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ORIGINAL ARTICLE

Urban–rural differentials in age-related biological risk among middle-aged and older Chinese

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Abstract

Objectives To assess urban–rural differentials in age-related biological risk among middle-aged and older Chinese and links to individual and community characteristics.

Methods Data come from the national baseline survey of the China Health and Retirement Longitudinal Study. Biological risk is assessed using a set of measured biomarkers that reflect cardiovascular, metabolic, and inflammatory processes.

Results Urban residents who are officially registered in urban areas have greater biological risk than rural residents. Having junior school or higher education provides an independent and persistent protective effect against biological risk and eliminates the effect of community-level measures. The reduced physical activity of urban dwellers with urban origins explains a substantial part of the difference in risk.

Conclusions Urban dwellers with urban household registration have elevated risk compared with their rural peers, indicating that lifetime exposure to urban areas is an important risk factor for increased biological risk in China. The urban–rural differential in risk is accounted for by adjusting for health behaviors, particularly physical activity. The reduced physical activity among urban dwellers with urban household registration appears to be highly related to their elevated risk. No significant associations between community-level characteristics and biological risk are found beyond individual characteristics.

Keywords Biomarkers · China · Health disparity · Urban–rural difference · CHARLS

Introduction

Urban–rural residency is a crucial health determinant in many developing countries including China. Over the course of its long history of unbalanced development, urban and rural China have been shown to differ strikingly in physical environment, education, income, diet, and lifestyles, which influence people's health and the aging process. The urban Chinese population generally has more education, higher income, and greater access to health services than the rural population (Gong et al. 2012) leading to an "urban advantage" in certain downstream aspects of health including life expectancy (Li and Dorsten 2010), cognitive functioning (Jia et al. 2014), depressive symptoms (Li et al. 2016), and disability (Kaneda et al. 2010). However, Western-style diets, lack of physical labor, and pollution are also more prevalent in urban areas. Studies have shown that urban residents are more likely to be overweight or obese and to have hypertension and diabetes (Hou 2008; Zhao et al. 2016). This study investigates urban-rural differences in multiple indicators of physiological dysregulation which are precursors or indicators of chronic diseases associated with aging.

Lifetime residence is not fixed, however. China has experienced massive urban growth from the movement of people to urban areas from rural areas. People who migrate to urban areas tend to move in early adulthood so they spend their early lives in rural areas and later lives in urban areas. Individuals who migrate to urban areas are likely to

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have physically demanding jobs but limited access to education, job opportunities, social programs, and municipal services because they cannot easily change their administrative registration, called "hukou," to their new place of residence (Hu et al. 2008). As a governmental household registration system, hukou status is not easy to change and it is the way individuals connect to social programs provided by the government and is a source of inequality between urban and rural China. An individual living in an urban area who still has a rural hukou is usually a migrant worker born and raised in a rural area who has moved to an urban area in adulthood. Because people living in different places are exposed at different points in life to varying physical, social, and service environments, differentials in health by urban–rural residency as well as hukou are likely to arise.

The urban/rural setting in China is related to socioeconomic (SES) differences. In China, the urban population has better education than the rural population. There is ample evidence that education is linked to better health (Cutler and Lleras-Muney 2006; Brown et al. 2012). Education protects against adverse health outcomes by influencing individuals' health behaviors and access to health care, by improving ability to use health-related information to manage health conditions, and by facilitating the acquisition of social and psychological resources (Mirowsky and Ross 2003; Ross and Wu 1995). Education is also linked to better economic situations. Higher income and wealth are paths through which socioeconomic conditions affect health (Sorlie et al. 1995). Individuals with greater economic resources may have better access to high-quality food and health care and suffer from fewer stressful life events (Seeman et al. 1997). Alternatively, in a developing country setting, higher income is also positively linked to unhealthier behaviors, such as smoking, drinking, and diets high in fat, sugar, and refined carbohydrates (Chen et al. 2010). We expect to find that the Chinese with higher SES will have lower biological risk and that higher SES will partially explain the urban–rural differentials. We further hypothesize that education will provide stronger protective effects than economic resources, because education reflects life-cycle socioeconomic circumstances and provides a more appropriate measure of cumulative and longstanding SES (Hayward et al. 2000).

