on health outcomes, respectively. Meanwhile, Lee & Waite (2018) assumed that the home environment may have a stronger effect than the neighborhood environment on the cognitive function among older adults, as the former is the more proximal environment whereas the latter is more distal. It remains unclear if their assumption holds for other health outcomes, such as depression and functional capacity.

Hughes and Waite (1999, 2002) have extensively studied the influence of the household environment, particularly living arrangement, on health outcomes. They proposed a theoretical framework that highlights the central role of the household in later life, serving as a repository for critical social roles and interactions that shape the well-being of aging individuals. According to their theory, the household members form a crucial web of interactions for the older adults, where the presence and roles of each member determine the obligations others need to fulfill and the potential for adjustments in these duties when the older adults experience functional or cognitive declines. This highlights the importance of social support and the role that household members play in addressing the needs and challenges faced by older adults.

Meanwhile, physical characteristics of the dwelling place, including housing quality, and the extent to which these characteristics are suited for the needs of healthy aging determine the demands the older adults need to deal with to perform activities of daily living. Socioeconomic and physical household conditions can be analyzed through the perspectives of resources and demands, and the combined impact of multiple conditions is determined by the balance between them. The combination of socio-

economic and physical household conditions influences functional capacity and other health outcomes, with the balance between resources and demands shaping the overall impact. The findings of Hughes and Waite indicate that individuals living in demanding and less supportive household environments tend to experience poorer functioning, whereas those in the most supportive household structures, such as married couples with or without children, exhibit higher levels of functioning. This suggests that the social and physical aspects of the household environment may be interconnected and can significantly influence the functional capacity and well-being of older adults.

In the present study, investigation will be conducted on the associations between various household conditions and the trajectory of self-reported functional limitation for community-dwelling middle-aged and older adults in China. Drawing upon the perspectives of the household resources, demands (Waite & Hughes, 1999) and strain (Lee & Waite, 2018), this study seeks to understand how household factors, including living arrangement, expenditure, indoor air pollution resulting from solid fuel usage, and housing quality, influence the rate of change in functional limitation over time.

Within the framework of household resources, the present study examines the impact of living with amenable and supportive household members, having sufficient life expenditure, using clean fuels and living in homes with good housing quality, on the maintenance of functional capacity among older adults. These resources are expected to play a crucial role in supporting and enhancing the functional abilities of individuals as they age. Meanwhile, the influence of household demands and/or strains, such as living alone without immediate family support, or living with young (grand)children but without adult children, as well as having insufficient economic resources, using solid fuels for cooking, and living in places of poor housing quality, are also investigated. Living in such household environment conditions in an extended period of time tend to

impose physical attrition and psychological stress to the older adults, which are believed to have negative impact on their functional outcomes. These expected outcomes are formally presented in our hypotheses in the next section.

We note that the present study lies in the extensive field of research on social determinants of health (SDOH). Examples of SDOH include education, employment opportunities, income and social protection, housing and basic amenities, air and water pollution, discrimination and violence, and other non-medical factors in built and neighborhood environment (DHHS, 2022). Numerous studies show that SDOH can be more influential than health care or lifestyle choices in health outcomes (WHO, 2022). All sectors and civil societies need to take actions to address SDOH appropriately for improving health and reducing longstanding inequities in health.

## HYPOTHESES

Based on the existing literature, we first hypothesize that the rate of functional decline is slower among older adults in favorable household conditions, including the least demanding living arrangement (living with a spouse and without children), higher living expenditure per capita, using clean fuels in cooking, and better housing quality, while the rate of decline is faster if these conditions are more demanding (such as living alone, using solid fuels in cooking, and living in places of poor housing quality).

However, it is important to note that the literature provides mixed results regarding the impact of living arrangement and household income or expenditure on functional capacity and its trajectories. Similarly, the available evidence on the effects of solid fuel use and housing quality on functional outcome is limited. Therefore, caution should be exercised in expecting these hypotheses to hold true for all household

conditions. It is likely that there will be variations in the evidence supporting these hypotheses across specific household conditions, as well as among different gender, residence, and age groups. Therefore, our study will consider these potential variations and explore how the associations between household conditions and the trajectory of functional limitation may differ among subgroups.

Our second hypothesis proposes that the impact of each household condition on the rate of functional decline varies across different gender, residence, and age groups. Specifically, we expect that the effects of household conditions will be more pronounced in groups that are more reliant on or more susceptible to these conditions. For instance, considering gender differences, females generally exhibit lower functional capacity and higher frailty levels compared to males. Therefore, living alone is expected to be more demanding for females than for males, potentially leading to a faster rate of functional decline among female respondents. Similarly, the age group of 60 and above tends to experience greater frailty and lower functional capacity compared to the younger age group. As a result, living alone is likely to be more challenging for older adults, leading to a faster decline in functional capacity compared to younger respondents in a similar living arrangement. Residence also plays a role, as urban areas in China generally offer more age-friendly environments with greater access to social, economic, medical, transportation, and entertainment resources compared to rural areas (Luo et al., 2019). Consequently, living alone in rural areas is expected to be more demanding and may result in a faster rate of functional decline compared to urban areas. Moreover, younger respondents in China often face greater economic burdens as they may need to support their children and possibly their parents, particularly if their parents reside in disadvantaged rural areas (Cheung & Lucas, 2015). This economic strain may be more pronounced for younger respondents with lower living expenditure per capita, potentially

leading to a faster rate of functional decline compared to older respondents who may be less financially burdened. In summary, similar household environmental strains may result in varying impact on different respondent groups, and the disadvantaged groups may experience a more rapid decline in functional capacity compared to other groups within the same household condition but with different characteristics.

## DATA AND METHOD

### Data and Sample

For our study, we utilized data from the China Health and Retirement Longitudinal Study (CHARLS), spanning four waves from 2011 to 2018. The CHARLS sample was obtained through a multistage stratified probability proportional to size (PPS) sampling method. The baseline survey was conducted in 2011 covering 28 provinces (including autonomous regions and municipalities), 125 cities (including prefectures and leagues), 450 villages/communities, 10,257 households, and 17,706 respondents aged 45 years and older, along with their spouses if available. The overall response rate for the baseline survey was 80.5%. Three national follow-up interviews were carried out in 2013, 2015, and 2018. Our sample consisted of respondents who participated in the 2011 survey and had complete information on personal demographics, cognition, depression, chronic conditions, falls history, grip strength, gait speed, chair stand and balance difficulties, smoking and drinking status, chronic pain, and household conditions of interest. Additionally, they needed to have answered functional limitation questions in at least one wave. The final sample size comprised 13,564 respondents, of whom 7,004 were females and 6,560 were males. Among them, 10,010 resided in rural areas and

3,554 lived in urban areas. Furthermore, 5,795 respondents were 60 years old or above, while 7,769 were between the ages of 45 and 59 at the baseline survey.

## Measures

### Function limitations

In the gerontology literature, functional decline usually refers to a decline in functional capacity to complete activities of daily living (ADL) or instrumental activities of daily living (IADL) (Jahan, 2017; Geyskens et al., 2022; Moreno-Martin et al., 2022). ADLs encompass essential self-care tasks that individuals perform on a daily basis, while IADLs involve activities that enable independent living within the community. Traditionally, functional assessments focusing on ADLs and IADLs have been predominantly conducted among respondents aged 65 years or older (Moreno-Martin et al., 2022), as younger individuals tend to have limited difficulties in these scales. However, we recognize the importance of considering a broader age range. For middle-aged respondents, understanding the trajectory of "situation-free" functional capacities is crucial. These capacities include tasks such as walking, lifting heavy objects, and climbing stairs, which exhibit a gradual change over time and may have a substantial impact on future ADL and IADL difficulties. To measure these situation-free functional capacities, we draw upon existing literature and utilize validated assessments used in studies such as Stenholm et al. (2014), Haas (2008), Pebley et al. (2021), Rundell et al. (2022), Wang et al. (2019), and Wei et al. (2019). By incorporating these measurements, we aim to capture a more comprehensive understanding of functional limitations across different age groups and their association with household conditions.

