Behavioural, social health and well-being among middle-aged and older adults in China

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A thesis with publications submitted in fulfilment of the requirements for the degree of Doctor of Philosophy

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Jan 2023

STATEMENT OF ORIGINALITY

This is to certify that to the best of my knowledge, the content of this thesis is my own work. This thesis has not been submitted for any degree or other purposes. I certify that the intellectual content of this thesis is the product of my own work and that all the assistance received in preparing this thesis and sources have been acknowledged. I further declare that I was the lead author of the conceptual work underpinning this thesis and led the analysis and writing of all publications included. Author contributions are outlined in Chapters 3-6, separately.

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ACKNOWLEDGEMENTS

At the time I am writing this part of my thesis, I finally realize that I am actually finishing my PhD, which is the hardest challenge in my life to date. As an international student who hasn't studied abroad before, I faced many challenges and obstacles during this journey, especially when I got stuck in my home country due to COVID-19. There were many times in the past four years that I lost faith in myself and felt that I couldn't make it. But, now, here I am, proud of myself, stronger than ever, and ready for the next chapter of my life and new challenges. I am deeply grateful to my amazing supervisors, my talented co-authors, my lovely colleagues, my close friends and my sweet family for their unwavering support and belief in me.

First and foremost, I'd like to express my gratitude to my supervisors, **Adrian**, **PH**, **Melody (丁玎)** and **Joel** for all their invaluable supervision, continuous support and patience during my PhD. Their guidance and support have been instrumental in helping me achieve so much personal and professional growth. Their immense knowledge, plentiful experience and ardent passion to research have encouraged me all the time throughout my academic research and in daily life.

In addition, I'd like to thank my colleagues from the Prevention Research Collaboration for being such a wonderful group of people, both in and out of the office. I feel obligated to single out my outstanding PhD peers, **Bronwyn, Bridget, Daniel, Lilian, Lucy** and **Neta** for being so nice to me and making me feel part of a group. I'd also like to thank my co-authors, **Andreas Holtermann**, **Borja del Pozo Cruz**, **Chenhao Yu**, **Emmanuel Stamatakis, Liangkai Chen, Nidhi Gupta**, **Zhiruo Zhang** and everyone else I have collaborated with.

There must be an extraordinary thanks to my partner, **Tasos**, for being patient and supportive, and making me happy every day in our daily life. To my sincere friends in China, **Ingrid (曹鹭)**, **Bella (徐丽)**, **Tina (方慰)** and many others, who have helped me throughout all these years.

Last but most importantly, I'd like to express my biggest thanks to my parents **Jingjun Su (苏静军)** and **Enlan Luo (罗恩兰)**, my little brother **Ben Su (苏奔)**, my uncle **Ping Su (苏平)**, and many other close family members in China. My gratitude to them is never-ending. I would like to thank them all for being so supportive during this amazing journey! I feel so lucky and privileged to have them as my family. I would always be grateful for helping me

make my dream come true and let me be whomever I want to be. Without their tremendous understanding and encouragement over the past four years, it would be impossible for me to achieve this.

(在此，我还想衷心感谢我的父亲**苏静军**、母亲**罗恩兰**、弟弟**苏奔**、三叔**苏平**和其他亲近的家人们。我对你们有着无穷无尽的感恩，感谢你们一路上对我的支持和帮助。我是如此幸运能有你们帮助我实现我的梦想，并且让我成为了我想要成为的人。没有你们在过去四年内对我理解包容和鼓励，我根本没有办法走到今天，成功完成我的博士学业。)

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ABBREVIATIONS

aOR	Adjusted odds ratio
BHPS	British Household Panel Survey
BMI	Body mass index
BRFSS	Behaviors Risk Factor Surveillance System
CCDC	China Centers for Disease Control and Prevention
CHARLS	China Health and Retirement Longitudinal Study
CI	Confidence interval
CKB	China Kadoorie Biobank
CLHLS	Chinese Longitudinal Healthy Longevity Survey
CNNS	China National Nutrition Surveys
CNY	Chinese Yuan
COPD	Chronic obstructive pulmonary disease
CVDs	Cardiovascular diseases
DALYs	Disability-adjusted life years
DAG	Directed acyclic graph
DPA	Domestic physical activity
DSP	Disease Surveillance Points
GBD	Global Burden of Disease
GDP	Gross domestic product
GPAQ	Global Physical Activity Questionnaire

HICs	High-income countries
HR	Hazards ratio
HRS	Health and Retirement Study
ICD	International Statistical Classification of Diseases
IQR	Interquartile range
LMICs	Low- to middle-income countries
LTPA	Leisure-time physical activity
MET	Metabolic equivalent of task
NCDs	Non-communicable diseases
OECD	Organisation for Economic Co-operation and Development
OPA	Occupational physical activity
OR	Odds ratio
PA	Physical activity
PURE	Prospective Urban Rural Epidemiology
SD	Standard deviation
SE	Standard error
SES	Socio-economic status
SPSS	Statistical Package for the Social Sciences
SAGE	Study on Global AGEing and Adult Health
SGPALS	Saltin-Grimby Physical Activity Level Scale
STEPS	WHO STEPwise approach to NCD risk factor surveillance

TPA	Transport physical activity
TPB	Theory of planned behaviours
24HR	24-hour dietary recall
UK	United Kingdom
UN	United Nations
US	United States
WHO	World Health Organization
WHOQOL-BREF	World Health Organization Quality of Life Instrument-Abbreviated Version
YLD	Years lived with disability

ABSTRACT

China has experienced a fast-growing population aging in the past 40 years and it will remain a major public health concern in the coming decades. To deal with the health and social problems related to population aging and inform future interventions, it is crucial to have a comprehensive understanding of the potential barriers to and facilitators of healthy aging in China. It is also important to incorporate multiple existing large-scale population-based surveys focusing on middle-aged and older adults into research to generate useful information to inform evidence-based practice.

This thesis explored risk factors for health, including physical, mental and behavioural health among middle-aged and older adults in China, using a socio-ecological framework, by examining: 1) different levels of correlates of domain-specific physical activity among older adults, including individual, community, and societal level **(Chapter 3)**; 2) the relationship between social engagement pattern, and lifestyle behaviours and subjective well-being of older adults **(Chapter 4)**; 3) the relationship between retirement and risky lifestyle behaviours among middle-aged and older population **(Chapter 5)**; 4) the relationship between occupational physical activity and mortality among middle-aged adults **(Chapter 6)**.

Overall, findings from the studies suggest that different levels of risk factors from the socio-ecological framework, including individual (gender, age, educational attainment, income level and working status), interpersonal (social engagement), community (physical activity at the workplace) and societal levels (place of residence and social capital), all contribute to health among middle-aged and older adults in China. Findings also confirmed that influences of correlates on health behaviours could interact across different levels. Implications of the findings for public health, surveillance data and policy, proposed solutions, and suggestions for future directions are discussed.

CHAPTER 1: Introduction and research overview

There are global challenges associated with population aging, especially in low- to middle-income countries (LMICs), where the aging population growth rates are disproportionately high (1). The United Nations (UN) has projected that the number of people aged over 65 years old will reach more than 1.5 billion in 2050, of which 80% will be living in the LMICs (2). The People's Republic of China (hereafter referred to as China), the world's most populous country with 1.4 billion people in 2020, has experienced one of the fastest-growing aging populations in the world in the past 40 years, and it will remain an issue of great concern for China in the coming decades (3). An aging population creates economic, public health and social challenges. To ensure that the health and social systems can support this demographic shift, understanding the social and environmental factors influencing healthy aging is important.

1.1 Epidemiological transition and changing burden of disease in China

The health of Chinese adults has improved significantly in the past few decades. Between the founding of the People's Republic of China in 1949 and the implementation of free-market reforms in 1978, China was a relatively poor country with high rates of infectious diseases, infant mortality and low life expectancy (4). However, China's economic rise in recent decades has led to an epidemiological transition, characterised by increasing life expectancy and increasing prevalence of chronic diseases or non-communicable diseases (NCDs). According to the Global Burden of Diseases Study 2019, the leading causes of death in China have shifted markedly from communicable, maternal, neonatal, and nutritional diseases to age-related NCDs, including cardiovascular diseases (CVDs), cancers, and diabetes (5, 6). The China Centres for Disease Control and Prevention (CCDC) estimated that a total of 5.1 million deaths were due to CVDs in 2019, of which stroke and ischemic heart disease were the two major causes, with an increase of 12.4% for stroke and 39.3% for ischemic heart disease from 2009 to 2019 (6). The rates of overweight and obesity have also increased, alongside China's rapid economic growth and urbanisation. In 2018, approximately 14.3% of Chinese adults were classified as having obesity (using the East Asian population cut-point for body mass index, BMI≥28.0 kg/m^2) and around 33.3% had abdominal obesity, compared to 5.2% and 32.0% in 2012-2014, respectively (7-9). According to the American Diabetes Association diagnostic criteria, the overall prevalence of diabetes among adults in China was

12.4% in 2018 compared to 10.9% in 2013, and approximately 38.1% were diagnosed with pre-diabetes in 2018 compared to 35.7% in 2013 (10). Given these changing disease patterns and increasing disease burdens in China, the early prevention and control of NCDs and the promotion of public health have been declared central to the Chinese Government's 'Healthy China 2030' plan (11, 12).

1.2 Major drivers of epidemiological transition

1.2.1 Economic development

Following the implementation of the economic reform in 1978, China experienced an average Gross Domestic Product (GDP) growth of almost 10 per cent per annum, resulting in a seven-fold increase in GDP per capita income from 1990 to 2014 (13); this has lifted more than half a billion people out of poverty (14). The economic boom sped up the pace of industrialisation, modernisation and urbanisation in China, with the country's main economy shifting from agriculture to manufacturing and services, and then on to e-economy and technology. By 2020, 63.9% of the population lived in urban areas, compared to 36.2% in 2000 (15). This rapid pace of urbanisation came with certain challenges. There are over 376 million rural-to-urban migrants in China now, many of whom cannot obtain urban *hukou* (a system of household registration used in China), which means that these people have limited access to urban public services and social security, such as health care, vaccination coverage and sick leave (16).

1.2.2 Demographic shift

Figure 1.1 presents and compares the demographic shift from 1960 to 2020 in China with the rest of the world using data from the World Bank. In addition to the global average and the average of high-income countries (HICs), data from four other fast-growing and emerging economies are presented - Brazil, Russia, India and South Africa, as well as two other LMICs - Ghana and Mexico; these countries were also included in the World Health Organization Study on Global AGEing and Adult Health (see Chapter 2 for more information on WHO SAGE survey data used in this dissertation). In Figure 1.1, metrics related to demographic shift were shown in five panels: life expectancy for males (Panel A), life expectancy for females (Panel B), number of people aged 65 and above (Panel C), proportion of males surviving to 65 years old (Panel D) and proportion of females surviving to 65 years old (Panel E).

Globally, the average life expectancy increased from 52.6 years in 1960 to 72.8 years in 2020 (17). China also has an aging population, with the World Bank data indicating that in 2020 life expectancy among Chinese men and women were 75.0 and 79.4 years, respectively, only slightly lower than the average life expectancy in HICs (see Panels A and B, Figure 1.1). Also noteworthy is China's rapid rise in life expectancy, at a relatively much faster rate than all other LMICs - Ghana, Mexico, South Africa, Brazil, India and Russia - included in the current analysis.

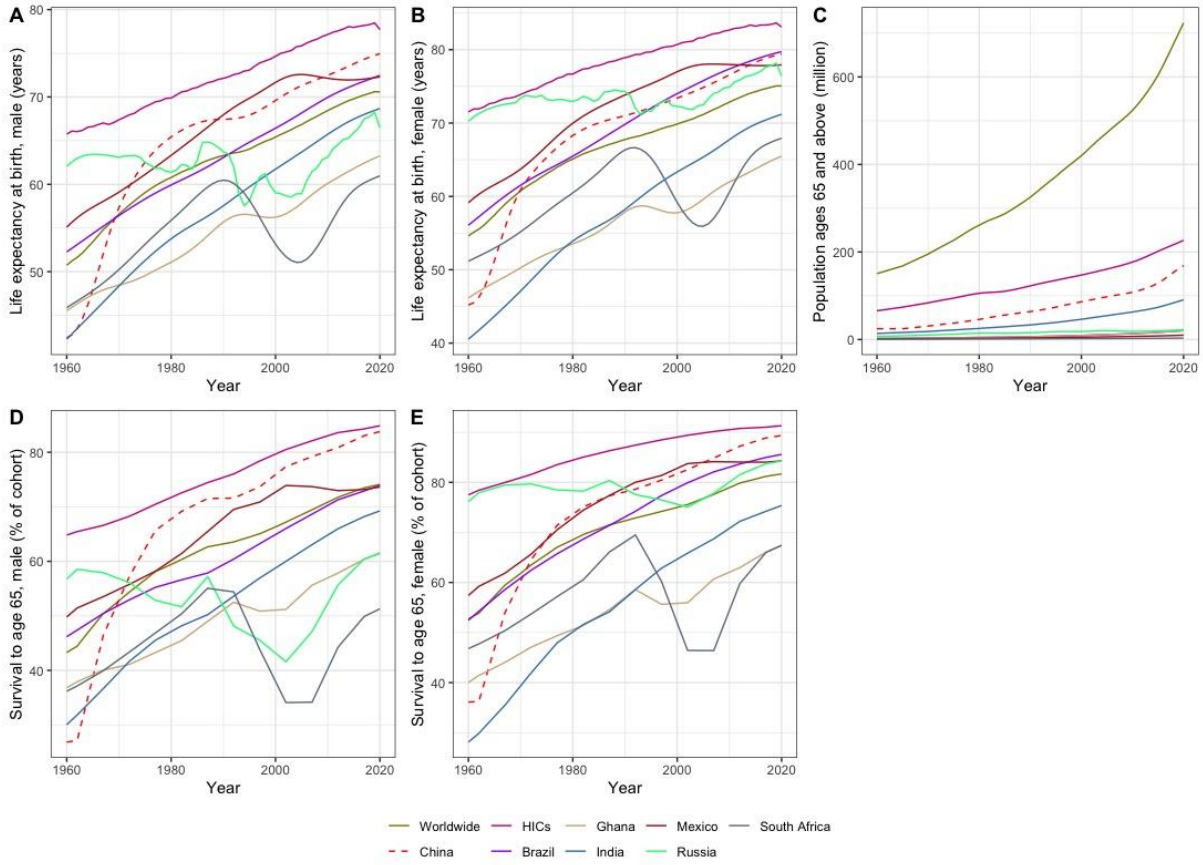


Figure 1.1 Population information in the selected countries from 1960 to 2020[1]

A. Life expectancy at birth, males (years); B. Life expectancy at birth, females (years);

C. Population aged 65 and above (million); D. Survival to age 65, males (% of the cohort);

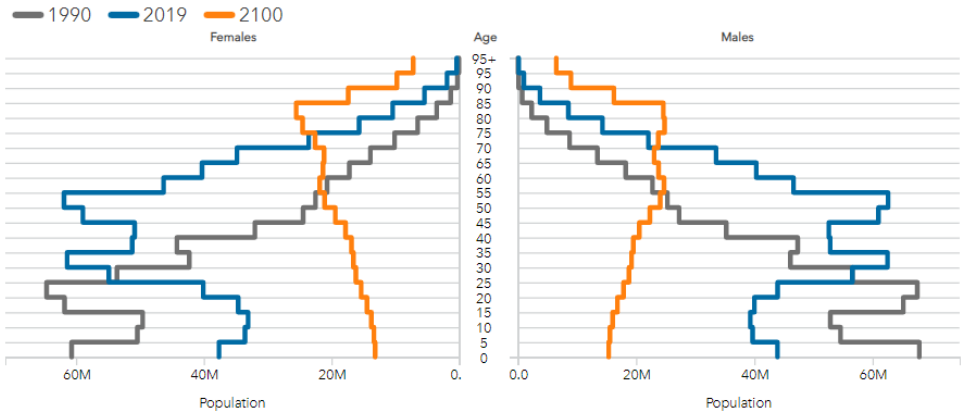
E. Survival to age 65, females (% of the cohort).

The survival rates in China have also been increasing much faster than the global average, with approximately 83.8% of Chinese males and 89.2% of Chinese females surviving to 65

[1] This figure was generated by the author using data from the World Bank. Please refer to this website: https://data.worldbank.org/indicator, for more details.

years old in 2020, which almost tripled the survival rates in 1962 (see Panels D and E, Figure 1.1). By 2020, people aged 65 years old had totalled 169 million in China, increasing much faster than other LMICs, except for India which had experienced a similar increase at almost the same speed as China (see Panel C, Figure 1.1). According to the WHO, 402 million people in China will be 60 years and older by 2040, accounting for approximately 28.0% of the country's total population (18).

A forecasting analysis for the Global Burden of Disease (GBD) study modelled population age structures for Chinese males and females in 1990, 2019 and 2100 (19). It predicted that the total population would decline by 48.0% to around 732 million by 2100, with a large shift in the population age structure towards mid-to-older adults (See Figure 1.2).



Population age structure for males and females in 1990, 2019 (reference scenario), and 2100 (reference scenario). Forecasted data based on Global Burden of Disease 2017 results.

Figure 1.2 Population age pyramid for females and males in China[2]

Many other rapidly industrializing countries in East Asia also have serious population aging problems, such as Japan and South Korea. In 2022, 30% of Japanese, 17% of South Korean and 14% of Chinese citizens were aged over 65 years, with Japan ranking second worldwide (17). These East Asian countries with some cultural similarities and rapidly aging populations, share similar issues of addressing health and prevention in an aging society. However, researchers predicted that even though China was about 30 years later than Japan in becoming an aging society, China's aging population would grow faster and catch up in the next 25 years (20).

[2] This figure was derived from Institute for Health Metrics and Evaluation website. Please refer to this webpage: https://www.healthdata.org/china, for more details.

1.2.3 Risk factor trends

Health-compromising behaviours such as unhealthy diet, physical inactivity, sedentary behaviour, smoking, and alcohol consumption have long been regarded as behavioural risks associated with chronic diseases in HICs (21). Profound changes in these risk factors have also been associated with the nutrition transition observed in LMICs (22). Many studies have supported the idea that most LMICs are rapidly moving away from the 'third stage' of nutrition transition, also known as Pattern 3 - end of famine (famine recedes as income rises and nutrition improves) to a 'fourth stage' or Pattern 4 - overeating and obesity-related diseases (people consume an abundance of high-calorie foods and becoming less active, leading to increases in obesity and NCDs) (23). Since 1985, China has experienced a shift from a classical Chinese diet rich in vegetables and carbohydrates with minimal animal-sourced foods, towards a Western energy-dense diet, dominated by cheap edible oils, animal-based foods, and increasing consumption of sweetened beverages and foods (24).

Changes in physical activity have also occurred concurrently. Urbanisation, mechanisation, and booming e-commerce in China have led to a significant shift in the labour market with the proportion of workers doing manual and heavy manual work declining, and the proportion of workers doing sedentary jobs increasing (25). Transportation mode and activity pattern in leisure time has also changed. According to the China National Health Survey, the weighted prevalence of active transportation decreased substantially from 83.8% to 54.3% from 2002 to 2012, and the proportion of inactive transportation (including motorcycles, taxis, and cars) tripled (26). Data from the China Health and Nutrition Survey have also found that the prevalence of older people being physically active remained almost the same from 2000 to 2015; this is in contrast to trends towards increased levels of physical activity among similar age groups in HICs, such as the United States (US), Australia and Spain (27-29). A temporal trends study by Ding and colleagues using data from the China National Nutrition and Healthy Survey in 2002 and 2010-2012 also showed that older Chinese people became more sedentary and spent more time watching television and reading books in their spare time (30).

Smoking remained a significant public health concern in China. In contrast to most HICs, such as Australia, Norway and Sweden where there has been a steady downward trend in tobacco smoking since 1990 with daily smoking rates around 9.0%-11.2% in 2019, standardised daily smoking prevalence has been consistently high in China (21.5%) (31-33). Epidemiological studies showed that in 2018, there were over half of the Chinese men were

current smokers (46.3% of urban men and 54.6% of rural men) (34); this compared to a global prevalence of 22.3% for the overall population in 2020 (36.7% for men and 7.8% for women) (31). The mean daily cigarettes consumed by an average smoker also increased from 14.6 to 16.3, and the age of smoking initiation decreased from 22.6 to 21.8 years old from 1991 to 2011 (35). Furthermore, the smoking prevalence among adolescent boys and girls increased substantially from 8.3% in 2003 to 12.5% in 2013 (36).

Alcohol is deeply entrenched in Chinese culture, and alcohol use has been traditionally accepted at social events, such as wedding parties and business dinners (37). As reported in the Global Status Report on Alcohol and Health 2018, total alcohol per capita consumption in China has increased from 4.1 litres in 2005 to 7.2 litres in 2016 (38). This number was projected to increase by another 0.9 litres of pure alcohol by 2025. Furthermore, approximately 67.2% of the recorded alcohol consumed in China are spirits, typically distilled spirit *baijiu*, which typically contains high concentrations of fermentation by-products such as acetaldehyde when produced cheaply, causing serious adverse health effects, such as poisoning or even death (38).

In summary, while China has achieved remarkable economic affluence in the past few decades, China is also confronted with contemporary public health challenges characterised by increasing chronic disease risk factors due to changing lifestyles associated with economic prosperity, and premature morbidity and mortality linked to high rates of chronic diseases such as CVDs, cancers, respiratory and liver diseases. The health and economic burdens are expected to worsen in the coming decades if no preventive public health actions are taken to address the knock-on effects associated with China's aging population that result from increasing life expectancy and changing risk factors (39).

1.3 Health and economic implications of population aging

1.3.1 Physical health

Older people are at increased risk of developing common health conditions, such as hearing loss, osteoarthritis, chronic obstructive pulmonary disease (COPD), diabetes, and chronic pain as they age (40). As discussed earlier, according to the GBD 2019, ischemic heart disease, stroke, diabetes, COPD and lung cancer were the leading causes of death in 2019 among middle-aged and older populations (50-74 years) in China, with around 90% of the death estimated to be from NCDs in 2020 (41, 42).

Population data from CCDC revealed that over 80% of China's urban and rural older people reported having been diagnosed with at least one NCD or associated risk factor in 2018 (43). According to a government report "Healthy China Action (2019-2030)", 18.3% of people aged 65-74 years lost the ability to take care of themselves and needed aged care support by 2015 (44). Hypertension, obesity and diabetes are also associated with increased risk of NCDs such as ischemic heart disease and stroke (45-47). Approximately 33.8% of urban and 29.8% of rural older Chinese adults reported a hypertension diagnosis, while 16.3% of older women and 10.4% of older men were obese in 2015 (48, 49). Based on the China Chronic Disease and Risk Factor Surveillance data, Wang and colleagues estimated the national prevalence of diabetes had increased from 20.1% in 2013 to 25.0% in 2018 among people aged over 60 years (10).

1.3.2 Mental health and social well-being

Older people also face challenges associated with poor mental health and social well-being. Mental health - which includes but is not limited to depression, anxiety disorder, dementia and so on - is a critical component of healthy aging. Approximately 20% of adults aged 60 and over suffer from at least one mental disorder globally (50). Mental disorders account for 6.6% of the total disability-adjusted life years (DALYs) and 17.4% of years lived with disability (YLDs) for this age group (50). The most common mental disorder among middle-aged and older adults in China is depression. According to the Chinese national censuses, 23.6% of the older population self-reported depressive symptoms in 2019 (44). Anxiety disorder was estimated to affect 3.8% of older Chinese adults, but the 'real' prevalence is likely to be much higher due to the social stigma surrounding mental health issues (51). Dementia is another major mental health issue in China, which rose from the 10th leading cause of death in 1990 to the 5th in 2019. According to the 2019 GBD research, there were more than 13.1 million people living with Alzheimer's disease and related dementias in China, accounting for about 25.5% of the global cases (52). Along with the accelerating increase in the aging population, the number of people with mental health issues is expected to expand rapidly in the next decade.

Social health, as a broader term, incorporates elements of personal characteristics and social skills, including socioeconomic status, social norms, social capital, etc. In this thesis, we particularly emphasized social well-being, which is broadly defined as the sharing, developing and sustaining of meaningful relationships with other people (53). Meaningful social connections are considered a critical component of healthy aging (54). It has been

reported that individuals with prolonged loneliness and social isolation are at increased risk of experiencing poorer health outcomes including psychological distress and myocardial infarction (55, 56). Unfortunately, rapid urbanisation and modernisation have accelerated the downsizing of traditional inter-generational households in China, where 44.8% of older adults now either live alone or just with their spouses by 2020, compared to less than 10.0% in 1990 (57, 58). Zhang and colleagues illustrated that about 14.8% of people aged over 65 years old reported having no children to visit, 18.9% had no siblings to visit, and 12.5% did not participate in any social activities between 2011 and 2014 (59). There were also 10.5% of older people who reported that they were not able to find anyone to ask for help when in need. Data from the Chinese Longitudinal Healthy Longevity Survey (CLHLS), a nationally representative sample of older adults, showed that about 36.6% of older Chinese adults reported feeling lonely in 2019, compared to 28% in 2010 (56, 60).

The poor physical, mental health and social well-being of older people in China have wide-ranging economic, social and public health implications (61). More focused and early prevention is necessary to reduce the impact of associated complications (premature disability and mortality) on individuals and the broader society.

1.3.3 Economic implication of population aging

Given the scale of the aging population in China, increasing demands for NCDs-related medical services coupled with exponential growth in health expenditure will likely continue to pose unique challenges to China's health and social system in the 21st century.

Chronic diseases have a substantial impact on health expenditures. With China's aging population projected to increase significantly over the next few decades, it is likely that healthcare spending related to chronic disease management and control for this age group will also increase rapidly in the same period. Zhao and colleagues analysed three waves of data from the CLHLS and reported that healthcare costs related to chronic diseases accounted for 55.2% of the total healthcare expenditure of older adults (62). Self-management of chronic disease conditions is essential to avoid frequent hospital admissions. However, many older Chinese with chronic disease conditions lack self-management skills, typically receiving treatment in the acute stage which imposes greater costs with hospitalisations (63). A study by Ma and colleagues showed that the number of discharged patients with CVDs and diabetes increased annually by around 9.9% and 13.6%, respectively, from 1980 to 2016 (64). The hospitalisation costs of CVDs increased with an annual growth rate of around 22.8%

from 2004 to 2016 (64). Another study found that the total economic cost for aging-related chronic conditions, including CVDs, cancer, diabetes, respiratory diseases and mental health conditions, over the period 2010-2030 was projected to be $7.7 trillion US dollars for China (65).

Furthermore, functional decline inevitably leads to a substantial increase in the number of older people with complex care needs, including basic assisting services in daily life (eating, bathing, safety care, etc.) and medical care services (management of NCDs, physical rehabilitation, etc.) (66). Data from the China Health and Retirement Longitudinal Study across five waves showed that 138.1 million older people would need special care in 2030, 35.9 million more than in 2020, especially the older-old group (≥70 years) (67). As a result, Organisation for Economic Co-operation and Development (OECD) Health Working Papers reported that China's long-term care and public health expenditure would account for 5.2% of GDP in 2030 compared to 3.0% in 2012, which increased much faster than other OECD countries and other key emerging economies (68).

Although the Chinese government has made significant investments in establishing public health insurance for every citizen, the public resources for aged care are still far from adequate (69). Given China's fast-growing aging population, increasing health expenditure will continue to put substantial economic burdens on the government and families.

1.4 Socio-ecological determinants of health-related behaviours

Human behaviours are complex and shaped by numerous influences throughout the lifespan. It is increasingly recognised that an individual's health and health behaviours are shaped and influenced by a multitude of interrelated factors. These factors are nonmedical and include individual characteristics such as psychological factors, health beliefs, income level, educational attainment, and other social and physical factors such as workplaces, neighbourhood environments, and societal and political factors all of which can enable or constrain health. This perspective is described as the "socio-ecological framework" and has been commonly used to examine and explain the relationships between the social, physical, and policy environments, and individual behaviours and health (70, 71). Figure 1.3 depicts a graphic example of the socio-ecological framework surrounding an individual, categorising the determinants into four levels of influences:

a) The most proximal level is the *individual level*, which identifies biological, psychological and personal factors.
b) The *interpersonal level* is related to the social circles surrounding the individual, including partners, friends, family members and co-workers.
c) The *community level* describes the setting in which people have social relationships, such as neighbourhoods, local groups or clubs, unions or organisations, and workplaces.
d) The most distal is the *societal level* and captures the broader environmental, policy and economic factors, including population-wide cultural and social norms, as well as economic, educational and social policy within the context of a specific country or region.

The socio-ecological framework helps to understand how people interact with the broader environment to change their behaviours and maintain health and should be utilised with three core principles, which stipulate that 1) there are multilevel factors that influence health behaviours; 2) proximal and distal levels of factors are of equal importance, though the relative influence may vary by context and by different behaviours; and 3) the influences on health behaviours interact across levels (72).

The socio-ecological framework has been used as guidance for identifying multilevel facilitators and barriers associated with health behaviours and health outcomes. For example, Bauman and colleagues used the socio-ecological approach to understand why some people are physically active while others are not, thus providing a good example of how multilevel factors influence people's behaviours (73). The authors concluded that individual-level factors, including age, sex, health status, self-efficacy, and previous physical activity influenced the current physical activity level. Physical and social environments, such as economic development, societal norms, urbanisation, and industrialisation were also important determinants of physical activity. In the context of physical activity research, the socio-ecological framework provides a useful framework for understanding the wide-ranging contributors of physical activity across multiple domains and at all levels (70, 71).

In this thesis, I used the socio-ecological framework (Figure 1.3) to guide research development and identify potential facilitators and barriers (correlates) of older people's physical and mental health and well-being in China.

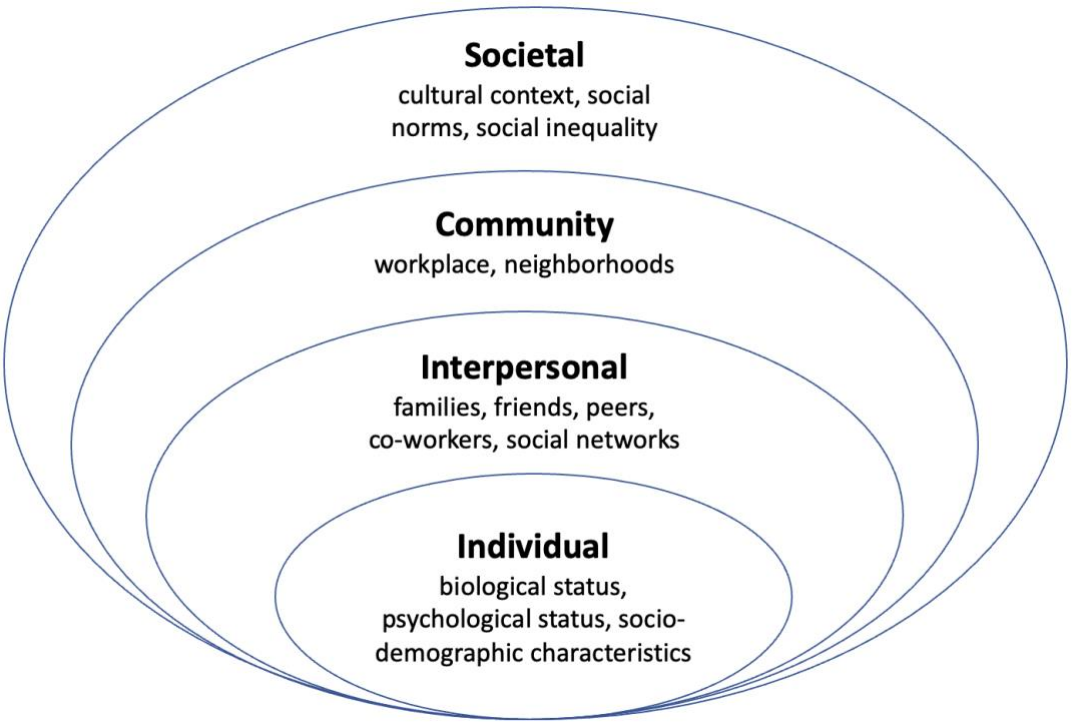


Figure 1.3 Socio-ecological framework for healthy aging in China

1.5 Aims of this research

The purpose of this thesis is to gain a deeper understanding of the risk factors for health, including physical, mental and behavioural health among middle-aged and older adults in China, using a socio-ecological lens. Both the terms "risk factors" and "barriers and facilitators" are interchangeable in this thesis. The specific aims of this research are to examine:

1) Different levels of correlates of domain-specific physical activity among older adults, including individual, community, and societal levels.
2) The relationship between social engagement pattern, and lifestyle behaviours and subjective well-being of older adults.
3) The relationship between retirement and risky lifestyle behaviours among the middle-aged and older population.
4) The relationship between occupational physical activity and mortality among middle-aged adults.

This thesis will address these research aims by using three population-level nationally representative surveys: World Health Organization Study on Global Ageing and Adult Health

(WHO SAGE), China Health and Retirement Longitudinal Study (CHARLS) and China Kadoorie Biobank (CKB). Chapter 2 describes in detail the data collection systems and characteristics of these population health surveys.

1.6 Structure of this thesis

This thesis is organised into seven chapters and presents findings relating to four peer-reviewed papers (three published, and one under review).

Chapter 1 provides an introduction and overview of the aging problem in China, and presents the research aims.

Chapter 2 discusses the role of population-based surveys in informing public health actions, and the extent to which large population-level survey data can provide critical information about the correlates and determinants of health behaviours and outcomes with examples.

Chapter 3 presents findings from a peer-reviewed paper that used nationally representative data to examine individual-level (sex, age, marital status, educational attainment, working status and income level), community-level (social capital) and societal-level (place of residence) variables in the socio-ecological framework of domain-specific physical activity among older populations in China.

Chapter 4 presents findings from a peer-reviewed paper examining the relationship between social engagement (interpersonal level) and multiple outcomes, including risky lifestyle behaviours (tobacco use, harmful drinking, low fruit and vegetable intake, physical inactivity, prolonged sitting time and unhealthy sleep time) and subjective well-being (perceived depression, poor self-rated health and low quality of life) using nationally representative samples.