While both rural and urban China have gone through epidemiological transitions resulting in chronic diseases being the leading causes of death (National Bureau of Statistics of China 2016; Yang et al. 2008), urban and rural residents face different risks of developing chronic conditions and different resources for management of conditions. The urban population has experienced greater changes in diet, lifestyle, and physical environment, which may place them at higher risk of chronic diseases. However, the lack of development in some rural environments is also likely to negatively impact heath as it offers less infrastructure for housing, sanitation, and health care. Older persons in China living in less developed communities, i.e., poor waste management, reliance on hay or coal for cooking fuel, and no tap water, have worse health (Smith et al. 2013). In this study, we expect to find those whose behavior is healthier (i.e., physically active) and who live in communities with better infrastructure will have lower biological risk. We also hypothesize that behavioral factors and community characteristics will partly explain urban–rural differentials in biological risk.

This study is unique in addressing differentials in biological risk by urban–rural residence and origin using data from a nationally representative survey in China. The acceleration of the chronic disease epidemic along with rapid population aging in China results in an urgent need to better document the biological risk profiles for middle-aged and older Chinese using data from a recent representative sample. As China ages rapidly, understanding behavioral and environmental factors that contribute to urban–rural differentials is crucial for planning public health initiatives and allocating health care to address the growing epidemic of chronic diseases.

This study incorporates information on hukou and current residency to help separate the effects of lifetime urban residence and later urban residence. It is also unique in incorporating indicators of individual and current community characteristics as most research among older Chinese includes individual characteristics but not neighborhood environmental aspects as factors influencing health and aging. By using measured physiological dysregulation, this study can provide a valuable picture of the current health of the Chinese population in urban and rural settings and clarify differentials in the aging process as well as the likely consequences of further urbanization. China provides a context for this study which is likely to be informative for other countries because it has a very significant rural population that is undergoing rapid urbanization as is common in many places in the developing world.

Methods

Dataset

Data for this study come from the first wave of the China Health and Retirement Longitudinal Study (CHARLS), a nationally representative survey of the Chinese population aged 45 and older living in households, conducted by Peking University in 2011–2012. CHARLS adopted a stratified multistage probability sampling design using all counties in mainland China except for those in Tibet. These were stratified by region, urban–rural, and county per capita GDP. From these, 150 rural counties/urban districts were randomly selected, and three rural villages/urban communities were randomly chosen from each county/district, resulting in 450 rural villages/urban communities in total. Sampling at the household level was done from a list all dwelling units in all residential buildings. After applying sampling weights, CHARLS baseline sample demographics match closely those of the population census in 2010 (Zhao et al. 2014b). The response rate for the baseline survey was 80.5% (94% in rural areas and 69% in urban areas) (Zhao et al. 2013). The study protocol was approved by the ethical review committee (IRB) of Peking University.

CHARLS questionnaires reflect information for individuals, households, and communities/villages. The community survey was administered with the person in charge of the community/village committee (Zhao et al. 2013). Anthropometric measurements and non-blood-based biomarkers, including blood pressure and pulse rate, were collected in the household along with the main household surveys. Blood-based biomarkers were collected in a subsequent visit to a local health facility. Medically trained staff from the Chinese Center for Disease Control and Prevention (China CDC) collected three tubes of venous blood based on a standard protocol. Respondents were asked to fast overnight before the blood draw, but a blood sample was collected even if a respondent did not fast. Blood was prepared at the local health facilities and shipped to Beijing where blood-based biomarkers were assayed from plasma. Further details of study design, collection, and processing procedures are available in Zhao et al. (2014a).