In this study, we utilize a self-reported measure of functional limitation based on the assessment of seven situation-free mobility activities. These activities include

walking one kilometer, getting up from a chair after sitting for a long period, climbing several flights of stairs without resting, stooping/kneeling/crouching, reaching or extending both arms above shoulder level, lifting or carrying weights over 5 kilograms, and picking up a small coin from a table. For each activity, respondents indicate their level of difficulty. A score of 0 is assigned if they can complete the activity without difficulties, 1 if they experience difficulties but can still complete it, and 2 if they have difficulties and require assistance or are unable to complete the activity. The functional limitation score ranges from 0 to 14, with higher scores indicating more severe limitations. This 3-level grading scale, consistent with the approach used in Botoseneanu et al. (2016), allows for a more accurate assessment of functional limitations compared to a 2-level scale that does not differentiate between completing activities independently with or without difficulties. In contrast to some studies that excluded respondents who had severe functional limitations in the baseline survey with limited room for further functional decline in follow-up surveys (Stuck et al., 1999; Moreno-Martin et al., 2022), our regression analysis of the 14-point functional limitation does not exclude any respondents. By employing this measurement approach, we aim to provide a comprehensive and accurate assessment of functional limitation, reducing potential biases introduced by respondent selection.

**Household Conditions**

In our analysis, we consider four key household conditions: living arrangement, annual household expenditure per capita, housing quality, and indoor air pollution due to cooking using solid fuels. Household social condition was indicated with living arrangement; economic condition was represented by annual household expenditure per capita; physical condition was characterized by housing quality and indoor air pollution due to solid fuel usage for cooking.

Living arrangement is categorized into six groups: (i) living with a spouse and without children or grandchildren, (ii) living alone, (iii) living with at least one adult children/grandchildren (22 years old or above) and without a spouse, (iv) living with spouse and at least one adult children/grandchildren, (v) living with young children/ grandchildren but no adult descendants, with or without spouse, and (vi) other types. Annual household expenditure per capita in Chinese Yuan was log-transformed in regression analysis. Research has shown that household expenditure provides a better measure of available economic resources than income in developing countries (Strauss & Thomas, 2007). Indoor air pollution caused by solid fuel usage for cooking is represented by a binary variable. A value of 1 indicates that the household uses solid fuel (such as coal, crop residue, and wood) for cooking, while a value of 0 indicates the use of clean fuel (such as natural gas, marsh gas, liquefied petroleum gas, or electricity). Housing quality is measured using a composite index that assesses the quality of six home amenities: toilet, running water, electricity, shower/bath facility, phone, and internet. Each amenity is assigned a score ranging from 1 to 3, with higher scores indicating better quality (Li et al., 2015). The housing quality index ranges from 6 to 18.

**Individual Controls**

In our analysis, we included several individual control variables to account for factors that would likely influence the relationship between functional limitation and household conditions. These control variables encompassed demographic characteristics, lifestyle characteristics, objective physical assessments, and chronic conditions. The demographic variables taken into account were gender, urban/rural residence, age in years, and educational levels (categorized as no formal education, primary school, middle school, and above). Other control variables include the baseline 31-point cognition score (10 points for immediate word recall, 10 points for delayed recall, 5 points for time

orientation, 5 points for numeric ability, and 1 point for visuo-construction), which is similar to the cognitive measurement in the Health and Retirement Study based on the Telephone Interview of Cognitive Status battery (TICS; Crimmins et al., 2011), and a 4-level depression scale based on responses to the CESD-10 questionnaire (Andresen et al., 1994). They also include the body-mass index (BMI), whether had falls in the past two years, grip strength (in kilograms), gait speed (time in seconds to walk 2.5 meters), difficulty in the repeated chair stand test, difficulty in the full-tandem stand balance test, ever smoked, currently drinking, hours of physical activities per week, number of different types of social activities participated, chronical pain, and the number of chronic conditions ever experienced. Chronic conditions considered include arthritis, asthma, diabetes, hypertension, stroke, and memory issues. These control variables have been shown to have significant associations with functional status in many health studies.

**Statistical Analysis**

We calculated average functional limitations at each wave and descriptive statistics for all other variables at the baseline survey for all respondents and separately for rural and urban respondents, female and male respondents, and those aged below 60 and at or above 60. We conducted *t*-tests or ANOVA tests (for continuous variables) and chi-square tests (for categorical variables) to test gender, urban/rural residence, and age differences in the mean values of these variables.

To utilize the longitudinal data spanning four waves, we intend to employ a linear growth curve model to explore the relationship between household characteristics and both the baseline functional limitation and its trajectory over the 7-year study period. The value of time indicates the number of years since the baseline, ranging from 0 to 7. The baseline survey year 2011 is denoted with time = 0. We considered the intercept(s)

(baseline functional limitation) and the slope(s) (yearly rate of change in functional limitation) as random effects, on both individual and household levels. The direction and significance of associations between different household conditions and the rate of functional decline were examined by the coefficients of the interactions between time and each household condition. With the functional limitation being the outcome, positive coefficients indicate an acceleration of functional decline, while negative coefficients suggest a deceleration of functional decline over time.

To include appropriate controls for the trajectory of functional decline, we also consider interaction terms between time and age, baseline objective functional test results (such as grip strength, gait speed, chair stand and balance difficulties), and the number of a particular set of chronical conditions (diabetes, hypertension, stroke, arthritis, asthma, and memory problems) that are closely connected to poor functioning. The interaction term between time and age will address the fact that functional capacity tends to decline more rapidly among older adults. By including this interaction, we can examine how the relationship between time and functional decline varies across different age groups. Similarly, incorporating the interaction between time and the number of certain chronic conditions will allow us to account for the fact that higher numbers and greater severity of certain chronic conditions are typically linked to more rapid functional decline. Furthermore, we will consider the interaction between time and baseline objective functional test results. Baseline functional capacity is a crucial factor associated with distinct functional trajectory patterns, such as “persistently low” or “rapidly declining” (e.g., Liu et al., 2014; Aggio et al., 2018; Jonkman et al., 2018; Chen et al., 2022; McAuley et al., 2009; Rundell et al., 2022); those with objective functional difficulties at the baseline may have stable or modest decline in subsequent years, possibly because their poor baseline functional capacity gives limited room for further dramatic declines

(Saito et al., 2019; Edjolo et al., 2020). Considering these interactions in our growth curve model will enhance the accuracy of evaluating the effect of household conditions on the rate of functional decline. By controlling for these important factors, we can better understand the unique contribution of household conditions in shaping the trajectory of functional limitations among middle-aged and older adults in China.

In our study, all independent and control variables at the individual and household levels are assessed at the baseline wave and remain constant over time. The use of such time-invariant covariates (TICs) in the growth curve model allows us to directly examine hypotheses regarding the prediction of higher or lower initial values of the dependent variable, as well as higher or lower rates of change over time (e.g., Curran et al., 2004; Curran et al., 2010). The main strength of growth curve models for our study is the capability for the estimation of between-individual and between-household variabilities in within-individual and within-household patterns of functional change over time. The growth curve model will be fit within the multi-level modeling framework (Raudenbush & Bryk, 2002; Singer & Willett, 2003) that accommodates the nesting of multiple individuals within a group, and it considers the clustering of observations (within individuals and households) by allowing residuals to be distributed and related across individuals and households (Curran et al., 2010). Another advantage of growth curve model is their ability to handle datasets where not all respondents were observed at all waves. In the case of CHARLS, some older respondents who were interviewed at the baseline survey were not interviewed in the subsequent waves due to relocation or death. Growth curve models can provide less biased results compared to complete case analyses when dealing with such datasets. Furthermore, growth curve models demonstrate robustness in spite of violations of homogeneity of variance assumptions (Curran et al.,

2010). This ensures that our analysis remains reliable even in scenarios where the assumption of equal variances across individuals and households is not fully met.