Chapter 5 presents findings from a peer-reviewed paper that investigated the influence of retirement transition (a factor related to the individual, interpersonal, community and societal level) on risky lifestyle behaviours (smoking and excessive alcohol consumption) using nationally representative longitudinal data.

Chapter 6 describes findings from a peer-reviewed paper investigating the association of occupational physical activity (community level) and all-cause and cardiovascular disease mortality in middle-aged working adults in urban China using large-scale cohort data.

Chapter 7 provides a comprehensive discussion on the significance of the studies in this thesis and its implications for developing national-level health-promoting strategies to support the aging population in China as well as recommendations for future research.

Appendix 1 is the questionnaire from the World Health Organization Study on Global Ageing and Adult Health, which was used in Chapters 3 and 4.

Appendix 2 is the questionnaire from the China Health and Retirement Longitudinal Study, which was used in Chapter 5.

Appendix 3 is the questionnaire from the China Kadioore Biobank study, which was used in Chapter 6.

Appendix 4 lists the published papers I co-authored during my PhD candidature. These works are not presented in my main thesis text, but they enriched my knowledge and skills in academic research. All these experiences are precious.

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CHAPTER 2: Population-based surveys and surveillance of chronic disease risk factors

This Chapter describes the use of large-scale population-representative surveys in understanding health risks among older adults, as this forms an important part of the research in this thesis. This is a complex area, as population surveys can be standalone representative surveys; part of ongoing surveillance system surveys; or population cohort samples which are followed longitudinally. All these types of population research can generate information that may be useful for public health policies and programs to address, in this case, chronic disease risk prevention among older adults. When analysed cross-sectionally, these studies examine "correlates", associations between attributes or characteristics and health risks or behaviours. If examined longitudinally, they more closely reflect "determinants", as they follow more of the criteria for causality, in other words, the factors being considered are on the causal pathway to the health risks or risk factors (1). In this section, examples are provided to show the use of surveys from surveillance systems and independent standalone large population cross-sectional surveys and their use in informing health risks amongst older adults. This is not a comprehensive literature review but illustrates their use in public health research into healthy ageing. These kinds of studies and related methodologies in this area are used in the research studies in this thesis.

2.1 Surveys from surveillance systems

One type of survey is part of a surveillance system. Public health surveillance was developed initially to address the major epidemics in human history, referring to the ongoing systematic collection, analysis, interpretation and dissemination of health data, which can be used to track health-related issues, benchmark progress and inform resource allocation (2). Although it started with reporting and handling infectious diseases, surveillance has expanded to include chronic diseases, healthy lifestyle behaviours, etc. (3)

Surveillance is the process of collecting population-level information and tracking it over time. Whilst this originated with communicable disease surveillance, in recent decades NCD surveillance has developed to monitor and track risk factors such as tobacco use, hazardous alcohol use and physical inactivity, and to examine them in relation to the subsequent risks of developing chronic diseases such as hypertension, obesity, diabetes or CVDs (4).

Examples of the use of surveys as part of surveillance systems

The first category of surveys are those used from surveillance systems, such as the large

national Behavioural Risk Factor Surveillance System (BRFSS) from the US Centers for Disease Control and Prevention (5), and the globally-implemented WHO STEPwise approach to NCD risk factor surveillance (STEPS) (6). Although they are predominantly used by governments to monitor chronic diseases and their antecedent risk factors, they are also used to describe factors associated with chronic disease risk. There are many examples of their use in understanding health among older adults. One example was the use of the BRFSS in identifying the correlates of alcohol use among the US population and in population sub-groups (7). Another study used the BRFSS to identify the relationships between different domains of physical activity and obesity and health-related quality of life (8). A third example is that of Cohen who described physical activity and diet according to small-area and county-level information and identified rural-urban differences in both obesity rates and access to healthy lifestyle choices (9). As is reported, BRFFS prevalence and correlates data have been used by policymakers, researchers and governmental municipalities across the US to implement public health programs and policies, such as legislation concerning drinking and air pollution (10, 11).

The WHO STEPS surveys have been used in more than 100 countries, and many of these were in LMICs. A few examples are presented here. Aung used the country-level STEPS survey to examine the prevalence, correlates and trends in diabetes among older adults in Myanmar (12). A study in Ethiopia used the STEPS survey to examine factors associated with hypertension in one city and found behavioural, social and urban factors associated with increased blood pressure (13). A study in Dhaka, Bangladesh reported on the correlates of tobacco use and found socioeconomic status (SES), education, occupation and slum residence were all associated with smoking (14). Some researchers have examined cross-country differences in risk factor prevalence and correlates using STEPS data, such as a 5-Asian nation comparison and a 3-low-income nation comparison (15, 16).

2.2 Population-based surveys and their characteristics

The second category of surveys are standalone, large-sample surveys, usually using cross-sectional designs. Population-based surveys are studies involving representative samples of individuals selected from a larger population. In public health, these surveys often collect a broad range of timely and accurate information including but not limited to health status, health behaviours, associated risk factors, socio-economic characteristics, and more (17).

Population-based surveys are used by government and public health authorities to plan, monitor, evaluate, and make decisions on need-based health interventions, as well as provide guidance for policy, legislation, and finance to reduce exposure to chronic disease risk factors.

Population-based surveys can assist the primary, secondary and tertiary prevention of NCDs as well as inform policy change. Population-based surveys vary in terms of size and scope, population groups and topics. Large-scale, country-level surveys from representative samples can provide population-level prevalence and distribution of health status, chronic disease risk factors and health behaviours (18). Repeated cross-sectional or cohort designs enable researchers and policymakers to track population trends over time, which may capture the epidemiological transition at the country level (19).

Participants in population-based surveys can be selected using different sampling methods, either probability sampling or nonprobability sampling (20). The former involves random selection to permit unbiased estimates of characteristics and make strong statistical inferences about the whole group, while the latter is based on convenience or other criteria to easily collect data (17). It is essential to choose a sampling method to meet the goals of the study as well as consider a combination of cost, precision, and accuracy. Multistage stratified random sampling is a commonly used probability sampling method used in country-level surveys where nationally representative survey data can be collected and generalized to the population in an entire country (21). These surveys can be used as an important public health resource for health surveillance and research opportunities.

Examples of the use of population surveys and cohorts to understand risk factors

Examples from HICs and LMICs abound, and illustrative examples here indicate the types of information that they generate. A Swedish study of older adults identified the associations between alcohol use and social connections, indicating the potential role of social activity in alcohol risk (22), and a British study used the Health Survey for England to identify the correlates of co-use of alcohol and other prescription drugs (23). The European Survey of Health, Ageing and Retirement examined the relationship between dietary intake and mental health/cognitive decline (24). Bandiera used the US Health and Retirement Study (HRS) to describe the determinants of tobacco use and applied longitudinal analyses to identify factors associated with quitting smoking (25). Islam used the National Family Health Survey in India to describe the correlates of smoking so that target groups could be identified for

tobacco control strategies (26). Pengpid examined older adults in India and explored the association between mental health and loneliness and NCD risk factors (27). Sinha explored the social determinants of obesity and diabetes in the Longitudinal Ageing Study in India (28). Mielgo-Ayuso examined the correlates of total physical activity in Spain and Aithal explored physical activity among 2200 older adults in Singapore (29, 30). Ryu explored the correlates of each domain of physical activity in older adults in Korea (31). Hlebichuk examined physical activity in the US HRS and identified associations with physical markers of chronic disease inflammation (32).

No matter whether surveillance data or cross-sectional/cohort studies are used, they usually collect a wide range of information, including demographic, socioeconomic, environmental variables, and so on. Therefore, many studies have applied a socio-ecological framework to investigate the correlates of health and behaviours using population surveys. Kim explored the societal-level indicators of older age life expectancy in 34 European countries using the World Bank and WHO databases (33). Nicolson used the Healthy Ireland Survey to identify the individual, social and environmental correlates of sedentary behaviour in 7,328 Irish adults (34). Bakhtari used a socio-ecological approach to evaluate different levels of predictors of physical activity in Iranian older adults (35), and Wu investigated the association between the built environment and physical activity in Nanjing, China (36).

Thus, there are many studies, and the examples above are only illustrative of the diversity of research questions that can be answered from many different research designs, all producing reasonable population-level information. These projects inform national governments and non-governmental organizations to provide target groups with strategies to target individual risk factors or more broadly, national NCD prevention programs.

2.3 Examples of the use of population-based surveys in China

Historically, China suffered poverty and food shortages, and the country experienced famine around 1960. Therefore, the first routine national survey in China, the China National Nutrition Surveys (CNNS) was initiated in 1959 to assess and monitor dietary intake by the CCDC (37). However, the standard of living has been dramatically improved since the late 1980s, leading to the nutrition transition (38). Thus, CNNS was followed up in 1982 and 1992 respectively, and these survey data allowed for trend analyses in nutrients and

monitored the epidemiological transition, manifesting as increases in the prevalence of overweight, hypertension and diabetes (39).

Population-based surveys have been used to identify high-risk population groups or geographical areas at particular NCD risk. For example, using data from the CKB, the largest prospective cohort study in China, researchers confirmed that alcohol drinking was associated with increased risks of mortality, morbidity and cancer in Chinese adults (40). Epidemiological studies also concluded that Chinese men, particularly younger men in Sichuan province and Harbin city, were influenced the most by harmful patterns of drinking (41). Other examples have explored risk factors of alcohol, smoking and physical activity among older Chinese adults using the CHARLS study, and identified geographic and demographic correlates (42). The CHARLS survey was also used to examine the regional distribution and trends in smoking by older adults across regions in China (43).

Many cross-sectional studies in China also illustrate the use of population survey data to understand the health and behaviours of older adults. Zhang explored psychosocial factors associated with tobacco use in five provinces in China using 6,071 random samples (44). Liu looked at the associations between smoking and depression symptoms in Chinese middle-aged and older men (45). Lee examined the earlier life exposure to passive smoking with health status and life satisfaction among older Chinese adults using the CLHLS (46). The same survey data were used by Lee to examine the correlates of alcohol use and dependence (47). Li also used the CLHLS to examine alcohol use and its correlates among older Chinese in 2019, and further compared these data with the Trøndelag Health Study in Norway (48). Alcohol correlates were also examined in the CHARLS in people aged 45 years and older (49). Other examples illustrate the diversity of samples and surveys used for correlates and determinants research in China. Ling explored the correlates of working among older Chinese, to examine policy influences, such as changes to the pension scheme in those that remained at work (50). Cross-sectional analyses can sometimes compare risk factors and healthcare utilisation, such as in a study of smoking and healthcare usage in China (51).

There were also several studies that applied the socio-ecological model to explore the risk factors of health outcomes among Chinese population. For example, Wang explored the socio-ecological factors related to leisure-time physical activity among older adults in Sichuan province (52). Quick and colleagues explored how the individual, interpersonal and environmental factors in a household affect young children's weights (53).

2.4 Population-based surveys used in this thesis

In the past twenty years, there has been a significant increase in the health data resources available from various organizations and authorities in China; however, only a few surveys covered aging-related issues. As this thesis focuses mostly on older adults, we used data from three large-scale population-based surveys in China. The following section provides detailed information on each of these three studies, and Table 1 summarizes survey characteristics and designs.

2.4.1 China Kadoorie Biobank (CKB)

CKB is a large prospective study launched in 2004, aiming to investigate slow-acting causes of common chronic diseases in the Chinese population (54). The CKB baseline study recruited over half a million middle-aged and older adults (30-79 years) from ten different areas carefully selected from freezing north to tropical south and from urban cities to rural villages. Besides the baseline questionnaire covering a wide range of risky behaviours (smoking, drinking, unhealthy diet, physical inactivity and sedentary behaviours), CKB also provides data on physical measurements, blood and biological samples, as well as prospective data on incident disease and cause-specific mortality from registries and health insurance till the end of 2016. Though CKB is not nationally representative, it is still one of the largest data resources on aging in China.

2.4.2 WHO Study on Global Ageing and Adult Health (WHO SAGE)

WHO SAGE was designed and implemented by WHO in six LMICs, including China, Ghana, India, Mexico, Russian Federation and South Africa, using nationally representative samples (55). The SAGE survey aims to compile comprehensive longitudinal data on the health and well-being of people aged over 50 years old and their aging process across different countries, through primary data collection, secondary data analysis and cross-study collaborations. The SAGE survey assesses health status and health systems from both a household and individual perspective, as well as perceptions of well-being and objective health measurements. In China, SAGE baseline Wave 1 data was collected in 2007-2010 with 14,813 participants, Wave 2 (2014-2015) data collection was completed in 2015, and Wave 3 has been implemented in 2017-2019. Unfortunately, by the time I am writing up this thesis (October 2022), only Wave 1 data is available and can be used for analyses in this thesis.

2.4.3 China Health and Retirement Longitudinal Study (CHARLS)

CHARLS is a nationally representative longitudinal survey of people aged 45 and older living in private households in mainland China, comparable to the US HRS (56). The baseline sample was recruited in 2011 with about 10,000 households and 17,500 individuals in 150 counties/districts and 450 villages/resident committees using a stratified, multistage probability sampling method, and then participants were followed up every two years (56). By 2022, four waves of data were released, which were Wave 1 (baseline, data collected in 2011-2012), Wave 2 (first follow-up, data collected in 2013), Wave 3 (second follow-up, data collected in 2015), and Wave 4 (third follow-up, data collected in 2018) (57). CHARLS included assessments of social, economic, and health circumstances of community residents, and examines health and economic adjustments to rapid aging in China. The CHARLS questionnaires collected comprehensive information on family structure, health status and functioning, work, retirement and pension, and so on.

These three large datasets make it possible to have a comprehensive understanding of the health status of middle-aged and older adults in China, as well as explore the correlates of behaviours, well-being and health among this population at a national level by applying a socio-ecological framework to the studies using these three large-scale population-based surveys.

The next part of this thesis, Chapters 3-6, presents findings from four interrelated studies using the aforementioned datasets to address the specific research questions outlined in Chapter 1.

Table 2.1 Overview of three large-scale population-based surveys used in this thesis

Name	Survey years	Sample size	Age range (years)	Sampling method	Study design	Data collected in the surveys			
						Socio-demographics	NCDs risk factors	Social health measures	Mortality data
CKB	2004-2008	512,891	30-79	Purposive sampling	Cohort	✓	✓	✗	✓
WHO SAGE	2007-2010	14,813	50+	Multistage stratified random sampling	Cross-sectional	✓	✓	✓	✗
CHARLS	2011-2012 (Wave 1) 2013 (Wave 2) 2015 (Wave 3) 2018 (Wave 4)	~17,500 per wave	45+	Multistage stratified random sampling	Longitudinal	✓	✓	✓	✗

2.5 Conclusion

In summary, the diversity of research questions relevant to the health of older adults and the scope of research designs used is very broad using population-based data. Their use is to track the prevalence, distributions and patterns of health problems, identify key groups and factors that might inform population-level intervention, as well as monitor progress towards stated health and well-being goals. In many countries, population surveys can be used to guide the development and implementation of public health programs, access progress in the effects of prevention strategies as well as inform global health indicators such as sustainable development goals (58). The work in this thesis extends the substantial body of work on older adults in China, examining different data sets that can answer NCD policy and prevention-relevant questions.

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CHAPTER 3: Correlates of domain-specific physical activity among older adults in six low- to middle-income countries: analysis of nationally representative samples from Study of Global Aging and Adult Health (SAGE) (Wave 1)

3.1 Preface to the chapter

This chapter presents findings published in a peer-review paper that examined the relationships between different levels of risk factors and domain-specific physical activity among older adults in China. These risk factors included individual-level variables, such as gender, age, educational attainment, income level and working status, and a societal-level variable, which was the place of residence. In addition, the lesser-known associations between social capital dimensions (including structural social capital, trust and perceived safety) and domain-specific physical activity were examined.

This chapter is important that it measured multiple components of the socio-ecological framework, including individual-, community- and societal-level, with respect to physical activity. It also looked at different domains of physical activity, including work and household-, transportation- and leisure-time-related physical activity, and examined whether the correlates were similar across different domains. This study contributed to our understanding of what drives older adults' behaviours to be active or not in different settings.

In this study, we used the data from WHO SAGE, a nationally representative sample of older adults aged 50 years old and above in China. Unfortunately, at the time of analysis, follow-up data of WHO SAGE were not available and hence, only data from Wave 1 (2007-2010) was used. Dissemination of this research and author contributions to this paper are described below.

3.2 Research dissemination

The research presented in this chapter has been disseminated as follows:

Published peer-review paper

Luo M, Phongsavan P, Bauman A, Negin J, Zhang Z, Ding D. Correlates of Domain-Specific Physical Activity Among Older Adults in Six Low- to Middle-Income Countries: Analysis of Nationally Representative Samples From Study of Global Aging and Adult Health (SAGE)

(Wave 1). *Journal of Aging and Physical Activity* 2021; 29(3), 475–495. https://doi.org/10.1123/japa.2019-0477.

Impact factor: 2.109

Citations (based on Google Scholar): 2

3.3 Author attribution statement

I, Mengyun Luo, was responsible for designing the study, conducting the data analysis, interpreting the results, writing drafts of the manuscript, submitting the manuscript, responding to reviewers' comments, and coordinating submission and publication of the manuscript.

My co-authors, D. Ding, P. Phongsavan, and A. Bauman helped to conceive and design the study. D. Ding, P. Phongsavan, A. Bauman, J. Negin, and Z. Zhang provided statistical advice and helped to interpret data. D. Ding, P. Phongsavan, and A. Bauman helped to revise the manuscript critically for important intellectual content.

All authors have read and approved the final version of the manuscript.

3.4 Paper in published format

Journal of Aging and Physical Activity, 2021, 29, 475-495
https://doi.org/10.1123/japa.2019-0477

Human Kinetics
ORIGINAL RESEARCH

Correlates of Domain-Specific Physical Activity Among Older Adults in Six Low- to Middle-Income Countries: Analysis of Nationally Representative Samples From Study of Global Aging and Adult Health (SAGE) (Wave 1)

Mengyun Luo, Philayrath Phongsavan, Adrian Bauman, Joel Negin, Zhiruo Zhang, and Ding Ding

The correlates of physical activity differ across domains. The authors explored the contribution of domain-specific physical activity to total physical activity and examined how different sociodemographic and social capital-related variables are associated with different physical activity domains in older adults, using nationally representative samples from six low- to middle-income countries. Activity at work and home combined plays an important role in contributing to total physical activity, while leisure-time physical activity accounted for an extremely small proportion. Some correlates of physical activity were similar across countries, such as working status and structural social capital, while other associations were country specific. Promoting structural social capital, trust, and perceived safety may confer positive benefits on older adults' activity.

Keywords: perceived safety, social capital, socioeconomic status, trust

Physical inactivity is associated with premature mortality (Lee et al., 2012), a range of noncommunicable diseases, such as type 2 diabetes, cancer, and cardiovascular disease (Lear & Yusuf, 2017; Warburton, Nicol, & Bredin, 2006), and substantial economic burden on society (Ding et al., 2016). Particularly for older adults, being physically active not only helps prevent and manage noncommunicable diseases, but also maintains physical function, including improved balance, bone strength, and muscle mass (Warburton et al., 2006). However, population surveillance data have consistently shown that physical activity declines with age (Hallal et al., 2012). With the proportion of people aged 50 years and older projected to increase in low- to middle-income countries (LMICs), from 10.0%–18.8% in 2010 to 16.2%–42.3% by 2050, the number of older people being physically inactive is also expected to increase (United Nations, 2019).

Physical activity can be accumulated across different domains: leisure-time physical activity (LTPA), performed as structured or unstructured activities; occupational physical activity (OPA), corresponding to work-related activities; domestic physical activity (DPA), such as household chores and gardening; and transport physical activity (TPA), such as active commuting by walking or cycling. According to the World Health Organization (WHO) Global Health Observatory data, compared with high-income countries, people living in LMICs have higher levels of total physical activity, TPA, and OPA, but lower LTPA (World Health Organization, 2016). However, there is evidence that economic development has led to a shift from labor intensive to more sedentary working patterns, which has resulted in decreasing OPA levels in many LMICs (Ng & Popkin, 2012). It is important to further understand physical activity within the context of specific domains to inform promotion strategies in LMICs. Public health programs that explicitly integrate societal and cultural factors such as education, income, social groupings, and characteristics specific to LMICs are also likely to be more relevant, acceptable, effective, and sustainable.

Correlates of total physical activity have been widely studied in high-income countries (Bauman et al., 2012). However, few studies have focused on more than one domain, and these studies found that correlates differed across physical activity domains. For example, a systematic review on socioeconomic inequalities in domain-specific physical activity among European adults reported a positive association between socioeconomic position and LTPA but no association with TPA and total physical activity (Beenackers et al., 2012). Even though the evidence on the correlates of domain-specific physical activity in LMICs is sparse, the results to date are distinctly different from HICs. For example, a study by Du et al. found no clear linear association between education or household income and mean LTPA level in China (Du et al., 2014), contrary to findings from Western countries (Beenackers et al., 2012; Cerin & Leslie, 2008).

Comparative research examining domain-specific correlates of physical activity across different LMICs is sparse. A 2011 study examined domain-specific physical activity in six Asia-Pacific countries (Bauman et al., 2011) and found mixed results in the associations between socioeconomic indicators and domain-specific physical activity across countries. The authors concluded that the observed patterns may reflect the varying levels of economic development in those countries. However, the study used different physical activity measures as well as survey sampling methods across these countries, making direct comparisons difficult (Bauman et al., 2011).

Research has found that total physical activity is socially patterned and is positively associated with high levels of social capital (i.e., social engagement, feeling of trust, and safety) in HICs (McNeill, Kreuter, & Subramanian, 2006; Ueshima et al., 2010). A study in China showed that higher levels of social trust and harmonious social relationship were positively associated with physical activity (Xue & Cheng, 2017). This study did not examine

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different types of physical activity, and as such, the role social capital plays across domain-specific physical activity has received little attention within the LMIC context. Given the lack of financial capital in resource-poor settings, understanding the potential of social capital and social relationships to promote physical activity is of particular importance. Such understanding is essential for informing community-based health promotion programs and the country-level implementation of the WHO Global Action Plan for Physical Activity (World Health Organization, 2019a).

As noted throughout, there is generally a paucity of insights from cross-national studies comparing country-specific factors that are associated with domain-specific physical activity. By moving beyond a single-country analysis, this multinational comparative research allows us to examine the universality and country-level specificity of domain-specific correlates of physical activity among older adults within and between different populations across low- to middle-income countries (LMICs), irrespective of the existence of physical activity strategies and policies in those countries.

Given the limitations identified in the literature, this study aimed to describe how physical activity is distributed by demographic and social factors within a country and across six LMICs. Specifically, the study examined (a) the contribution of domain-specific physical activity to total physical activity and (b) how different sociodemographic variables and social capital variables are associated with domain-specific physical activity among older adults.

Methods

Samples

The WHO Study on global AGEing and adult health (SAGE) is a longitudinal study of adults aged 50 years and older, plus a small proportion of adults aged 18–49 as a comparison group, from nationally representative samples in China, the Russian Federation, India, Ghana, South Africa, and Mexico. More information about WHO SAGE can be found on the official website (World Health Organization, 2019b). Only data on the first wave of SAGE (Wave 1, 2007–2010) were available for the current analysis. This study focused on older adults aged ≥50 years ($n = 13,367$ in China, 3,938 in Russia, 7,150 in India, 4,724 in Ghana, 3,840 in South Africa, and 2,315 in Mexico). Excluded from the analysis were respondents with proxy responses ($n = 305$), people with cognitive limitations ($n = 1,297$), people with missing or implausible physical activity responses based on the analysis guide ($n = 430$), and those who reported severe or extreme difficulty in carrying out activities of daily living ($n = 3,074$). Answers with missing or zero value for poststratified individual probability weights ($n = 172$) were removed from the analysis. Our final sample was composed of 12,374 older adults in China, 3,236 in Russia, 5,295 in India, 3,946 in Ghana, 3,319 in South Africa, and 1,886 in Mexico. More details of the sample selection are shown in the STROBE flow chart (Figure 1). This study is a secondary data analysis of the WHO SAGE data set, which is publicly available. The data collection was approved by the Ethics Review Committee of the World Health Organization (Kowal et al., 2010). Written informed consents were obtained from all participants.

Measures

Sociodemographic variables. All participants were categorized into four age groups: 50–59, 60–69, 70–79, and ≥80 years old. Marital status was categorized into "not in a relationship" (including never married, separated, divorced, or widowed) and "in a relationship" (married or not married but cohabiting). People living in "urban" areas (towns, cities, and metropolitan areas) were compared with those living in "rural" areas (commercial farms, small settlements, rural villages, and other areas that are farther away from towns and cities). Working status was classified as "still

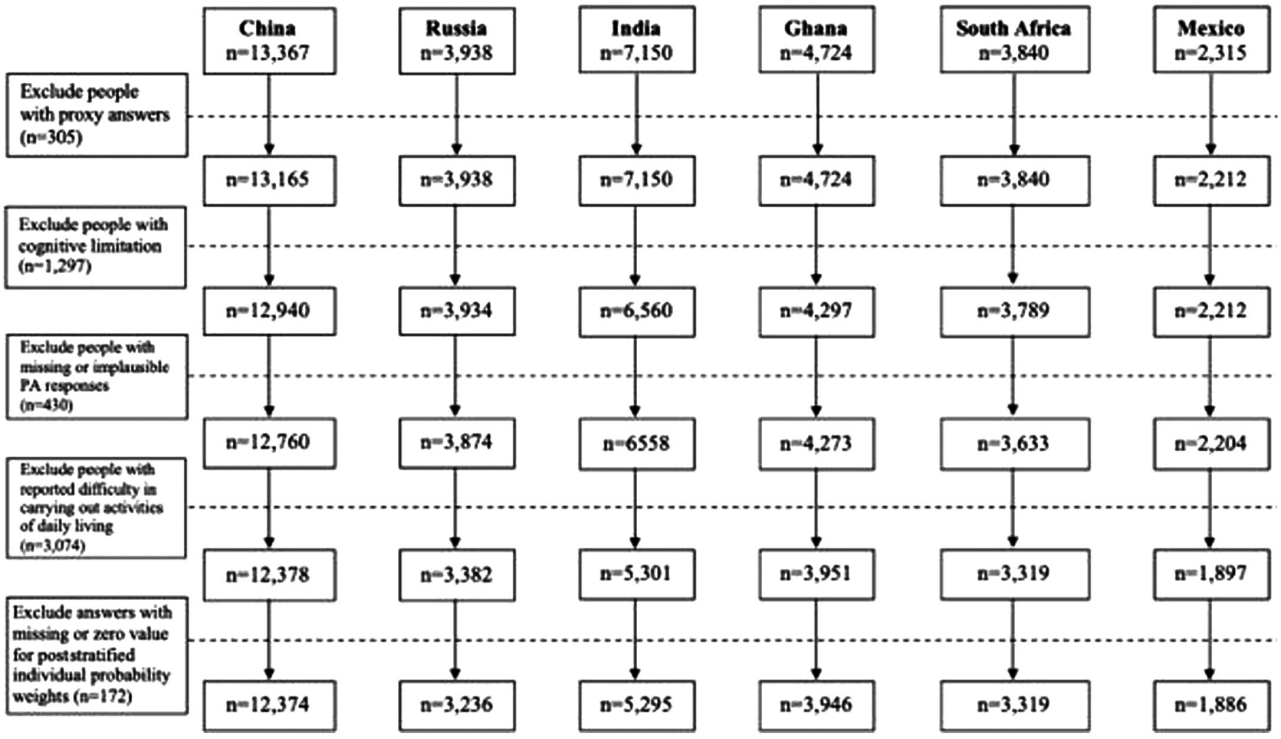

Figure 1 — STROBE flow diagram.

working" if they reported at least 2 days' work during the last 7 days, and the remainder were classified as "not working," which included people who were retired, unemployed, or worked only one day in the last 7 days.

Information on educational attainment was categorized into four groups: "never been to school," "secondary school and less," "completed high school/equivalent," and "college/university and above." This was used for the pooled analysis and all six countries, except Russia, where the first two groups were combined, due to the low proportion of people who had never been to school (0.7%). Income quintiles were calculated based on income distribution within each country.

Social capital variables. An 11-item Likert scale was used to assess three dimensions of social capital, including structural social capital, trust, and perceived safety. Structural social capital contains five questions about the frequency of people attending public or private activities in the last 12 months. Trust was measured by four questions, asking about whether one could trust strangers, neighbors, or coworkers, and trust in general. Perceived safety was assessed through questions about one's feelings when alone at home and when walking down the street alone after dark. We further dichotomized responses into "high" and "low" categories, based on previous WHO SAGE work, using the same variables (Ng & Eriksson, 2015). Having an answer of "high" in at least one of the items in each dimension was recoded as "high" for this dimension; otherwise, it was "low." These questions are listed in Appendix Table 1. The Cronbach's alpha values ranged from .67 to .75, which were considered acceptable.

Total and domain-specific physical activity. The Global Physical Activity Questionnaire (GPAQ) is a widely used international survey with good reliability and validity among adults (Bull, Maslin, & Armstrong, 2009). The GPAQ asks questions about domain-specific physical activity in a typical week, including paid or unpaid work (occupational and domestic), travel to and from places, and recreational (leisure-time) activities. For each domain, people who engaged in some activities (reported in minutes) in a typical day were classified as "have any activity," while those who reported 0 min were regarded as "have no activity." To determine physical activity intensity, 4 METs were assigned to moderate activities and 8 METs were assigned to vigorous activities, using the GPAQ protocol (Armstrong & Bull, 2006). Total physical activity was calculated by summing the MET minutes across the three domains, a method which has been previously published using these WHO SAGE data (in a secondary analysis; Kyu et al., 2016). It was then recoded as a dichotomized variable based on the WHO recommendations (World Health Organization, 2010), with achieving 600 MET-min/week being equivalent to "meeting WHO physical activity recommendations."

In this study, we reported physical activity data as both continuous and categorical variables for different analyses. The individual proportion of domain-specific physical activity to total physical activity was used to understand the contribution of each domain to total physical activity, while the dichotomous data (meeting physical activity guidelines or not) were used to examine the correlates of domain-specific and total physical activity.

Analysis

To ensure the representativeness of the sample and adjusting for the complex survey sampling design, poststratified individual nonzero probability weights were used in each country. Country-specific cluster and strata were also used to estimate the 95% confidence intervals (95% CIs). Weighted percentages were presented for all independent and dependent variables. In order to better understand the contribution of each domain to total physical activity with a skewed data distribution, we calculated the individual proportion of domain-specific physical activity to total physical activity and obtained the mean, median, and interquartile range for working and nonworking populations. We performed multiple logistic regressions with forced entry to examine the relationships between various independent variables (sociodemographic and dimensions of social capital) and physical activity, and all the variables in the multiple regression models were mutually adjusted. Four separate models were built with domain-specific (any vs. zero) and total (meets WHO recommendations vs. not) physical activity as the outcomes. To further tease out OPA from DPA, a sensitivity analysis was performed to examine the relationship between independent variables and physical activity at work among people who are currently working (where the response represented combined OPA and DPA) and also those who are not currently working (where the response represented DPA only). We calculated the odds ratios and 95% CIs. A p value of less than .05 (two-sided test) was considered statistically significant. The analyses were performed with complex samples analysis using SPSS (version 24.0, IBM Corp., IBM SPSS Statistics for Windows, Armonk, NY).

Results

Sample Characteristics

Weighted demographic data are shown in Table 1. In China, Russia, South Africa, and Mexico, the majority were female, while there was a slightly higher proportion of males in India and Ghana. In all countries, the majority were aged 50–69 years and currently in a relationship. Over half of the participants in Russia had completed high school, compared to lower proportions in the other five countries. The proportions of rural residents were much higher in China, India, and Ghana, whereas Russia, South Africa, and Mexico had more participants living in urban areas. Most older adults reported not currently working, except for Ghana. The majority reported high levels of structural social capital, trust and, perceived safety; however, over half of the Chinese participants reported low levels of structural social capital, and two-thirds of the Mexicans had a low level of perceived safety.

The Contribution of Each Domain to Total Physical Activity

Table 2 presents the distribution of the individual proportion of domain-specific to total physical activity, according to working status. Among nonworking populations, Russians reported the highest median proportion of OPA/DPA to total physical activity, following by Ghanaians and Indians. For TPA, China had the highest median proportion to total physical activity, while South Africa had the lowest. In contrast, none of these six countries had a median proportion of LTPA to total physical activity other than 0.0%, and all the interquartile ranges were 0.0%–0.0%.

Among those who were currently working, four out of six countries had median values greater than or equal to 75.0%, and South Africa was the only country with a median value below 50%. For TPA, Indians had the highest median value of 18.5%, following by Russians and Mexicans. Again, for LTPA, none of these six countries had a median value other than 0.0%, and all the interquartile ranges were 0.0%–0.0%.