Analytic sample

The survey collected information from 17,290 respondents aged 45 and above, of whom 9928 provided a blood sample and a physical assessment. We excluded participants who did not provide a blood sample at a subsequent clinic visit ($N = 7362$), did not fast or for whom fasting status was not recorded ($N = 1009$), those with missing data on one or more of the biomarker measures ($N = 407$), and 13 respondents who did not provide information on gender or hukou. The final analytic sample consists of 8499 individuals. Respondents who were excluded from the analytic sample are more likely to be male and urban residents. No significant age or educational differences are observed. Women and rural respondents were more likely to provide blood (69% for women, 65% for men; 71% for rural respondents, 60% for urban respondents). A biomarker weight was created by the CHARLS team to correct for both initial non-participation in the survey and non-participation in blood collection. It combines the individual-level sampling weight with a correction for non-participation in the blood sample collection using an inverse probability weighting factor constructed from a logit regression of whether the individuals in the blood collection (Zhao et al. 2014a). Details on sample selection and missing data analysis are given in "Appendix of Electronic Supplementary Material."

Measures

Biological risk

We capture age-related physiological dysregulation using a set of biomarkers that reflect cardiovascular, metabolic, and inflammatory processes. These include systolic blood pressure, diastolic blood pressure, pulse rate, total cholesterol, high-density lipoprotein (HDL) cholesterol, low-density lipoprotein (LDL) cholesterol, triglycerides, plasma glucose, body mass index (BMI), and C-reactive protein (CRP). These indicators of biological risk are recognized as risk factors for major health outcomes in old age: cardiovascular diseases, metabolic diseases, loss of cognitive and physical function, and mortality (Seeman et al. 2001). A dichotomous indicator for each biomarker indicates "high risk" or "not high risk" based on clinical cutoff values (Table 1). The prevalence of high-risk levels for each biomarker is presented in Table 1. More than a quarter of the sample has high systolic blood pressure (29.0%) and low HDL cholesterol (25.8%). High CRP is found in 18.7% of the sample; 13.6% of the sample has high diastolic blood pressure; and about 14% has high triglycerides. There are relatively few individuals with a rapid pulse (5.5%) or who are obese (4.9%). The total number of biological risks is calculated by summing the numbers of biomarkers in the high-risk range. Measures such as this have been used to describe differences in risk within populations (Beltrán-Sánchez and Crimmins 2013; Crimmins et al. 2009; Geronimus et al. 2006; Seeman et al. 2001).

Urban–rural

Urban–rural participants are categorized based on their usual place of residence and their assigned hukou. Three categories were created: rural residency, urban residency and rural hukou, and urban residency and urban hukou. The small percentage (< 2%) who live in rural areas but have urban hukou are included in the rural residency category. This three-category variable separates those living in urban areas by their ability to use services and obtain benefits.

Table 1 Biological risk indicators, China Health and Retirement Longitudinal Study, China, 2011–2012

	High-risk criteria	% high risk, weighted
High systolic blood pressure	$\geq$ 140 mm Hg	29.0
High diastolic blood pressure	$\geq$ 90 mm Hg	13.6
Low diastolic blood pressure	$<$ 60 mm Hg	7.7
Rapid pulse rate at 60 s	$\geq$ 90	5.5
High total cholesterol	$\geq$ 240 mg/dL	10.9
Low HDL cholesterol	$<$ 40 mg/dL	25.8
High LDL cholesterol	$\geq$ 160 mg/dL	10.5
High triglycerides	$\geq$ 200 mg/dL	13.9
High plasma glucose	$\geq$ 126 mg/dL	11.8
Obesity (high BMI)	$\geq$ 30 kg/m^2	4.9
High C-reactive protein	$\geq$ 3.0 mg/L	18.7

Socioeconomic status (SES)

Individual educational attainment and an indicator of household resources—tertile of per capita expenditures (PCE) (determined before weighting)—indicate the availability and accessibility of socioeconomic resources (Zhao et al. 2016). Four education categories are denoted: illiterate, literate without schooling (can read and write but no formal schooling), primary school, and junior/secondary school or higher.