# RESULTS

## Descriptive Statistics

Table 1 shows descriptive statistics of the variables included in this study. Among all respondents in the baseline survey, the average functional limitation score was 1.76 out of a total of 14, indicating a relatively low level of functional limitations. However, this score showed a steady increase in each follow-up survey, suggesting a worsening of functional limitations over time. When considering demographic characteristics, it was observed that urban respondents had lower functional limitations compared to their rural counterparts. Similarly, male respondents had lower functional limitations than female respondents. Furthermore, younger individuals (below the age of 60) exhibited lower functional limitations compared to older individuals (aged 60 and above).

In terms of household economic conditions, the average annual living expenditure per capita was ¥7,170 (approximately $1,000). This provides insight into the financial resources available to households in the study. Approximately 53.20% of the households used solid fuels for cooking, indicating a potential risk of indoor air pollution. The average housing quality index was 11.75 out of 18, indicating a moderate level of housing quality. Additionally, it was found that 27.78% of the residents were living with a spouse and without children or grandchildren, which represent a modest proportional of respondents in the reference living arrangement.

In the baseline survey, a comparison between rural and urban respondents revealed several differences in their demographic characteristics and various health-related factors. Urban respondents were slightly older on average compared to their rural counterparts. They also had a higher proportion of female respondents. Additionally, urban respondents tended to have higher levels of education and cognition scores, indicating potentially better cognitive functioning.

In terms of physical health, urban respondents had a higher average body mass index (BMI) compared to rural respondents. They also had a lower prevalence of depression and reported fewer falls in the past two years. Furthermore, urban respondents exhibited slightly higher grip strength. The gait speed, however, showed similar levels between urban and rural residents. When considering lifestyle factors, urban residents had a lower prevalence of smoking and drinking compared to rural residents. They also reported a lower prevalence of chronic pain and experienced fewer difficulties in activities such as chair stand and balance tests. Regarding chronic conditions, urban respondents had a slightly higher number of chronic conditions compared to rural respondents. In terms of physical activity, urban residents engaged in lower levels of physical exercise compared to their rural counterparts. However, they participated in a higher number of social activities, indicating potentially better social engagement. Economically, urban households had much higher average household expenditures, indicating potentially greater financial resources. They also had better housing quality compared to rural households. Additionally, urban residents were significantly less likely to use solid fuels for cooking, which indicates a lower risk of indoor air pollution associated with cooking practices. These differences between rural and urban respondents provide insights into the varying demographic characteristics, health-related factors, lifestyle behaviors, and household conditions that exist between these two populations.

Compared to female respondents, male respondents at the baseline were slightly older, less likely to live in urban areas, had higher education and cognition score, lower depression, lower BMI, lower rate of falls, much stronger grip strength, faster gait speed, a much higher prevalence in smoking and drinking, a lower prevalence in chronic pain, chronic conditions, chair standup and balance difficulties, and had more physical exercises and social activities. Males were more likely to live with spouse and no (grand)children and less likely to live with adult (grand)children and no spouse than females, but the differences in other household conditions were relatively small since most respondents live with spouse in the same household.

Younger respondents aged below 60 at the baseline survey were more likely to be female, had higher education and cognition score, lower depression, higher BMI, a lower rate of falls, a lower prevalence in smoking but higher in drinking, a lower prevalence in chronic pain and chronic conditions, higher grip strength and gait speed, lower chair stand and balance test difficulties, more physical exercises and social activities than the older respondents. Younger respondents are much less likely to live with spouse and no (grand)children, living alone, or with adult (grand)children and no spouse. They also had higher household expenditures, better housing quality, and were less likely to use solid fuels for cooking than the older respondents.

The average functional limitation scores across different subgroups in the four waves of interviews provide insights into the patterns of functional decline over time. The results indicate that female respondents and older individuals experienced more rapid functional decline compared to their male and younger counterparts, respectively. Specifically, the increase in functional limitation score from wave 1 to wave 4 was 1.03 for females and 0.67 for males, highlighting a greater progression of functional limitations among females during this study period. Similarly, the older group exhibited a

larger increase in functional limitation (1.22) compared to the younger group (0.71), suggesting a faster decline in functional capacity among older individuals.

Table 1. Descriptive Statistics of Baseline Individual and Household Characteristics