Table 1 Weighted Descriptive Information of the Study Sample in Six Countries

Variables	Pooled (*N* = 30,056) %	China (*N* = 12,374) %	Russia (*N* = 3,236) %	India (*N* = 5,295) %	Ghana (*N* = 3,946) %	South Africa (*N* = 3,319) %	Mexico (*N* = 1,886) %
Sex							
Male	49.3	50.0	40.1	54.4	53.4	44.8	48.3
Female	50.7	50.0	59.9	45.6	46.6	55.2	51.7
Age group (years)							
50–59	49.3	46.0	48.8	53.0	41.8	52.4	53.0
60–69	29.9	32.2	25.8	30.5	28.0	30.6	25.2
70–79	16.9	18.1	19.8	14.0	22.0	12.5	16.4
≥80	3.9	3.7	5.6	2.5	8.3	4.5	5.3
Marital status							
Not in a relationship	22.6	14.2	39.3	19.7	39.2	42.8	25.9
In a relationship	77.4	85.8	60.7	80.3	60.8	57.2	74.1
Educational attainment							
Never been to school	25.9	21.4	0.5	48.0	53.2	23.3	16.2
Secondary school and less	46.9	60.9	23.9	36.3	25.4	61.2	72.9
Completed high school/equivalent	19.1	13.0	56.3	9.6	17.6	9.3	2.4
College/university and above	8.1	4.7	19.3	6.0	3.8	6.2	8.5
Place of residence							
Urban	49.5	48.1	72.0	29.6	40.6	65.4	78.3
Rural	50.5	51.9	28.0	70.4	59.4	34.6	21.7
Working status							
Not working	54.5	55.6	55.9	50.9	27.0	67.5	59.7
Working	45.5	44.4	44.1	49.1	73.0	32.5	40.3
Income quintiles (within country)[a]							
Lowest	16.1	15.7	14.7	17.5	18.6	19.6	13.5
Second	19.3	17.8	19.2	19.5	19.1	20.1	25.9
Middle	19.1	20.4	18.5	18.4	20.1	18.8	16.4
Fourth	21.4	23.7	21.9	19.6	20.5	20.3	16.5
Highest	24.2	22.4	25.8	25.1	21.7	21.1	27.7
Structural social capital							
Low structural social capital	46.2	62.2	45.7	33.2	5.9	4.9	43.4
High structural social capital	53.8	37.8	54.3	66.8	94.1	95.1	56.6
Trust							
Low trust	23.2	5.8	50.6	22.2	24.8	53.7	38.5
High trust	76.8	94.2	49.4	77.8	75.2	46.3	61.5
Perceived safety							
Low perceived safety	30.0	14.3	55.0	30.0	13.9	69.9	37.1
High perceived safety	70.0	85.7	45.0	70.0	86.1	30.1	62.9
Activity at work or home							
Report any activity	66.5	59.8	78.7	74.4	77.3	47.0	46.0
Travel to and from places							
Report any activity	72.8	70.6	74.4	79.4	75.6	44.7	64.9
Leisure-time physical activities							
Report any activity	14.6	18.3	9.6	15.0	15.7	11.1	7.0
Total physical activity							
Meets WHO recommendations	79.0	77.3	84.7	82.8	80.7	51.9	69.5

Note: All descriptive statistics were based on weighted estimates. Poststratified individual nonzero probability weights were used in each country. WHO = World Health Organization.

[a]Quintiles are so varying around 20% because this is based on the weighted estimates.

Table 2 The Distribution of Individual Proportion of Domain-Specific PA to Total PA, Separated by Working Status

Not Working Population						
Variables	China (*n* = 7,447) %	Russia (*n* = 2,047) %	India (*n* = 2,876) %	Ghana (*n* = 1,064) %	South Africa (*n* = 2,364) %	Mexico (*n* = 1,328) %
OPA/DPA						
Mean	26.0	58.4	51.7	47.3	32.1	30.5
Median	0.0	72.0	62.0	63.2	0.0	0.0
IQR	0.0–54.6	8.7–91.3	0.0–90.0	0.0–89.8	0.0–83.7	0.0–80.0
TPA						
Mean	40.7	26.2	33.0	25.7	23.6	38.3
Median	25.0	14.6	20.0	8.9	0.0	11.3
IQR	0.0–100.0	0.0–39.1	0.0–50.0	0.0–33.3	0.0–33.3	0.0–100.0
LTPA						
Mean	11.6	1.6	3.5	3.6	2.7	3.2
Median	0.0	0.0	0.0	0.0	0.0	0.0
IQR	0.0–0.0	0.0–0.0	0.0–0.0	0.0–0.0	0.0–0.0	0.0–0.0
Working Population						
	China (*n* = 4,885) %	Russia (*n* = 1,188) %	India (*n* = 2,419) %	Ghana (*n* = 2,869) %	South Africa (*n* = 930) %	Mexico (*n* = 558) %
OPA/DPA						
Mean	58.2	64.8	61.1	69.5	45.5	48.9
Median	75.0	75.5	73.6	81.8	41.0	63.4
IQR	0.0–95.2	48.5–91.4	37.5–91.1	63.1–93.0	0.0–97.0	0.0–94.1
TPA						
Mean	26.1	25.7	30.7	19.6	18.2	34.9
Median	10.0	16.7	18.5	12.3	0.0	13.0
IQR	0.0–37.2	4.0–35.9	5.7–45.5	3.5–25.0	0.0–20.0	0.0–98.3
LTPA						
Mean	5.1	3.9	4.3	2.7	4.7	4.1
Median	0.0	0.0	0.0	0.0	0.0	0.0
IQR	0.0–0.0	0.0–0.0	0.0–0.0	0.0–0.0	0.0–0.0	0.0–0.0

Note. All descriptive statistics were based on weighted estimates. Poststratified individual nonzero probability weights were used in each country. PA = physical activity; OPA = occupational PA; DPA = domestic PA; TPA = transport PA; LTPA = leisure-time PA.

The Percentage of People Reporting Any Activity in Each Domain

In general, over half of the participants met the WHO recommendation of total physical activity. Around 66.5% of the participants reported OPA/DPA, with the highest proportion (78.7%) in Russia and the lowest in South Africa (47.0%) and Mexico (46.0%). The majority reported some TPA, while only a small number of older adults reported any LTPA, ranging from 7.0% in Mexico to 18.3% in China (Table 1).

Sociodemographic Characteristics as Correlates of Physical Activity

The sociodemographic and social capital correlates of total and domain-specific physical activity are presented separately in Tables 3–6. Significant associations were observed between all these variables and OPA/DPA. Females, those currently in a relationship, those living in rural areas, and those working had higher odds of reporting OPA/DPA, while older people had lower odds of being active at work or home compared to their 50- to 59-year-old counterparts. People with higher educational attainment had lower odds of reporting OPA/DPA. In the pooled analysis, compared with people who have never been to school, people who completed high school and college/university had 28% and 37% lower odds of reporting OPA/DPA. As for the income levels, those who were affluent were more active at work or at home than those with lower income; this association was observed only in Russia.

Among all sociodemographic variables, only age and working status were related to active travel. Those who were currently working had 1.52 times the odds of reporting transport activity compared with nonworking people, while older adults had lower odds of being active through transport. Females reported less active travel than males in Ghana and Mexico only. There was no evidence for the association between educational attainment and active travel across countries, except for Russia, where better educated people had higher odds of reporting active travel. Income quintiles were inversely related to active travel in China, but

Table 3 Correlates of Reporting Any Activity at Work or Home Among Adults Aged 50+ Years

Variables	Pooled OR (95% CI)	China OR (95% CI)	Russia OR (95% CI)	India OR (95% CI)	Ghana OR (95% CI)	South Africa OR (95% CI)	Mexico OR (95% CI)
Country							
China	1						
Russia	**4.13** (2.80–6.08)**						
India	**1.72** (1.34–2.20)**						
Ghana	**1.93** (1.50–2.48)**						
South Africa	**0.69** (0.51–0.93)**						
Mexico	0.65 (0.41–1.03)						
Sex							
Male	1	1	1	1	1	1	1
Female	**1.49** (1.30–1.71)**	**1.17** (1.02–1.34)**	1.19 (0.83–1.71)	**3.49** (2.39–5.10)**	1.07 (0.83–1.38)	1.06 (0.80–1.42)	1.12 (0.69–1.83)
Age group (years)							
50–59	1	1	1	1	1	1	1
60–69	**0.86** (0.77–0.96)**	0.92 (0.84–1.02)	1.11 (0.78–1.58)	**0.73** (0.60–0.89)**	1.16 (0.91–1.46)	0.79 (0.59–1.06)	0.70 (0.41–1.21)
70–79	**0.64** (0.54–0.76)**	**0.61** (0.50–0.73)**	0.68 (0.43–1.06)	0.71 (0.48–1.04)	**0.70** (0.51–0.97)**	0.69 (0.47–1.03)	1.07 (0.60–1.91)
≥80	**0.33** (0.26–0.42)**	**0.29** (0.23–0.37)**	**0.45** (0.24–0.84)**	**0.26** (0.16–0.41)**	**0.55** (0.37–0.82)**	**0.43** (0.24–0.76)**	0.45 (0.18–1.14)
Marital status							
Not in a relationship	1	1	1	1	1	1	1
In a relationship	**1.16** (1.00–1.34)**	0.96 (0.80–1.13)	1.04 (0.73–1.48)	1.20 (0.94–1.53)	**1.51** (1.16–1.96)**	1.17 (0.88–1.55)	**2.53** (1.43–4.48)**
Educational attainment							
Never been to school	1	1	1	1	1	1	1
Secondary school and less	1.03 (0.89–1.20)	1.01 (0.87–1.17)		**1.62** (1.29–2.03)**	0.77 (0.58–1.03)	**0.66** (0.47–0.91)**	1.02 (0.54–1.93)
Completed high school/equivalent	**0.72** (0.56–0.93)**	**0.58** (0.45–0.74)**	1.12 (0.72–1.76)	1.49 (0.80–2.78)	1.05 (0.73–1.51)	**0.38** (0.21–0.69)**	**0.14** (0.04–0.48)**
College/university and above	**0.63** (0.49–0.82)**	**0.39** (0.27–0.57)**	0.81 (0.51–1.31)	1.07 (0.72–1.59)	0.69 (0.40–1.18)	0.63 (0.30–1.32)	1.13 (0.38–3.39)
Place of residence							
Urban	1	1	1	1	1	1	1
Rural	**1.71** (1.35–2.17)**	**2.08** (1.40–3.10)**	1.26 (0.68–2.36)	**1.49** (1.00–2.21)**	**2.18** (1.51–3.13)**	0.83 (0.57–1.21)	0.53 (0.22–1.28)
Working status							
Not working	1	1	1	1	1	1	1
Working	**2.63** (2.25–3.07)**	**2.60** (2.01–3.37)**	**2.67** (1.45–4.91)**	**2.66** (2.08–3.40)**	**3.36** (2.66–4.25)**	**1.76** (1.29–2.41)**	**2.41** (1.42–4.09)**
Income quintiles							
Lowest	1	1	1	1	1	1	1
Second	0.97 (0.75–1.24)	1.11 (0.95–1.31)	1.43 (0.75–2.71)	0.94 (0.64–1.40)	**0.64** (0.45–0.92)**	0.95 (0.56–1.64)	**0.30** (0.13–0.71)**
Middle	1.18 (0.97–1.44)	0.98 (0.80–1.21)	**3.43** (2.07–5.69)**	**0.72** (0.53–0.97)**	**0.66** (0.44–0.98)**	1.37 (0.78–2.38)	1.57 (0.73–3.37)
Fourth	0.83 (0.68–1.02)	**0.77** (0.61–0.98)**	**2.07** (1.07–3.99)**	**0.54** (0.39–0.75)**	**0.34** (0.23–0.50)**	0.81 (0.45–1.47)	0.58 (0.25–1.33)
Highest	**0.73** (0.57–0.92)**	**0.50** (0.34–0.74)**	**2.94** (1.70–5.07)**	**0.54** (0.39–0.75)**	**0.35** (0.23–0.54)**	1.06 (0.55–2.04)	**0.41** (0.18–0.90)**

(continued)

Table 3 *(continued)*

Variables	Pooled OR (95% CI)	China OR (95% CI)	Russia OR (95% CI)	India OR (95% CI)	Ghana OR (95% CI)	South Africa OR (95% CI)	Mexico OR (95% CI)
Structural social capital (ref: low structural social capital)	1.14 (0.97–1.34)	1.04 (0.87–1.25)	1.19 (0.68–2.09)	**1.33** (1.00–1.76)**	**1.64** (1.03–2.62)**	1.17 (0.64–2.14)	1.55 (0.99–2.43)
Trust (ref: low trust)	1.03 (0.87–1.22)	0.83 (0.68–1.03)	0.90 (0.63–1.28)	1.00 (0.77–1.30)	**1.76** (1.35–2.29)**	1.28 (0.92–1.77)	1.31 (0.80–2.14)
Perceived safety (ref: low perceived safety)	1.16 (0.98–1.37)	0.90 (0.68–1.19)	1.21 (0.78–1.89)	1.11 (0.88–1.40)	**1.93** (1.36–2.75)**	1.10 (0.77–1.57)	**2.33** (1.35–4.04)**

Note. The results were based on adjusted analysis, and all the variables in the model were mutually adjusted. All statistics tests were based on weighted estimates. Poststratified individual nonzero probability weights were used in each country. Country-specific cluster and strata were also used to estimate the 95% CIs. OR = odds ratio; CIs = confidence intervals. The significance of the bold values is $p < .05$. (See Appendix Table 4 for a more visible version of this table.)
**$p < .05$.

Table 4 Correlates of Reporting Any Active Travel Among Adults Aged 50+ Years

Variables	Pooled OR (95% CI)	China OR (95% CI)	Russia OR (95% CI)	India OR (95% CI)	Ghana OR (95% CI)	South Africa OR (95% CI)	Mexico OR (95% CI)
Country							
China	1						
Russia	1.14 (0.79–1.63)						
India	**1.52** (1.16–1.98)**						
Ghana	1.11 (0.87–1.40)						
South Africa	**0.31** (0.23–0.41)**						
Mexico	0.76 (0.55–1.06)						
Sex							
Male	1	1	1	1	1	1	1
Female	0.91 (0.80–1.05)	0.94 (0.83–1.06)	1.50 (0.99–2.29)	0.78 (0.58–1.06)	**0.78** (0.63–0.97)**	0.76 (0.56–1.04)	**0.55** (0.32–0.96)**
Age group (years)							
50–59	1	1	1	1	1	1	1
60–69	0.93 (0.83–1.05)	0.93 (0.81–1.07)	0.74 (0.46–1.20)	1.00 (0.81–1.23)	1.16 (0.93–1.44)	**0.64** (0.47–0.87)**	0.69 (0.42–1.14)
70–79	**0.82** (0.70–0.94)**	**0.68** (0.59–0.78)**	**0.57** (0.33–0.96)**	0.95 (0.68–1.33)	0.90 (0.69–1.16)	**0.62** (0.42–0.93)**	0.68 (0.39–1.20)
≥80	**0.38** (0.30–0.49)**	**0.38** (0.30–0.47)**	**0.16** (0.08–0.33)**	**0.53** (0.32–0.86)**	1.01 (0.72–1.44)	**0.49** (0.30–0.81)**	**0.27** (0.12–0.64)**
Marital status							
Not in a relationship	1	1	1	1	1	1	1
In a relationship	0.96 (0.82–1.12)	1.05 (0.88–1.25)	0.81 (0.53–1.24)	1.03 (0.82–1.28)	1.24 (0.98–1.55)	1.01 (0.75–1.35)	0.68 (0.36–1.29)
Educational attainment							
Never been to school	1	1	1	1	1	1	1
Secondary school and less	1.03 (0.89–1.21)	0.91 (0.79–1.05)		1.08 (0.82–1.42)	0.88 (0.67–1.15)	0.77 (0.57–1.03)	1.08 (0.52–2.23)
Completed high school/equivalent	1.26 (1.00–1.60)	0.82 (0.62–1.08)	**1.45** (1.18–1.77)**	1.23 (0.79–1.94)	0.99 (0.69–1.43)	0.69 (0.40–1.20)	3.51 (0.75–16.38)

(continued)

Table 4 *(continued)*

Variables	Pooled OR (95% CI)	China OR (95% CI)	Russia OR (95% CI)	India OR (95% CI)	Ghana OR (95% CI)	South Africa OR (95% CI)	Mexico OR (95% CI)
College/university and above	1.04 (0.77–1.41)	0.76 (0.49–1.16)	**1.57** (1.22–2.03)**	1.68 (0.90–3.13)	**0.59** (0.36–0.99)**	0.62 (0.33–1.16)	0.59 (0.18–1.92)
Place of residence							
Urban	1	1	1	1	1	1	1
Rural	0.96 (0.75–1.22)	**0.47** (0.35–0.63)**	1.69 (0.98–2.92)	1.46 (0.98–2.17)	1.40 (0.97–2.03)	**1.48** (1.02–2.15)**	1.55 (0.91–2.63)
Working status							
Not working	1	1	1	1	1	1	1
Working	**1.52** (1.31–1.76)**	**1.49** (1.20–1.86)**	1.47 (0.99–2.19)	**2.08** (1.54–2.80)**	**1.95** (1.53–2.48)**	1.24 (0.93–1.65)	1.44 (0.81–2.58)
Income quintiles							
Lowest	1	1	1	1	1	1	1
Second	1.12 (0.94–1.33)	1.07 (0.89–1.28)	**1.78** (1.11–2.85)**	1.08 (0.81–1.44)	0.89 (0.65–1.21)	0.87 (0.53–1.41)	1.26 (0.58–2.70)
Middle	0.89 (0.72–1.09)	**0.67** (0.53–0.84)**	**2.19** (1.22–3.94)**	0.92 (0.59–1.44)	1.09 (0.80–1.48)	0.70 (0.43–1.15)	0.54 (0.23–1.30)
Fourth	0.86 (0.72–1.03)	**0.62** (0.49–0.79)**	**1.85** (1.09–3.14)**	0.96 (0.67–1.38)	**0.63** (0.44–0.90)**	0.81 (0.48–1.35)	0.64 (0.31–1.30)
Highest	0.97 (0.76–1.24)	**0.73** (0.56–0.96)**	1.16 (0.64–2.10)	1.07 (0.72–1.61)	0.78 (0.52–1.19)	0.87 (0.48–1.58)	0.78 (0.40–1.53)
Structural social capital (ref: low structural social capital)	**1.20** (1.06–1.36)**	1.04 (0.91–1.19)	1.10 (0.81–1.49)	1.20 (0.91–1.57)	**3.06** (1.93–4.86)**	1.61 (0.79–3.30)	**2.76** (1.78–4.27)**
Trust (ref: low trust)	1.08 (0.91–1.29)	1.01 (0.80–1.27)	0.95 (0.69–1.30)	0.95 (0.74–1.22)	**1.40** (1.05–1.85)**	1.26 (0.89–1.79)	1.70 (0.97–3.00)
Perceived safety (ref: low perceived safety)	1.01 (0.83–1.23)	1.12 (0.90–1.40)	1.48 (0.83–2.62)	**0.52** (0.37–0.74)**	**1.72** (1.23–2.40)**	**1.56** (1.09–2.23)**	**2.02** (1.21–3.37)**

Note. The results were based on adjusted analysis, and all the variables in the model were mutually adjusted. All statistics tests were based on weighted estimates. Poststratified individual nonzero probability weights were used in each country. Country-specific cluster and strata were also used to estimate the 95% CIs. OR = odds ratio; CIs = confidence intervals. The significance of the bold values is $p < .05$. (See Appendix Table 5 for a more visible version of this table.)
**$p < .05$.

positively associated in Russia, and not significant in the other four countries.

As for LTPA, the respondents who were in a relationship and currently working were as active as those who were not in a relationship or not working, while females, the older age group, and those living in rural areas had lower odds of reporting LTPA. Table 5 shows the adjusted association between educational attainment, income, and LTPA across six countries. Those with higher educational attainment in all six countries had higher odds of participating in LTPA, except for South Africa. There was a consistent positive association between income quintiles and LTPA.

In terms of total physical activity, marital status was marginally significantly associated with higher odds of total physical activity. Females were more active than males in India, while females in Ghana were less active. Compared with people aged 50–59, the older old (aged 70–79) and the oldest old (aged ≥80) people had lower odds of meeting the WHO recommendation. However, currently working was positively correlated with meeting PA recommendations. Educational attainment was no longer significantly related to total physical activity. However, in China, India, and Ghana, higher income was associated with lower odds of meeting the WHO recommendation for total physical activity. In contrast, people in Russia with higher income had higher odds of being physically active overall, while those in the middle quintile of income in Mexico had higher odds of being sufficiently active.

Social Capital Correlates of Physical Activity

Structural social capital showed significant positive associations with TPA, LTPA, and total physical activity across all six LMICs. The participants with a high level of structural social capital had 1.20 and 1.29 times the odds of performing TPA and LTPA, respectively. They also had higher odds of meeting total physical activity recommendations. Trust was only positively associated with LTPA, and perceived safety was only positively associated with total physical activity. Those with high perceived safety showed higher odds of meeting PA-recommended levels than those with low perceived safety.

Sensitivity Analysis

Because the GPAQ questions did not separate OPA and DPA, we conducted sensitivity analysis by testing the correlates of OPA/DPA stratified by working status. The findings were similar to those from the main analysis, expect that females were no longer more active than males at work or home among the working population, and education was not related with OPA/DPA among

Table 5 Correlates of Reporting Any Leisure-Time Physical Activities Among Adults Aged 50+ Years

Variables	Pooled OR (95% CI)	China OR (95% CI)	Russia OR (95% CI)	India OR (95% CI)	Ghana OR (95% CI)	South Africa OR (95% CI)	Mexico OR (95% CI)
Country							
China	1						
Russia	**0.30** (0.20–0.45)**						
India	0.88 (0.70–1.12)						
Ghana	0.81 (0.61–1.08)						
South Africa	**0.37** (0.27–0.51)**						
Mexico	**0.24** (0.14–0.41)**						
Sex							
Male	1	1	1	1	1	1	1
Female	**0.74** (0.64–0.85)**	**0.81** (0.70–0.93)**	0.71 (0.43–1.17)	**0.67** (0.46–0.96)**	**0.76** (0.59–0.97)**	0.79 (0.50–1.24)	**0.38** (0.15–0.97)**
Age group (years)							
50–59	1	1	1	1	1	1	1
60–69	1.06 (0.93–1.22)	1.02 (0.87–1.19)	1.44 (0.90–2.28)	1.00 (0.77–1.28)	1.14 (0.87–1.51)	0.62 (0.35–1.09)	2.10 (0.93–4.73)
70–79	**0.82** (0.67–0.99)**	0.87 (0.69–1.11)	0.68 (0.26–1.76)	0.70 (0.48–1.02)	1.01 (0.71–1.42)	0.92 (0.51–1.66)	0.92 (0.41–2.06)
≥80	**0.59** (0.43–0.81)**	**0.56** (0.36–0.87)**	0.81 (0.31–2.10)	**0.26** (0.09–0.74)**	**1.91** (1.18–3.07)**	0.58 (0.21–1.64)	1.56 (0.64–3.78)
Marital status							
Not in a relationship	1	1	1	1	1	1	1
In a relationship	0.90 (0.78–1.04)	1.02 (0.85–1.23)	**0.64** (0.42–0.97)**	0.89 (0.64–1.22)	**0.71** V(0.55–0.91)**	1.14 (0.73–1.76)	0.91 (0.52–1.61)
Educational attainment							
Never been to school	1	1	1	1	1	1	1
Secondary school and less	**1.21** (1.02–1.43)**	1.06 (0.89–1.27)		**1.41** (1.07–1.85)**	**1.61** (1.15–2.26)**	1.01 (0.58–1.77)	1.43 (0.68–2.97)
Completed high school/equivalent	**1.49** (1.16–1.91)**	1.11 (0.84–1.47)	2.07 (0.91–4.71)	**1.61** (1.05–2.47)**	**2.33** (1.57–3.46)**	1.97 (0.95–4.08)	1.64 (0.22–12.22)
College/university and above	**2.33** (1.73–3.13)**	**1.36** (1.02–1.80)**	**4.65** (1.73–12.46)**	**2.25** (1.30–3.90)**	1.71 (0.97–3.01)	1.74 (0.73–4.14)	**4.01** (1.43–11.24)**
Place of residence							
Urban	1	1	1	1	1	1	1
Rural	**0.35** (0.28–0.45)**	**0.17** (0.12–0.24)**	0.74 (0.29–1.89)	**0.57** (0.41–0.80)**	0.70 (0.45–1.10)	1.06 (0.61–1.84)	1.22 (0.40–3.76)
Working status							
Not working	1	1	1	1	1	1	1
Working	1.12 (0.95–1.31)	0.93 (0.76–1.14)	1.53 (0.89–2.64)	**1.63** (1.23–2.16)**	**1.39** (1.02–1.91)**	1.27 (0.72–2.24)	1.00 (0.40–2.52)
Income quintiles							
Lowest	1	1	1	1	1	1	1
Second	1.02 (0.81–1.28)	1.01 (0.78–1.30)	1.19 (0.46–3.06)	1.04 (0.72–1.51)	**1.77** (1.18–2.67)**	1.68 (0.70–4.06)	0.63 (0.29–1.94)
Middle	1.07 (0.85–1.35)	1.09 (0.85–1.40)	1.10 (0.52–2.36)	0.81 (0.50–1.31)	**2.21** (1.55–3.16)**	**2.97** (1.22–7.27)**	1.82 (0.63–5.22)

(continued)

Table 5 *(continued)*

Variables	Pooled OR (95% CI)	China OR (95% CI)	Russia OR (95% CI)	India OR (95% CI)	Ghana OR (95% CI)	South Africa OR (95% CI)	Mexico OR (95% CI)
Fourth	**1.36**** **(1.07–1.72)**	1.12 (0.88–1.42)	2.04 (0.93–4.50)	1.29 (0.84–1.97)	**2.18**** **(1.44–3.28)**	**3.02**** **(1.21–7.50)**	2.74 (0.83–9.02)
Highest	**1.49**** **(1.15–1.93)**	1.28 (0.92–1.79)	1.46 (0.61–3.50)	1.43 (0.94–2.18)	**3.27**** **(2.06–5.19)**	**4.46**** **(1.77–11.19)**	2.05 (0.47–9.04)
Structural social capital (ref: low structural social capital)	**1.29**** **(1.12–1.49)**	**1.30**** **(1.11–1.53)**	**1.70**** **(1.06–2.72)**	1.15 (0.88–1.50)	**4.73**** **(1.83–12.22)**	**3.24**** **(1.26–8.33)**	1.06 (0.43–2.60)
Trust (ref: low trust)	**1.24**** **(1.02–1.51)**	0.83 (0.66–1.05)	**2.04**** **(1.28–3.25)**	1.11 (0.82–1.50)	**3.44**** **(2.35–5.03)**	1.42 (0.96–2.10)	0.86 (0.45–1.66)
Perceived safety (ref: low perceived safety)	0.91 (0.78–1.07)	1.08 (0.90–1.29)	1.09 (0.70–1.71)	**0.70**** **(0.54–0.91)**	1.06 (0.73–1.54)	**1.65**** **(1.02–2.65)**	1.55 (0.81–2.97)

Note. The results were based on adjusted analysis, and all the variables in the model were mutually adjusted. All statistics tests were based on weighted estimates. Poststratified individual nonzero probability weights were used in each country. Country-specific cluster and strata were also used to estimate the 95% CIs. OR = odds ratio; CIs = confidence intervals. The significance of the bold values is $p < .05$. (See Appendix Table 6 for a more visible version of this table.)
**$p < .05$.

Table 6 Correlates of Meeting Total Physical Activity Recommendation Among Adults Aged 50+ Years

Variables	Pooled OR (95% CI)	China OR (95% CI)	Russia OR (95% CI)	India OR (95% CI)	Ghana OR (95% CI)	South Africa OR (95% CI)	Mexico OR (95% CI)
Country							
China	1						
Russia	**1.99**** **(1.38–2.88)**						
India	1.25 (0.95–1.63)						
Ghana	0.95 (0.72–1.25)						
South Africa	**0.32**** **(0.24–0.42)**						
Mexico	0.69 (0.48–1.00)						
Sex							
Male	1	1	1	1	1	1	1
Female	1.12 (0.97–1.29)	0.95 (0.84–1.08)	1.19 (0.70–2.02)	**2.08**** **(1.50–2.90)**	**0.75**** **(0.58–0.97)**	0.90 (0.67–1.22)	0.83 (0.47–1.45)
Age group (years)							
50–59	1	1	1	1	1	1	1
60–69	**0.81**** **(0.72–0.91)**	0.90 (0.81–1.00)	0.74 (0.50–1.10)	**0.73**** **(0.57–0.93)**	0.94 (0.72–1.23)	**0.69**** **(0.52–0.92)**	0.71 (0.42–1.20)
70–79	**0.57**** **(0.48–0.67)**	**0.59**** **(0.48–0.74)**	**0.46**** **(0.26–0.81)**	**0.49**** **(0.36–0.67)**	**0.51**** **(0.36–0.71)**	**0.63**** **(0.43–0.92)**	0.73 (0.39–1.37)
≥80	**0.32**** **(0.25–0.40)**	**0.30**** **(0.24–0.39)**	**0.25**** **(0.12–0.51)**	**0.27**** **(0.17–0.43)**	**0.52**** **(0.34–0.79)**	**0.38**** **(0.21–0.68)**	**0.36**** **(0.15–0.88)**
Marital status							
Not in a relationship	1	1	1	1	1	1	1
In a relationship	1.15 (1.00–1.34)	1.03 (0.90–1.18)	1.04 (0.70–1.53)	1.16 (0.86–1.58)	1.26 (0.96–1.67)	1.23 (0.93–1.62)	1.50 (0.81–2.77)

(continued)

Table 6 ***(continued)***

Variables	Pooled OR (95% CI)	China OR (95% CI)	Russia OR (95% CI)	India OR (95% CI)	Ghana OR (95% CI)	South Africa OR (95% CI)	Mexico OR (95% CI)
Educational attainment							
Never been to school	1	1	1	1	1	1	1
Secondary school and less	1.06 (0.90–1.25)	1.04 (0.87–1.24)		**1.31** (1.03–1.68)**	0.76 (0.57–1.03)	**0.72** (0.52–0.98)**	1.57 (0.78–3.19)
Completed high school/equivalent	1.05 (0.81–1.36)	0.84 (0.61–1.16)	0.97 (0.59–1.60)	1.81 (0.98–3.36)	1.06 (0.70–1.61)	**0.38** (0.21–0.71)**	2.18 (0.50–9.48)
College/university and above	0.89 (0.66–1.20)	**0.61** (0.39–0.97)**	0.76 (0.46–1.26)	1.67 (0.89–3.10)	0.76 (0.44–1.31)	0.73 (0.35–1.53)	1.46 (0.51–4.14)
Place of residence							
Urban	1	1	1	1	1	1	1
Rural	1.15 (0.91–1.47)	0.69 (0.46–1.03)	1.69 (0.87–3.28)	**1.62** (1.16–2.24)**	**1.87** (1.22–2.86)**	1.23 (0.83–1.82)	1.34 (0.74–2.42)
Working status							
Not working	1	1	1	1	1	1	1
Working	**2.25** (1.88–2.70)**	**2.11** (1.54–2.89)**	**2.59** (1.40–4.77)**	**3.67** (2.68–5.02)**	**2.98** (2.33–3.81)**	**1.84** (1.34–2.54)**	**1.88** (1.04–3.40)**
Income quintiles							
Lowest	1	1	1	1	1	1	1
Second	1.08 (0.88–1.32)	1.07 (0.89–1.29)	**1.84** (1.10–3.07)**	0.89 (0.63–1.26)	0.75 (0.50–1.11)	0.95 (0.56–1.63)	0.99 (0.47–2.13)
Middle	1.20 (0.98–1.46)	0.92 (0.75–1.13)	**3.83** (2.08–7.07)**	0.73 (0.51–1.06)	0.75 (0.50–1.14)	1.09 (0.62–1.89)	**1.95** (1.04–3.66)**
Fourth	0.92 (0.75–1.14)	**0.73** (0.55–0.98)**	**3.47** (1.98–6.10)**	0.69 (0.47–1.00)	**0.36** (0.23–0.55)**	0.94 (0.53–1.69)	0.49 (0.23–1.05)
Highest	0.93 (0.73–1.20)	**0.68** (0.47–0.98)**	**2.74** (1.61–4.65)**	**0.67** (0.45–0.98)**	**0.34** (0.21–0.55)**	1.13 (0.57–2.24)	0.63 (0.31–1.27)
Structural social capital (ref: low structural social capital)	**1.28** (1.10–1.49)**	1.13 (0.94–1.36)	1.28 (0.83–1.97)	**1.44** (1.14–1.81)**	**2.65** (1.71–4.11)**	1.25 (0.70–2.25)	**2.22** (1.42–3.46)**
Trust (ref: low trust)	0.97 (0.82–1.15)	0.95 (0.73–1.24)	0.81 (0.55–1.19)	0.95 (0.74–1.22)	**2.23** (1.72–2.90)**	1.06 (0.79–1.42)	1.15 (0.70–1.88)
Perceived safety (ref: low perceived safety)	**1.27** (1.07–1.52)**	1.15 (0.88–1.50)	1.22 (0.65–2.28)	1.02 (0.78–1.33)	**2.14** (1.50–3.04)**	1.23 (0.87–1.74)	**3.14** (1.91–5.15)**

Note: The WHO recommendation for total physical activity is 600 MET-min/week. The results were based on adjusted analysis, and all the variables in the model were mutually adjusted. All statistics tests were based on weighted estimates. Poststratified individual nonzero probability weights were used in each country. Country-specific cluster and strata were also used to estimate the 95% CIs. OR = odds ratio; CIs = confidence intervals; WHO = World Health Organization. The significance of the bold values is $p < .05$. (See Appendix Table 7 for a more visible version of this table.)
**$p < .05$.

the not working population. Details of these analyses are provided in Appendix Tables 2 and 3.

Discussion

The current study is one of the few international comparative studies on correlates of domain-specific physical activity, involving six LMICs with sizeable population representative samples. Total physical activity in the six counties was mainly driven by OPA/DPA, with very small contributions from LTPA. Some correlates were similar across countries, such as working status and structural social capital, while others were less consistent.

Although the proportion of OPA/DPA varied across countries and differed between working and not working people, in general, it appears to play an important role in contributing to total physical activity. However, LTPA accounts for an extremely small proportion of total physical activity. This finding is similar to previous studies. Based on the large-scale China Kadoorie Biobank Study, Du et al. (2014) found that the mean total physical activity was 21.7 MET-hr/day among general adults, with 88% from occupation activities and housework chores and only 4% from LTPA. It is important to note that, even in HICs, OPA and DPA together may still account for a substantial proportion of total physical activity. For example, a study from Canada found that OPA and DPA together accounted for more than 80% of overall daily MET hours among people aged between 35 and 69, regardless of gender (Csizmadi, Lo Siou, Friedenreich, Owen, & Robson, 2011). However, in the same research, LTPA-related energy expenditure accounted for about 16.6% for males and 15.2% for females, which were much higher than the proportion in the current study. The policy relevance of these findings is that domestic and occupational settings provide physical activity for people in LMICs, and if industrialization results in decreased occupational energy expenditure (Church et al., 2011), it may have a major impact on population-level physical activity in LMICs.