Health behaviors

We control for three health behavior indicators: smoking, drinking, and physical activity. Non-smokers are those who never smoked; respondents who reported they do/did smoke are classified as smokers. Drinking indicates how often the respondents drank liquor, wine, rice wine, and beer per month in the last year. We use a gender-specific cutoff point to construct the measure of alcohol consumption (US Department of Health and Human Services 2015). Those who did not drink in the last year are classified as non-drinkers; women who had up to one drink per day and men who had up to two drinks per day are classified as moderate drinkers; women who drank more than one drink and men who drank more than two drinks per day are classified as heavy drinkers. Dummy variables are constructed that represent the level of daily physical activity: no regular physical activity, performing moderate physical activities at least 10 min routinely, and performing vigorous activities at least 10 min routinely.

Community characteristics

A growing literature has reported association between neighborhood or community environment and health (Li et al. 2016; Smith et al. 2013; Yen et al. 2009). Following the approach of Li et al. (2016), we develop a community infrastructure deficiency index based on a principal components analysis of seven indicators of community infrastructure, including road type, days annually with unpassable roads, community accessible by bus, community having a sewer system, main type of toilet in the community, main type of cooking fuel, and main source of drinking water. Communities are divided into four quartiles based on the infrastructure deficiency index scores.

Analysis

We use STATA 14.1 for all analyses. Because individuals are nested within communities and our dependent variable, the number of biological risks, is an over-dispersed count variable, we use multilevel negative binomial regression models. To understand the overall urban–rural differentials in biological risk, we present the urban–rural differentials with only age and gender controlled in Model 1. In Model 2, indicators of individual and family SES, education and household expenditure, are added to examine how much of the urban–rural difference is due to SES variation. We subsequently add indicators of health behaviors (Model 3) and community characteristics (Model 4). Analyses are weighted by the CHARLS biomarker weight to adjust for the complex sampling design and for being in the biomarker sample to ensure the representativeness of results for the country. Robust standard errors for the regression coefficients are computed that allow for clustering at the community level.

Because the questions on physical activities were asked only of a random half sample, Models 3 and 4 which include these variables have a smaller N. Since the selection process was random, the sample should remain nationally representative. In "Appendix of Electronic Supplementary Material," we relate the variables used in the analysis to the likelihood of being in this half sample. We find only being in the top tertile of wealth is linked to differential—higher—response to this question. To test the robustness of our results, we rerun Models 1 and 2 using the same half sample and compared the results with the results from the full sample. The coefficients are very close, and the statistical significance is the same.

Results

Descriptive analysis

Descriptive characteristics of the sample are given in Table 2. Just over half (54%) of the sample resides in rural areas. The urban population is equally split between those with urban hukou and rural hukou (23% vs. 23%). Overall, individuals in the sample have a mean biological risk score of 1.5 and urban Chinese have a higher level of biological risk than rural Chinese. The average number of biological risks is 1.8 for urban residents with urban hukou, 1.6 for urban residents with rural hukou, and 1.4 for rural residents.

Our descriptive results show marked urban–rural gradients in many aspects, especially in SES and physical activities. In this sample, educational attainment ranges from illiterate (25.8%), literate without schooling (17.4%), primary school educated (22.1%) to junior/secondary school and higher (34.7%). About 50% of rural residents but only about 17% of urban residents with urban hukou did not complete primary education. The percentage with a junior/secondary school or higher education is 23.3% for rural residents, 33.8% for urban residents with rural hukou, and 61.8% for urban residents with urban hukou. Similarly, a large urban–rural difference in household expenditures is

Table 2 Sample characteristics, China Health and Retirement Longitudinal Study, China, 2011–2012 (weighted)