| | All (N = 13,564) | | Rural (N = 10,010) | | Urban (N = 3,554) | | *p* of rural-urban diff. | Female (N = 7,004) | | Male (N = 6,560) | | *p* of gender diff. | Age < 60 (N = 7,769) | | Age ≥ 60 (N = 5,795) | | *p* of age diff. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean/% | SD | Mean/% | SD | Mean/% | SD | | Mean/% | SD | Mean/% | SD | | Mean/% | SD | Mean/% | SD | |
| *Individual characteristics* | | | | | | | | | | | | | | | | | |
| Functional limitation 2011 | 1.76 | 2.51 | 1.89 | 2.57 | 1.38 | 2.29 | ** | 2.12 | 2.68 | 1.38 | 2.26 | ** | 1.28 | 2.03 | 2.41 | 2.92 | ** |
| Functional limitation 2013 | 2.04 | 2.71 | 2.14 | 2.77 | 1.73 | 2.51 | ** | 2.48 | 2.86 | 1.57 | 2.46 | ** | 1.52 | 2.22 | 2.73 | 3.13 | ** |
| Functional limitation 2015 | 2.14 | 2.77 | 2.27 | 2.85 | 1.68 | 2.42 | ** | 2.64 | 2.96 | 1.59 | 2.43 | ** | 1.61 | 2.26 | 2.91 | 3.21 | ** |
| Functional limitation 2018 | 2.64 | 3.14 | 2.76 | 3.20 | 2.20 | 2.86 | ** | 3.15 | 3.26 | 2.05 | 2.88 | ** | 1.99 | 2.64 | 3.63 | 3.56 | ** |
| Female | 51.64% | | 50.96% | | 53.55% | | ** | | | | | | 53.91% | | 48.59% | | ** |
| Age | 58.77 | 9.44 | 58.65 | 9.37 | 59.13 | 9.65 | ** | 58.29 | 9.52 | 59.29 | 9.34 | ** | 52.09 | 4.48 | 67.73 | 6.47 | ** |
| Urban | 26.20% | | | | | | | 27.17% | | 25.17% | | ** | 25.83% | | 26.70% | | |
| Education | | | | | | | | | | | | | | | | | |
| No formal education | 25.66% | | 30.64% | | 11.62% | | ** | 38.59% | | 11.84% | | ** | 19.20% | | 34.31% | | ** |
| Primary school | 39.87% | | 43.51% | | 29.63% | | | 35.48% | | 44.56% | | | 36.08% | | 44.95% | | |
| Middle school/higher | 34.47% | | 25.85% | | 58.75% | | | 25.93% | | 43.60% | | | 44.72% | | 20.74% | | |
| Fell in past 2 years | 15.70% | | 16.79% | | 12.63% | | ** | 17.56% | | 13.72% | | ** | 13.46% | | 18.71% | | ** |
| Ever smoked | 39.94% | | 41.36% | | 35.96% | | ** | 8.07% | | 73.98% | | ** | 37.50% | | 43.23% | | ** |
| Drink | 33.14% | | 33.44% | | 32.30% | | | 11.95% | | 55.76% | | ** | 35.08% | | 30.54% | | ** |
| Physical activities hours/week | 26.30 | 17.11 | 30.08 | 17.05 | 15.68 | 12.09 | ** | 24.17 | 16.82 | 28.58 | 17.13 | ** | 29.22 | 16.75 | 22.39 | 16.81 | ** |
| Types of social activities | 0.72 | 0.89 | 0.66 | 0.82 | 0.91 | 1.04 | ** | 0.69 | 0.84 | 0.76 | 0.93 | ** | 0.78 | 0.93 | 0.66 | 0.82 | ** |
| Chronic pain | 23.93% | | 26.61% | | 16.38% | | ** | 28.68% | | 18.86% | | ** | 23.04% | | 25.13% | | ** |
| Number of chronicle conditions (out of 6) | 0.77 | 0.84 | 0.76 | 0.82 | 0.80 | 0.89 | ** | 0.83 | 0.86 | 0.71 | 0.82 | ** | 0.64 | 0.76 | 0.95 | 0.91 | ** |
| Cognition | 14.79 | 5.49 | 13.94 | 5.41 | 17.17 | 5.00 | ** | 13.87 | 5.81 | 15.77 | 4.94 | ** | 15.87 | 5.14 | 13.34 | 5.61 | ** |
| Depression | 1.84 | 0.64 | 1.90 | 0.65 | 1.66 | 0.56 | ** | 1.93 | 0.67 | 1.74 | 0.59 | ** | 1.79 | 0.62 | 1.90 | 0.65 | ** |
| BMI | 23.64 | 3.89 | 23.28 | 3.82 | 24.65 | 3.88 | ** | 24.11 | 3.95 | 23.13 | 3.75 | ** | 24.05 | 3.78 | 23.08 | 3.96 | ** |
| Grip strength | 31.99 | 10.40 | 31.81 | 10.44 | 32.51 | 10.26 | ** | 26.09 | 7.51 | 38.28 | 9.31 | ** | 34.34 | 10.12 | 28.84 | 9.92 | ** |
| Time (sec) to walk 2.5ms | 4.07 | 1.66 | 4.08 | 1.65 | 4.03 | 1.68 | | 4.27 | 1.76 | 3.84 | 1.52 | ** | 3.59 | 0.76 | 4.71 | 2.23 | ** |
| Chair stand difficulty | 1.39% | | 1.46% | | 1.18% | | ** | 1.79% | | 0.96% | | ** | 0.57% | | 2.49% | | ** |
| Balance difficulty | 24.17% | | 24.74% | | 22.55% | | ** | 29.79% | | 18.16% | | ** | 18.28% | | 32.07% | | ** |
| *Household conditions* | | | | | | | | | | | | | | | | | |
| Living arrangement | | | | | | | | | | | | | | | | | |
| Living with spouse and no (grand)children | 27.78% | | 27.12% | | 29.63% | | ** | 26.24% | | 29.42% | | ** | 20.84% | | 37.08% | | ** |
| Living alone | 5.41% | | 5.22% | | 5.94% | | | 5.65% | | 5.15% | | | 2.75% | | 8.97% | | |
| Living with adult (grand)children & no spouse | 7.95% | | 7.97% | | 7.88% | | | 11.14% | | 4.54% | | | 5.24% | | 11.58% | | |
| Living with spouse & adult (grand)children | 37.07% | | 37.55% | | 35.71% | | | 36.22% | | 37.97% | | | 40.87% | | 31.98% | | |
| Living with young (grand)children & no adult (grand)children | 21.24% | | 21.56% | | 20.34% | | | 20.29% | | 22.26% | | | 29.68% | | 9.92% | | |
| Living with others | 0.55% | | 0.57% | | 0.51% | | | 0.46% | | 0.66% | | | 0.62% | | 0.47% | | |
| Annual expenditures per capita in ¥1,000 | 7.17 | 7.43 | 5.89 | 5.99 | 10.79 | 9.58 | ** | 7.00 | 6.99 | 7.35 | 7.87 | ** | 7.54 | 7.53 | 6.68 | 7.25 | ** |
| Solid fuel usage for cooking | 53.20% | | 65.93% | | 17.33% | | ** | 52.97% | | 53.45% | | | 49.52% | | 58.14% | | ** |
| Housing quality | 11.75 | 3.02 | 11.06 | 2.72 | 13.68 | 2.98 | ** | 11.80 | 3.01 | 11.69 | 3.03 | * | 11.92 | 3.07 | 11.52 | 2.94 | ** |

In contrast, the difference in functional limitation increase between rural and urban groups was relatively small. The increase in functional limitation was 0.87 for the rural group and 0.82 for the urban group, indicating a similar rate of functional decline between these two groups. This finding contrasts with the substantial urban-rural differences observed in the rate of cognitive decline during the same period of time, as evidenced by previous studies (e.g., Luo et al., 2021; Chen et al., 2022). These results highlight the unique patterns of functional decline across different subgroups. Female respondents and older individuals appear to be particularly vulnerable to faster functional decline over time. Additionally, while urban-rural disparities are prominent in cognitive decline, they seem to be much more muted in the rate of functional decline. These findings contribute to our understanding of how gender, age, and urban-rural residence can impact the trajectory of functional limitations over time.

**Choice of Regression Model**

Tables 2 present the findings from four linear growth curve models examining functional limitation at the baseline survey and its trajectories. Each model incorporates an expanded set of control variables, while all models include the four household conditions and their interactions with time. Model 1 includes personal demographic variables such as gender, urban/rural residence, age, and education. It also includes the interaction between age and time, accounting for the fundamental influence of age on the rate of functional decline. It serves as a baseline model for assessing the direct relationship between household conditions and the trajectory of functional limitation. In addition to the household conditions and age, model 2 includes lifestyle variables such as smoking and drinking, the levels of physical and social activities, and a few health and functioning variables such as the number of chronic conditions, falls in the past two years, and cognition and depression evaluations. These additional control variables have been shown in the literature to have significant associations with functional status among older adults. The interaction between chronic conditions and time is also involved to reflect the significant acceleration impact of certain chronic conditions on the rate of functional decline. Model 3 further incorporates objective physical test results such as BMI, grip strength, gait speed, chair stand and balance test difficulties, and their interactions with time, enabling the exploration of how variations in baseline physical capabilities relate to the trajectory of functional limitation. These physical tests are reliable measures widely used to perform functional assessment for older adults. Expanding further, model 4 includes interactions between time and demographic variables such as gender, urban/rural residence, and educational level. This allows for an evaluation of how these socio-demographic factors interact with time in shaping the

Table 2. Regression Coefficients from four Linear Growth Curve Models of Trajectories of Cognitive Function among Middle-aged and Older Adults in China