In the current study, the prevalence of people achieving the WHO recommendation for health-enhancing physical activity ranged from 51.9% to 84.7%. According to the Prospective Urban Rural Epidemiology (PURE) study involving 17 countries of different income levels, people were more likely to have lower levels of total physical activity and LTPA in lower income countries, but not for OPA and TPA (Lear et al., 2017). In order to meet the WHO target of a 15% relative reduction in physical inactivity by 2030 (World Health Organization, 2018a), the challenge for LMICs is how to offset putative declines in OPA and TPA that may be associated with economic development, industrialization, and lifestyle change. Increasing LTPA at population levels is likely to remain a policy challenge for national physical activity strategies in these countries.

The women in our study reported similar total physical activity to men, which differs from studies from HICs, where women generally reported lower levels of physical activity (World Health Organization, 2018b). This may be because women in LMICs spend more time in DPA (Y.S. Lee, 2005; Quadlin & Doan, 2018). Our findings regarding age and physical activity echoed previous research that found an inverse association between age and total and domain-specific physical activity (Lim & Taylor, 2005).

The relationship between marital status and physical activity was mixed across domains, and married people reported more total physical activity and OPA/DPA, while they reported similar amounts of TPA and LTPA. Previous studies have also reported inconsistent patterns of association. Pettee et al. (2006) found that the relationship between marital status and LTPA was not significant, but there was a trend toward higher LTPA participation in well-functioning married people aged 70–79 years ($p = .05$). Findings from the National Health and Nutrition Examination Survey in the United States revealed that married people expended more energy in total physical activity than individuals in nonmarried relationships (Sobal & Hanson, 2010). However, they were less likely to report moderate and vigorous LTPA, which is in line with our results.

Our results show that rural residents reported lower levels of LTPA, but higher OPA/DPA compared with urban residents. This is expected, as rural residents were more likely to work in labor-intensive occupations, such as farming (Yadav & Krishnan, 2008).

Socioeconomic inequalities by the physical activity domain have been researched among adults in HICs (Beenackers et al., 2012; O'Donoghue et al., 2018), with considerable differences in the direction of association by domains. In our study of LMICs, educational attainment and income were both inversely related to OPA/DPA, with both indicators showing strong and consistent positive associations with LTPA. However, no significant relationship was found between socioeconomic status and TPA. For total physical activity, education showed no relationship, and income was inversely associated with total physical activity in China, India, and Ghana, which contrasts findings from HICs, where higher socioeconomic status is found to be consistently associated with more physical activity overall (Van Cauwenberg, De Clercq, Deforche, Cardon, & Chastin, 2019).

Social capital has been noted as a positive correlate of physical activity (McNeill et al., 2006), which was confirmed by the current study. However, few previous studies considered different dimensions of social capital or data from LMICs. Structural social capital (i.e., network of social relations) was positively related to almost all domain-specific and total physical activity in our study, which is consistent with findings from HICs (Lindstrom, Moghaddassi, & Merlo, 2003; Ueshima et al., 2010) and should be fostered to maintain physical activity levels in LMICs. Trust was found to be associated only with LTPA in our study, which has been identified elsewhere (Lindstrom, 2011). While evidence from HICs have suggested a positive association between safety and physical activity, this has been less explored in LMICs (Rees-Punia, Hathaway, & Gay, 2018). In our study, perceived safety was associated with total physical activity, but not significantly associated with LTPA, which echoed findings from Brazil (Parra et al., 2011). People may have low levels of perceived safety because of being exposed to crime, violence, and social incivilities, which discourages physical activity participation (Sawyer, Ucci, Jones, Smith, & Fisher, 2017). The importance of all three dimensions of social capital and their potential influence on physical activity behavior in the six LMICs is evident, suggesting the need to build community programs and environmental supports to facilitate physical activity across the different domains.

Limitations

A number of limitations need to be noted. Key methodological limitations include the use of self-reported physical activity measures and cross-sectional study design. However, to date, the assessment of domain-specific physical activity is mainly based on questionnaire measures. It is also arguable that there might be the potential for differential over- or underestimation across physical activity domains. Finally, although GPAQ is used worldwide and has established reliability and validity, the combination of OPA and DPA in the single work-related activity question has limited the interpretability of the findings.

Conclusion

This research contributes to the limited literature on the socio-demographic and social capital-related correlates of domain-specific physical activity among older adults in LMICs. These results generate new information for policymakers in LMICs attempting to develop national physical activity strategies. The identified groups, such as the oldest age groups and those of higher socioeconomic status, warrant attention. Relationships between social capital and physical activity may inform health promotion strategies that focus on increasing social interactions and perceptions within communities. Finally, interventions should focus on improving neighborhood-level environment and community-level activities to cultivate a sense of trust and safety.

Acknowledgments

This study was conceived and designed by M. Luo, D. Ding, P. Phongsavan, and A. Bauman. M. Luo conducted the data analysis, with statistical advice and contributions from D. Ding, P. Phongsavan, A. Bauman, J. Negin, and Z. Zhang on the interpretation of the results. M.L. wrote the draft manuscript, with writing contributions from D. Ding, P. Phongsavan, A. Bauman. All authors approved the final version.

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Appendix Table 1: Questions Used in the Construction of Social Capital Variables

Questions	Response categories	
	Low	High
Structural social capital		
How often in the last 12 months have you ...		
... attended any public meeting in which there was discussion of local or school affairs?	Never/once or twice per year	Once or twice per month/once or twice per week/daily
... met personally with someone you consider to be a community leader?	Never/once or twice per year	Once or twice per month/once or twice per week/daily
... attended any group, club, society, union, or organizational meeting?	Never/once or twice per year	Once or twice per month/once or twice per week/daily
... had friends over to your home?	Never/once or twice per year	Once or twice per month/once or twice per week/daily
... attended religious services (not including weddings and funerals)?	Never/once or twice per year	Once or twice per month/once or twice per week/daily
Trust		
Generally speaking, would you say that most people can be trusted or that you can't be too careful in dealing with people?	Can't be too careful	Can be trusted
First, think about people in your neighborhood. Generally speaking, would you say that you can trust them?	Neither great nor small extent/to a small extent/to a very small extent	To a very great extent/To a great extent
Now, think about people whom you work with. Generally speaking, would you say that you can trust them?	Neither great nor small extent/to a small extent/to a very small extent	To a very great extent/To a great extent
And how about strangers? Generally speaking, would you say that you can trust them?	Neither great nor small extent/to a small extent/to a very small extent	To a very great extent/To a great extent
Perceived safety		
In general, how safe from crime and violence do you feel when you are alone at home?	Moderately safe/slightly safe/not safe at all	Completely safe/very safe
How safe do you feel when walking down your street alone after dark?	Moderately safe/slightly safe/not safe at all	Completely safe/very safe

Appendix Table 2: Correlates of Reporting Any Activity at Work or Home Among Adults Only Who Are Currently Working (Sensitivity Analysis)

Variables	Pooled ($n = 12,849$)	China ($n = 4,885$)	Russia ($n = 1,188$)	India ($n = 2,419$)	Ghana ($n = 2,869$)	South Africa ($n = 930$)	Mexico ($n = 558$)
Country							
China	1						
Russia	**7.27 (4.25–12.44)**						
India	1.31 (0.96–1.80)						
Ghana	**2.03 (1.40–2.93)**						
South Africa	0.72 (0.45–1.15)						
Mexico	0.74 (0.32–1.71)						
Sex							
Male	1	1	1	1	1	1	1
Female	0.98 (0.79–1.22)	0.95 (0.76–1.19)	0.57 (0.28–1.19)	**2.08 (1.09–3.97)**	1.15 (0.81–1.64)	0.63 (0.38–1.04)	0.38 (0.13–1.13)
Age group (years)							
50–59	1	1	1	1	1	1	1
60–69	0.99 (0.81–1.21)	0.93 (0.72–1.20)	0.66 (0.29–1.51)	0.97 (0.69–1.36)	**1.37 (1.03–1.82)**	0.78 (0.43–1.42)	0.65 (0.30–1.38)
70–79	0.94 (0.66–1.33)	**0.59 (0.39–0.89)**	0.40 (0.12–1.31)	1.26 (0.66–2.41)	0.84 (0.54–1.29)	**0.48 (0.24–0.92)**	3.04 (1.22–7.60)
≥80	**0.55 (0.32–0.95)**	**0.29 (0.17–0.48)**	–	0.64 (0.18–2.30)	**0.52 (0.29–0.95)**	2.56 (0.51–12.86)	0.27 (0.51–1.43)
Marital status							
Not in a relationship	1	1	1	1	1	1	1
In a relationship	1.16 (0.88–1.51)	0.83 (0.57–1.20)	1.12 (0.59–2.14)	0.70 (0.49–1.27)	**1.51 (1.04–2.21)**	0.93 (0.59–1.46)	**3.18 (1.28–7.89)**
Educational attainment							
Never been to school	1	1	1	1	1	1	1
Secondary school and less	0.98 (0.76–1.26)	0.96 (0.72–1.26)		**1.62 (1.02–2.58)**	0.74 (0.50–1.09)	**0.33 (0.19–0.58)**	1.55 (0.52–4.61)
Completed high school/equivalent	0.64 (0.40–1.04)	**0.62 (0.41–0.94)**	1.14 (0.46–2.79)	1.29 (0.53–3.14)	1.12 (0.70–1.80)	**0.09 (0.04–0.23)**	0.65 (0.09–4.53)
College/university and above	**0.51 (0.32–0.83)**	**0.25 (0.12–0.51)**	0.64 (0.23–1.82)	0.86 (0.46–1.63)	0.80 (0.37–1.73)	**0.21 (0.09–0.46)**	3.56 (0.43–29.49)
Place of residence							
Urban	1	1	1	1	1	1	1
Rural	**2.26 (1.57–3.23)**	**3.94 (2.29–6.76)**	1.66 (0.55–5.06)	1.65 (0.95–2.88)	**2.51 (1.56–4.03)**	**0.53 (0.30–0.96)**	0.34 (0.04–1.27)
Income quintiles							
Lowest	1	1	1	1	1	1	1
Second	0.99 (0.67–1.47)	**1.45 (1.11–1.90)**	1.61 (0.74–3.51)	1.09 (0.53–2.22)	0.68 (0.41–1.13)	0.83 (0.38–1.79)	**0.10 (0.02–0.39)**
Middle	1.19 (0.87–1.63)	1.07 (0.77–1.51)	2.77 (0.88–8.69)	1.08 (0.62–1.87)	0.79 (0.47–1.35)	**2.29 (1.01–5.19)**	0.71 (0.22–2.24)
Fourth	0.77 (0.58–1.01)	0.88 (0.64–1.21)	2.18 (0.81–5.90)	**0.50 (0.31–0.80)**	**0.32 (0.18–0.54)**	1.52 (0.66–3.52)	**0.13 (0.03–0.55)**
Highest	**0.61 (0.43–0.88)**	**0.47 (0.27–0.81)**	**2.95 (1.11–7.84)**	**0.47 (0.27–0.82)**	**0.27 (0.15–0.47)**	1.00 (0.45–2.21)	**0.08 (0.02–0.36)**
Structural social capital (ref: low structural social capital)	1.26 (0.98–1.61)	0.99 (0.73–1.34)	1.41 (0.65–3.09)	1.24 (0.85–1.82)	**2.08 (1.12–3.85)**	0.45 (0.09–2.35)	**3.40 (1.58–7.32)**
Trust (ref: low trust)	1.31 (0.99–1.73)	0.90 (0.55–1.50)	1.50 (0.80–2.82)	0.89 (0.59–1.34)	**1.72 (1.23–2.41)**	**1.81 (1.13–2.91)**	**3.99 (1.71–9.31)**
Perceived safety (ref: low perceived safety)	1.22 (0.95–1.56)	1.15 (0.65–2.06)	0.94 (0.54–1.63)	1.21 (0.87–1.68)	**2.33 (1.54–3.52)**	1.44 (0.80–2.59)	**2.62 (1.05–6.52)**

Note: The results were based on adjusted analysis, and all the variables in the model were mutually adjusted. All statistics tests were based on weighted estimates. Poststratified individual nonzero probability weights were used in each country. Country-specific cluster and strata were also used to estimate the 95% CIs. CIs = confidence intervals. The significance of the bold values is $p < .05$.

Appendix Table 3: Correlates of Reporting Any Activity at Work or Home Among Adults Only Who Are Not Currently Working (Sensitivity Analysis)

Variables	Pooled ($n = 17,126$)	China ($n = 7,447$)	Russia ($n = 2,047$)	India ($n = 2,876$)	Ghana ($n = 1,064$)	South Africa ($n = 2,364$)	Mexico ($n = 1,328$)
Country							
China	1						
Russia	**3.60 (2.34–5.54)**						
India	**2.08 (1.56–2.78)**						
Ghana	**1.84 (1.34–2.51)**						
South Africa	0.73 (0.52–1.02)						
Mexico	**0.63 (0.41–0.98)**						
Sex							
Male	1	1	1	1	1	1	1
Female	**1.75 (1.50–2.05)**	**1.26 (1.07–1.47)**	1.57 (0.95–2.57)	**4.12 (2.88–5.90)**	1.05 (0.71–1.56)	1.35 (0.95–1.90)	**1.93 (1.14–3.25)**
Age group (years)							
50–59	1	1	1	1	1	1	1
60–69	**0.77 (0.67–0.90)**	**0.84 (0.74–0.96)**	1.47 (0.96–2.25)	**0.52 (0.37–0.73)**	0.77 (0.49–1.21)	0.75 (0.54–1.05)	0.80 (0.47–1.35)
70–79	**0.57 (0.48–0.69)**	**0.57 (0.46–0.71)**	0.82 (0.50–1.33)	**0.48 (0.34–0.67)**	**0.48 (0.29–0.79)**	0.71 (0.48–1.04)	0.97 (0.51–1.86)
≥80	**0.31 (0.24–0.40)**	**0.29 (0.22–0.39)**	**0.53 (0.29–0.98)**	**0.15 (0.09–0.26)**	**0.47 (0.27–0.82)**	**0.41 (0.24–0.70)**	0.61 (0.26–1.46)
Marital status							
Not in a relationship	1	1	1	1	1	1	1
In a relationship	**1.16 (1.00–1.33)**	0.99 (0.81–1.21)	1.03 (0.75–1.41)	1.22 (0.91–1.64)	**1.55 (1.07–2.26)**	1.26 (0.89–1.79)	**1.77 (1.06–2.95)**
Educational attainment							
Never been to school	1	1	1	1	1	1	1
Secondary school and less	1.06 (0.88–1.28)	0.98 (0.82–1.17)		**1.55 (1.17–2.04)**	0.81 (0.50–1.32)	0.84 (0.58–1.23)	1.21 (0.57–2.59)
Completed high school/equivalent	0.77 (0.59–1.01)	**0.56 (0.40–0.77)**	1.14 (0.69–1.88)	1.76 (0.89–3.47)	0.95 (0.58–1.54)	0.78 (0.37–1.62)	**0.14 (0.02–0.96)**
College/university and above	0.80 (0.59–1.10)	**0.52 (0.34–0.81)**	0.98 (0.57–1.69)	**1.95 (1.08–3.54)**	0.64 (0.31–1.31)	1.03 (0.41–2.63)	0.81 (0.26–2.52)
Place of residence							
Urban	1	1	1	1	1	1	1
Rural	**1.41 (1.09–1.81)**	1.45 (0.96–2.20)	1.12 (0.56–2.23)	1.36 (0.93–1.98)	**1.77 (1.18–2.65)**	1.02 (0.67–1.56)	0.87 (0.46–1.65)
Income quintiles							
Lowest	1	1	1	1	1	1	1
Second	0.92 (0.70–1.22)	0.93 (0.75–1.16)	1.37 (0.65–2.89)	0.84 (0.58–1.21)	**0.60 (0.37–0.96)**	1.02 (0.54–1.92)	0.44 (0.19–1.01)
Middle	1.15 (0.89–1.48)	0.87 (0.69–1.10)	**3.71 (2.05–6.72)**	**0.52 (0.36–0.77)**	**0.51 (0.29–0.89)**	1.16 (0.61–2.17)	1.76 (0.74–4.18)
Fourth	0.84 (0.65–1.09)	**0.66 (0.51–0.86)**	**2.32 (1.11–4.82)**	**0.58 (0.40–0.86)**	**0.35 (0.20–0.60)**	0.68 (0.35–1.33)	0.96 (0.42–2.19)
Highest	**0.77 (0.59–1.00)**	**0.49 (0.33–0.72)**	**2.86 (1.62–5.07)**	**0.57 (0.39–0.83)**	**0.50 (0.29–0.85)**	1.09 (0.52–2.26)	0.57 (0.26–1.26)
Structural social capital (ref: low structural social capital)	1.11 (0.92–1.35)	1.04 (0.86–1.27)	1.12 (0.63–2.00)	**1.44 (1.02–2.03)**	1.39 (0.78–2.46)	1.33 (0.63–2.79)	1.12 (0.71–1.77)
Trust (ref: low trust)	0.92 (0.77–1.10)	0.81 (0.65–1.01)	0.73 (0.50–1.05)	1.07 (0.80–1.42)	**1.81 (1.28–2.55)**	1.05 (0.72–1.55)	0.71 (0.43–1.17)
Perceived safety (ref: low perceived safety)	1.09 (0.90–1.33)	0.80 (0.62–1.04)	1.30 (0.81–2.10)	1.04 (0.75–1.43)	1.45 (0.92–2.29)	0.97 (0.65–1.45)	**2.49 (1.37–4.52)**

Note. The results were based on adjusted analysis, and all the variables in the model were mutually adjusted. All statistics tests were based on weighted estimates. Poststratified individual nonzero probability weights were used in each country. Country-specific cluster and strata were also used to estimate the 95% CIs. CIs = confidence intervals. The significance of the bold values is $p < .05$

Appendix Table 4: Correlates of Reporting Any Activity at Work or Home Among Adults Aged 50+ Years

Variables	Pooled	China	Russia	India	Ghana	South Africa	Mexico
Country (ref = China)							
Russia	+						
India	+						
Ghana	+						
South Africa	–						
Mexico	0						
Sex (ref = male)							
Female	+	+	0	+	0	0	0
Age group (years) (ref = 50–59)							
60–69	–	0	0	–	0	0	0
70–79	–	–	0	0	–	0	0
≥80	–	–	–	–	–	–	0
Marital status (ref = not in a relationship)							
In a relationship	+	0	0	0	+	0	+
Educational attainment (ref = never been to school)							
Secondary school and less	0	0		+	0	–	0
Completed high school/equivalent	–	–	0	0	0	–	–
College/university and above	–	–	0	0	0	0	0
Place of residence (ref = urban)							
Rural	+	+	0	+	+	0	0
Working status (ref = not working)							
Working	+	+	+	+	+	+	+
Income quantiles (ref = lowest)							
Second	0	0	0	0	–	0	–
Middle	0	0	+	–	–	0	0
Fourth	0	–	+	–	–	0	0
Highest	–	–	+	–	–	0	–
Structural social capital (ref: low structural social capital)	0	0	0	+	+	0	0
Trust (ref: low trust)	0	0	0	0	+	0	0
Perceived safety (ref: low perceived safety)	0	0	0	0	+	0	+

Note. + for positive relationship, 0 for nonsignificant relationship, – for negative relationship. The results were based on adjusted analysis, and all the variables in the model were mutually adjusted. All statistics tests were based on weighted estimates. Poststratified individual nonzero probability weights were used in each country. Country-specific cluster and strata were also used to estimate the 95% confidence intervals.

Appendix Table 5: Correlates of Reporting Any Active Travel Among Adults Aged 50+ Years

Variables	Pooled	China	Russia	India	Ghana	South Africa	Mexico
Country (ref = China)							
Russia	0						
India	+						
Ghana	0						
South Africa	–						
Mexico	0						
Sex (ref = male)							
Female	0	0	0	0	–	0	–
Age group (years) (ref = 50–59)							
60–69	0	0	0	0	0	–	0
70–79	–	–	–	0	0	–	0
≥80	–	–	–	–	0	–	–
Marital status (ref = not in a relationship)							
In a relationship	0	0	0	0	0	0	0
Educational attainment (ref = never been to school)							
Secondary school and less	0	0		0	0	0	0
Completed high school/equivalent	0	0	+	0	0	0	0
College/university and above	0	0	+	0	–	0	0
Place of residence (ref = urban)							
Rural	0	–	0	0	0	+	0
Working status (ref = not working)							
Working	+	+	0	+	+	0	0
Income quantiles (ref = lowest)							
Second	0	0	+	0	0	0	0
Middle	0	–	+	0	0	0	0
Fourth	0	–	+	0	–	0	0
Highest	0	–	0	0	0	0	0
Structural social capital (ref: low structural social capital)	+	0	0	0	+	0	+
Trust (ref: low trust)	0	0	0	0	+	0	0
Perceived safety (ref: low perceived safety)	0	0	0	–	+	+	+

Note. + for positive relationship, 0 for nonsignificant relationship, – for negative relationship. The results were based on adjusted analysis, and all the variables in the model were mutually adjusted. All statistics tests were based on weighted estimates. Poststratified individual nonzero probability weights were used in each country. Country-specific cluster and strata were also used to estimate the 95% confidence intervals.

Appendix Table 6: Correlates of Reporting Any Leisure-Time Physical Activities Among Adults Aged 50+ Years

Variables	Pooled	China	Russia	India	Ghana	South Africa	Mexico
Country (ref = China)							
Russia	–						
India	0						
Ghana	0						
South Africa	–						
Mexico	–						
Sex (ref = male)							
Female	–	–	0	–	–	0	–
Age group (years) (ref = 50–59)							
60–69	0	0	0	0	0	0	0
70–79	–	0	0	0	0	0	0
≥80	–	–	0	–	+	0	0
Marital status (ref = not in a relationship)							
In a relationship	0	0	–	0	–	0	0
Educational attainment (ref = never been to school)							
Secondary school and less	+	0		+	+	0	0
Completed high school/equivalent	+	0	0	+	+	0	0
College/university and above	+	+	+	+	0	0	+
Place of residence (ref = urban)							
Rural	–	–	0	–	0	0	0
Working status (ref = not working)							
Working	0	0	0	+	+	0	0
Income quantiles (ref = lowest)							
Second	0	0	0	0	+	0	0
Middle	0	0	0	0	+	+	0
Fourth	+	0	0	0	+	+	0
Highest	+	0	0	0	+	+	0
Structural social capital (ref: low structural social capital)	+	+	+	0	+	+	0
Trust (ref: low trust)	+	0	+	0	+	0	0
Perceived safety (ref: low perceived safety)	0	0	0	–	0	+	0

Note. + for positive relationship, 0 for nonsignificant relationship, – for negative relationship. The results were based on adjusted analysis, and all the variables in the model were mutually adjusted. All statistics tests were based on weighted estimates. Poststratified individual nonzero probability weights were used in each country. Country-specific cluster and strata were also used to estimate the 95% confidence intervals.

Appendix Table 7: Correlates of Meeting WHO Recommendations of Total Physical Activity Among Adults Aged 50+ Years

Variables	Pooled	China	Russia	India	Ghana	South Africa	Mexico
Country (ref = China)							
Russia	+						
India	0						
Ghana	0						
South Africa	–						
Mexico	0						
Sex (ref = male)							
Female	0	0	0	+	–	0	0
Age group (years) (ref = 50–59)							
60–69	–	0	0	–	0	–	0
70–79	–	–	–	–	–	–	0
≥80	–	–	–	–	–	–	–
Marital status (ref = not in a relationship)							
In a relationship	+	0	0	0	0	0	0
Educational attainment (ref = never been to school)							
Secondary school and less	0	0		+	0	–	0
Completed high school/equivalent	0	0	0	0	0	–	0
College/university and above	0	–	0	0	0	0	0
Place of residence (ref = urban)							
Rural	0	0	0	+	+	0	0
Working status (ref = not working)							
Working	+	+	+	+	+	+	+
Income quantiles (ref = lowest)							
Second	0	0	+	0	0	0	0
Middle	0	0	+	0	0	0	+
Fourth	0	–	+	0	–	0	0
Highest	0	–	+	–	–	0	0
Structural social capital (ref: low structural social capital)	+	0	0	+	+	0	+
Trust (ref: low trust)	0	0	0	0	+	0	0
Perceived safety (ref: low perceived safety)	+	0	0	0	+	0	+

Note. + for positive relationship, 0 for nonsignificant relationship, – for negative relationship. The results were based on adjusted analysis, and all the variables in the model were mutually adjusted. All statistics tests were based on weighted estimates. Poststratified individual nonzero probability weights were used in each country. Country-specific cluster and strata were also used to estimate the 95% CIs. CI = confidence intervals; WHO = World Health Organization.

3.5 Concluding summary from this chapter and knowledge gained from this study

To our knowledge, this paper is one of the few international comparative studies on the correlates of domain-specific physical activity with sizeable population representative samples from low- to middle-income countries. Based on the results from Chinese older adults, we observed that 22.7% did not meet the WHO recommended level for total physical activity, and activity was predominantly derived from the work and home domains, while leisure-time physical activity accounted for only 7.5%. It was found that people at older ages, better educated and with higher income levels were less likely to meet the WHO physical activity recommendations among adults aged 50 years and older in China. It also showed that people who were still working were more active compared to those who were not working. However, we did not observe any relationship between social capital domains and physical activity. Some of the findings were very different from what was observed among older adults from HICs. For example, in HICs, people with higher socioeconomic status, such as higher education levels and higher income, are more active; however, in China, it's the opposite. Given the limited nature of the cross-sectional study design, additional research is needed to confirm the longitudinal association between different levels of influences and physical activity in the future.

CHAPTER 4: Social engagement pattern, health behaviours and subjective well-being of older adults: an international perspective using WHO-SAGE survey data

4.1 Preface to the chapter

This chapter presents findings from a peer-reviewed journal paper that examined the associations between social engagement and a range of health-related lifestyle behaviours (i.e., tobacco and alcohol consumption, fruit and vegetable intake, physical activity, sedentary behaviour and sleep duration) and subjective well-being (i.e., depression, self-rated health, and quality of life) among older adults in China, as described in Chapter 1. This extends the community-level variables presented in Chapter 3. Social engagement is an interpersonal-level factor based on the socio-ecological framework, and it is comprised of interpersonal relationships that provide a sense of belonging and fulfilment. This paper added evidence on how social engagement influenced older people's health behaviours and mental well-being, which has not been examined in the LMICs setting. We also assessed how the relationships between social engagement and different outcomes were patterned, which could further help inform policy and public health action.

Data used in the current study were also from WHO SGAE (Wave 1). Dissemination of this research and author contributions to this paper are described below.

4.2 Research dissemination

The research presented in this chapter has been disseminated as follows:

Published peer-review paper

Luo M, Ding D, Bauman A, Negin J, Phongsavan, P. Social engagement pattern, health behaviors and subjective well-being of older adults: an international perspective using WHO-SAGE survey data. *BMC Public Health* 2020; 20(1), 99. https://doi.org/10.1186/s12889-019-7841-7.

Impact factor: 4.135

Citations (based on Google Scholar): 65

Conference/showcase presentations

Luo M, Ding D, Bauman A, Negin J, Phongsavan, P. Social engagement pattern, health behaviors and subjective well-being of older adults: an international perspective using WHO-

SAGE survey data. Sydney School of Public Health 2019 Research Showcase, Sydney, Australia, 2019. [Oral presentation]

4.3 Author attribution statement

I, Mengyun Luo, was responsible for designing the study, conducting the data analysis, interpreting the results, writing drafts of the manuscript, submitting the manuscript, responding to reviewers' comments, and coordinating submission and publication of the manuscript.

My co-authors, P. Phongsavan, D. Ding, and A. Bauman helped to conceive and design the study, interpret the results, draft the manuscript and revise the manuscript critically for important intellectual content.

All authors have read and approved the final version of the manuscript.

4.4 Paper in published format

BMC Public Health

RESEARCH ARTICLE Open Access

Social engagement pattern, health behaviors and subjective well-being of older adults: an international perspective using WHO-SAGE survey data

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Abstract

Background: Social engagement forms the basis of social relationships by providing a sense of belonging, social identity, and fulfillment. Previous research demonstrates that social engagement was associated with positive health behaviors among older adults. However, the results have been different across health-related behaviors, and mostly based on data from high-income countries. For example, studies from the US and UK showed that social engagement was protective against smoking, while others found social engagement encouraged more smoking in many Asian cultures. In this study, we aim to examine the association between social engagement and a range of health-related behaviors and subjective well-being among older adults in six low- to middle-income countries.

Methods: Data from the WHO Study on Global Ageing and Adult Health (SAGE Wave 1) were used. A total of 33,338 individuals aged 50 and older in China, Russia, India, Ghana, South Africa, and Mexico were included. Social engagement, tobacco use, alcohol consumption, fruit and vegetable intake, physical activity, sedentary behavior, sleep duration, depression symptoms, self-rated health status, and quality of life were assessed using established self-reported measures. Multiple logistic regression models were used to examine the relationship between social engagement and nine outcome variables, adjusting for socio-demographic characteristics.

Results: Lower levels of social engagement were positively related to physical inactivity, prolonged sitting time, unhealthy sleep duration, perceived depression, poor self-rated health, and low quality of life. However, the associations between social engagement and tobacco use, excessive drinking, and insufficient fruit and vegetable intake were mixed across countries.

Conclusion: This international study found high social engagement as a potential health-promoting factor in some low- to middle-income countries. Although the impacts of social engagement on tobacco and alcohol use and diet were complicated and culture-specific, interventions at both individual and community levels should encourage healthy lifestyles through positive social engagement.

Keywords: Social engagement, Health behavior, Lifestyle, Subjective well-being, Low- to middle-income countries, Ageing

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Background

WHO defines healthy aging as the process of developing and maintaining the functional ability that enables wellbeing in older age [1]. One important component of functional ability is to build and maintain relationships, as well as contribute to society, which means to engage in both individual- and society-level activities. Social engagement, also called social participation or social involvement, forms the basis of social relationships or participation in a community, and provides a sense of belonging, social identity, and fulfillment. Evidence from cross-sectional studies among older adults suggests positive associations of socially meaningful relations with mental well-being and quality of life, and inverse associations with depressive symptoms [2, 3]. In addition, several longitudinal studies have shown that social engagement was associated with a lower risk of heart disease, cancers and all-cause mortality [4, 5].

Social engagement has been found to be associated with positive health behaviors among older adults [6]. For example, higher levels of social engagement were reported to be positively associated with consuming at least five daily servings of fruit and vegetable and moderate-to-vigorous physical activity [7, 8]. Kawachi and Berkman suggested that engaging in social activities promoted healthy behaviors and discouraged unhealthy ones by enhancing psychosocial processes through the provision of emotional support from trusted social networks, such as family, friends, neighbors and community [9].

However, the results so far have differed across health-related lifestyle behaviors. For example, Hiroyuki et al. showed that those with higher social engagement spent approximately 10–20% less time on leisure time sedentary behaviors [8], while others reported inconsistent findings or no associations [10]. Lindstrom and Samuel et al. showed that social engagement was protective against smoking in the US and UK [7, 11], while Sapag et al. [12] found that networks encouraged more smoking in many Asian cultures, where social norms supported smoking in social settings [13]. Similarly, social engagement was found to facilitate alcohol consumption among older Australians [14]. These findings suggest that the relationships between social engagement and health behaviors may differ by culture and by health behavior. To date, most studies on social engagement and health behavior are based on data from high-income countries (HICs). Therefore, comparison across multiple health behaviors using established measures across multiple low- to middle-income countries (LMICs) may fill an important knowledge gap by shedding light on the role that social engagement plays in health.

In this study, we examined the association between social engagement and a range of health-related lifestyle behaviors (i.e., tobacco and alcohol consumption, fruit and vegetable intake, physical activity, sedentary behavior and sleep duration) and subjective well-being (i.e., depression, self-rated health, and quality of life), among older adults in six LMICs. Having a better understanding of how these relationships are patterned could help inform policy and public health actions within a LMIC context.

Methods

Study design

This study used nationally representative data from the World Health Organization's Study on Global Ageing and Adult Health (WHO SAGE) Wave 1, which was carried out in six LMICs (China, Russia, India, Ghana, South Africa and Mexico) from 2007 to 2010. Although SAGE is a longitudinal study and a baseline survey (SAGE Wave 0) was created during 2002–2004, only Wave 1 data were used in this study because China and South Africa did not follow up Wave 0 respondents for Wave 1. China, Russia, India, Ghana and South Africa all used stratified multi-stage clustered sampling strategy, and Mexico included extra supplementary and replacement samples in Wave 1 to account for losses to follow up since Wave 0 [15]. SAGE was approved by the Ethics Review Committee of the World Health Organization.

Participants

WHO SAGE (Wave 1) focused on older adults aged 50+ years old (n = 13,367 in China, 3938 in Russia, 7150 in India, 4724 in Ghana, 3840 in South Africa, 2315 in Mexico). Participants with proxy answers, cognitive limitations, implausible answers in physical activity, invalid answers in social engagement, and missing or zero value for post-stratified individual probability weights were removed from the analysis. The final sample sizes included in this analysis were: 12,837 for China, 3682 for Russia, 6551 for India, 4273 for Ghana, 3609 for South Africa, and 2193 for Mexico.

Exposure variable

The 9 social engagement questions asked of participants in all six countries are listed in Appendix 1. These questions asked about the frequency of several social activities in the previous 12 months, which had been used before and reported elsewhere [16]. The response options were rated on a 5-point Likert scale ranging from 1 (never) to 5 (daily). Scores from these questions were summed and divided by 9 to derive a mean social engagement score for India, Ghana, South Africa and Mexico. Due to the low prevalence of religious practices in China and Russia, only

8 items (excluding the religious service question) were used for these two countries. For China and Russia, the summed score from the 8 questions was divided by 8, the total number of questions used in these two countries. Social engagement was used as a continuous variable in this study, with higher scores representing higher levels of social engagement. The Cronbach's alpha internal consistency coefficients for these groups of social engagement items ranged from 0.63 to 0.81 across six countries. (See more details in Appendix 1).