	Full sample			Rural residency			Urban residency, rural hukou			Urban residency, urban hukou		
	N = 8499			N = 5452 (54%)			N = 1760 (23%)			N = 1287 (23%)		
	%	95% CI		%	95% CI		%	95% CI		%	95% CI	
Age, mean (SD)	59.7 (9.9)			59.9 (10.0)			58.1 (9.9)			60.8 (9.4)		
Female	52.2	50.8	53.7	51.3	50.1	52.6	54.4	52.0	56.8	52.2	46.5	57.8
Education (N = 8497)												
Illiterate	25.8	23.4	28.4	34.7	32.3	37.2	23.5	19.3	28.3	7.7	5.6	10.4
Literate, no formal schooling	17.4	15.7	19.2	20.2	18.6	22.0	19.0	15.7	22.7	9.3	6.7	12.8
Primary school	22.1	20.5	23.8	21.8	20.1	23.6	23.8	20.1	27.9	21.1	14.7	29.4
Junior/secondary school or higher	34.7	31.7	37.9	23.3	21.3	25.4	33.8	25.7	42.9	61.8	54.8	68.5
Per capita expenditure (N = 8462)												
Top tertile	41.3	36.8	45.6	27.9	25.4	30.5	41.5	33.6	49.9	71.3	64.4	77.3
Second tertile	30.4	28.0	33.0	33.9	31.8	36.0	33.0	28.0	38.4	20.0	15.8	24.9
Bottom tertile	28.5	25.7	31.4	38.2	35.5	41.1	25.5	20.6	31.2	8.8	6.3	12.0
Ever smoke (N = 8497)	39.5	37.5	41.5	40.8	39.2	42.5	40.6	37.1	44.2	35.4	27.9	43.7
Drinking (N = 8497)												
Non-drinkers	80.4	77.9	79.9	79.7	78.0	81.3	82.5	78.9	85.6	79.9	70.7	86.8
Moderate drinkers	17.6	15.5	17.4	17.6	16.3	19.1	15.7	12.8	19.0	19.5	12.7	28.8
Heavy drinkers	2.0	1.65	2.7	2.7	2.2	3.4	1.9	1.3	2.7	0.6	0.3	1.1
Physical activity (N = 3619)												
Sedentary	37.7	33.0	42.7	28.2	25.1	31.6	44.1	30.0	59.3	54.1	47.6	60.5
Moderate	30.0	27.1	33.1	28.3	25.6	31.3	28.6	21.0	37.6	36.0	30.3	42.2
Vigorous	32.3	28.9	35.8	43.4	39.9	47.0	27.3	19.8	36.4	9.9	6.8	14.1
Community infrastructure												
Least deficient	27.2	21.2	34.2	2.0	0.6	6.1	35.6	24.2	48.8	75.6	66.2	83.0
Somewhat deficient	23.9	19.5	29.0	19.7	14.6	26.2	37.6	27.3	49.1	20.4	13.8	29.1
Deficient	25.2	20.7	30.3	39.2	32.4	46.5	16.9	10.4	26.3	1.8	0.7	4.1
Most deficient	23.7	19.3	28.7	39.1	32.3	46.4	10.0	5.1	18.4	2.2	0.5	9.6
Number of biological risk factors, mean (SD)	1.5 (1.4)			1.4 (1.3)			1.6 (1.5)			1.8 (1.5)		

found. Urban residents with urban hukou are more likely to be in the top tertile of PCE (71.3%) and much less likely to be in the bottom tertile (8.8%), whereas the percentage of individuals who belong to the bottom tertile is much higher for rural residents and urban residents with rural hukou (38.2% and 25.5%, respectively). About 40% of the sample has smoked and 17.6% drinks moderately. The percentage of heavy drinkers is very low, regardless of residency or hukou status. Rural residents have the highest levels of physical activity. About 30.0% and 43.4% of rural residents routinely engage in moderate and vigorous physical activities, respectively. The percentages engaging in vigorous activities are lower for urbanites and individuals with urban hukou are the most sedentary (54.1%). The indicators of the community environment differ significantly across urban–rural settings. Infrastructure is more deficient for rural villages.