| | Model 1 | Mode 2 | Model 3 | Model 4 | Model 5 |
|---|---|---|---|---|---|
| Intercept | 0.9451*** | 0.5491*** | -0.7067*** | -0.6051*** | -0.6399*** |
| Change rate: Time | 0.1185*** | 0.1038*** | 0.1959*** | 0.1402*** | 0.1598*** |
| *Individual controls* | | | | | |
| Female | 0.8411*** | 0.3137*** | -0.0892* | -0.1642*** | -0.1836*** |
| Age (centered at 45) | 0.0680*** | 0.0364*** | 0.0108*** | 0.0103*** | 0.0104*** |
| Urban | -0.0521 | -0.2679*** | -0.3140*** | -0.3182*** | -0.3216*** |
| Education (ref = none) | | | | | |
| Primary school | -0.3068*** | -0.1889*** | -0.1173*** | -0.0598 | -0.0605 |
| Middle school & above | -0.5099*** | -0.1502*** | -0.0515 | 0.0578 | 0.0611 |
| Ever smoked | | 0.0907*** | 0.1302*** | 0.1306*** | 0.1051** |
| Drink | | -0.2470*** | -0.2051*** | -0.2043*** | -0.1974*** |
| Total physical activities hours/week | | -0.0263*** | -0.0211*** | -0.0211*** | -0.0222*** |
| Types of social activities | | -0.1158*** | -0.0869*** | -0.0870*** | -0.0799*** |
| Chronic pain | | 0.8516*** | 0.7478*** | 0.7476*** | 0.8426*** |
| Number of chronic conditions (out of 6) | | 0.4892*** | 0.3959*** | 0.3961*** | 0.3796*** |
| Fell in past 2 years | | 0.4068*** | 0.3403*** | 0.3401*** | 0.4108*** |
| Cognition | | -0.0437*** | -0.0318*** | -0.0317*** | -0.0319*** |
| Depression | | 0.7850*** | 0.6963*** | 0.6962*** | 0.7367*** |
| BMI | | | 0.0404*** | 0.0404*** | 0.0395*** |
| Grip strength | | | -0.0222*** | -0.0256*** | -0.0247*** |
| Time (secs) to walk 2.5m | | | 0.2696*** | 0.2726*** | 0.2683*** |
| Chair stand difficulty | | | 2.6034*** | 2.5940*** | 2.5658*** |
| Balance difficulty | | | 0.4593*** | 0.4685*** | 0.4531*** |
| *Household conditions* | | | | | |
| Living arrangement (ref = living with spouse, no (grand)children) | | | | | |
| Living alone | -0.2292** | -0.3466*** | -0.3419*** | -0.3348*** | -0.3435*** |
| Living with adult (grand)children & no spouse | 0.1642** | -0.0462 | -0.0443 | -0.0268 | -0.0326 |
| Living with spouse & adult (grand)children | 0.0887* | 0.0426 | 0.0268 | 0.0264 | 0.0256 |
| Living with young (grand)children & no adult (grand)children | 0.0733 | 0.0617 | 0.0451 | 0.0430 | 0.0433 |
| Living with others | 0.4604* | 0.0252 | -0.0323 | -0.0394 | -0.0480 |
| Ln (Living expenditure per capita) | 0.0614*** | 0.0420** | 0.0483*** | 0.0452*** | 0.0439*** |
| Solid fuel cooking | 0.3366*** | 0.2035*** | 0.2032*** | 0.2131*** | 0.2032*** |
| Housing quality | -0.0865*** | -0.0311*** | -0.0191*** | -0.0193*** | -0.0181*** |
| *Change rate* | | | | | |
| Time × Age (centered at 45) | 0.0073*** | 0.0067*** | 0.0071*** | 0.0074*** | 0.0073*** |
| Time × Number of chronic conditions (out of 6) | | 0.0334*** | 0.0344*** | 0.0342*** | 0.0427*** |
| Time × Grip strength | | | -0.0018*** | 0.0000 | -0.0004 |
| Time × Time (secs) to walk 2.5m | | | -0.0099*** | -0.0116*** | -0.0093*** |
| Time × Chair stand difficulty | | | -0.1238*** | -0.1188*** | -0.1038*** |
| Time × Balance difficulty | | | -0.0077 | -0.0123 | -0.0041 |
| Time × Female | | | | 0.0388*** | 0.0493*** |
| Time × Urban | | | | 0.0014 | 0.0031 |
| Time × Primary School | | | | -0.0302*** | -0.0300*** |
| Time × Secondary School | | | | -0.0574*** | -0.0592*** |
| Time × Ever smoked | | | | | 0.0135 |
| Time × Drink | | | | | -0.0035 |
| Time × Total physical activities hours/week | | | | | 0.0006** |
| Time × Types of social activities | | | | | -0.0038 |
| Time × Chronic pain | | | | | -0.0499*** |
| Time × Fell in past 2 years | | | | | -0.0372*** |
| Time × Cognition | | | | | 0.0001 |
| Time × Depression | | | | | -0.0219*** |
| Time × BMI | | | | | 0.0005 |
| Time × Living alone | 0.0617*** | 0.0640*** | 0.0648*** | 0.0610*** | 0.0657*** |
| Time × with adult (grand)children & no spouse | 0.0195 | 0.0171 | 0.0143 | 0.0056 | 0.0084 |
| Time × with spouse & adult (grand)children | 0.0014 | 0.0021 | 0.0023 | 0.0025 | 0.0027 |
| Time × with young (grand)children & no adult (grand)children | 0.0101 | 0.0114 | 0.0124 | 0.0137 | 0.0134 |
| Time × with others | -0.0241 | -0.0300 | -0.0282 | -0.0224 | -0.0163 |
| Time × Ln (Living expenditure per capita) | -0.0050 | -0.0061* | -0.0059 | -0.0041 | -0.0035 |
| Time × Solid fuel cooking | 0.0119 | 0.0109 | 0.0104 | 0.0050 | 0.0103 |
| Time × Housing quality | -0.0035** | -0.0029** | -0.0029** | -0.0028** | -0.0035** |
| *Random effects* | | | | | |
| Household-level variance | | | | | |
| Intercept | 0.6585 | 0.2987 | 0.2934 | 0.2932 | 0.2952 |
| Change rate | 0.0151 | 0.0157 | 0.0155 | 0.0153 | 0.0147 |
| Individual-level variance | | | | | |
| Intercept | 2.4446 | 1.5949 | 1.2708 | 1.2716 | 1.2710 |
| Change rate | 0.0401 | 0.0418 | 0.0438 | 0.0434 | 0.0432 |
| Residual variance | 2.7216 | 2.7031 | 2.6857 | 2.6852 | 2.6838 |
| Observations | 47,084 | 47,084 | 47,084 | 47,084 | 47,084 |
| Wald Chi-square | 5119.44 | 11675.85 | 14390.74 | 14457.24 | 14560.19 |
| *df* | 23 | 33 | 42 | 46 | 55 |

*Note*. *$p$ < .1. **$p$ < .05. ***$p$ < .01 (two-tailed tests).

trajectory of functional limitation. Finally, we also considered a full model (model 5) incorporating the interactions between time and all control variables.

The regression results become largely stable in model 2 and more complex models. Models 4 and 5 provide some evidence that female respondents experience a faster rate of functional decline compared to males; on the other hand, urban/rural residence does not have a direct association with the rate of functional decline, which aligns with the observations from Table 1. It is interesting to see that the significance of the interaction between grip strength and time in model 3 disappeared in models 4 and 5 when the interaction between gender and time is added. Since male's grip strength is much higher than female's, this suggests that gender difference likely accounts for the role of grip strength in model 3. In addition, individuals with higher education show a slightly slower functional decline, consistent with the findings by Zimmer et al. (2014) among Taiwanese older adults. Compared to model 3, the inclusion of more demographic variables by time in model 4 did not significantly alter the coefficients of the household conditions, by or not by time, both in their values and statistical significance. Model 5 accounted for interactions of each control variable with time and exhibited similar roles of household conditions, suggesting that the individual impact of each household condition on the trajectory of functional limitation remains consistent with the findings in models 3 and 4. Compared to model 4, model 5 further shows that the total hours of physical activities per week has a statistically significant but quite modest positive relationship with the rate of functional decline, whereas falls in the past two years, chronic pain, and higher levels of depression at the baseline are significantly associated with slower functional decline in subsequent years. Since respondents who fell in recent years, had chronic pain, and had higher level of depression at the baseline tend to have higher baseline functional limitations, their rate of decline seems to level off thereafter.

The regression results of living arrangement, solid fuel usage, and housing quality for the baseline and the trajectory of functional limitations become stable in model 2 and more complex models. However, the interaction between time and living expenditure per capita is significant in model 2 but loses significance in more complex models. This suggests a lack of consistent evidence to support the significance of living expenditure in the connection with the rate of functional decline. Moreover, the Pearson correlation between baseline functional limitation and BMI, grip strength, gait speed (time to walk 2.5 meters), chair stand and balance difficulties for all respondents are 0.0292, -0.3354, 0.4011, 0.2146, and 0.2803, respectively. Since these values are not very small (except BMI), it is reasonable to consider model 3 that includes these additional control variables. In addition, the Wald Chi-square value of model 3 (14390.74) is significantly higher than that of model 2 (11675.85), but it increased only marginally in model 4 (14457.24) and model 5 (14560.19). Models 4 and 5 are more complex than model 3, but it did not provide additional insight into the effects of household conditions considered in this study, for both the baseline and the trajectory of functional limitations.