Outcome variables

Tobacco and alcohol use and diet

"Tobacco use" was defined as currently smoking tobacco or using any tobacco products. Harmful drinking was defined as consuming 14 or more standard drinks per week for both men and women. Information on fruit and vegetable intake was based on the number of servings on a typical day. Less than five servings per day were considered insufficient [17].

Activity-related behaviors

Physical inactivity was measured by the Global Physical Activity Questionnaire (GPAQ), which collected information about physical activity in three domains (activity at work (paid/unpaid), travel to and from places, recreational activities) and sedentary behavior [18]. This questionnaire is the standard physical activity measure for population surveillance in the WHO STEPS program [19].

Sedentary behavior was assessed using a single item derived from GPAQ about the time usually spent sitting or reclining on a typical day. This included sitting at a desk, sitting with friends, travelling in car, bus, train, reading, playing cards or watching television. More than 7 hours/day was regarded as prolonged sitting time [20].

Sleep duration was self-reported by the participants, which was comparable with single-item instruments used by previous studies. Either less than 7 hours/day or more than 9 hours/day was considered unhealthy [21, 22]. As Mexico did not collect any information about sleep duration, this outcome variable was not considered for Mexico.

Subjective well-being

Perceived depression symptom was assessed by one question, "Overall in the last 30 days, how much of a problem did you have with feeling sad, low or depressed?" [23] The answer ranged from 1 (none) to 5 (extreme). Those who responded with "none" were classified as not having perceived depression, while all other answers were regarded as having perceived depression.

Self-rated health status was measured by one question, "In general, how would you rate your health today?" The answer ranged from 1 (very good) to 5 (very bad). Those who answered 4 or 5 were classified as "poor self-rated health".

Quality of life was assessed using EUROHIS-QOL 8-item index, a shortened version of the World Health Organization Quality of Life Instrument-Abbreviated Version (WHOQOL-BREF) and had acceptable reliability and validity [24]. Response to each question was based on a 5-point likert scale. A binary categorization of the EUROHIS-QOL was created as low quality of life (range 0–3) and high quality of life (range 3.01–5); this was based on mean score dichotomization for the total score (Cronbach's $\alpha > 0.8$ for all countries).

Covariates

Sociodemographic information including sex, age, marital status, education level, place of residence (urban/rural), country-specific income quintiles and working status were treated as covariates in this study. Age was categorized as 50–59, 60–69, 70–79, and 80 years and older.

Statistical analysis

To ensure the representativeness of the sample and adjusting for the complex survey sampling design, post-stratified individual non-zero probability weights, and country-specific strata and clustering were used for all statistical analysis in each country. Social engagement scores were presented as means and standard errors, while the sociodemographic information was reported as weighted percentages. We used forced entry logistic regression models to examine the association between social engagement and each outcome variable separately in each country. Multiple logistic regression models were used following univariate models to examine the association between social engagement and the outcome variables after controlling for sex, age, marital status, education level, place of residence, income quintiles, and working status. All analyses were performed with complex samples analysis using SPSS Version 24.0. The significant level was set at 0.05.

Results

Weighted sample characteristics are presented in Table 1. A total of 33,145 individuals in the six countries were included in this analysis. China had the largest sample ($n = 12{,}837$), while Mexico had the smallest ($n = 2193$). The distributions of the sociodemographic characteristics varied across six countries. Over half of the sample were females except in India and Ghana. All six countries had the highest proportion of participants in the age group 50–59 years. The majority were currently married or cohabiting in all six

Table 1 Weighted sample characteristics across six countries

Socio-demographics	China (*n* = 12,837) %	Russia (*n* = 3682) %	India (*n* = 6551) %	Ghana (*n* = 4273) %	South Africa (*n* = 3609) %	Mexico (*N* = 2193) %
Sex						
Male	49.8	39.1	51.0	52.3	43.9	46.7
Female	50.2	60.9	49.0	47.7	56.1	53.3
Age group						
50–59 years	45.2	45.2	48.6	39.8	49.6	49.1
60–69 years	32.0	24.7	30.9	27.5	31.0	25.7
70–79 years	18.5	21.6	16.0	23.1	13.9	17.9
≥ 80 years	4.3	8.5	4.5	9.6	5.5	7.3
Marital status						
Never married/ Separated/ Divorced/ Widowed	14.6	41.6	23.1	40.8	44.0	27.1
Currently married/ Cohabiting	85.4	58.4	76.9	59.2	56.0	72.9
Education level						
Never been to school	22.3	0.7	51.2	54.0	23.6	17.3
Secondary school and lower	60.4	26.9	35.0	25.3	61.9	72.2
High school (or equivalent) completed	12.8	54.2	8.6	17.2	8.7	2.4
College and above	4.6	18.3	5.1	3.6	5.8	8.1
Place of residence						
Urban	47.7	72.7	28.9	41.1	65.2	78.4
Rural	52.3	27.3	71.1	58.9	34.8	21.6
Income quintiles (within country)						
Lowest	16.1	16.1	18.2	18.3	20.0	15.3
Second	18.0	19.6	19.5	19.1	20.0	25.0
Middle	20.3	19.0	18.8	20.6	18.8	16.4
Fourth	23.6	20.8	19.6	20.6	20.0	16.6
Highest	22.0	24.4	23.9	21.4	21.2	26.7
Working status						
Not working	56.4	59.8	56.9	30.9	69.7	62.6
Still working	43.6	40.2	43.1	69.1	30.3	37.4

Note: Weighted estimates

countries. India and Ghana had the lowest education level, with over 50% reporting no schooling. In contrast, half of the people in Russia had completed high school or equivalent and around one fifth had a college degree or above. Most of the samples in Russia, South Africa and Mexico lived in urban areas, while more than half of the participants lived in rural areas in India, Ghana and China. Ghana had the highest proportion of people who were currently working, while South Africa had the lowest proportion.

Social engagement scores

Table 2 shows the mean score of social engagement across six countries stratified by sociodemographic variables. Ghana had the highest total mean score, while Mexico had the lowest. Males, those who are currently married or cohabiting, those living in rural areas, those younger and better educated were more likely to have higher social engagement scores. Those with higher income levels also reported higher social engagement, except for Ghana, where the middle-income quintile group had the highest level of social engagement, and South Africa, where the second-income quintile group had the highest mean score. People who were still working had a higher mean score than those who were not working in all six countries.

Relationship between social engagement and tobacco and alcohol use and diet

The logistic regression results are presented in Appendix 2 (unadjusted model) and Table 3 (adjusted model). Appendix 2 presents the univariate logistic

Table 2 Mean social engagement score by socio-demographic characteristics across six countries, Mean (Standard Error)

	China	Russia	India	Ghana	South Africa	Mexico
Total	1.76 (0.01)	1.77 (0.02)	1.97 (0.02)	2.68 (0.02)	2.37 (0.02)	1.68 (0.04)
Sex						
Male	1.78 (0.01)	1.79 (0.04)	2.16 (0.02)	2.78 (0.03)	2.41 (0.03)	1.72 (0.07)
Female	1.73 (0.02)	1.75 (0.02)	1.76 (0.02)	2.56 (0.02)	2.34 (0.03)	1.64 (0.04)
Age group						
50–59	1.81 (0.01)	1.92 (0.04)	2.05 (0.02)	2.81 (0.03)	2.44 (0.03)	1.67 (0.08)
60–69	1.76 (0.01)	1.75 (0.02)	1.94 (0.03)	2.69 (0.03)	2.36 (0.03)	1.73 (0.05)
70–79	1.67 (0.02)	1.62 (0.04)	1.85 (0.02)	2.55 (0.03)	2.28 (0.04)	1.66 (0.04)
≥ 80	1.52 (0.03)	1.39 (0.03)	1.67 (0.04)	2.38 (0.06)	2.03 (0.07)	1.59 (0.05)
Marital status						
Never married/ Separated/ Divorced/ Widowed	1.67 (0.02)	1.69 (0.03)	1.73 (0.03)	2.53 (0.03)	2.32 (0.03)	1.60 (0.04)
Currently married/ Cohabiting	1.77 (0.01)	1.82 (0.02)	2.04 (0.02)	2.78 (0.02)	2.41 (0.03)	1.71 (0.06)
Education level						
Never been to school	1.67 (0.02)	1.35 (0.05)	1.84 (0.02)	2.58 (0.03)	2.32 (0.04)	1.57 (0.05)
Secondary school and lower	1.78 (0.01)	1.61 (0.05)	2.03 (0.03)	2.82 (0.04)	2.40 (0.02)	1.66 (0.05)
High school (or equivalent) completed	1.80 (0.03)	1.78 (0.03)	2.23 (0.04)	2.74 (0.04)	2.31 (0.09)	1.81 (0.18)
College and above	1.78 (0.05)	2.00 (0.06)	2.41 (0.07)	2.88 (0.06)	2.41 (0.13)	2.03 (0.13)
Place of residence						
Urban	1.69 (0.02)	1.77 (0.02)	1.91 (0.05)	2.55 (0.03)	2.35 (0.03)	1.68 (0.05)
Rural	1.81 (0.01)	1.76 (0.04)	1.99 (0.02)	2.77 (0.03)	2.40 (0.03)	1.68 (0.11)
Income quintiles						
Lowest	1.63 (0.02)	1.61 (0.04)	1.83 (0.03)	2.52 (0.04)	2.35 (0.05)	1.66 (0.05)
Second	1.74 (0.01)	1.73 (0.04)	1.89 (0.02)	2.68 (0.04)	2.40 (0.04)	1.43 (0.05)
Middle	1.78 (0.02)	1.69 (0.05)	1.96 (0.03)	2.78 (0.04)	2.39 (0.04)	1.79 (0.11)
Fourth	1.79 (0.02)	1.85 (0.03)	2.03 (0.03)	2.75 (0.03)	2.34 (0.05)	1.61 (0.04)
Highest	1.80 (0.03)	1.90 (0.06)	2.09 (0.03)	2.64 (0.04)	2.37 (0.05)	1.89 (0.08)
Working status						
Not working	1.68 (0.02)	1.63 (0.03)	1.80 (0.02)	2.26 (0.03)	2.26 (0.02)	1.65 (0.04)
Still working	1.86 (0.01)	1.98 (0.04)	2.19 (0.02)	2.86 (0.02)	2.62 (0.03)	1.73 (0.09)

Mean social engagement score was calculated based on the number of the items used. The summed score was divided by 8 for China and Russia, while it was divided by 9 for India, Ghana, South Africa and Mexico
Note: Weighted estimates

regression results examining the relationship between social engagement and six unhealthy lifestyle behaviors as well as subjective well-being across six countries. The results changed slightly after adjusting for sex, age group, marital status, education level, place of residence, income quintiles and working status (see Table 3). In China, higher level of social engagement was associated with higher risk of smoking, while in Ghana and South Africa, an inverse relationship was observed. For India, the relationship was no longer significant after controlling for the sociodemographic characteristics.

Social engagement was not associated with harmful drinking in any of these six countries. And only in Ghana, high social engagement had a positive relationship with low fruit and vegetable intake, while an inverse relationship was found in China, Russia, and India.

Relationship between social engagement and activity-related behaviors

Social engagement was found to have an inverse relationship with physical inactivity across all six countries. It was also found that social engagement was inversely associated with prolonged sitting time in Ghana and South Africa, while no significant relationship in China, Russia, India, and Mexico. Social engagement was inversely associated with the risk of unhealthy sleep duration in China and Ghana only.

Table 3 Association between social engagement and unhealthy lifestyle behaviors as well as subjective well-being across six countries (adjusted logistic regression models)

	China OR (95% CI)	Russia OR (95% CI)	India OR (95% CI)	Ghana OR (95% CI)	South Africa OR (95% CI)	Mexico OR (95% CI)
Tobacco and alcohol use and diet						
Tobacco use (Ref: not current smokers)	1.19 (1.02–1.40)	0.79 (0.52–1.20)	0.96 (0.82–1.12)	0.81 (0.66–0.98)	0.58 (0.45–0.74)	1.20 (0.69–2.09)
Harmful drinking (Ref: < 14 standard drinks/week)	1.21 (0.94–1.55)	0.98 (0.44–2.21)	1.76 (0.90–3.43)	1.10 (0.86–1.42)	0.73 (0.40–1.33)	1.00 (0.37–2.73)
Low fruit and vegetable intake (Ref: ≥ 5 serves/day)	0.48 (0.35–0.65)	0.45 (0.30–0.68)	0.56 (0.45–0.70)	1.30 (1.13–1.51)	0.88 (0.69–1.12)	0.82 (0.48–1.42)
Activity-related behaviors						
Physical inactivity (Ref: ≥ 600 MET-minutes/week)	0.64 (0.47–0.86)	0.31 (0.19–0.50)	0.59 (0.49–0.72)	0.38 (0.32–0.45)	0.77 (0.60–0.97)	0.42 (0.29–0.60)
Prolonged sitting time (Ref: ≤ 7 hours/day)	0.87 (0.68–1.12)	1.40 (0.90–2.18)	0.99 (0.81–1.22)	0.70 (0.58–0.84)	0.40 (0.24–0.65)	0.58 (0.22–1.57)
Unhealthy sleep time (Ref: 7–9 hours/day)	0.73 (0.63–0.85)	0.86 (0.66–1.11)	0.84 (0.70–1.01)	0.74 (0.64–0.84)	1.15 (0.94–1.40)	–
Subjective well-being						
Perceived depression (Ref: not perceived depression)	0.80 (0.65–0.99)	0.53 (0.39–0.73)	0.88 (0.74–1.05)	1.13 (0.97–1.31)	1.05 (0.83–1.33)	0.61 (0.38–0.99)
Poor self-rated health (Ref: moderate and good self-rated health)	0.72 (0.58–0.89)	0.52 (0.32–0.86)	0.76 (0.63–0.91)	0.53 (0.45–0.63)	0.67 (0.49–0.93)	0.36 (0.15–0.83)
Low quality of life (Ref: high quality of life)	0.54 (0.44–0.67)	0.35 (0.22–0.56)	0.54 (0.44–0.66)	0.57 (0.49–0.66)	0.68 (0.52–0.89)	0.19 (0.07–0.50)

Adjusted for sex, age group, marital status, education level, place of residence, and income quintiles
Note: Weighted estimates

Relationship between social engagement and subjective well-being

There was strong evidence for an association between high levels of social engagement and poor self-rated health and low quality of life in all six countries, as well as perceived depression (not significant in India, Ghana and South Africa) even after adjusting for the other sociodemographic variables.

Discussion

This study is among the first to compare the relationships between social engagement and multiple lifestyle behaviors as well as subjective well-being in LMICs using nationally representative samples. Our study found consistent relationships between social engagement and activity-related behaviors as well as subjective well-being, while the relationships with tobacco and alcohol use and diet vary considerably across countries.

Tobacco, alcohol use and diet

Our study showed that, in China, higher levels of social engagement were associated with higher risk of smoking, while an inverse association was found in Ghana and South Africa. The results from China are contrary to those found in other studies. Results from the longitudinal British Household Panel Survey (BHPS), showed that active social participation was positively associated with smoking cessation [11]. In a US Study, Samuel et al. also reported that emotional social support and neighborhood social cohesion were generally linked to lower smoking rates [7]. However, in the same paper, the authors pointed out that social support and social cohesion may be associated with higher smoking rate in groups with high rates of smoking, which is in line with previous research [25–27] and the current study. Past research has shown that the greater the social network size, the more likely a person is to smoke, especially in Asian cultures where collectivism is valued [28]. China consumes about 40% of the world's cigarettes, and the prevalence of smoking remained high in men (54.0% prevalence for current-smoking) [29]. In many Asian countries [30], smoking with others is seen as a way to foster relationships between family members, peers, and business associates [31]. Tobacco can also be exchanged as "social currency" for social opportunities and benefits, which permeates every aspect of family life and wider social interactions [32, 33]. As there were no widespread anti-smoking public health program implemented in these countries, people view smoking in social activities as acceptable or even desirable, rather than a behavior to be reprimanded or punished [33]. This might explain

the positive association between social engagement and smoking in China.

Social engagement was not found to be associated with alcohol consumption across the six LMICs, which is different from that reported in some HICs, where highest levels of alcohol consumption were noted [34]. Research in the United States [35] and Australia [14] found that social drinking was part of the social fabric among older peoples and retirees. Many participants in HICs emphasized the social nature of their alcohol use, as something to be enjoyed with others. During social activities, people may be less aware of how much they were drinking, and thus consume more than they would in non-social situations [14].

In our study, low levels of social engagement were associated with low fruit and vegetable consumption in China, Russia and India, but an inverse association was found in Ghana. This is a novel finding to our knowledge. A healthy diet is important to health and well-being at all stages in life; however, the determinants of dietary health change with age. Older adults are prone to developing an unhealthy dietary pattern for many reasons, including reduced mobility and/or fewer financial resources to spend on food [6, 7]. Moreover, socially isolated older adults are at a greater risk of poor dietary behavior because of the lack of social support [36]. Jones et al. found that getting out of the house and being active were effective in stimulating appetite [37], and eating with others has been shown to increase food intake by 60% in healthy older adults aged 65 and over [38]. Holmes also suggested that those who usually eat alone at home may substitute a cooked or hot meal with convenient food that can be easily accessed and prepared, such as sandwiches [38]. There was no evidence in the literature that explained why low social engagement was inversely associated with low fruit and vegetable intake in Ghana. One possible reason might be that when eating out, people usually have a high intake of meat products and beverage instead of fruit and vegetable [39, 40]. To fully understand this question, more culturally specific information about social eating behavior and the cultural context of food in Ghana is required.

Activity-related behaviors

Our study showed that social engagement was inversely related to physical inactivity, prolonged sitting time and unhealthy sleep duration. These results are similar across the six countries and consistent with previous research. In the study by Samuel et al. [7], social support and neighborhood social cohesion were associated with achieving the recommended level of physical activity. Hiroyuki and colleagues [8] had similar findings among a Japanese sample, where men and women reporting higher social participation were less likely to be physically inactive. The possible mechanism could be that social engagement provides older people with more opportunities and social reasons to go outside to join physical activities [8].

According to ecological models [41], the physical and social environment in which people live are important determinants of sedentary behavior. In our study, we found that social engagement was inversely associated with prolonged sitting time in Ghana and South Africa, while no relationship was found in China, Russia, India and Mexico. Hiroyuki's study [8] showed that higher levels of social participation was associated with less sedentary time, such as television watching, sitting around and listening or talking while sitting. But Van Holle et al. [10] found no evidence for the association between social isolation and talking with neighbors, with sedentary time. One possible explanation for the inconsistent results across countries might be the unmeasured domains of sedentary behaviors, for example mentally-active sedentary behavior (e.g. reading books). It is important to distinguish between different types of sedentary behaviors instead of considering them as one entity because social participation pattern may vary across domains of sedentary activities. Additionally, these results may also be partly influenced by age and working status, as well as whether the sitting time was self-reported or objectively measured, which requires further study.

Our study showed that people with higher levels of social engagement were less likely to be outside the optimal sleep range. This might be because a lack of social contacts in older people's lives may result in the flattening of their circadian rhythm and reduced needs for sleep in the evening [42]. Thida et al. [43] found that having lower neighborhood social capital was associated with insufficient sleep among Japanese adults, particularly in the men. Tarja and colleagues [44] found that people with high levels of social support were more likely to have adequate duration of sleep. Such findings from observational studies have been confirmed by a cluster randomized trial by Joachim and colleagues among nursing home residents, where social activity sessions, including parlor games and group discussions, improved subjective sleep quality of the participants at both clinical and statistical significance levels [45].

Subjective well-being

In our study, higher level of social engagement was consistently associated with less perceived depression, better self-rated health and higher quality of life. A Japanese longitudinal study showed that social engagement improves older people's mental health, including

depressive symptoms and psychological distress. Results from the 4th National Household Health Survey [46] also found that social contacts were positively associated with quality of life among Chinese older adults in urban areas. Snorri [47] observed that social network size and contact frequency were positively and independently related to future subjective well-being in English adults aged 50 and older. Findings from the National Social Life, Health, and Aging Project [48] among older Americans confirmed that networks with a wider range of social ties were related to better well-being, independent of demographic and health characteristics.

Social engagement could increase people's social networks, which leads to attachment, esteem, social approval, belongingness, social identity and increasing access to social support [49]. In particular, social network could provide access to functional support and assistance from family members, neighbors and friends. This type of support is important and have been shown to be related to older adults' improved sense of control, enhanced quality of life and well-being [47].

Overall, this international study found high level of social engagement as a consistent correlate of health in some LMICs. Regarding subjective well-being, social engagement appears to be protective of perceived depression, poor self-rated health and low quality of life. However, for lifestyle risk behaviors, the associations varied by the outcome and the country, possibly as a result of the different ways people socialize. It is also important to note that as a cross-sectional study, the relationships between social engagement, lifestyle behaviors and subjective well-being could be bidirectional, that is either social engagement promotes healthier behaviors and mental health or healthy behaviors and subjective well-being lead to higher levels of social engagement. Additionally, across countries, social engagement was associated with almost all outcomes in Ghana and China, but less so in other countries. This suggests that the relationship between social engagement and lifestyle behavior is complicated and culture-specific. Future research should focus on examining various cultural elements when measuring both social engagement and health behaviors.

Strengths and limitations

Strengths of this study include comparable data from six LMICs with nationally representative samples. This paper is among the first to examine a broad range of lifestyle behaviors and subjective well-being, in relation to social engagement with a large sample size across LMICs. However, some limitations should be noted. First, a cross-sectional design limits causal inferences. Second, self-reported measures are subject to reporting bias. Third, some unknown confounders, such as BMI and existing chronic disease, were not collected and therefore could not be adjusted for. Finally, it is arguable that there might be differences in the interpretation of social engagement questions across countries because of the inherent differences in cultural and social norms. Thus, these societal aspects are worthy of further exploration to help explain our findings.

Conclusion

In conclusion, our study extends prior research by exploring the associations between social engagement and multiple lifestyle behaviors as well as subjective well-being in LMICs. Although the associations were mixed across countries, findings are generally consistent in supporting the notion that higher levels of social engagement may promote activity-related behaviors and subjective well-being. Our findings highlight the need for policy makers to consider how social engagement can be incorporated in preventive health, with a potential range of benefits to the health of older populations. Interventions at individual and community levels should encourage and facilitate older adults to become more socially engaged within specific cultural context.

Appendix

Table 4 Social engagement items and Cronbach's α coefficient for each country

How often in the last 12 months have you …						
Q1 … attended any public meeting in which there was discussion of local or school affairs?						
Q2 … met personally with someone you consider to be a community leader?						
Q3 … attended any group, club, society, union or organizational meeting?						
Q4 … worked with other people in your neighbourhood to fix or improve something?						
Q5 … had friends over to your home?						
Q6 … been in the home of someone who lives in a different neighbourhood than you do or had them in your home?						
Q7 … socialized with co-workers outside of work?						
Q8 … attended religious services (not including weddings and funerals)?						
Q9 … gotten out of the house/your dwelling to attend social meetings, activities, programs or events or to visit friends or relatives?						
	China*	Russia*	India	Ghana	South Africa	Mexico
Cronbach's α	0.63	0.73	0.75	0.81	0.75	0.72

* Cronbach's alpha coefficient based on 8 items (excluding Q8)

Table 5 Association between social engagement and unhealthy lifestyle behaviors as well as subjective well-being across six countries (unadjusted logistic regression models)

	China OR (95% CI)	Russia OR (95% CI)	India OR (95% CI)	Ghana OR (95% CI)	South Africa OR (95% CI)	Mexico OR (95% CI)
Tobacco and alcohol use and diet						
Tobacco use (Ref: not current smokers)	1.45 (1.25–1.69)	1.20 (0.84–1.72)	1.36 (1.15–1.62)	0.81 (0.72–0.93)	0.63 (0.50–0.80)	1.26 (0.64–2.48)
Harmful drinking (Ref: < 14 standard drinks/week)	1.75 (1.43–2.15)	1.03 (0.56–1.92)	2.58 (1.55–4.29)	1.53 (1.20–1.97)	0.80 (0.45–1.43)	0.43 (0.07–2.56)
Low fruit and vegetable intake (Ref: ≥ 5 serves/day)	0.41 (0.30–0.55)	0.49 (0.36–0.66)	0.42 (0.35–0.50)	1.22 (1.08–1.39)	0.84 (0.66–1.06)	0.75 (0.35–1.59)
Activity-related behaviors						
Physical inactivity (Ref: ≥ 600 MET-minutes/week)	0.55 (0.41–0.72)	0.15 (0.09–0.27)	0.43 (0.36–0.51)	0.32 (0.28–0.37)	0.67 (0.53–0.84)	0.44 (0.27–0.71)
Prolonged sitting time (Ref: ≤ 7 hours/day)	0.79 (0.63–0.99)	1.52 (0.94–2.46)	0.95 (0.79–1.14)	0.79 (0.67–0.92)	0.42 (0.23–0.75)	0.64 (0.29–1.39)
Unhealthy sleep time (Ref: 7–9 hours/day)	0.65 (0.56–0.76)	0.65 (0.48–0.88)	0.89 (0.73–1.09)	0.73 (0.64–0.83)	1.00 (0.82–1.22)	–
Subjective well-being						
Perceived depression (Ref: not perceived depression)	0.72 (0.59–0.89)	0.36 (0.26–0.51)	0.68 (0.59–0.79)	0.98 (0.87–1.12)	1.04 (0.84–1.30)	0.58 (0.38–0.88)
Poor self-rated health (Ref: moderate and good self-rated health)	0.64 (0.53–0.76)	0.22 (0.13–0.37)	0.52 (0.43–0.62)	0.41 (0.35–0.48)	0.64 (0.49–0.85)	0.38 (0.16–0.91)
Low quality of life (Ref: high quality of life)	0.48 (0.39–0.59)	0.22 (0.14–0.35)	0.36 (0.30–0.45)	0.47 (0.41–0.54)	0.68 (0.54–0.86)	0.27 (0.11–0.69)

Note: Weighted estimates

Abbreviations

GPAQ: Global Physical Activity Questionnaire; HICs: High Income Countries; LMICs: Low- to Middle-Income Countries; SAGE: Study on Global Ageing and Adult Health; WHO: World Health Organization; WHOQOL-BREF: World Health Organization Quality of Life Instrument-Abbreviated Version

Acknowledgements

We thank all team members and participants for the World Health Organization's Study on Global Ageing and Adult Health (Wave 1). We thank Dr. Leah Shepherd for providing statistical advice in the re-analysis of the data.

Authors' contributions

This study was conceived and designed by ML, PP, DD, and AB. ML conducted the data analysis, with statistical advice and contributions from PP, DD and AB on the interpretation of results. ML wrote the draft manuscript with writing contributions from PP, DD, AB and JN. All authors approved the final version.

Funding

ML is supported by the Fong Family Bursary. DD is funded by a Future Leader Fellowship (#101234) from the National Heart Foundation of Australia. The Fong Family Bursary and National Heart Foundation of Australia had no role in the study design, collection, analysis or interpretation of the data, writing the manuscript, or the decision to submit the paper for publication.

Availability of data and materials

The datasets used and analyzed during this study are publicly available on the official website, https://www.who.int/healthinfo/sage/cohorts/en/.

Ethics approval and consent to participate

The protocol of the WHO SAGE was approved by the Ethics Review Committee of the World Health Organization. Signed consent forms were obtained from the participants before data collection.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

Received: 16 July 2019 Accepted: 24 October 2019
Published online: 23 January 2020

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Publisher's Note

4.5 Concluding summary from this chapter and knowledge gained from this study

This study is among the first to explore patterns in the relationships between social engagement and unhealthy lifestyle behaviours. This study also examined subjective well-being and used nationally representative samples from LMICs. After adjusting for a wide range of potential confounders, such as age, gender and educational level, social engagement was found to be negatively associated with some of the unhealthy lifestyle behaviours, including insufficient fruit and vegetable consumption, physical inactivity, prolonged sitting time and unhealthy sleep duration. There was also strong evidence for an inverse relationship between social engagement and worse subjective well-being (including perceived depression, poor self-rated health and low reported quality of life). However, we also observed a potentially harmful effect of high social engagement levels on smoking behaviours. China is the world's largest consumer of tobacco and tobacco permeated every aspect of people's families and social life, more frequent interpersonal interactions could foster a more favourable environment for social smoking. Our findings could suggest ways that social engagement might be considered in preventive health, with a range of benefits but also potential drawbacks for the health of older people in China.

CHAPTER 5: Retirement transition, smoking and drinking behaviours in older Chinese adults: Analysis from the CHARLS study

5.1 Preface to the chapter

This chapter presents findings from a peer-review paper that investigated the longitudinal effects of the retirement transition on risky lifestyle behaviours (including smoking and excessive alcohol consumption) among people aged over 45 years in mainland China, as described in Chapter 1. Retirement is an important personal life transition, which influences older people's behaviours in a complex system. According to the socio-ecological framework, retirement may influence behaviours at all four levels, including individual identity loss (individual level), family relationship change (interpersonal level), workplace environment relief (community level), and the cultural context (societal level). This study reflected the importance of researchers using system thinking to explore the complexity of influences on people's health.

In the current study, we used the data from CHARLS, a nationally representative cohort study consisting of older adults in China. Four waves of data from 2011 to 2018 were used to investigate the longitudinal associations. Dissemination of this research and author contributions to this paper are described below.

5.2 Research dissemination

The research presented in this chapter has been submitted to Preventive Medicine Reports and it is under review at the time of thesis submission.

Peer-review paper (under review)

Luo M, Bauman A, Phongsavan P, Ding D. Retirement transition, smoking and drinking behaviors in older Chinese adults: Analysis from the CHARLS study. *Preventive Medicine Reports*

5.3 Author attribution statement

I, Mengyun Luo, was responsible for conceptualizing the study, confirming the analytic methodology, conducting the data analysis, interpreting the results, writing drafts of the

manuscript, submitting the manuscript, responding to reviewers' comments, and coordinating submission and publication of the manuscript.

My co-authors, D. Ding, A. Bauman and P. Phongsavan helped to conceive and design the study, provided statistical advice and helped to interpret data. All my co-authors helped to revise the manuscript critically for important intellectual content.

All authors have read and approved the final version of the manuscript.

5.4 Paper in published format

Abstract

Smoking and drinking are important public problems and a substantial part of work culture in mainland China. However, little is known about the effect of retirement on these behaviors. Thus, this study examined the relationships between retirement transition, smoking and excessive drinking among older Chinese adults.

Repeated longitudinal data from a nationally representative sample of Chinese adults were collected in 2011, 2013, 2015 and 2018. Respondents completed a structured questionnaire regarding work status and health behaviors. Modified mixed-effects Poisson regression models were used to explore the associations, with additional analysis stratified by gender.

Of the 10,378 participants included, 62.6% and 20.1% of men reported current smoking and excessive drinking at study entry; compared to 4.4% and 1.5% of women, respectively. There was no significant association between retirement and smoking in men, women or the combined sample. We found a dose-response relationship between time in retirement and excessive drinking in the adjusted model where those who retired >= 2 years ago had a 30% lower risk of excessive drinking (risk ratio (RR)=0.70, 95% confidence interval (CI)=0.56-0.86), and those who retired < 2 years ago had a 16% lower risk of excessive drinking (RR=0.84, 95%CI=0.73-0.97), compared with those who remained working. This pattern remained when analyzed separately for men and women, although not all results reached statistical significance.

Chinese older adults are more likely to reduce drinking following retirement. Such evidence supports the positive framing of retirement in public discourse and the need for workplace interventions to address excessive drinking in China.

Keywords

Retirement transition; Low- to middle-income country; Tobacco smoking; Excessive drinking; Longitudinal research

Introduction

Smoking and excessive drinking are major health issues in China, ranking the 1st and 8th contributing risk factors to disability-adjusted life years (DALYs) lost.[1] In China, both risk behaviors are much more common in men than in women, with 50.5% of men and 2.1% of women estimated to be current smokers,[2] and 56% of men and 15% of women current drinkers. Among those who drink, 57% of the male drinkers and 27% of the female drinkers reported excessive drinking.[3]

Retirement transition is a universal experience and is widely considered as a major life transition. Previous research suggests that retirement may have profound effects on lifestyle and health due to changes in time availability, daily routines, work-related stress, identity/purpose, financial resources and social interactions.[4] Findings from previous studies suggest that the effects of retirement on health differed by the specific outcomes examined and the study population. The existing evidence on the effects of retirement on smoking and drinking behaviors is mixed, and is mostly based on Western data. For example, Kim, Motegi, and Ding found that retirees were less likely to be heavy smokers or drinkers compared to their employed counterparts among the older population in Korea, Japan, and Australia while others found either a positive association between retirement and smoking/alcohol intake or no significant association at all.[4-8]

To date, evidence on retirement and smoking/drinking behaviors in China, a rapidly aging country with an early mandatory retirement age (~60 for men, ~55 for women), is still limited. In China, both smoking and drinking behaviors are deeply rooted in the social environment. They are considered as such important social and cultural practices that offering cigarettes and alcoholic drinks is used to break down social barriers with strangers, foster friendships with co-workers and build bonding with business partners.[9] Meanwhile, the tobacco and alcohol industries take advantage of such cultural norms by promoting their products as ‘facilitators’ or

49 'proof' for friendships, social bonds and business partnerships.[10] A recent study found that
50 around 97% of current smokers reported sharing and 90% reported gifting cigarettes in China.[11]
51 Due to the social and cultural context of smoking and drinking, one may hypothesize that
52 retirement may result in changes in both behaviors due to different social prompts, pressure, and
53 reinforcement for smoking and drinking. Evidence from China, an aging country with an early
54 mandatory retirement age (~60 for men, ~55 for women), different social environments and
55 gender-specific lifestyle risk profiles, could offer unique insights. This study aims to examine the
56 relationship of retirement transitions with smoking/ excessive drinking in older Chinese men and
57 women.
58
59 **Methods**
60 **Participants and settings**
61 The China Health and Retirement Longitudinal Study (CHARLS) is a nationally representative
62 longitudinal survey of Chinese adults aged 45 and up.[12] The CHARLS 2011 baseline survey was
63 conducted in 28 provinces across the country, using a multistage, stratified, probability
64 proportionate-to-size sampling strategy. Repeated data were then collected in 2013, 2015 and
65 2018. Ethical approval was obtained from the Biomedical Ethics Review Committee of Peking
66 University, and all participants provided written informed consent.
67 Data analysis of the current study was restricted to those who provided complete data for
68 employment status in at least two waves and who reported 'working' upon entering the study (in
69 2011, 2013 or 2015), so that retirement transition status could be ascertained. The final study
70 sample includes 33,570 observations from 10,378 participants.
71 **Measurement**

Based on reported working status and retirement time, we classified employment status into "working", "retired for < 2 years", "retired for 2-4 years" and "retired for 4-7 years" (7 years was the maximum time since retirement between 2011 and 2018). Due to the small sample size of participants who retired for 4-7 years, we decided to combine the last two groups together to be "retired for >= 2 years".

Current smoking was defined as having ever smoked 100+ cigarettes (lifetime), and currently smoking. Participants reported the frequency of consuming each type of alcohol (beer, wine/rice wine, liquor) in a month and the volume consumed on one occasion. The total amount of pure alcohol consumed (in grams) was estimated using the formula "volume(ml) ×concentration(%)×0.8", based on the following alcohol content by volume: beer 4%, wine/rice wine 13.5%, liquor 45.5%.[13] "Excessive drinking" was defined as consuming an average of 25+ grams/day for men and 15+ grams for women, according to the Chinese Dietary Guidelines.[14] Covariates considered included gender (men/women), age (continuous in years), marital status (married/not married), educational attainment (no formal education/primary school or below/middle school or above), and place of residence (rural/urban). Binary variables (yes/no) were created for diagnosed chronic diseases, where participants responded to a pre-defined list of conditions including hypertension, diabetes or high blood sugar, cancer (excluding non-malignant skin cancers), chronic lung disease, heart disease, stomach or other digestive diseases, and arthritis or rheumatism.

Statistical analysis

Descriptive statistics are presented as mean values and standard error (SE) for continuous variables, and numbers and weighted percentages for categorical variables. Since each individual had multiple measurements at different time points and individuals were clustered within

communities, we examined the associations between retirement and smoking/excessive drinking using modified mixed-effects Poisson regression models,[15] with random intercepts across individuals and fixed effects of retirement on smoking/excessive drinking. We constructed the models sequentially, with Model 1 unadjusted, Model 2 adjusted for socio-demographic characteristics and Model 3 additionally adjusted for chronic disease variables. Post-stratification weights were applied to ensure population-representativeness. Considering the well-documented differences between men and women in smoking and drinking behaviors in the Chinese context,[2,3] we tested a gender × retirement multiplicative interaction term followed by gender-stratified analysis. All analyses were conducted using R version 4.2.1 and Stata/BE 17.0 for Windows.

Results

Table 1 presents descriptive statistics of the final sample (n=10,378). Included participants were on average 54.5 years old with a relatively balanced gender distribution, and over 90% of the participants were married upon entry. Around 90% of men and 63% of women received formal school education. Most participants lived in rural areas. Of the chronic diseases examined, arthritis, digestive problems and hypertension were the most common. The prevalence of smoking and excessive drinking was 62.6% and 20.1% in men and 4.4% and 1.5% in women, respectively.

Table 2 presents the association of retirement with smoking and excessive drinking. There was a significant inverse relationship between time since retirement and smoking behavior in the unadjusted model. However, that association disappeared after adjusting for socio-economic status and chronic diseases. A dose-response relationship was observed between retirement and excessive drinking in all models, despite minimal attenuation in magnitude after adjustment in

Models 2 and 3. In Model 3, compared with those who remained working, those who retired less than 2 years ago and more than 2 years ago had 16% and 30% reductions in the risk of excessive drinking, respectively. Gender × retirement interaction was significant for smoking (p=0.021 for retired for < 2 years vs working, p=0.225 for retired for >= 2 years vs working), while not significant for excessive drinking (pooled p=0.377). The dose-response pattern remained similar when analyzing men and women separately in the stratified analysis, though not reaching statistical significance for people who retired less than 2 years.

Discussion

Our study found an inverse association between time since retirement and excessive drinking, but not smoking behavior in older Chinese adults. This finding confirmed the protective effect of retirement on some lifestyle behaviors even after adjusting for a range of confounders.[4,16] Previous research suggested that retirement could offer a unique opportunity for positive lifestyle change,[16] potentially explained by changes in social networks, roles, and stressors.[17] Several factors may explain our findings. First, in China, drinking behavior in a workplace setting with colleagues or clients is considered necessary for building business connections ('Guanxi 关系'), securing business deals and career advancement.[10] Thus, from a social network's perspective, retirement reduces exposure to socially reinforcing environments for drinking, especially among men.[18] Second, self-identification with one's role could affect their post-retirement adjustment.[19] In China, around 58% of older adults aged 45-79 years care for their grandchildren.[20] Therefore, the idea of being a good role model may motivate grandparents to cease excessive drinking.[21] Third, removal of work-related stress may lead to reduction in stress-coping behaviors, such as drinking. Moreover, reduced income could also limit the financial resources to buy alcoholic

drinks.[22] Finally, retirement has been considered as a potential window of opportunity for health behavior change, prompting older adults to rethink their lifestyle. In China, 'Yangsheng 养生' (meaning 'health-keeping practices') is a popular concept among retirees and older adults, which may prompt them to quit unhealthy behaviors.[16,23]

Though all the factors mentioned above could also be applied to smoking, the main difference between tobacco and alcohol consumption in China is that smoking is ubiquitous and less setting-specific. People who are addicted to nicotine may be able to smoke nearly anytime and anywhere without social prompts or specific occasions. As the largest producer and consumer of tobacco in the world, over half of the Chinese men are current smokers and cigarettes are served as "social currency", to the degree that cigarettes are exchanged on a daily basis as gifts.[24] Therefore, the sole removal from particular social settings may not be sufficient for reducing smoking in China. Instead, comprehensive tobacco control policies, such as taxation, plain packaging, and smoking bans in public places, are needed to fundamentally address the high smoking prevalence among Chinese men.

Limitations

Several limitations need to be acknowledged. First, retirement status was self-reported and information regarding participants' jobs (e.g., blue- vs white-collar jobs, occupation, work demands), which could be potential effect modifiers, was not collected. Second, due to the limited follow-up period, only short-to-medium-term (up to seven years) effects of retirement could be tested. Third, our analysis was underpowered to test the full dose-response relationship between time since retirement and smoking/drinking outcomes due to the small sample sizes in the "retired for 4-7 years" group. Future research with a larger sample size and long follow-up

periods is needed. Finally, the findings may not be generalizable to populations outside of mainland China.

Conclusion

We found that older Chinese adults were likely to reduce drinking, but not quit smoking following retirement. Such evidence supports a positive framing around retirement in public discourse and highlights the need for evidence-based interventions to address the workplace risk of drinking in China.

Acknowledgements

ML and DD conceptualized and designed the study. ML analyzed the data and drafted the study. AB, PP, and DD all contributed to study writing (review and editing) and supervision. All the authors reviewed the results, provided input during critical revisions and approved the submitted manuscript. All authors have final responsibility for the decision to submit for publication. We thank Dr. Philip Clare for providing statistical advice in the reanalysis of the data.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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Table 1 Baseline characteristics of the analytical sample of the CHARLS study (mean values and standard error; weighted proportion)

Characteristics	Total (n=10,378)	Men (n=5,027)	Women (n=5,351)
Men; n(%)	5,027 (48.8%)		
Age; mean (SE)	54.51 (0.11)	55.10 (0.16)	53.95 (0.15)
Married; n(%)	9,578 (91.9%)	4,674 (92.7%)	4,904 (91.2%)
Educational attainment; n(%)			
No formal education	2,637 (24.1%)	575 (10.8%)	2,062 (36.7%)
Primary school or below	4,330 (40.6%)	2,245 (43.3%)	2,085 (37.9%)
Middle school or above	3,411 (35.4%)	2,207 (45.9%)	1,204 (25.4%)
Rural residence; n(%)	7,380 (64.6%)	3,547 (63.9%)	3,833 (65.2%)
Have been diagnosed with the following disease by a doctor:			
Hypertension; n(%)	1,898 (17.7%)	888 (17.8%)	1,010 (17.7%)
Diabetes or high blood sugar; n(%)	382 (3.6%)	170 (3.4%)	212 (3.7%)
Cancer (excluding minor skin cancers); n(%)	77 (0.7%)	16 (0.3%)	61 (1.1%)
Chronic lung disease; n(%)	819 (7.2%)	455 (8.3%)	364 (6.2%)
Heart disease; n(%)	807 (7.3%)	325 (6.2%)	482 (8.3%)
Stomach or other digestive disease; n(%)	2,393 (21.9%)	1,049 (20.2%)	1,344 (23.6%)
Arthritis or rheumatism; n(%)	3,400 (30.7%)	1,470 (27.9%)	1,930 (33.3%)
Smoking; n(%)	3,495 (32.8%)	3,238 (62.6%)	257 (4.4%)
Excessive drinking; n(%)	1,162 (10.6%)	1,077 (20.1%)	85 (1.5%)

Note: SE, standard error.

Table 2 Association of retirement with smoking and excessive drinking among 10,378 Chinese older population

	Total (n=10,378)			Men (n=5,027)			Women (n=5,351)		
	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
	RR(95%CI)	RR(95%CI)	RR(95%CI)	RR(95%CI)	RR(95%CI)	RR(95%CI)	RR(95%CI)	RR(95%CI)	RR(95%CI)
Smoking									
Working	1	1	1	1	1	1	1	1	1
Retired for < 2 years	**0.95 (0.91-0.99)**	1.03 (0.98-1.09)	1.04 (0.98-1.09)	**0.99 (0.94-1.05)**	1.01 (0.96-1.07)	1.02 (0.97-1.08)	**1.16 (1.02-1.31)**	1.09 (0.96-1.24)	1.10 (0.97-1.25)
Retired for >= 2 years	**0.87 (0.81-0.93)**	1.02 (0.94-1.11)	1.04 (0.95-1.13)	1.00 (0.92-1.09)	1.02 (0.94-1.11)	1.05 (0.96-1.14)	1.14 (0.96-1.35)	0.97 (0.80-1.17)	0.95 (0.78-1.15)
Excessive drinking									
Working	1	1	1	1	1	1	1	1	1
Retired for < 2 years	**0.79 (0.68-0.91)**	**0.83 (0.72-0.96)**	**0.84 (0.73-0.97)**	**0.86 (0.74-0.99)**	0.87 (0.75-1.01)	0.88 (0.76-1.02)	0.68 (0.42-1.13)	0.62 (0.37-1.04)	0.62 (0.37-1.03)
Retired for >= 2 years	**0.59 (0.48-0.73)**	**0.67 (0.54-0.83)**	**0.70 (0.56-0.86)**	**0.72 (0.58-0.91)**	**0.75 (0.59-0.94)**	**0.78 (0.62-0.98)**	0.59 (0.32-1.10)	**0.42 (0.22-0.79)**	**0.43 (0.23-0.80)**

Model 1: unadjusted.

Model 2: adjusted for socio-demographic variables only, including gender (in overall analysis), age, marital status, educational attainment, and place of residence.

Model 3: adjusted for both socio-demographic and chronic disease variables, including gender (in overall analysis), age, marital status, educational attainment, and place of residence, hypertension, diabetes or high blood sugar, cancer (excluding minor skin cancers), chronic lung disease, heart disease, stomach disease or other digestive disease, and arthritis or rheumatism.

Note: All the results were weighted. Boldface indicates statistical significance ($p<0.05$). CI: confidence interval; RR: risk ratio.

5.5 Concluding summary from this chapter and knowledge gained from this study

Using the repeated longitudinal data from a nationally representative sample of Chinese middle-aged and older adults collected in 2011, 2013, 2015 and 2018, we found an inverse dose-response relationship between time in retirement and excessive drinking, while no significant association was found for smoking behaviours. Both smoking and drinking are addictive behaviours; however, retirement may influence these two behaviours in complex and different ways. Identity-loss post-retirement may increase mental stress among older adults, and this may result in both enhanced smoking and drinking behaviours; however, the pervasive smoking norm at the societal level may maintain smoking behaviours while escaping from the drinking culture at work after retirement may reduce social drinking behaviours. To fully understand why and how retirement influences older adults' behaviours, future studies using system thinking are needed.

CHAPTER 6: Revisiting the 'physical activity paradox' in a Chinese context: occupational physical activity and mortality in 142,302 urban working adults from the China Kadoorie Biobank study

6.1 Preface to the chapter

Chinese workers are well known for their hard work and diligence, and they spend more than one-third of the time in a day on working. Thus, workplace environment, as one of the community-level influences instructed by the socio-ecological framework, is especially important for Chinese working adults. This chapter presents findings from a peer-reviewed journal paper that examined the relationship between occupational physical activity (OPA) and mortality among middle-aged and older urban working adults in China as described in Chapter 1. "Physical activity paradox" has been rarely tested in an LMIC setting that whether OPA benefits health similarly as leisure-time physical activity (LTPA). In addition, we further explored the less discussed topic of the interaction of factors across different levels, by investigating the interactive effect of OPA and several individual-level factors, including sex and educational attainment. This study contributed to our understanding of how work-related factors influence people's health, especially paying attention to cardiovascular disease mortality, and whether the effects were consistent across different population subgroups.

In this study, we used data from the China Kadioore Biobank, a large-scale prospective study consisting of over half a million adults aged over 30 years old in China. OPA and sociodemographic data were derived from the self-reported baseline questionnaire in 2004-2008, and mortality data were linked to the national death registry up until 31st December 2016. Dissemination of this research and author contributions to this paper are described below.

6.2 Research dissemination

The research presented in this chapter has been disseminated as follows:

Published peer-review paper

Luo M, Gupta N, Holtermann A, Stamatakis E, Ding D. Revisiting the 'physical activity paradox' in a Chinese context: Occupational physical activity and mortality in 142,302 urban

working adults from the China Kadoorie Biobank study. *The Lancet Regional Health Western Pacific* 2022: 23, 100457. https://doi.org/10.1016/j.lanwpc.2022.100457.

Impact factor: 8.559

Citations (based on Google Scholar): 2

Conference/showcase presentations

Luo M, Gupta N, Holtermann A, Stamatakis E, Ding D. Revisiting the 'physical activity paradox' in a Chinese context: Occupational physical activity and mortality in 142,302 urban working adults from the China Kadoorie Biobank study. Asia-Pacific Society for Physical Activity (ASPA) Conference, Melbourne, Australia, 2022. [Oral presentation]

6.3 Author attribution statement

I, Mengyun Luo, was responsible for conceptualizing and designing the study, conducting the data analysis, interpreting the results, writing drafts of the manuscript, responding to reviewers' comments, and coordinating the publication of the manuscript.

My co-authors, D. Ding and N Gupta helped to conceive and design the study, provided statistical advice and helped to interpret data. D. Ding helped to draft the study, and all the authors reviewed the results, provided input during critical revisions and approved the submitted manuscript.

All authors have read and approved the final version of the manuscript.

6.4 Paper in published format

Revisiting the 'physical activity paradox' in a Chinese context: Occupational physical activity and mortality in 142,302 urban working adults from the China Kadoorie Biobank study

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The Lancet Regional Health - Western Pacific 2022;23: 100457
Published online 17 May 2022
https://doi.org/10.1016/j.lanwpc.2022.100457

Summary

Background Previous research suggests that while leisure-time physical activity (LTPA) is beneficial, occupational physical activity (OPA) may be detrimental to health, known as the 'physical activity paradox'. However, the current evidence is primarily based on data from Western countries. We examined the association of OPA with all-cause and cardiovascular disease mortality in working adults in urban China.

Methods This prospective longitudinal study was based on a sample of 142,302 urban working adults aged 30–79 years from the China Kadoorie Biobank study. Self-reported OPA (mainly sedentary, standing occupation, and manual work) was collected at baseline (year 2004–2008) and linked to death registries until 31st December 2016. Multivariable Cox proportional hazards models were used to examine the relationship between OPA and mortality outcomes, with further tests for effect modification by sex, educational attainment and LTPA.

Findings During a median follow-up of 10·2 years, 4,077 deaths occurred, of which cardiovascular disease was the primary cause for 727 deaths. Crude modelling showed that compared with the sedentary workers, manual work was associated with increased risk of all-cause mortality. However, after adjusting for socio-demographic and life-style variables, the association was attenuated to null (HR=1·00, 95%CI: 0·93–1·08). In subgroup analysis, higher OPA was associated with lower risk of all-cause mortality in the least educated group (HR=0·84, 95%CI: 0·75–0·95 for manual work, and HR=0·86, 95%CI: 0·75–0·99 for standing occupation), but harmful in the most educated group (HR=1·17, 95%CI: 1·01–1·36) and in those who reported regular LTPA (HR=1·20, 95%CI: 1·01–1·43).

Interpretation OPA was not associated with mortality risk in the overall sample. However, findings support the 'physical activity paradox' within better educated Chinese workers.

Funding None.

Keywords: Physical activity; Mortality; Epidemiology; China; Low and middle income countries; LMIC

DOI of original article: http://dx.doi.org/10.1016/j.lanwpc.2022.100437

Abbreviations: OPA, Occupational physical activity; LTPA, Leisure-time physical activity; LMICs, Low-to-middle income countries; SGPALS, Saltin-Grimby Physical Activity Level Scale; BMI, Body mass index; ICD, International Statistical Classification of Diseases; DSP, Disease Surveillance Points; UK, United Kingdom; CVD, Cardiocascular disease; USD, United States Dollars; CNY, Chinese Yuan; IQR, Interquartile range; HR, Hazard ratio; CI, Confidence interval

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Research in context

Evidence before this study

While the evidence for the protective effects of overall physical activity and leisure-time physical activity on health and longevity is well established, evidence on occupational physical activity (OPA) is inconclusive. Several studies found OPA to be harmful, which has been widely considered as the 'physical activity paradox'. We reviewed the literature to identify prospective cohort studies that aimed at exploring the association between OPA and mortality risk by using the following terms in PubMed on 30th September 2021: "occupational physical activity", "mortality", and "cardiovascular disease", finding more than 30 studies with conflicting findings. The most recent and comprehensive systematic review and meta-analysis published in 2018 concluded that high levels of OPA were associated with higher risk of all-cause mortality among male workers, but not females. Since then, two more large cohort studies were published but had inconsistent findings. To date, the evidence on OPA and mortality almost all came from high-income countries. Considering the different socioeconomic structures and occupational environment in low- to middle-income countries (LMICs), it is unclear whether the evidence generated from Western samples can be generalized to non-Western LMICs, such as China.

Added value of this study

Our study extends the previous evidence on 'physical activity paradox' to a non-Western LMICs setting, by following a population representative sample from urban China for more than 10 years. Our findings suggest that within a LMICs setting, whether OPA is harmful may depend on educational attainment, where high OPA appears harmful in those with higher education and protective in those with lower education. Such novel findings may be partially explained by China's rapid economic growth and structural shift in the labor market. As one of the first studies on OPA and mortality from a LMICs setting, our study adds unique contribution to the current literature which is dominated by studies from high-income Western countries.

Implications of all the available evidence

In contrast to 'physical activity paradox' that was repeatedly observed in Western cohorts, we found that in China, high levels of OPA were not associated with higher or lower mortality risk when socio-demographic and lifestyle confounders were adjusted for. However, our novel findings of effect modification by educational attainment and LTPA highlight the importance of context for OPA research. Considering that OPA accounts for the majority of physical activity in LMICs, and that many of these countries are experiencing mechanization and related transition in the labor structure, it is important to continue to investigate the health effects of OPA within a LMICs context. Such emerging evidence base could inform decision making to ensure the health, wellbeing and longevity of workers in LMICs.

Introduction

Physical activity prevents non-communicable diseases and premature death,[1] and improves mental health,[2] physical function and wellbeing.[3] It is considered as today's 'best buy in public health'.[4] However, most studies to date have been based on overall or leisure-time physical activity (LTPA). For most working adults, work constitutes the largest part of their awake hours, and for some workers, particularly those in low- to middle-income countries (LMICs), occupational physical activity (OPA) constitutes a much larger proportion of their total physical activity than LTPA.[5,6] However, whether OPA benefits health similarly as LTPA remains inconclusive.[7–9]

The current evidence on the association between OPA and mortality is mixed. Earlier evidence, as synthesized in a 2011 meta-analysis of 82,412 participants from 6 cohort studies,[10] suggested a protective effect of OPA. However, a 2018 meta-analysis of 193,696 participants from 17 cohort studies using similar searching terms concluded the opposite — that high levels of OPA were associated with higher risk of all-cause mortality among male workers.[11] Such findings that OPA may be harmful to health in contrast to LTPA have been widely considered as the 'physical activity paradox'.[12]

To date, the evidence on OPA and mortality is almost exclusively based on Western samples.[11,13] For example, only two of the 33 studies included in the 2018 systematic review and meta-analysis were based on non-Western populations,[11] namely from Iran and Taiwan.[14,15] Both of the studies were based on small samples selected from specific regions, and they had conflicting findings. Furthermore, considering the different socioeconomic structures and occupational environment in LMICs and the context-specific nature of the existing evidence, whether the evidence generated from Western samples can be generalized to non-Western LMICs, such as China, remains unknown.

In the past few decades, China, the largest manufacturing economy of the world, has experienced rapid economic development and urbanization.[16] Technological innovations, mechanization, and the booming e-commerce in China have led to significant shifts in the labor market. For example, the share of 'routine manual workers' (e.g., factory and construction workers) declined from 57% in 1990 to 32% in 2015.[17] Such changes in employment structure, paired with rapidly increasing educational levels,[18,19] have led to a 'reshuffling' of jobs, characterized by a more diverse composition of the labor market, where traditional manufacturing jobs coexist with emerging professional, managerial and technical jobs.[17] This transition has also led to job loss and under employment, as it has become more challenging for Chinese workers to find jobs compatible with their educational levels.[17] Considering this unique transitional situation of the Chinese labor market, which may apply to some other emerging

economies, it is particularly important to test whether the 'physical activity paradox' holds true in China.

In this study, we examined the association between OPA and all-cause and cardiovascular disease (CVD) mortality in 142,302 working adults sampled from geographically diverse urban areas in China. Furthermore, we tested whether the association differed by sex and LTPA, as implied in previous studies,[8,9,11] and by educational attainment, considering the impact of the economic transition on the Chinese labor market across socioeconomic spectrum. We hypothesize that, according to the 'physical activity paradox', OPA was positively associated with mortality risk in China, and that the association differed by sex, educational attainment and LTPA.

Methods

Study design and participants

Data are from the China Kadoorie Biobank, a large prospective cohort study of 512,891 Chinese adults. Detailed information about the study design and baseline characteristics of the participants has been reported previously.[20] Briefly, between June 2004 and July 2008, adults aged 30–79 years old living in 10 geographically defined areas (5 urban and 5 rural) were invited to participate. The selected urban areas were Qingdao, Harbin, Liuzhou, Suzhou, and Haikou, and rural areas were Sichuan, Zhejiang, Hunan, Gansu, and Henan. These areas were strictly selected via China's nationally representative Disease Surveillance Points (DSP) system to cover a wide range of disease patterns and to maximize socioeconomic diversity rather than to represent the general population in China.

Trained health workers administered a laptop-based questionnaire on demographic, socioeconomic, and lifestyle risk factors (e.g., smoking, alcohol drinking, diet, and physical activity) and measured standing height (using a stadiometer) and body weight (using body mass index [BMI] composition analyzer (TBF-300GS)).[20] Ethical approval was obtained from the China Center for Disease Control and Prevention (Beijing, China, approval number: 005/2004, 9.7.2004) and the Oxford Tropical Research Ethics Committee, University of Oxford (UK, approval number: 025–04, 3.2.2005), and all participants provided written informed consent before participation.

For the current study, we restricted analysis to urban residents because rural residents were asked different OPA questions, which were not comparable with those asked to the urban participants. We further excluded those who were retired or not currently working at baseline, and those with missing data on independent variables or covariates. To minimize the risk of reverse causation (i.e. severe health conditions precede lifestyle change), we further excluded those who reported having the following conditions at baseline: diagnosed coronary heart disease, stroke (including transient ischemic attack), rheumatic heart disease, cancer and continuous pain lasting for ≥3 months.[9] We did not choose the less severe conditions, such as gallstone, arthritis and fracture, because they were less likely to lead to reverse causation. Final analysis included 142,302 urban participants (Figure 1).

Exposure assessment

At baseline (year 2004–2008), an adapted OPA question of the Saltin-Grimby Physical Activity Level Scale (SGPALS) was asked "During the past 12 months, how active were you at work?". Mutually exclusive response options were "Mainly sedentary (e.g. office worker)", "Standing occupation (e.g. security guard, shop assistant)", "Manual worker (e.g. plumber, carpenter)", and "Heavy manual worker (e.g. miner, construction worker)". This question has been widely used to measure OPA,[21–23] and a comparison between this scale and accelerometer measures suggested high validity in ranking of physical activity levels based on SGPALS (22). Given the small percentage of participants selecting "heavy manual worker" (1.4%), we combined this category with "manual workers".

Outcome assessment

Study outcomes included all-cause and CVD mortality. In all 10 study regions, the vital status of the participants was ascertained from the DSP death registries and health insurance systems, supplemented by information obtained from neighborhood committees or village administrators. Death data in all 10 study areas were updated annually from baseline until 31st December 2016. Causes of death were coded until 31st December 2014 and were classified using the International Statistical Classification of Diseases (ICD)-10 by trained staff. We used ICD-10 codes I00-I99 for CVD death, similarly to previous investigation.[24]

Covariates

We selected covariates from the baseline questionnaire based on an a-priori developed directed acyclic graph (Supplementary Figure 1). These covariates included socio-demographic characteristics, working hours and lifestyle risk factors.

Socio-demographic characteristics included sex (male, female), marital status (married, not married), educational level (primary school or below, middle school, high school or above), and household income (low: <20,000, middle: 20,000–34,999, high: ≥35,000 Chinese Yuan (CNY) per year; 1 CNY=~0.125 USD at the time of the survey). Participants were also asked to report the total number of hours they usually

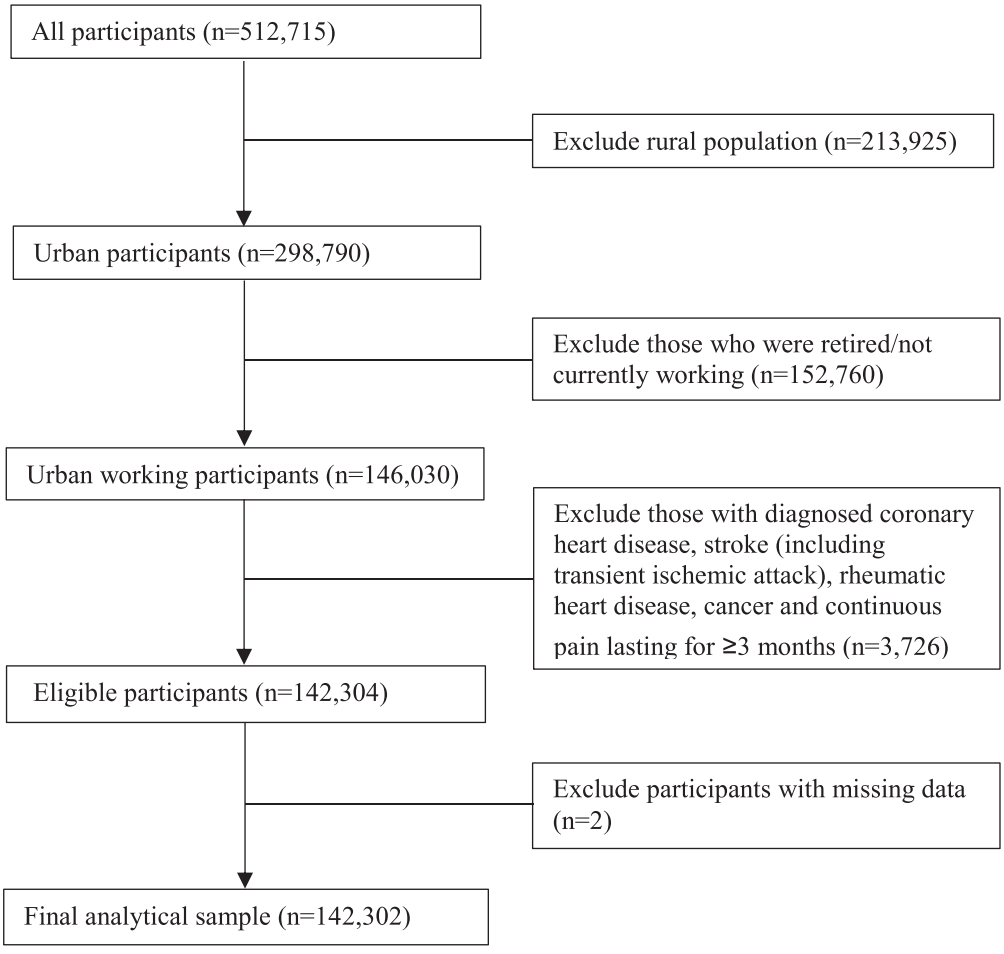

Figure 1. Participants flow.

worked in a typical week, and working hours was handled as a continuous variable.

Lifestyle risk factors included BMI, smoking, alcohol consumption, diet, and LTPA. BMI (kg/m^2) was calculated from the objectively measured height and weight using the formula BMI=weight (kg)/height^2 (m^2). We further categorized BMI into "underweight (<18·5)", "normal (18·5–23·9)", "overweight (24·0–27·9)", and "obesity (≥28·0)", using Chinese-specific cut-off points recommended by Cooperative Meta-analysis Group of China Obesity Task Force.[25] Current smoking was defined as having smoked at least 100 cigarettes in one's lifetime and being a current smoker. Alcohol consumption was measured by asking "During the past 12 months, how often did you drink any alcohol?". Participants were categorized as currently drinking alcohol "at least weekly" vs "less than weekly". Fruit intake was measured using the question "During the past 12 months, about how often did you eat fruit?" with response options of "never/rarely", "monthly", "1–3 days per week", "4–6 days per week" and "daily". Fruit consumption was dichotomized as "0-3 days per week" vs "4+ days per week". We did not include vegetable intake as a dietary indicator because 97% of the participants chose the highest category of "daily". LTPA was derived from a validated set of questions regarding different types of LTPA.[6,26] Participants were asked about the frequency of performing any activities (examples include Taichi, walking for leisure, ball games, jogging/aerobic exercise, and swimming, and an "Other" option was also provided) in one's spare time during the past 12 months, with answers including "never or almost never", "1–3 times/month", "12 times/week", "3–5 times/week" and "daily or almost every day". Considering the very low prevalence of LTPA among the Chinese adults, we dichotomized responses into "no regular LTPA" if a participant responded "never or almost never", or "1–3 times/month", and "regular LTPA" if otherwise.

Statistical analysis

We presented descriptive statistics of the participants at baseline by providing counts and percentages for categorical variables and median and interquartile range

(IQR) for continuous variables. We calculated person-years at risk from the baseline to death, loss to follow-up or 31st December 2016, whichever occurred first. We used a multivariable Cox proportional hazards model to estimate the hazard ratio (HR) and 95% confidence interval (CI), with age as the underlying time scale and age at recruitment (ascertained from date of birth) as entry time. The proportional hazards assumption for the Cox model was checked based on the Schoenfeld residuals, and no violation was found (Supplementary Figure 2). Considering that missing data were minimal ($n = 2$), complete case analysis was used.

To delineate the influence of confounding, we sequentially built four models for each mortality outcome: Model 1 was univariate analysis and accounted for age as the underlying timescale; Model 2 adjusted for sex only; Model 3 additionally adjusted for socio-demographic variables (marital status, educational attainment and household income) and working hours; and Model 4 additionally adjusted for BMI categories, smoking, drinking, fruit consumption, and LTPA.

We tested sex, educational attainment and LTPA as potential effect modifiers graphically (using marginal plots), as well as adding multiplicative interaction terms in Model 4, followed by subgroup analysis. Finally, to reduce the risk of reverse causation, we conducted sensitivity analysis by excluding the first two years of follow-up data as a 'wash-out' period (Supplementary Figure 3). Further, we conducted a sensitivity analysis using the Fine-Gray model of competing risk to account for the marginal probability of the 'sub-distribution' (those who died from CVD versus from non-CVD causes).[27] We conducted all analyses in R Studio (Version 1.2.5033).

Role of the funding source
No funding sources to report.

Results

Participants in the final analysis were on average 45.9 ± 7.6 years old at baseline. Of the 142,302 participants, 51.8% were men; 94.3% were married; 72.7% had completed at least middle school education. 40.0% were doing sedentary work, 24.3% had a standing occupation, and 35.6% were doing manual work.

Baseline characteristics by OPA are presented in Table 1. Overall, compared with standing and sedentary workers, a larger proportion of manual workers were males and of lower educational levels. Manual workers were also more likely to smoke and drink alcohol at least weekly, while less likely to regularly consume fruit or participate in regular LTPA. Those with standing occupation reported the lowest prevalence of weekly alcohol consumption, while sedentary workers had the highest BMI, reported the shortest daily working hours and the highest levels of LTPA.