Altogether, model 3 included a variety of control variables whose associations with functioning have been largely consistent in the literature. In consideration of the regression result and the complexity, it seems reasonable to select model 3 for further exploration of household conditions in subsequent studies, considering all respondents as well as different age, gender, and residence subgroups. This model provides valuable insights into the relationship between household conditions and functional decline, controlling for relevant individual factors and chronic conditions.

**Regression results: Household Conditions and Baseline Functional Limitation**

In Table 3, we report the results of the baseline survey from model 3. Most of the control variables have significant associations with the baseline functional limitation. In

general, protective factors include younger age, living in urban areas, higher education and cognition, lower depression, lower BMI, no falls in the past two years, higher grip strength and gait speed, no smoking ever but are drinking alcohol, more physical exercises and social activities, no chronic pain, no chair stand and balance test difficulties, and fewer chronic diseases.

After accounting for individual characteristics, several household conditions show significant associations with the baseline functional limitation. Specifically, living alone (compared to living with a spouse and no (grand)children) and having a better housing quality index are linked to a lower baseline functional limitation. On the other hand, living with others, a higher living expenditure per capita, and using solid fuels for cooking are associated with a higher baseline functional limitation.

For each group of respondents classified by gender, urban/ rural residence, and age, the associations between baseline functional limitation and each household condition generally remained similar to those in the group of all respondents, with varying levels of significance. Living expenditure is most significant for the female and the younger respondents; indoor air pollution by solid fuels is significant for all subgroups; housing quality is most significant for rural, male, and the younger groups.

**Regression results: Household Conditions and Functional Limitation Trajectories**

The associations between household conditions and functional limitation trajectories over the 7-year study period for all respondents and different groups are presented under the "change rate" section in the lower panel of Table 3. For the entire group of respondents, older age and a higher number of chronic conditions were found to be significantly associated with a faster decline in functional ability over time. On the other hand, individuals who needed longer time to walk 2.5 meters or had chair stand test difficulties, indicating lower mobility capability, showed a significant association with a

slower decline in functional ability. As explained earlier from Table 2, the result suggesting higher grip strength is significantly associated with slower functional decline is likely a reflection of the gender difference that males experience slower decline than females. The variables of age and certain chronic conditions were consistently very significant across nearly all demographic groups, indicating their strong influence on the trajectories of functional limitation.

When controlling for personal characteristics, several household conditions showed significant associations with the trajectories of functional decline for the entire group of respondents. Living alone, compared to living with a spouse and no children/grandchildren was associated with a faster decline in functional ability. Meanwhile, a better housing quality index was significantly connected to a slower decline in functional ability. It is important to note that the impact of living alone varied across different subgroups. Living alone had a more detrimental effect on rural, female, and older respondents compared to urban, male, and younger individuals, both in terms of the rate of decline and the level of statistical significance. For the urban group, living with young (grand)children but no adult children had a significant negative effect. Living with others showed moderate significance in the female and male groups, albeit with opposite effects. But since the sample of respondents living with others is quite small, caution should be taken to interpret these statistically significant results.

The association between higher living expenditure per capita and a slower functional decline was significant only in the younger group. Using solid fuels for cooking did not have significant association with the rate of functional decline in any group. A better housing quality index was consistently associated with a more favorable trajectory of functional limitation across all groups, except for the rural group and the older group where its effect was not significant.

In summary, living alone emerged as a consistent factor for accelerating functional decline, while a better housing quality index showed a reliable positive association with slower functional decline. The impact of other household conditions varied across different subgroups, indicating the importance of considering these factors within specific demographic contexts when studying the trajectory of functional limitation over time.

# DISCUSSION AND CONCLUSION

## Summary of Findings

The present study concerns the associations between four household social, economic, and physical characteristics and the trajectory of functional limitation among middle-aged and older adults in China over a 7-year period. Our contributions include

applying a linear growth curve model to investigate the effects of different household conditions on the trajectories of functional limitation. In addition, an in-depth study was conducted on how these effects varied across different demographic groups. We also extended previous research by examining the joint effects of multiple household environments. In general, the associations found between each individual household condition and the trajectory of functional limitation did not seem to have significant interferences with each other, as the effect of each individual condition on the functional limitation trajectory did not appear contradictory in direction with most conclusions in the literature that study each condition alone. The key findings of our study indicate that older individuals living alone experienced faster functional decline, while those with better housing quality had slower functional decline. Also, living with young children and no adult children for urban respondents, and lower living expenditure per capita for

younger respondents aged below 60 were associated with faster functional declines. These findings support our first hypothesis that older adults living in more supportive or less demanding household environments experience slower functional decline than those in more demanding conditions. Variations in the strength and significance of the impact by living arrangement and living expenditure on the rate of functional decline provide some evidence for the second hypothesis that the effects of household conditions are more pronounced in groups that are more reliant on these conditions.

Before discussing the impact on the trajectory of functional decline, we briefly comment on the baseline results. The finding that living alone at the baseline is related to a lower functional limitation is aligned with previous studies by Chen et al. (2015b), St. John et al. (2015), Chen et al. (2022), and Weissman & Russel (2018), though opposite findings have been reported as reviewed. This suggests that respondents living alone at baseline have greater functional independence. The positive association between living expenditure per capita and baseline functional limitation is consistent with Seeman (1990) and Zimmer et al. (2017), but there exist divergent findings. The connections between functional limitation and indoor solid fuel usage as well as housing quality are similar to the findings by Liu et al. (2020), Cao et al. (2021), and Byrnes et al. (2006). Most of the significant associations at baseline are also consistent with those found by Wu el al. (2018). These associations between baseline functional limitation and various household conditions are in line with expectations and provide insights into the factors that may influence individuals' baseline functional well-being. Our subsequent discussion is focused on household factors that may impact the trajectory of functional limitation.

**Living Alone**

Living arrangement is among the most important factors related to the health among older adults China. Zimmer (2008) claims that it is more strongly associated with

Table 3. Regression Coefficients from Linear Growth Curve Model 3 of Trajectories of Cognitive Function among Middle-aged and Older Adults in China