Occupational physical activity and mortality risk

During a median follow-up of 10.2 years (1.44 million person-years), 4,077 deaths occurred by 31st December 2016. Of the 3,688 with cause of death coded by 31st December 2014, CVD was the primary/underlying cause for 727 deaths. Table 2 shows the hazard ratios and 95% confidence intervals for the relationship between OPA and all-cause and CVD mortality after adjusting for different covariates sequentially. Compared with sedentary workers, manual workers had a higher risk of all-cause mortality in the crude model (Model 1). However, the association was attenuated once sex was adjusted for (Model 2), and further attenuated to null after other socio-demographic (Model 3) and lifestyle variables (Model 4) were introduced into the model. The association between OPA and CVD mortality was of similar magnitude but not statistically significant in any model as a result of wider confidence intervals.

In model 4, we found significant effect modification by educational attainment ($p = 0.007$ for all-cause mortality and $p = 0.029$ for CVD mortality). Both statistical tests and graphical exploration of interactions involving sex ($p = 0.102$ for all-cause mortality and $p = 0.785$ for CVD mortality), and by LTPA ($p = 0.111$ for all-cause mortality and $p = 0.346$ for CVD mortality) were not significant at 0.05 (Supplementary Figures 4–9). However, considering that the power for detecting significant interactions was generally much lower than that for main effects, we considered meaningful effect modification based on data plots, subgroup analysis and confidence intervals in addition to p values for the interaction terms.[28]

Subgroup analysis

Figures 2 and 3 shows the associations between OPA and mortality outcomes by sex, educational attainment and LTPA based on the covariates adjusted for in Model 4. In most cases, estimates were similar across strata. However, among those with the lowest educational attainment (i.e. primary school or below), both standing occupation and manual work were inversely associated with all-cause mortality (HR: 0.86; 95%CI: 0.75–0.99; HR: 0.84; 95%CI: 0.75–0.95), while the direction of association was the opposite for those with higher educational attainment, where manual work appeared harmful compared with sedentary workers with high school education or above (HR: 1.17; 95%CI: 1.01–1.36). Among those who regularly participated in LTPA, manual workers had higher risks of all-cause mortality (HR: 1.20; 95%CI: 1.01–1.43) than sedentary workers.

Sensitivity analysis

Excluding the first 2 years of follow-up (analytical sample n=141,865); Supplementary Table 1) did not appreciably change the associations between OPA and the two

	Sedentary work (*n* = 56,991)	Standing occupation (*n* = 34,637)	Manual work (*n* = 50,674)	*p*-value
Socio-demographic variables				
Sex				
Male	27,923 (49·0%)	15,922 (46·0%)	29,897 (59·0%)	<0.001
Age group (years)				
30-39	14,932 (26·2%)	9012 (26·0%)	10,809 (21·3%)	<0.001
40-49	27,316 (47·9%)	16,708 (48·2%)	24,019 (47·4%)	
50-59	12,154 (21·3%)	7366 (21·3%)	13,258 (26·2%)	
≥ 60	2589 (4·5%)	1551 (4·5%)	2588 (5·1%)	
Marital status				
Married	53,657 (94·1%)	32,737 (94·5%)	47,820 (94·4%)	0.057
Educational attainment				
Primary school or below	9180 (16·1%)	9324 (26·9%)	20,406 (40·3%)	<0.001
Middle school	15,488 (27·2%)	12,398 (35·8%)	18,729 (37·0%)	
High school or above	32,323 (56·7%)	12,915 (37·3%)	11,539 (22·8%)	
Household income (CNY/year)				
Low (<20,000)	14,152 (24·8%)	10,575 (30·5%)	16,252 (32·1%)	<0.001
Middle (20,000-34,999)	19,651 (34·5%)	12,980 (37·5%)	19,498 (38·5%)	
High (≥ 35,000)	23,188 (40·7%)	11,082 (32·0%)	14,924 (29·5%)	
Lifestyle risk factors				
Currently smoking	16,731 (29·4%)	9874 (28·5%)	20,306 (40·1%)	<0.001
Currently drinking alcohol at least weekly	12,680 (22·2%)	6730 (19·4%)	13,080 (25·8%)	<0.001
Regular consumption of fruit (≥ 4 days/week)	28,064 (49·2%)	14,572 (42·1%)	15,018 (29·6%)	<0.001
Regular leisure-time physical activity (at least '1-2 times/week')	15,170 (26·6%)	6725 (19·4%)	6361 (12·6%)	<0.001
Body mass index categories (kg/m^2)				
Underweight (<18·5)	1398 (2·5%)	944 (2·7%)	1401 (2·8%)	<0.001
Normal (18·5-23·9)	27,119 (47·6%)	17,502 (50·5%)	26,816 (52·9%)	
Overweight (24·0-27·9)	21,681 (38·0%)	12,584 (36·3%)	17,683 (34·9%)	
Obesity (≥28·0)	6793 (11·9%)	3607 (10·4%)	4774 (9·4%)	
	Median (IQR)	Median (IQR)	Median (IQR)	
Working hours (hours/day)	8·0 (8·0–10·0)	9·6 (8·0–11·2)	9·6 (8·0–11.2)	<0.001

***Table 1*: Baseline characteristics of the analytical sample by occupational physical activity (year 2004–2008, *n* = 142,302).**
CNY (Chinese Yuan): 1 CNY=~0·125 USD at the time of the survey.
IQR: interquartile range.

mortality outcomes (Supplementary Table 2). The results of the subgroup analysis were similar to the main analysis, except that standing occupation was found to be protective against all-cause mortality among females (HR: 0.85; 95%CI: 0.72–1.00), but not among males (Supplementary Figure 10 and Supplementary Figure 11). Furthermore, the magnitude of several previously significant associations in subgroups (i.e., standing occupation and all-cause mortality in those with the lowest education and manual work and all-cause mortality in those with the highest education and those who reported regular LTPA) remained similar but the confidence intervals widened to include 1. There was little difference observed between a conventional Cox proportional hazards model and a Fine-Gray competing risk model (Supplementary Figure 12).

Discussion

Based on data from 142,302 urban Chinese workers with a median follow-up of more than 10 years, we found no evidence for OPA being harmful or beneficial in the overall sample. However, the association between OPA and mortality seems to differ by educational attainment and LTPA. High OPA was found to be protective in the least educated group, but harmful in the group with the highest educational levels. In addition, high OPA was associated with higher risk of all-cause mortality in those who reported regular LTPA.

As compared with LTPA, which has been the most studied physical activity domain with well-established health benefits,[29] OPA may be less health-enhancing due to its lower intensity, longer durations and insufficient recovery time, which could lead to prolonged

Occupational physical activity	All-cause mortality				
	Deaths/n	Model 1 HR (95%CI)	Model 2 HR (95%CI)	Model 3 HR (95%CI)	Model 4 HR (95%CI)
Sedentary work	1,513/56,991	1·00 (ref)	1·00 (ref)	1·00 (ref)	1·00 (ref)
Standing occupation	935/34,637	1·05 (0·96−1·14)	1·03 (0·95−1·12)	0·99 (0·91−1·07)	0·99 (0·91−1·07)
Manual work	1,629/50,674	1·15 (1·07-1·24)***	1·08 (1·01−1·16)*	1·02 (0·94−1·10)	1·00 (0·93−1·08)
Occupational physical activity	**Cardiovascular disease mortality**				
	Deaths/n	**Model 1 HR (95%CI)**	**Model 2 HR (95%CI)**	**Model 3 HR (95%CI)**	**Model 4 HR (95%CI)**
Sedentary work	269/56,991	1·00 (ref)	1·00 (ref)	1·00 (ref)	1·00 (ref)
Standing occupation	175/34,638	1·12 (0·92−1·35)	1·08 (0·89−1·30)	1·07 (0·88−1·30)	1·09 (0·90−1·33)
Manual work	283/50,674	1·15 (0·97−1·35)	1·06 (0·88−1·22)	1·06 (0·89−1·27)	1·09 (0·91−1·30)

***Table 2*: Associations between occupational physical activity and all-cause and cardiovascular disease mortality (n = 142,302).**
HR: hazard ratio; 95%CI: 95% confidence interval.
Model 1: unadjusted model accounting for age as the underlying timescale;
Model 2: Model 1 + sex;
Model 3: Model 2 + marital status, educational attainment, household income and working hours;
Model 4: Model 3 + lifestyle risk factors: body mass index categories, smoking, drinking, fruit consumption, and leisure-time physical activity.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

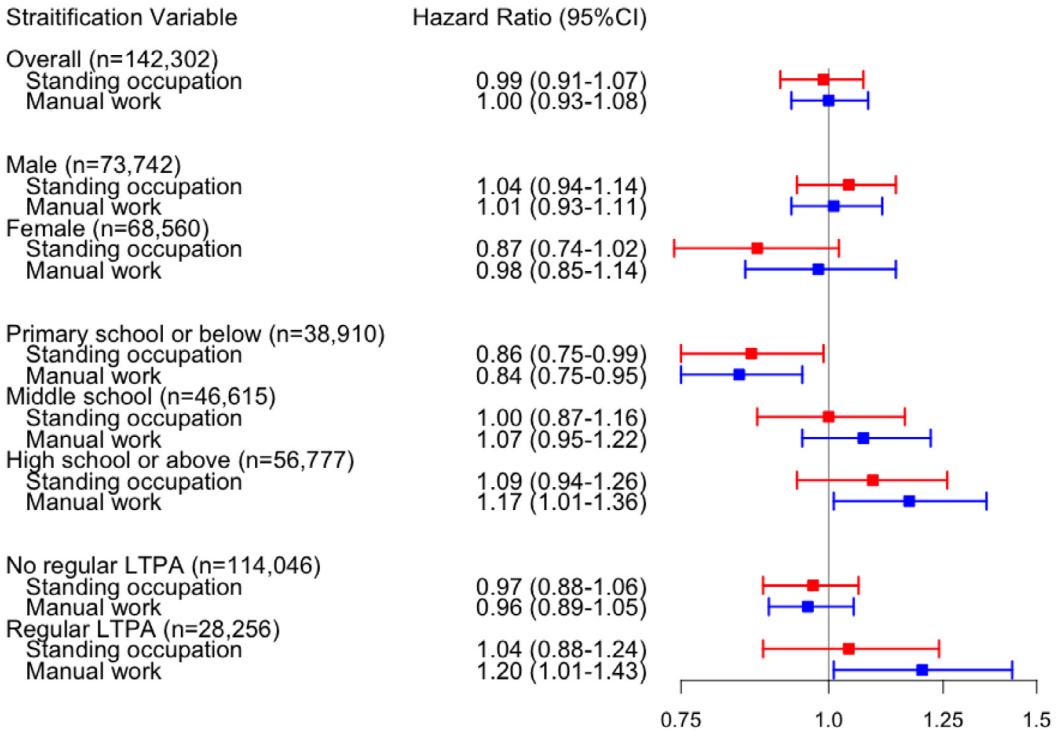

Figure 2. Multivariable-adjusted* associations between occupational physical activity and all-cause mortality stratified by sex, educational level and leisure-time physical activity (n = 142,302).

* All the subgroup analysis were based on the fully adjusted models: accounted for age as the underlying timescale and adjusted for sex (except for in sex-stratified analysis), working hours, marital status, educational level (except for in education-stratified analysis), household income, body mass index categories, smoking, drinking, fruit consumption, and leisure-time physical activity (LTPA, except for in LTPA-stratified analysis). The x-axis is plotted on a log scale.

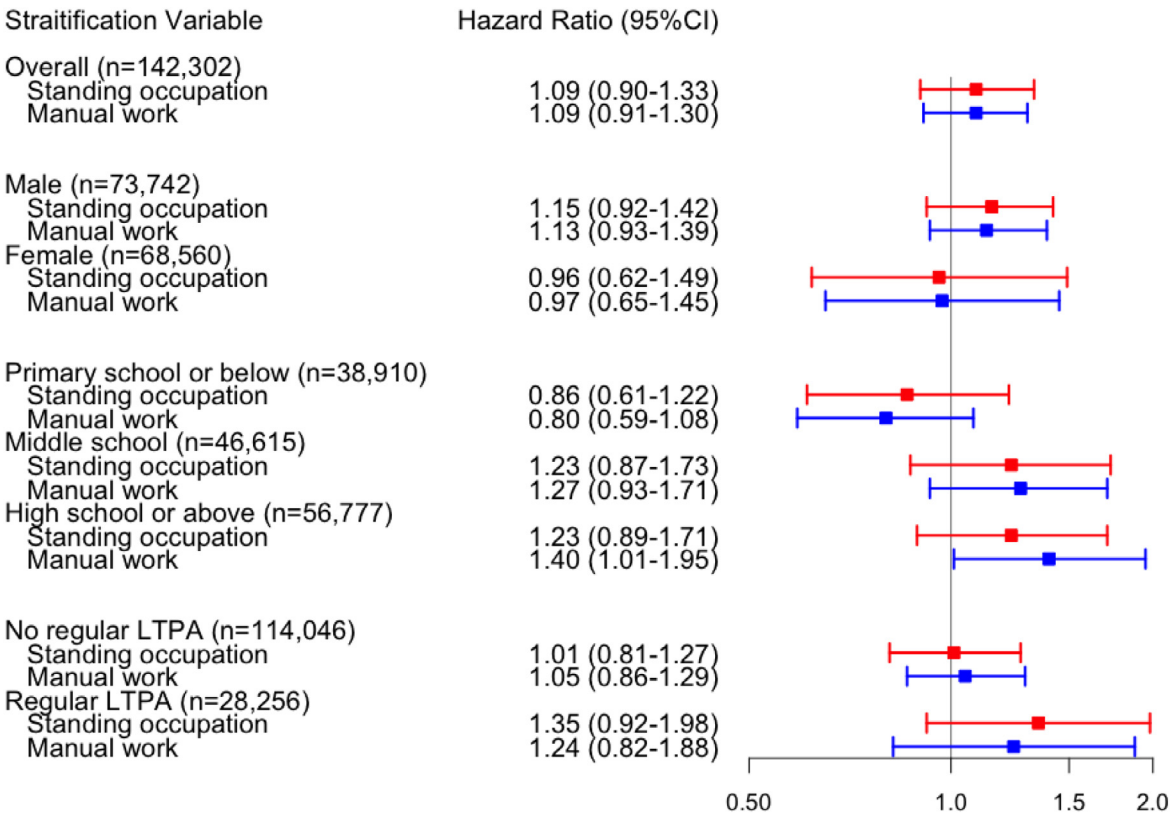

Figure 3. multivariable-adjusted associations between occupational physical activity and cardiovascular disease mortality stratified by sex, educational attainment and leisure-time physical activity (*n* = 142,302).

elevated heart rate and increased levels of inflammation.[7] It is also less volitional, not done for enjoyment or recreation, and potentially placing higher physical demands than LTPA. Several Western studies as well as a study based on a small Taiwanese cohort have found a harmful effect of high OPA on mortality,[8,14,21,30] hence supporting the 'physical activity paradox'.[12] To our knowledge, the current study is one of the first studies to test this paradox in a LMICs setting and our findings support the paradox in some subpopulation but not in the overall sample.

Previous reviews suggested that insufficient adjustment of potential confounders may have contributed to the repeatedly observed 'physical activity paradox'.[12] We specifically addressed confounding by entering covariates sequentially in each model. In our study, the positive association between OPA and mortality in the overall sample seemed to attenuate to null by accounting for socioeconomic status and working hours, as manual workers in our sample reported the longest working hours, the lowest socioeconomic status (both in terms of income and education), and the worst lifestyle profile. Our findings highlight the importance of accounting for confounders in exploration of the health effects of OPA. Previous studies repeatedly suggested that the association between OPA and mortality could be sex-specific,[8,9,13] where OPA appeared to be more harmful in men than women. Findings from our study provided preliminary evidence that in China, standing occupation may be protective against all-cause mortality in female workers when compared with sedentary workers, based on findings from sensitivity analysis. In the early 2000s, many female sedentary workers worked in garment factories, infamous for their long working hours, poor conditions, low wages, and repetitive sedentary work without a break.[31] In contrast, female workers in standing occupation tended to work in sales and services, which often involved better working conditions and substantial opportunities for incidental physical activity. We speculate that the potential differential mortality risk between those in standing and sedentary jobs may be a result of both physical activity and working conditions. Unfortunately, confirming this potential explanation would require additional data about the participants' jobs, such as industry, working conditions, and activities performed at work, none of which was collected by the China Kadoorie Biobank study.

A novel finding of our study is the significant effect modification by socioeconomic status. We found high OPA to be protective against all-cause mortality among

those with the lowest level of educational attainment, while the association pointed the opposite direction among those with higher educational attainment. One potential explanation is that the reference category (i.e., sedentary workers) may be different across socioeconomic strata. For example, the 'sedentary workers' group within the highest educational level primarily includes professional (29%) and managerial staff (26%; Supplementary Table 3) while the sedentary workers group within the lowest educational level is primarily comprised of factory workers (41%) and those who either selected 'other' or declined to report on occupation (25%; which may be an indication of a lack of stable jobs). Perhaps as a result, sedentary workers with low education had the highest crude death rate, more than twice as high as the sedentary workers with the highest educational category (Supplementary Table 4). In the last three decades, China has been transitioning out of a manufacture-focused economy towards a more diverse economy, where many of the blue-collar jobs have been replaced by white-collar jobs.[17] While the educational levels of the population have dramatically improved,[18,19] educational requirement for white-collar jobs has increased over time, forcing some of the former manual workers out of the labor market.[17] This may have acerbated the 'Healthy Worker Effect' where those who were older, less fit and with lower educational levels were forced to leave full-time manual work.[32] Conversely, higher educational levels used to guarantee a 'good' job, exemplified by the 1990 census statistics that 61% of university graduates occupied managerial and technical jobs, but the proportion declined to less than 30% in 2015.[17] As a result, some university graduates had to move into manual jobs, for which they were over-qualified. In fact, the proportion of university-educated Chinese adults working in manual jobs increased from 9% in 1990 to 14% in 2015. Perhaps, particularly for those with higher educational levels, working in a manual job because of no better options could lead to status loss and poor quality of life, which, according to the literature,[33] may result in 'deaths of despair'. Our findings underline the importance of long-term monitoring of occupational health, so that we can examine the potential effects of economic, social, and labor market changes on workers' health and wellbeing. Such evidence should be considered in decision making to avoid any unintended negative consequences of economic development and labor market transition.

Another interesting finding from this study is the interaction between OPA and LTPA. Based on this finding, we speculate that for manual workers who work long hours every day (nearly 10 hours daily for our sample), being active in leisure time may be harmful to health, as a result of continuous strains and no recovery. However, this counterintuitive finding may also be an artifact of different reference categories, as over 63% of the participants who reported regular LTPA had high school education or above, therefore, the reason for which high OPA is harmful in those who reported regular LTPA may be similar to that for the group with the highest education. To date, only a small number of studies examined this interaction between OPA and LTPA and the findings were mixed. For example, while a Danish study found no evidence of interaction,[8] a recent Norwegian study found a significant interaction between OPA and LTPA,[34] where the protective effects of LTPA were only observed in the two lowest OPA categories, but not in participants with the highest level of OPA. Findings from these studies suggest that there may be a risk of 'doing too much'. While the evidence base is only emerging, future studies should aim to understand the 'balance' between strain and recovery within the context of daily physical activity.[35]

This study provides new insights on the relationship between OPA and mortality in a non-Western LMICs context. Based on a large population-representative sample, we examined confounding and effect modification by socio-demographic and lifestyle risk factors and identified new findings, such as the effect modification by socioeconomic status and LTPA. However, results should be interpreted in light of limitations. First, physical activity and occupational characteristics were self-reported, and are therefore subject to reporting bias. Future studies should consider a combination of self-reported and devise-based measures to quantify both the intensity and duration of OPA. Second, measures of important occupational characteristics, such as work-related stress, strains, and other hazards were not measured. Third, OPA was only measured at one time-point, which prevented us from capturing the long-term dynamic patterns of OPA. Finally, findings may not be generalizable to contexts outside of urban China, and future studies should be undertaken to explore the health effects of OPA in rural population.

In a large sample of urban Chinese workers, high levels of OPA were not associated with mortality risk in an overall sample. However, high levels of OPA seemed protective among participants with the lowest levels of education, while harmful in those with the highest levels of education and those who participated in LTPA regularly. These findings seem to support the 'physical activity paradox' within the context of the better educated Chinese workers. Considering that OPA accounts for the majority of physical activity in LMICs, and that many of these countries, similar to China, are experiencing mechanization and related transitions in the labor structure,[5,6] it is important to continue to investigate the health effects of OPA, independent of and interactive with other domains of physical activity. Such emerging evidence base should be considered in decision making to ensure the health, wellbeing and longevity of workers in LMICs.

Contributors

ML, NG and DD conceptualized and designed the study. ML analyzed the data with the help of NG and DD, and drafted the study with DD. All the authors reviewed the results, provided input during critical revisions and approved the submitted manuscript. All authors have final responsibility for the decision to submit for publication.

Data sharing

The data used in this study are available from the China Kadioore Biobank website with approved access.

Declaration of interests

We declare no competing interests.

Acknowledgments

The authors thank Joseph Van Buskirk for statistical advice during the revision.

Supplementary materials

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.lanwpc.2022.100457.

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6.5 Concluding summary from this chapter and knowledge gained from this study

To our knowledge, this paper is one of the first large-scale studies on exploring the relationship between OPA and mortality among middle-aged and older adults in an LMICs setting. “Physical activity paradox” was tested in many HICs that higher levels of OPA were negatively associated with CVDs and mortality, in contrast to LTPA being consistently protective for health. However, we found no evidence of a statistically significant association in the overall urban working samples in China. A novel finding of the current study is that the association between OPA and mortality seems to differ by educational attainment. High OPA was found to be protective among people who were less educated, while harmful in the better-educated group. This further confirmed the importance of exploring the interaction of factors across different levels of the socio-ecological framework, that the same risk factors might impact older adults’ health in diverse ways and opposite directions among different subgroups.

CHAPTER 7: Discussion and conclusions

7.1 Overview

China has an aging population, with a projection that adults aged over 65 years old will comprise 28% of the total population by 2040. Population aging will contribute to an increase in health and social problems and pose an economic burden on the social welfare and healthcare systems. In order to tackle the problem and inform interventions, it is important to understand the potential barriers to and facilitators of healthy aging. This thesis explored the risk factors for behavioural, social health and well-being among middle-aged and older adults in China guided by a socio-ecological framework outlined earlier in Chapter 1.

Four interrelated studies were conducted to address the specific research questions outlined in Chapter 1, with the relevant findings and implications of each study discussed in published/submitted journal papers and presented in Chapters 3 to 6.

This final chapter provides an overview of the main findings, including a discussion about the significance and implications of the findings for public health, surveillance data and policy, methodological strengths and limitations, and suggestions for future directions.

7.2 Significance of the findings

The socio-ecological framework illustrates the potential influences on lifestyle behaviours and health at different levels, including individual-, interpersonal-, community- and societal-level factors that contribute to health. This framework recognizes that health outcomes are not influenced by intra-individual factors alone, but also by the interactions across a complex range of social, economic, and environmental factors including the cultural and geographic context in which individuals live (1-3). The socio-ecological framework offers a framework for classifying some of the factors associated with health behaviours identified in this research among older Chinese residents. This framework enables a discussion of behavioural correlates at different levels among older adults and lays the groundwork for future research and interventions.

This research should be viewed in the light of 1) its contribution to understanding facilitators and barriers at multiple levels to healthy aging in China, and 2) its potential to suggest new partnerships among diverse stakeholders (individuals, community-engaged partnerships, policymakers, etc.) that might contribute to better health among older adults in China.

To help gain an overall picture of the findings in this thesis, Table 7.1 summarizes the main findings, using the socio-ecological framework. This table demonstrates the level of influence at each stage of the socio-ecological model for each of the studies in this thesis.

Table 7.1 Summary of findings from the published papers according to the four levels of correlates in the socio-ecologic framework

Thesis chapter	Study aims	Levels of correlates	Dataset	Main findings
3	Examine different levels of correlates of domain-specific physical activity among older adults, including individual, community, and societal levels.	Individual Community Societal	WHO SAGE	Among Chinese older adults, individual-level variables including gender, age, educational attainment, income level and working status, as well as the place of residence (societal level) were associated with either one or more domains of physical activity, including work and household-, transportation-, or leisure time- physical activity. Social capital variables (community level) were not associated with physical activity, except that a higher level of structural social capital was positively related to physical activity during leisure time.
4	Examine the relationship between social engagement pattern, and lifestyle behaviours and subjective well-being of older adults.	Interpersonal	WHO SAGE	In China, higher social engagement (interpersonal level) was positively associated with tobacco use, while negatively related to other unhealthy lifestyle behaviours (including inadequate fruit and vegetable intake, physical inactivity, prolonged sitting time and unhealthy sleep time) as well as subjective well-being (including perceived depression, poor self-rated health and low quality of life).
5	Examine the relationship between retirement and risky lifestyle	Individual Interpersonal	CHARLS	There was no significant association between time in retirement (individual, interpersonal, community and societal factors) and smoking. However, a

	behaviours among the middle-aged and older population.	Community Societal		dose-response relationship was observed between retirement and excessive drinking.
6	Examine the relationship between occupational physical activity and mortality among middle-aged adults.	Community	CKB	Physical activity at the workplace (community level) was not associated with mortality in a sample of middle-aged working population in China. In subgroup analyses, higher occupational physical activity (OPA, community level) was associated with a lower risk of all-cause mortality in the least educated group, but harmful among the most educated group and in those who reported regular leisure-time physical activity.

7.2.1 Individual-level facilitators and barriers

Each of the following sections discusses the thesis findings across levels of the socio-ecological framework. This part of the discussion considers the most proximal factors, individual-level components of the socio-ecological framework.

As indicated in the previous chapters, many individual-level factors affected the health of older adults, including gender, age, educational attainment, income level and working status. Most of these are sociodemographic characteristics that cannot be easily changed.

We found noticeably different patterns of health behaviours by gender. As is shown in Chapter 3, although there was no difference by gender in the prevalence of meeting the WHO guidelines for total physical activity, domain-specific physical activity patterns differed: Chinese women were more active at home, while men were more active during their leisure time. These findings were in line with a survey by the National Bureau of Statistics that women in China spent substantial time on housework (including household chores, grocery shopping and taking care of children/grandchildren), with approximately 2.1 hours a day on average (4). Moreover, in Chapter 5, we found that the prevalence of smoking and excessive drinking in Chinese men was much higher than that in Chinese women (62.6% vs 4.4% for smoking and 20.1% vs 1.5% for excessive drinking). Gender differences among community-dwelling older adults were also noted in quality of life and self-reported sleep in many other LMICs, including Ghana, India, Russia, and South Africa (5, 6). It was not surprising that men were more likely to participate in unhealthy lifestyle behaviours that were traditionally considered ‘masculine’, such as smoking and heavy drinking, while women were often discouraged from participating in such behaviours (7).

Chapter 3 examined physical activity across different age groups and found that people aged over 70 years old were less likely to maintain physical activity levels compared to their 50-59 counterparts, both in transportation and in their leisure time. The existing literature confirmed that physical activity levels decreased with age; this is accompanied by loss of muscle mass and strength and is associated with an increased risk of developing NCDs (8). Researchers also concluded that chronological age is a good predictor of functional ability, health status, and disease burden (9, 10). With increasing life expectancy, older people are more likely to live with chronic illnesses (11). However, research also showed that people who were older tended to have healthier eating habits and quit smoking, mainly because they were motivated to maintain or improve their health (12, 13).

SES indicators, such as educational attainment and income level, have consistently been strong predictors of health behaviours and outcomes. However, the association between SES and some NCDs risk factors, such as diet and physical activity, may depend on context, particularly where a country is in the process of nutrition transition, a change from traditional dietary patterns to less healthy diets (14, 15). In HICs, low SES is a strong and consistent predictor of poorer diet, lower physical activity and high prevalence of obesity and NCDs; however, in LMICs, the associations are sometimes in the opposite direction (16). In Chapter 3, we found that people with higher SES, such as higher income and higher education, were less likely to be active at work or through active transportation, but more likely to engage in leisure-time physical activity, suggesting that the association between SES and physical activity is domain-specific. Interestingly, a previous study comparing data from three middle-income countries (Colombia, Mexico and South Africa) and two HICs (England and US) revealed differences across these countries: those who were less educated were less likely to participate in leisure-time vigorous exercise in Colombia, England and the US, while the opposite was true in Mexico (17). Further, low educational level was positively associated with obesity and diabetes in England and US, while inverse associations were observed in South Africa. These observed disparities may be related to the level of development of the countries, with many LMICs shifting from a subsistence economy to an industrialized economy, in contrast to HICs where this happened at least half a century ago (17-19). Ongoing surveillance data are needed to further assess these issues and compare the changes in LMICs with HICs.

Working status is another important factor contributing to health. In Chapter 3, we explored the relationship between working status and physical activity domains. It was not surprising to find that people who were working were more likely to be active at work and in transportation, but not in their leisure time; this could be explained because older participants in the SAGE China dataset were either retired or too old to work. To date, whether or not working in later life is good for health remains inconclusive and may depend on the type of employment, quality of the job and reason for re-employment after retirement (20). Minami found that working part-time was associated with the maintenance of mental health and higher-level functional capacity for people aged 65 and above in Japan (20). Baxter's systematic review including 16 studies from developed countries concluded that staying in the labour force, mostly part-time, may be beneficial for some older people (21). However, some older adults who extended their working years and continued working full time were

doing so for financial reasons, especially those with high-demand or low-reward work (21). In this case, working in later life could be detrimental to both physical and mental health.

Though several individual-level factors were identified, there are many other variables that were not captured in the current thesis as most of the datasets used in this thesis were designed for surveillance and did not include many variables that are conceptually or theoretically important to healthy aging. These variables, usually intrapersonal or interpersonal, can contribute to explaining some health behaviours among older adults. For example, according to the Health Belief Model, an individual's values and beliefs had an impact on physical activity level and could predict future health behaviours (22). A meta-analysis carried out by Gwaltney and colleagues indicated that a higher level of self-efficacy, a major component of the Social Cognitive Theory that measures one's confidence in their ability to change behaviours, was positively associated with future smoking cessation (23).

7.2.2 Interpersonal-level facilitators and barriers

Health-related behaviours and health status are influenced by factors surrounding but external to the individual, including their immediate social networks and influences (e.g., partners, children, friends and peers). These interpersonal factors are included in the second level of the socio-ecological framework (see Figure 1.3 in Chapter 1).

A good relationship with life partners contributes to the health of older adults in later life. Evidence on the relationship between marriage and mortality has been well established; married or partnered people have been found to live longer and have better health status compared with their un-partnered counterparts (24). Unmarried older adults (single, divorced, separated or widowed) were at a higher risk of poor mental health and well-being, including loneliness, depression and perceived stress (25, 26). Many studies also identified that the relationship between marital (partner) status and health was modified by gender where men seemed to benefit more from married/cohabiting relationships and suffer more from loss of relationships than women (27-30). Researchers argued that gender inequality within marriage should be considered as one explanation for the diminishing gains that women experienced (31). Surprisingly, in Chapter 3, we did not observe any statistically significant associations between marital status and domain-specific physical activity in China. However, the married/partnered group had higher odds of being active during leisure time in some other LMICs, such as Russia and Ghana. As is indicated in Cobb's study exploring the spousal

influence on physical activity among older adults in the US, one's physical activity was positively associated with his/her spousal's physical activity level (32). And Beverly also found similar results for dietary behaviours (33). Since an individual's behaviours can be influenced by their partner's behaviours, more information on spousal behaviours should be examined to further explore how marital/partner status influences health among older adults in China (34).

Relationships with adult children can also affect older adults' physical health and well-being either positively or negatively, depending on how older parents perceive their relationship with their children (35). Interestingly, a comparison study revealed cross-cultural differences showing that a closer relationship between older parents and their adult children was associated with better cognitive functions and fewer depressive symptoms in China, while no significant association was found in the US (36). This is possibly because older adults living in Western countries receive social support from a variety of community sources, while Chinese older adults receive both financial and mental support primarily from their adult children (37). In China, due to the unique cultural context, filial piety ("孝道"), the traditional extended family in which three generations coexist is the most common (38). Adult children are responsible for caring for their older parents, while retired grandparents serve a key function in taking care of grandchildren. Evidence from other studies in China showed that compared to non-caregivers, grandparent caregivers had better self-rated health and fewer physical limitations (39, 40). However, this could also be explained by reverse causality, as more able grandparents could then become better caregivers. Chang revealed that adult children proving both financial and emotional support were critical to protecting the mental health of the older adults who provided care for grandchildren (41).

Older adults have more leisure time, which may imply that they have more opportunities to be socially influenced by their friends and peers (42). In Chapter 3, we found that structural social capital, the network to access people and resources, was positively associated with leisure-time physical activity. This finding was confirmed in Chapter 4, where we found consistent associations between social engagement and multiple lifestyle behaviours as well as subjective well-being. The social engagement items asked about the frequency of meeting friends, co-workers or people living in the same neighbourhood. In Chapter 4, we found that active social participation could benefit people across several behaviours, including increased fruit and vegetable consumption, physical activity, shorter sitting time and better sleep. Moreover, higher levels of social engagement were consistently associated with better self-

rated health, higher quality of life and less reported depression. A number of studies, both from HICs and LMICs, have suggested that active social engagement was associated with better health, especially mental health in older adults (43-46). Since one's behaviours can be influenced by close family and friends, and over half of the men in China are current smokers, it is not surprising to find that social engagement was related to a higher risk of smoking, though the direction of the association is the opposite of those from other studies and other countries. For example, a multi-ethnic study in the US showed that social engagement was associated with lower smoking prevalence, and results from British Household Panel Survey (BHPS) suggested that active social participation was positively associated with smoking cessation (47, 48).

In this thesis, we were not able to model other potential interpersonal correlates in this thesis, such as subjective norms, which have been researched using the Theory of Planned Behaviour (TPB) (49). Motalebi suggested that subjective norms and perceived behavioural control, two important concepts of TPB, were strong determinants of exercise intention among older adults (50), and TPB could also predict intention to increase physical activity and behaviour change over time well in the intervention setting (51). Future exploration of integrating interpersonal-level theories in large-scale population-based surveys and epidemiological studies is needed.

7.2.3 Community-level facilitators and barriers

The settings in which social relationships occur, such as workplaces and neighbourhoods, have effects on middle-aged and older people's health. This is the third level of the socio-ecological framework.