| | All | Rural | Urban | Female | Male | Age < 60 | Age ≥ 60 |
|---|---|---|---|---|---|---|---|
| Intercept | -0.7067*** | -0.8393*** | -0.6668* | -1.0734*** | 0.0104 | -4.2550*** | -0.8603** |
| Change rate: Time | 0.1959*** | 0.1763*** | 0.2155*** | 0.1272** | 0.1696*** | 0.5430*** | 0.0634 |
| *Individual controls* | | | | | | | |
| Female | -0.0892* | -0.0351 | -0.2141** | | | -0.3416*** | -0.0544 |
| Age (centered at 45) | 0.0108*** | 0.0123*** | 0.0067 | 0.0213*** | -0.0036 | -0.0898*** | 0.0345*** |
| Urban | -0.3140*** | | | -0.4236*** | -0.1943*** | -0.1874*** | -0.4076*** |
| Education (ref = none) | | | | | | | |
| Primary school | -0.1173*** | -0.1076** | -0.0646 | -0.0749 | -0.1400** | -0.0012 | -0.0708 |
| Middle school & above | -0.0515 | -0.0122 | -0.0937 | 0.0166 | -0.1083 | 0.1931*** | -0.1478 |
| Ever smoked | 0.1302*** | 0.1470*** | 0.0983 | 0.2764*** | 0.0617 | 0.0236 | 0.2243*** |
| Drink | -0.2051*** | -0.2322*** | -0.1352** | -0.1672** | -0.2525*** | -0.1282*** | -0.2719*** |
| Total physical activities hours/week | -0.0211*** | -0.0209*** | -0.0208*** | -0.0209*** | -0.0201*** | -0.0079*** | -0.0305*** |
| Types of social activities | -0.0869*** | -0.0800*** | -0.1109*** | -0.1118*** | -0.0715*** | -0.0441*** | -0.1646*** |
| Chronic pain | 0.7478*** | 0.7395*** | 0.7717*** | 0.7783*** | 0.6875*** | 0.5289*** | 0.8113*** |
| Number of chronicle conditions (out of 6) | 0.3959*** | 0.4054*** | 0.3846*** | 0.4379*** | 0.3515*** | 0.2527*** | 0.4474*** |
| Fallen in past 2 years | 0.3403*** | 0.3166*** | 0.4292*** | 0.2863*** | 0.3785*** | 0.1938*** | 0.4103*** |
| Cognition | -0.0318*** | -0.0311*** | -0.0334*** | -0.0286*** | -0.0340*** | -0.0129*** | -0.0424*** |
| Depression | 0.6963*** | 0.7112*** | 0.6177*** | 0.7352*** | 0.6634*** | 0.4834*** | 0.8702*** |
| BMI | 0.0404*** | 0.0437*** | 0.0312*** | 0.0407*** | 0.0395*** | 0.0274*** | 0.0514*** |
| Grip strength | -0.0222*** | -0.0221*** | -0.0230*** | -0.0259*** | -0.0267*** | -0.0122*** | -0.0294*** |
| Time (secs) to walk 2.5m | 0.2696*** | 0.2802*** | 0.2437*** | 0.2532*** | 0.2770*** | 1.3597*** | 0.1616*** |
| Chair stand difficulty | 2.6034*** | 2.2966*** | 3.8189*** | 2.4270*** | 2.8827*** | 2.4406*** | 2.1845*** |
| Balance difficulty | 0.4593*** | 0.4902*** | 0.3611*** | 0.4053*** | 0.5269*** | 0.2452*** | 0.5394*** |
| *Household conditions* | | | | | | | |
| Living arrangement (ref = living with spouse, no (grand)children) | | | | | | | |
| Living alone | -0.3419*** | -0.3040*** | -0.4138*** | -0.4352*** | -0.2869** | -0.4475*** | -0.5563*** |
| Living with adult (grand)children & no spouse | -0.0443 | -0.0554 | -0.0203 | 0.0253 | -0.3024** | -0.3001*** | -0.1462 |
| Living with spouse & adult (grand)children | 0.0268 | 0.0195 | 0.0461 | -0.0104 | 0.0503 | 0.1048** | -0.0377 |
| Living with young (grand)children & no adult (grand)children | 0.0451 | 0.0450 | 0.0235 | 0.0404 | 0.0005 | 0.0251 | -0.1889* |
| Living with others | -0.0323 | 0.0215 | -0.2365 | -0.1152 | -0.0772 | -0.2481 | -0.0812 |
| Ln (Living expenditure per capita) | 0.0483*** | 0.0468** | 0.0524** | 0.0576*** | 0.0341 | 0.0650*** | 0.0559** |
| Solid fuel cooking | 0.2032*** | 0.2011*** | 0.2277*** | 0.2320*** | 0.1643*** | 0.1518*** | 0.1888*** |
| Housing quality | -0.0191*** | -0.0275*** | 0.0011 | -0.0147* | -0.0199** | -0.0156** | -0.0157 |
| *Change rate* | | | | | | | |
| Time × Age (centered at 45) | 0.0071*** | 0.0072*** | 0.0074*** | 0.0077*** | 0.0083*** | 0.0096*** | 0.0099*** |
| Time × Number of chronicle conditions (out of 6) | 0.0344*** | 0.0413*** | 0.0144* | 0.0359*** | 0.0328*** | 0.0503*** | 0.0324*** |
| Time × Grip strength | -0.0018*** | -0.0017*** | -0.0022*** | 0.0004 | -0.0005 | -0.0032*** | -0.0016** |
| Time × Time (secs) to walk 2.5m | -0.0099*** | -0.0132*** | -0.0001 | -0.0043 | -0.0216*** | -0.0880*** | -0.0011 |
| Time × Chair stand difficulty | -0.1238*** | -0.0748* | -0.3527*** | -0.1392*** | -0.0680 | -0.1491** | -0.1068* |
| Time × Balance difficulty | -0.0077 | -0.0148 | 0.0155 | -0.0178 | 0.0036 | 0.0030 | -0.0053 |
| Time × Living alone | 0.0648*** | 0.0683*** | 0.0463 | 0.0719*** | 0.0571** | 0.0269 | 0.0776*** |
| Time × with adult (grand)children & no spouse | 0.0143 | 0.0234 | -0.0160 | 0.0170 | -0.0045 | 0.0271 | 0.0119 |
| Time × with spouse & adult (grand)children | 0.0023 | 0.0004 | 0.0074 | 0.0171 | -0.0105 | -0.0054 | 0.0110 |
| Time × with young (grand)children & no adult (grand)children | 0.0124 | 0.0039 | 0.0477** | 0.0237 | 0.0027 | 0.0042 | -0.0147 |
| Time × with others | -0.0282 | -0.0402 | 0.0050 | 0.1684* | -0.1179* | 0.0173 | -0.1110 |
| Time × Ln (Living expenditure per capita) | -0.0059 | -0.0047 | -0.0067 | -0.0066 | -0.0050 | -0.0109** | -0.0022 |
| Time × Solid fuel cooking | 0.0104 | 0.0072 | 0.0166 | 0.0060 | 0.0155 | 0.0144 | 0.0173 |
| Time × Housing quality | -0.0029** | -0.0011 | -0.0058** | -0.0035* | -0.0039** | -0.0030* | -0.0036 |
| *Random effects* | | | | | | | |
| Household-level variance | | | | | | | |
| Intercept | 0.2934 | 0.2846 | 0.3235 | 1.70e-09 | 1.99e-06 | 0.0393 | 0.3977 |
| Change rate | 0.0155 | 0.0155 | 0.0155 | 1.70e-08 | 4.66e-08 | 0.0117 | 0.0209 |
| Individual-level variance | | | | | | | |
| Intercept | 1.2708 | 1.2990 | 1.2062 | 1.6859 | 1.3845 | 0.6727 | 1.7271 |
| Change rate | 0.0438 | 0.0463 | 0.0339 | 0.0583 | 0.0588 | 0.0408 | 0.0580 |
| Residual variance | 2.6857 | 2.8731 | 2.0502 | 3.1504 | 2.1844 | 1.9310 | 3.6595 |
| Observations | 47,084 | 35,941 | 11,143 | 24,537 | 22,547 | 27,497 | 19,587 |
| Wald Chi-square | 14390.74 | 10897.41 | 3342.70 | 7808.70 | 6156.12 | 9217.50 | 6255.95 |
| *df* | 42 | 41 | 41 | 41 | 41 | 42 | 42 |

*Note.* *$p < .1$. **$p < .05$. ***$p < .01$ (two-tailed tests).

functional limitation than other health indicators, whereas health indicators are more strongly related for those not married. Notably, the inclusion of interactions with time in previous research on household conditions and functional limitation trajectories has been primarily carried out on living arrangements. Our findings align with existing studies, indicating that older age and not living with a spouse (or being unmarried) are reliable predictors of an increased risk of severe functional deterioration (Li, 2005; Stineman et

al., 2013; Monserud, 2019). However, previous research has presented divergent conclusions regarding the role of living alone (Liu et al., 2014; St. John et al., 2015; Jonkman et al., 2018). Significantly, our study provides novel evidence suggesting that living alone (compared to living with a spouse and no children/grandchildren) is associated with a substantial and accelerated functional decline among older adults in mainland China. In addition, our results highlight that living alone poses a particularly high risk of faster functional decline in rural, female, and older groups. These groups, due to less supportive neighborhoods or lower functional capacity, are more reliant on the presence of supportive family members compared to their urban, male, and younger counterparts. These findings support the second main hypothesis, which posits that the impact of each household condition on the rate of functional decline is more pronounced among groups that are more reliant on such conditions. While other living arrangements also exhibit a tendency towards faster functional decline among all respondents, most of these associations were not statistically significant. This suggests that the effects of other living arrangements on functional limitation trajectories are relatively limited compared to the significance of living alone.