As one of the community-level factors, the workplace environment may facilitate or hinder the maintenance of good health, as well as healthy lifestyle changes such as quitting smoking and excessive or binge drinking. Workplaces include both interpersonal (e.g., colleague's behaviours) and community-level components (e.g., work environment and culture), we, therefore, consider them to span across both levels according to the socio-ecological framework.

Any occupation-specific risk factors, such as carcinogens, airborne particulates, noise and ergonomic stressors can contribute to the burden of disease and injury (52), which account for approximately 9% of the global burden of mortality from unintentional injuries (53, 54).

As is indicated, 90% of reported occupational diseases in China were pneumoconiosis, because more than 200 million Chinese workers were exposed to dust, chemicals and toxins at work based on a 2018 estimate (55). Furthermore, the work culture in China is often characterized as hard work over long hours with minimal rest or recovery. Such a pattern of working has been recently coined the '996' working hours system, which refers to the requirement for employees to work from 9 am to 9 pm, 6 days per week (56). Manual workers in China usually don't take any days off during weekends because they are only paid for the actual days on which they work. This long-term work demand is neither health-promoting nor sustainable (56). Based on our study in Chapter 6, over one-third of the urban workers aged 30-79 were doing manual work, including plumbers, carpenters, miners and construction workers, and they worked an average of 9.6 hours per day. These structural workplace conditions may influence health status among older workers both during their working years and after retirement.

One recent development in the field of physical activity is the "physical activity paradox", which implies that in contrast to leisure-time physical activity, which is consistently associated with health benefits, OPA may not be as health-enhancing (57-61). Holtermann et al. proposed that manual workers may be at higher risk of psychological well-being and increased risk of CVDs and mortality through various stressors such as heavy physical activity, long working hours, poor working conditions and low autonomy (57, 62-65). However, our investigation into the "physical activity paradox" within the Chinese context revealed different findings. In Chapter 6, our study followed a population representative middle- to old-aged sample from urban China for more than 10 years and found that unlike the studies on occupational paradox to date, there was no significant association between higher levels of OPA and higher mortality risk in the overall sample. But we found that the associations between OPA and mortality outcomes differed by sex, educational level and leisure-time physical activity, which will be further discussed in the later section 7.2.5.

The business culture in China values establishing good relationships ('Guanxi') within the workplace. It was discussed in Chapter 5 that socializing with colleagues after work was quite common in China. Gifting your managers, directors, clients and business partners cigarettes and alcohol is widely considered necessary for building up connections, securing business deals and career advancement, which further encourages people to maintain unhealthy lifestyle behaviours (66, 67).

Due to age-related declines in physical function and not going to work, older people spend more time in their local neighbourhoods. Thus, the neighbourhood environment may play an important role in promoting health among older adults. Community-level social capital is important, especially for those living in disadvantaged neighbourhoods, and facing discrimination and violence (68, 69). There is continuing evidence showing that a lack of municipal-level trust, solidarity and safety was associated with worse health. A Japanese study found that rich civic participation was inversely associated with frailty among older adults (70), and studies from multiple LMICs (e.g., Chile, Indonesia, India, and South Africa) also showed that higher levels of social capital were associated with less cognitive dysfunction, less depressive symptoms, lower level of physical inactivity, improved subjective well-being and better self-reported health (71-75). However, in Chapter 3, we did not observe statistically significant associations between social capital and physical activity in China. Compared to many other LMICs, most cities in China are safe with very low rates of violent crime. This is reflected by findings in Chapter 3 where only 5.8% of participants reported low trust and 14.3% reported low perceived safety in the neighbourhoods. This likely 'ceiling effect', where the majority of the data are close to the upper limit, may explain the non-significant association between social capital and physical activity in our study (76).

7.2.4 Society-level facilitators and barriers

Inequality between urban and rural older adults remains a major problem in many countries, including China. Based on WHO SAGE data in Chapter 4 and The World Bank data, there were around 52.3% of older adults in China living in rural areas in 2009, which was similar to rural residency rates in Thailand (57.5%) and Indonesia (50.1%), higher than those in some other LMICs, such as South Africa (34.8%), Russia (27.3%) and Mexico (21.6%), but lower than those in Vietnam (70.2%), Myanmar (71.3%) and Cambodia (80.1%) (77). In Chapter 3, we examined the relationships between the place of residence and physical activity domains and found that people who lived in rural areas reported more activities at work but much less activity during leisure time, which is in line with other studies showing that place of residence is a particularly robust correlate of healthy lifestyle behaviours and functional health in China (78, 79). Feng and colleagues found that middle-aged and older Chinese adults living in rural areas were more likely to be daily smokers, and less likely to do sufficient physical activity and consume adequate vegetables and fruit (80). It has also been well-documented in HICs that rural residents tend to have poorer health outcomes (81-84).

Existing research has suggested that this might be linked to poorer access to preventive and health services and lower pensions/income after retirement among rural adults in China (85). The quantity and quality of healthcare services vary significantly by location in China, with world-class healthcare facilities in big cities, but only smaller district-level clinics and limited healthcare resources in rural regions (86, 87). Furthermore, there is a huge gap in pension income between urban and rural workers after they retire, where retired rural workers may not have enough to cover their basic daily living and may need ongoing financial support from their adult children (88).

7.2.5 Interaction of factors across different levels

As discussed in Chapter 1, different levels of the socio-ecological framework interact with each other, which leads to the observed outcomes, here assessed as mortality among older adults (3). In addition to understanding the effects of factors from the four levels, we also explored the interactive effects of individual- and community-level factors that influence health. In Chapter 6, we tested whether the association between OPA and mortality differed by sex and educational attainment. Though previous studies suggested the associations between OPA and mortality outcomes could be sex-specific in HICs, we did not observe that in the Chinese population (57, 64, 89). However, we found that education level is an important effect modifier, where high OPA was protective against all-cause mortality among those in the least educated group, but harmful among the most educated group. This interesting finding may be related to the different reference categories across education strata in our study, because sedentary workers with low education (likely to be factory workers and people with unstable/casual jobs) had the highest crude death rate, more than twice as high as the sedentary workers with the highest educational category (likely to be professionals and managerial workers). Furthermore, the 'Healthy Worker Effect', where those who were healthier and fitter were more likely to stay in full-time manual work, could also partially explain the results observed in our study (90). Studies from other countries also suggested that SES is an important modifying factor of psychological health in the workplace. Kim and Cho found that work-life conflict had a stronger negative association with mental health for people with high educational and income levels (91). Hasselgren and colleagues illustrated the significant interacting effect of class-based inequities and work exposure on dementia (92). Toivanen found that people from low occupational class and exposed to high work

stress were at high risk of reporting psychological distress, musculoskeletal pain and poor self-rated health (93).

7.2.6 Proposed solutions

This thesis has demonstrated the complexity of healthy aging in middle-aged and older Chinese adults. All health behaviours and outcomes examined are highly context-specific and influenced by a broad range of facilitators and barriers at different levels. Such behavioural facilitators and barriers do not exist in a vacuum and they interact with each other on health behaviours and outcomes. These factors are interrelated 'drivers' within a complex system (94). Understanding the complexity of the systems helps identify the 'root causes' of the problems and potential solutions to 'wicked problems' such as chronic diseases (95, 96).

Based on the findings from this thesis, it seems that multilevel interventions might be more likely to influence health behaviours that are critical to healthy aging in China. Based on the overall patterns of findings identified through my thesis, I suggest that future public health interventions consider the following issues when addressing health aging in China.

First, gender inequalities need to be addressed as they have been an underlying theme across findings from my thesis Chapters 3-6 (97, 98). Although the social status of women has been continuously improved in China, men are still regarded as superior to women as a result of the long-standing influences of the traditional culture (99). According to the data from the Survey on Social Status of Women in China, the gender gap in health has substantially enlarged in the past two decades (100). Women, particularly older women, are still disadvantaged in accessing public health care resources. Therefore, public health professionals and decision-makers should particularly consider the gender gaps in access to healthcare services and opportunities for living a healthy life at an older age. To date, the existing literature reveals a limited number of public health interventions targeting middle-aged to older women worldwide, which set good and valuable examples for future guidance. Barene and colleagues conducted a 12-week training intervention among female healthcare workers, where they found that soccer and Zumba training outside working hours can improve their total body fat percentage and total body fat mass (101). Friedenrich conducted a one-year program in breast cancer screening settings, which showed substantial improvement in adiposity biomarkers among women in the intervention group (102).

Second, health interventions in China should not only target older adults themselves but also consider people in their immediate (local) supportive social environment, according to the results from Chapters 3 and 4. Research has shown that couple-focused and family-based interventions can be effective in promoting healthy lifestyle behaviours in older adults, including physical activity and a healthy diet (103, 104). For example, Franks and colleagues revealed that partners who participated in the intervention together demonstrated increases in physical activity among older adults (103). It was also demonstrated that compared with individual-based interventions, couple and family interventions could motivate participants to better adhere to the intervention protocol and achieve greater improvements in behavioural change (105). Such family-based approaches may be particularly relevant to a Chinese context as the traditional Chinese culture values family relationships and multi-generational living is common in China (106).

Third, healthcare services in China need to focus more on prevention and community health (107, 108). For decades, the healthcare system in China was primarily hospital-centred and fragmented (109). In 2016, the family doctor registration system was introduced in China and many community health centres were established to provide Chinese residents with preventative medicine and basic medical care. However, these resources were underused and far from reaching the goal of universal coverage (110). In the future, along with the expansion of establishing more community health centres, existing centres could be transformed into integrated medical care with primary care and eldercare services together, similar to the community senior centres in many HICs (110, 111). For example, there are more than 300 senior centres in New York City that provide healthy meals, educational programs and social services. Pardasani concluded that older adults benefit from socializing and making friends in senior centres, leading to improved physical and mental health (111).

Fourth, improving reliable institutional elder care and long-term care systems is critical to tackling population aging in China and substantial government support is needed (112, 113). With the outmigration of adult children in the past two decades, China has been transitioning from predominantly traditional family care to complementarily institutional and long-term care for older adults. Experiences from countries with aged populations and strong long-term care systems, such as Japan, Korea and Germany should shed light on China. In the aforementioned countries, the governments played an important role in prompting senior care by launching mandatory public long-term care insurance system and following strict regulations (114). Findings from studies showed that formal care services, including home

visits and day care for seniors, were associated with lower mortality and better mental well-being, and could prevent older adults from being institutionalized (115).

Fifth, equal access to primary care services for rural older residents is important, based on our findings in Chapter 3. Although the Chinese government has made considerable efforts to provide rural residents with improved access to healthcare services in the past decade, substantial differences between urban and rural regions persist. For example, China initiated the National Essential Public Health Package in 2009 to narrow the gap in accessing public health services between urban and rural areas, but the efficiency was much lower in rural areas in contrast to urban areas from 2014 to 2019 (116). Data suggest that the coverage rate of some basic primary healthcare infrastructures, diagnostic tools and medicines remains low in rural regions. In 2021, there were only 43.0% of the rural township health centres had refrigerators, 5.7% had x-ray machines and 11.0% had insulin injections, compared to much higher proportions in the urban community health centres (68.2% for refrigerators, 45.5% for x-ray machines and 45.5% for insulin injections) (117). Moreover, the primary healthcare professionals were distributed unevenly between urban and rural areas (118). Thus, more convenient and higher-quality prevention services should be provided to benefit older adults living in underdeveloped rural areas (119, 120).

Last but not the least, interventions targeting one level of the socio-ecological framework may not be sufficient for sustained improvements. Building an "age-friendly" society requires contributions from stakeholders from different sectors and combined efforts from the whole society. As is promoted by the WHO, in an age-friendly city, policies, services, settings and structures should work together to enable and support people to age actively and healthily (121). Akita in Japan is a good example of an age-friendly city, where the one-coin bus service is provided to older adults aged over 65 years old so that they could go out and travel around the area at an affordable price (122). In addition, an intergenerational group has been formed in Akita city to encourage friendships between generations and enhance social networks, and facilities, such as public benches and free fitness equipment, have been provided in neighbourhoods to motivate older people to be active and sociable outside their homes.

In short, multisectoral and multistakeholder partnerships are needed to implement complex preventive health interventions and promote healthy aging in China. Representatives from the government, non-governmental organizations, academic institutions and private sectors

should all contribute to providing the older population with social, environmental and economic opportunities to maintain a healthy lifestyle and enjoy good health.

7.3 Strengths and limitations

One of the strengths of this thesis was the use of different population-based surveys with large representative samples to understand healthy aging. Through the WHO SAGE (Wave 1), CHARLS and CKB studies, a comprehensive range of sociodemographic, economic, cultural as well as health-related data were available, providing complementary information to gain a better picture of behavioural, social health and well-being among middle-aged and older adults in China. It should be noted that CHARLS is a large longitudinal cohort study, which allows us to examine changes in behaviour and health status of the target population. Furthermore, CKB provides access to some additional physical measurements (i.e. BMI, random blood glucose, etc.) as well as linkage to administrate health data, such as death registries. This use of multiple and large population-based surveys allowed for the triangulation of data and provided opportunities to explore a broad range of risk factors and their facilitators and barriers.

Several methodological limitations need to be acknowledged. First, the data used in this thesis were not collected by the authors, so not all conceptually important variables were collected and sample size calculations were not conducted a priori. Second, although WHO SAGE was designed to be an ongoing project to collect comprehensive longitudinal information on the aging process of older adults, the project was suspended because of the COVID-19 outbreak, and only Wave 1 data (2007-2010) was publicly available until late 2022, which may not reflect the current disease burden and associations between risk factors and health outcomes. Furthermore, this also limited the opportunities to explore long-term health and behavioural patterns and longitudinal associations using the WHO SAGE data. A similar situation applied to the CKB, which only provided the all-cause mortality data until 31st December 2016 and cause-specific mortality data until 31st December 2014 at the time of our analysis. Thus, the longer-term effect of OPA on mortality outcomes could not be explored. Third, information on socio-demographic factors, lifestyle behaviours and mental well-being were all self-reported, and were therefore subject to reporting bias. However, most measures were commonly used for such population surveillance data, and most of them have been validated in older adults (123-125). Last, in all studies residual confounding is still

possible because some important potential confounders were not measured or poorly measured; for example, occupational characteristics (work-related stress, the degree of job strain, and other hazards) were not measured in CKB.

7.4 Directions for future research

Guided by the socio-ecological framework, this thesis sheds light on some of the facilitators of and barriers to behavioural, social health and well-being among middle-aged and older adults in China. There are emerging nationally representative public health data resources in China, and capitalizing on these data is an important way of informing evidence-based practice. Thus, future research could benefit from incorporating theories and more comprehensive and valid measures repeated over years. Linkage to quality registries, such as hospital records, primary care and death registration data, offers the opportunity to evaluate long-term health outcomes continuously and accurately.

As discussed earlier, it is important to integrate studies across the levels of socio-ecological framework and work towards a systems-based understanding of complex health behaviours. Thus, additional research is needed to examine how different levels of risk factors from the socio-ecological framework interact with each other. More advanced simulation techniques and complex systems models could be applied to public health topics by integrating individual and collective behaviours with complex ecological and social dynamic systems (126-128). This will accelerate research in understanding the dynamic behaviours of complex systems to inform multilevel interventions. For example, Tobias and colleagues from the New Zealand Ministry of Health used system dynamic modelling to understand smoking behaviours and predicted that combined enhanced smoking cessation intervention scenarios, including raising tax rates on tobacco products and developing less addictive and less toxic cigarettes with lower nicotine levels, would significantly lower smoking prevalence, the total amount of tobacco consumption and tobacco attributable mortality (129, 130).

7.5 Conclusions

This thesis suggests that different levels of risk factors from the socio-ecological framework, including individual, interpersonal, community and societal levels, contribute to health among middle-aged and older adults in China. Not only do the studies included in this thesis add to limited existing literature using multiple large-scale population-based public health

survey data in China, but these studies also provide new insights for researchers and policymakers to better understand the complexity of real-world problems. My thesis has outlined the groundwork for future research on healthy aging in China, with the potential to inform further interventions, programs and policies.

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APPENDIX 1: Questionnaire from the World Health Organization Study on Global Ageing and Adult Health used in Chapters 3 and 4

Section 0100: Sampling Information

Q0104. Setting:

1 Urban (An urban area that has been legally proclaimed as being urban. Such areas include towns, cities and metropolitan areas.)

2 Rural (All other areas that are not classified as being urban. This includes commercial farms, small settlements, rural villages and other areas which are further away from towns and cities.)

Section 1000: Socio-Demographic Characteristics

Q1009. Interviewer: Record sex of the respondent

1 Male

2 Female

Q1011. How old are you now?

_____ age in years

Q1012. What is your current marital status?

1 Never married

2 Currently married

3 Cohabiting

4 Separated/Divorced

5 Widowed

Q1015. Have you ever been to school?

1 Yes

2 No

Q1016. What is the highest level of education that you have completed?

1 Less than primary school

2 Primary school completed

3 Secondary school completed

4 High school (or equivalent) completed

5 College/Pre-univeristy/University completed

6 Post graduate degree completed

Section 1500: Work History and Benefits

Q1503. Have you worked for at least 2 days during the last 7 days?

1 Yes

2 No

Section 2000: Health State Descriptions

Q2000. In general, how would you rate your health today?

1 Very good

2 Good

3 Moderate

4 Bad

5 Very bad

Q2018. Overall in the last 30 days, how much of a problem did you have with feeling sad, low or depressed?

1 None

2 Mild

3 Moderate

4 Severe

5 Extreme/Cannot do

Section 3000: Risk Factors and Preventive Health Behaviours

Q3001. Have you ever smoked tobacco or used smokeless tobacco?

1 Yes

2 No

Q3002. Do you currently use (smoke, sniff or chew) any tobacco products such as cigarettes, cigars, pipes, chewing tobacco or snuff?

1 Yes, daily

2 Yes, but not daily

3 No, not at all

Q3009. During the past 7 days, how many drinks of any alcoholic beverage did you have each day? (Record the number of standard drinks)

Q3009a. Monday ____ drinks

Q3009b. Tuesday ____ drinks

Q3009c. Wednesday ____ drinks

Q3009d. Thursday ____ drinks

Q3009e. Friday ____ drinks

Q3009f. Saturday ____ drinks

Q3009g. Sunday ____ drinks

Q3012. How many servings of fruit do you eat on a typical day? (banana, mango, apple, orange, papaya, tangerine, grapefruit, peach, pear) ____ Servings

Q3013. How many servings of vegetables do you eat on a typical day? (tomato, cauliflower, potato, cucumber, peas, corn lettuce, squash, bean) ____ Servings

Next I am going to ask you about the time you spend doing different types of physical activity in a typical week. Please answer these questions even if you do not consider yourself to be an active person. Think first about the time you spend doing work. Think of work as the things that you have to do such as paid or unpaid work, household chores, harvesting food/crops, fishing or hunting for food, providing care or seeking employment. In answering the following questions 'vigorous activities' require hard physical effort and cause large increases in breathing or heart rate, 'moderate activities' require moderate physical effort and cause small increases in breathing or heart rate.

Q3016. Does your work involve vigorous-intensity activity that causes large increase in breathing or heart rate, [like heavy lifting, digging or chopping wood] for at least 10 minutes continuously?

1 Yes

2 No

Q3017. In a typical week, on how many days do you do vigorous-intensity activities as part of your work? ____ days

Q3018. How much time do you spend doing vigorous-intensity activity that causes small increases in breathing or heart rate [such as brisk walking, carrying light loads, cleaning, cooking, or washing clothes] for at least 10 minutes continuously? ___ hours ___ minutes

Q3019. Does your work involve moderate-intensity activity that causes small increases in breathing or heart rate [such as brisk walking, carrying light loads, cleaning, cooking, or washing clothes] for at least 10 minutes continuously?

1 Yes

2 No

Q3020. In a typical week, on how many days do you do moderate-intensity activities as part of your work? ____ days

Q3021. How much time do you spend doing moderate-intensity activities at work on a typical day? ____ hours ____ minutes

The next questions exclude the physical activities at work that you've already mentioned. Now I would like to ask you about the usual way you travel to and from places. For example, getting to work, to shopping, to the market, to place of worship.

Q3022. Do you walk or use a bicycle (pedal cycle) for at least 10 minutes continuously to get to and from places?

1 Yes

2 No

Q3023. In a typical week, on how many days do you walk or bicycle for at least 10 minutes continuously to get to and from places? ____ days

Q3024. How much time would you spend walking or bicycling for travel on a typical day? ____ hours ____ minutes

The next questions exclude the work and transport activities that you have already mentioned. Now I would like to ask you about sports, fitness, leisure and recreational activities.

Q3025. Do you do any vigorous intensity sports, fitness or recreational (leisure) activities that cause large increases in breathing or heart rate [like running or football], for at least 10 minutes continuously?

1 Yes

2 No

Q3026. In a typical week, on how many days do you do vigorous intensity sports, fitness or recreational (leisure) activities? ____ days

Q3027. How much time do you spend doing vigorous intensity sports, fitness or recreational activities on a typical day? ____ hours ____ minutes

Q3028. Do you do any moderate-intensity sports, fitness or recreational (leisure) activities that causes a small increase in breathing or heart rate [such as brisk walking, cycling or swimming] for at least 10 minutes at a time?

1 Yes

2 No

Q3029. In a typical week, on how many days do you do moderate-intensity sports, fitness or recreational (leisure) activities? ____ days

Q3030. How much time do you spend doing moderate intensity sports, fitness or recreational (leisure) activities on a typical day? ____ hours ____ minutes

The following question is about sitting or reclining at work, at home, getting to and from places, or with friends including time spent [sitting at a desk, sitting with friends, travelling in car, bus, train, reading, playing cards or watching television], but do not include time spent sleeping.

Q3031. How much time do you usually spend sitting or reclining on a typical day? ____ hours ____minutes

Section 6000. Social Cohesion

How often in the last 12 months have you … (Q6001-Q6009)

1 Never
2 Once or twice per year
3 Once or twice per month
4 Once or twice per week
5 Daily

Q6001. … attended any public meeting in which there was discussion of local or school affairs?

Q6002. … met personally with someone you consider to be a community leader?

Q6003. …attended any group, club, society, union or organizational meeting?

Q6004. … worked with other people in your neighborhood to fix or improve something?

Q6005. … had friends over to your home?

Q6006. … been in the home of someone who lives in a different neighbourhood than you do or had them in your home?

Q6007. … socialized with coworkers outside of work?

Q6008. … attended religious services (not including weddings and funerals)?

Q6009. … gotten out of the house/your dwelling to attend social meetings, activities, programs or events or to visit friends or relatives?

Q6012. Generally speaking, would you say that most people can be trusted or that you can't be too careful in dealing with people?

1 Can be trusted
2 Can’t be too careful

Q6014. First, think about people in your neighbourhood. Generally speaking, would you say that you can trust them?

1 To a very great extent
2 To a great extent

3 Neither great nor small extent

4 To a small extent

5 To a very small extent

Q6015. Now, think about people whom you work with. Generally speaking, would you say that you can trust them?

1 To a very great extent

2 To a great extent

3 Neither great nor small extent

4 To a small extent

5 To a very small extent

Q6016. And how about strangers? Generally speaking, would you say that you can trust them?

1 To a very great extent

2 To a great extent

3 Neither great nor small extent

4 To a small extent

5 To a very small extent

Q6017. In general, how safe from crime and violence do you feel when you are alone at home?

1 Completely safe

2 Very safe

3 Moderately safe

4 Slightly safe

5 Not safe at all

Q6018. How safe do you feel when walking down your street alone after dark?

1 Completely safe

2 Very safe

3 Moderately safe

4 Slightly safe

5 Not safe at all

Section 7000: Subjective Well-Being and Quality of Life

Now, we'd like to ask for your thoughts about your life and life situation. We want to know how you feel about your health and quality of life.

Q7001. Do you have enough energy for everyday life?

1 Completely
2 Mostly
3 Moderately
4 A little
5 None at all

Q7002. Do you have enough money to meet your needs?

1 Completely
2 Mostly
3 Moderately
4 A little
5 None at all

Please tell us how satisfied you are with the following issues.

How satisfied are you with… (Q7003-Q7007)

1 Very satisfied
2 Satisfied
3 Neither satisfied nor dissatisfied
4 Dissatisfied
5 Very dissatisfied

Q7003. … your health?

Q7004. … yourself?

Q7005. … your ability to perform your daily living activities?

Q7006. … your personal relationship?

Q7007. … the conditions of your living place?

Q7009. How would you rate your overall quality of life?

1 Very good
2 Good
3 Moderate
4 Bad
5 Very bad
6 Don't know

Q7518. How many hours did you sleep last night? ____ hours ____minutes

APPENDIX 2: Questionnaire from the China Health and Retirement Longitudinal Study used in Chapter 5

A. Household roster
A002. Gender of this household member: (1) Male (2) Female **A004.** What is [name]'s marital status? (1) Married with spouse present (2) Married but not living with spouse temporarily for reasons such as work (3) Separated (4) Divorced (5) Widowed (6) Never married
B. Demographic backgrounds
BA002. When were you born? _____year _____month _____day **BB002.** What is the type of your birth place? Is it rural village or urban community? (1) Rural Village (2) Urban Community **BD001.** What is the highest level of education you have attained? (1) No formal education (illiterate) (2) Did not finish primary school but capable of reading and/or writing (3) Sishu/home school (4) Elementary school (5) Middle school (6) High school (7) Vocational school (8) Two-/Three-Year College/Associate degree (9) Four-Year College/Bachelor's degree (10) Master's degree (11) Doctoral degree/Ph.D.
D. Health status and functioning
DA007. Have you been diagnosed with [conditions listed below] by a doctor? [IWER: Read one by one. 1=yes, 2=no.]

(1) Hypertension

(2) Diabetes or high blood sugar

(3) Cancer or malignant tumor (excluding minor skin cancers)

(4) Chronic lung diseases, such as chronic bronchitis, emphysema (excluding tumors, or cancer)

(5) Heart attack, coronary heart disease, angina, congestive heart failure, or other heart problems

(6) Stroke

(7) Stomach or other digestive disease (except for tumor or cancer)

(8) Arthritis or rheumatism

INTRO. Next, I would like to ask whether you have had the habit of smoking cigarettes/smoking a pipe/chewing tobacco, now or in the past. By smoking we mean smoking more than 100 cigarettes in your life)

DA059. Have you ever chewed tobacco, smoked a pipe, smoked self-rolled cigarettes, or smoked cigarettes/cigars?

(1) Yes

(2) No……Skip to DA067

DA060. Which products did/do you normally use?

(1) Smoking a pipe

(2) Smoking self-rolled cigarettes

(3) Filtered cigarette

(4) Unfiltered cigarette

(5) Cigar

(6) Water cigarettes

DA061. Do you still have the habit or have you totally quit?

(1) Still have……Skip DA062

(2) Quit

DA062. At what age did you totally quit smoking? _____years

Now, I am going to ask you how often and how much you drank during the past year. Please tell me how often you drank per month, and how much you drank at a time on average. I will repeat the questions for different types of alcoholic beverages.

DA072. How often did you drink liquor, including white liquor, whisky, and others per month in the last year?

(1) Once a month

(2) 2-3 times a month

(3) Once a week

(4) 2-3 times a week

(5) 4-6 times a week

(6) Once a day

(7) Twice a day

(8) More than twice a day

DA073. The last time you drank liquor last year, how many liang of liquor did you drink? (1 liang=50cc/50 ml) _____ liang

DA074. How many times per month did you drink beer in the last year?

(1) Once a month

(2) 2-3 times a month

(3) Once a week

(4) 2-3 times a week

(5) 4-6 times a week

(6) Once a day

(7) Twice a day

(8) More than twice a day

DA075. The last time you drank beer last year, how many bottles of beer did you drink? (1bottle=2.5 mugs, 1mug=220cc) _____ bottles or _____ mugs

DA076. How often did you drink wine or rice wine per month in the last year?

(1) Once a month

(2) 2-3 times a month

(3) Once a week

(4) 2-3 times a week

(5) 4-6 times a week

(6) Once a day

(7) Twice a day

(8) More than twice a day

DA077. The last time you drank it last year, how many liang of wine did you drink? (1 liang=50cc/50 ml) _____ liang

F. Work, retirement and pension

FA001. Did you engage in agricultural work (including farming, forestry, fishing, and husbandry for your own family or others) for more than 10 days in the past year?

(1) Yes……Skip to FB001

(2) No

FA002. Did you work for at least one hour last week? We consider any of the following activities to be work: earn a wage, run your own business and unpaid family business work, et. al. Work does not include doing your own housework or doing activities without pay, such as voluntary work.

(1) Yes……Skip to FB001

(2) No

FB011. Have you completed retirement procedures （including early retirement） or internal retirement（Note: Retirement from government departments, enterprises and institutions, not including retirement in the sense of getting agricultural insurance）?

(1) Yes……skip FB012

(2) No

FB012. Have you completed receding position procedures？您是否办理了退职手续？

(1) Yes

(2) No

APPENDIX 3: Questionnaire from China Kadioore Biobank study used in Chapter 6

Section 1: Background information
1.2 Sex: □ Male □Female
1.3 Date of Birth: _____
1.6 What is the highest level of school education you ever received?
□ No formal school □ Primary School
□ Middle School □ High School
□ Technical school/college □ University
1.7 What is your current occupation?
□ Agriculture & related workers □ Factory worker
□ Administrator/manager □ Professional/Technical
□ Sales & service workers □ Retired
□ House wife/husband □ Self-employed
□ Unemployed □ Other or not stated
1.9 What is your current marital status?
□ Married □ Separated/divorced
□ Widowed □ Never married
1.10 What is the total income last year in your household?
□ <2,500 yuan □ 2,500-4,999 yuan
□ 5,000-9,999 yuan □ 10,000-19,999 yuan
□ 20,000-34,999 yuan □ ≥35,000 yuan
Section 3: Alcohol consumption
3.1 Have you drunk any alcohol today? □ Yes □ No
3.2 During the past 12 months, how often did you drink any alcohol?
□ Never or almost never □ Only occasionally
□ Only at certain seasons □ Every month but less than weekly
□ Usually at least once a week □ Go to Q3.4
Section 4: Smoking history
4.1 Have you smoked any tobacco today? □ Yes □ No
4.2 How often do you smoke tobacco now?
□ Do not smoke now □ Only occasionally
□ Yes, on most days □ Yes, daily or almost every day
□ Go to Q4.7

4.3 In the past, how frequently did you smoke?

□ Did not smoke □ Smoked only occasionally

□ Smoked on most days □ Smoked daily or almost every day

4.4 In your life time, have you smoked a total of at least 100 cigarettes or equivalent?

□ Yes □ No

Section 5: Diet

5.1 During the past 12 months, about how often did you eat the following foods?

	Daily	4-6 days	1-3 days	Monthly	Never/rarely
Fresh fruit	□	□	□	□	□
Fresh vegetable	□	□	□	□	□

Section 7: Personal & family medical history

7.4 Has a doctor EVER told you that you had had the following disease?

	Diagnosed disease?		Age at first diagnosis	Still on treatment?	
	Yes	No		Yes	No
CHD	□	□	_____	□	□
Stroke or TIA	□	□	_____	□	□
Rheumatic heart dis.	□	□	_____	□	□
Cancer	□	□	_____	□	□

Section 8U: Physical activities (Urban)

8.1 During the past 12 months, how active were you at work?

□ Mainly sedentary (e.g. office worker)

□ Standing occupation (e.g. guard, shop assistant)

□ Manual work (e.g. plumber, carpenter)

□ Heavy manual work (e.g. miner, construction worker)

□ Retired or housewife/husband or unemployed or disabled

8.2 In a typical week, about how many hours did you usually work? _____ hours

Section 8C: Physical activities (Common to both rural farmers and urban)

8.8 During the past 12 months, how often did you do exercise in your leisure time?

□ Never or almost never □ 1-3 times/month

□ 3-5 times/week □ 1-2 times/week

□ Daily or almost every day

8.9 What is your main type of exercise? (tick one box only)

□ Taichi/Qigong □ Walking

□ Jogging/aerobic exercise	□ Swimming
□ Ball games (basketball, table tennis, etc)	□ Other (eg. mountain climbing)
Section 11: Physical examination	
11.1 Standing height (without shoes) …….. □□□□ m	
11.5 Weight (without shoes, but in light clothing) …….. □□□□ Kg	
11.6 BMI ……. □□□ Kg/m^2	

APPENDIX 4: Additional publications

Additional peer-reviewed publications outside the scope of my thesis, for which I co-authored during my PhD candidature, are listed below.

List of additional published peer-reviewed papers

Surkalim DL, **Luo M**, Eres R, et al. The prevalence of loneliness across 113 countries: systematic review and meta-analysis. *BMJ*. 2022;376:e067068. doi:10.1136/bmj-2021-067068

Wu Y, **Luo M**, Tan X, Chen L. Stair climbing, genetic predisposition, and the risk of incident type 2 diabetes: A large population-based prospective cohort study. *Journal of Sport and Health Science*. 2022;S2095-2546(22)00102-8. doi:10.1016/j.jshs.2022.10.002

Mu X, Liu S, Fu M, **Luo M**, Ding D, Chen L, et al. Associations of physical activity intensity with incident cardiovascular diseases and mortality among 366,566 UK adults. *International Journal of Behavioral Nutrition and Physical Activity*. 2022;19(1):151. doi:10.1186/s12966-022-01393-y

Lv Y, Ding D, **Luo M**, Tan X, Xia Y, Chen L. Physical activity intensity, genetic predisposition, and risk of non-alcoholic fatty liver disease: A prospective cohort study. *Clinical Gastroenterology and Hepatology*. 2023;S1542-3565(23)00069-1. Advance online publication. doi:10.1016/j.cgh.2023.01.011

Luo M, Yu C, Del Pozo Cruz B, Chen L, Ding D. Accelerometer-measured intensity-specific physical activity, genetic risk and incident type 2 diabetes: a prospective cohort study. *British Journal of Sports Medicine*. Published Online First: 05 June 2023. doi:10.1136/bjsports-2022-106653