**Housing Quality**

Our study appears to be the first to establish the role of housing quality in functional trajectories among older adults in China. The findings revealed a significant association between better housing quality and slower functional decline, with the exception of the rural and the older groups. The *p*-value of the coefficient of housing quality by time is 0.20 and 0.12, respectively, in these two groups. This result supports our first hypothesis but seems inconsistent with our second hypothesis. In the rural group, the lack of significance of housing quality by time might be attributed to the lower availability of financial, medical, transportation, and entertainment resources in rural

communities compared to urban areas in China (Luo et al., 2019). These factors could potentially moderate the relationship between housing quality and functional limitation trajectories in rural settings, but have not been taken into our consideration. This issue deserves further study in the future.

Table 3 reveals that the impact of housing quality did not exhibit substantial variation across the gender groups. In addition, this condition actually did not show very different effects across the age groups either, as the *p*-value of housing quality by time is 0.07 in the younger group vs. 0.12 in the older group. This suggests that housing quality may have comparable effects that are not sensitive to individual demographics on the trajectory of functional limitation. This is a support to our first hypothesis, but the lack of prominent gender and age differences merits additional investigation.

**Other Household Conditions**

Living expenditure per capita was not found to be significantly associated with functional decline trajectories in all groups, except for the younger group, for whom a higher living expenditure was associated with a slower functional decline. This finding supports our second hypothesis, which suggests that the younger group mostly rely on sufficient living expenditure, as it faces the highest level of financial pressure to support not only themselves, but likely also their children and parents, particularly if their parents are rural residents. Consequently, a higher living expenditure is most crucial for this group and has the strongest impact on their functional trajectory. Living expenditure did not seem to have a pronounced impact on the rate of functional decline in all other groups, probably because their overall financial burden is not as heavy as that for the young group. This is consistent with the findings that higher levels of life satisfaction by earning more on average and over time has stronger effects for midlife individuals than for the younger and the older ones (Cheung & Lucas, 2015). Further research is needed to

explore the specific mechanisms and factors that contribute to the varying impacts of financial resources on functional trajectories among different respondent groups. Our result here is consistent with a study by Dong et al. (2017), which similarly found that income was not associated with the rate of functional decline, and indicates that other factors may be more influential in shaping the functional trajectories of older adults in those particular groups. In contrast to Beydoun & Popkin (2005) and Zimmer et al. (2010), our findings suggest that among the criteria of socio-economic status (SES), living expenditure (or income) per capita is probably not as important as education in the significance of associations with the functional trajectory among older adults in China.

Another observation worth mentioning is that living with young children and no adult children is significantly associated with faster functional decline only in the urban group. A possible explanation is that raising a child from birth to adulthood in modern urban China is quite demanding. It is likely a long-term stress and attrition to the parents, even though urban residents have significantly more financial, educational, medical, transportation, and entertainment resources than rural residents. Such a lasting household demand is probably not so prominent in other gender, residence, and age groups as in the younger group, which may explain the unique significance of this living arrangement in this group only. This is another evidence supporting the second hypothesis, as the group most susceptible to a particular household demand is most likely to see significant influence of this factor on the rate of functional decline.

In contrast to studies that focused on indoor solid fuel usage alone and argued for the significance of this factor in shaping the functional decline trajectory, Table 3 shows that solid fuel usage for cooking did not have a significant association with the rate of functional decline in any group. Since solid fuel usage has a consistently significant association with higher functional limitation at baseline, its impact on the trajectory may

have leveled off in subsequent years. In addition, we found that solid fuel usage showed a significant association with the trajectory if the composite housing quality index is not considered. Therefore, the effect of housing quality on the trajectory may still exist.

Our results underscore the relevance of study of the joint effects of multiple household factors, which may identify true significant predictors more accurately. Since indoor solid fuel usage is closely correlated to the housing quality index, which is a significant predictor, it is likely that the rate of functional decline is affected more by the overall condition of housing amenities, instead of a particular condition such as solid fuel usage. Meanwhile, this observation may also be attributed to the lack of accuracy of this dichotomous variable as the single indicator of indoor air pollutions.

**Limitations**

Our study acknowledges several limitations that should be taken into account. Firstly, we recognize that household social conditions encompass factors beyond those included in our analysis, such as living arrangement concordance and change. The concordance between individuals in the same living arrangement may have significant implications for health outcomes (Sereny & Gu, 2011). Also, Zimmer (2008) shows that changes in living arrangements occur frequently, and a health event is more likely to trigger a living arrangement change for a woman. Future research could explore the impact of living arrangement concordance and change on functional limitation trajectories. Secondly, the dichotomous variable used to indicate indoor air pollution from solid fuel use may not capture the precise impact of different types and levels of air pollutants. Additionally, we did not consider the effects of transitioning from solid fuels to clean fuels, which has been actively promoted and implemented in recent years in China (Carter et al., 2020; Shen et al., 2022). Further investigations could delve into the specific effects of different types of fuel use and the potential health benefits of

transitioning to cleaner fuels. Thirdly, while we used objective measures to assess household conditions, it is important to recognize that these measures may not fully capture the psychological well-being of the respondents. Subjective measures, such as self-reported levels of perceived social support, strain, and threat from household members, could provide deeper insights into how household conditions affect health outcomes (Lee & Waite, 2018). Future studies could incorporate subjective measures to gain a more comprehensive understanding of the complex relationships between household conditions and functional limitation. Lastly, neighborhood conditions were not considered in the analysis, which may act as moderators in the relationship between household conditions and functional limitation. Exploring the interplay between household and neighborhood factors could provide valuable insights into the contextual influences on health outcomes. Considering these limitations, further research can address these aspects to provide a more comprehensive understanding of the complex dynamics between household conditions, neighborhood factors, and functional limitation trajectories among middle-aged and older adults.

**Conclusion**

Despite the aforementioned limitations, our study provides a comprehensive analysis of the combined impact of multiple household conditions on the trajectory of functional limitation among middle-aged and older adults in China. We discovered that living alone, despite being associated with higher functional capacity at the baseline, is significantly linked to faster functional decline, especially among rural, female, and older respondents (aged 60 and above). This underscore the importance of raising social awareness, implementing supportive policies, and providing long-term support for these vulnerable populations. In addition, we found that better housing quality is associated with a slower rate of functional decline for most respondent groups, emphasizing the

potential health benefits of improving housing conditions. This supports initiatives such as the Renovation Program of Dilapidated Houses and the Reconstruction of Urban Shantytowns, Dilapidated Houses, and Supporting Infrastructure in China (Zhang et al., 2022; The State Council of China, 2015). Furthermore, we found that household income per capita significantly influences the functional decline rate for the younger group (aged 45 to 59), and living with young children and no adult children is connected with faster functional decline for urban residents. These findings have implications for policy reforms such as the development of a senior pension system aimed at alleviating the financial stress on the oldest senior rural residents and on their adult children, and child tax credit that relieves the burden on their parents. These reforms are expected to mitigate functional decline among middle-aged and older adults in China.

Overall, our study advances the understanding of household conditions and their influence on functional decline trajectories by incorporating interactions between time and key household as well as individual characteristics. By elucidating the unique risks faced by specific subgroups, we provide important evidence for the development of targeted interventions and policies aimed at fostering supportive living environments for middle-aged and older adults. Our study can serve as a foundation for investigating the combined effects of household and neighborhood environments on functional trajectories. Furthermore, comparing our results with similar studies conducted in other countries can contribute to the development of policies aimed at enhancing living conditions and addressing functional decline among older adults on a global scale.

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