Regression analysis

Results from regression models are presented in Table 3. From Model 1 where only age and gender are controlled, the level of biological risk for individuals who live in urban areas with urban hukou is elevated (rate ratio = 1.32, significant at the 0.1% level) relative to rural residents. When we add education and per capita expenditure in Model 2, the urban–rural differential in biological risk persists (rate ratio = 1.36, significant at the 0.1% level). Individuals who completed junior/secondary school have a 10% reduced risk compared with the illiterate (rate ratio = 0.90 in Model 2, significant at the 5% level).

We find strong impacts of behavioral factors on biological risk. Smoking is associated with an about 11% higher relative risk (rate ratio = 1.11 in Model 3 and Model 4, significant at the 5% level). Performing vigorous physical activities is correlated with about a 20% reduced relative risk (rate ratio = 0.81 in Model 3, rate ratio = 0.82 in Model 4, significant at the 0.1% level). Performing moderate physical activity also displays a negative association with biological risk, but the effect is small and not significant.

Once behavioral factors are controlled, the urban–rural differences are significantly reduced (rate ratio is reduced from 1.36 to 1.19 from Model 2 to Model 3). This means behavioral factors explain a substantial part of the initial higher urban risk observed in Models 1 and 2. In Model 4, we control for community infrastructure. The effects of community measures are small and not significant, they eliminate the significant urban–rural difference in biological risk when controlled, but the coefficient is not reduced.

Discussion

CHARLS provides measured biological risk profiles for the middle-aged and older Chinese. The nationally representative sample allows us to clarify the situation in China as a whole as well as for representative population subgroups. In addition, the use of objective measures to define biological risk provides objective information for a population in which exposure to the medical system and knowledge of physiological measures of health may be limited and differential (Zhao et al. 2016). Our approach to defining biological risk reflects an absolute level of clinical risk rather than relative level of risk as is used in some studies. This index which includes indicators of cardiovascular, metabolic, and inflammatory risk is desirable for examining change over time or across places.

This study focuses on urban–rural differences in biological risk and aims to identify individual characteristics and environmental factors at the community level associated with age-related biological risk. We find urban dwellers with urban hukou have elevated risk compared with their rural peers. The fact that those who have rural origins and live in urban areas do not differ from the rural group may mean that the lifetime exposure to urban areas is an important risk factor for the increased biological risk. The higher status of urban dwellers is not the source of their poorer physiology. However, their reduced physical activity appears to be highly related to their elevated risk. The urban–rural differential in biological risk is accounted for by adjusting for health behaviors, particularly physical activity. Our descriptive analysis shows that the rural population is more physically active than urban residents with urban hukou, and urban residents with rural hukou are in-between.

Worse physiological dysregulation in urban areas differs from the association often found in high-income countries but it is found in other developing countries (Crimmins 2015). The difference in the social patterning of behavioral factors in various settings suggests that the association between risk factors for chronic conditions and socioeconomic status depends on the stage of the epidemiological transition and the level of development and differentials may change with development (Stringhini and Bovet 2017). In many developing countries, individuals with high socioeconomic status are less physically active and consume more fats, salt, and processed food (Allen et al. 2017), resulting in higher risk of chronic conditions. Our findings indicate that continued urbanization is likely to present major public health challenges in China. As rural areas continue to urbanize, migrants continue to move from rural to urban areas, and fewer people work in physically demanding occupations, more Chinese will adopt Western-style diets and sedentary lifestyles. Although a variety of

Table 3 Rate ratios from multilevel negative binomial models estimating number of biological risks, China Health and Retirement Longitudinal Study, China, 2011–2012

	Model 1 (N = 8499)		Model 2 (N = 8460)		Model 3 (N = 3604)		Model 4 (N = 3604)	
	Rate ratio	S.E.	Rate ratio	S.E.	Rate ratio	S.E.	Rate ratio	S.E.
Urban–rural (ref = rural residency)								
Urban residency, rural hukou	1.09	(0.10)	1.11	(0.09)	1.11	(0.07)	1.09	(0.06)
Urban residency, urban hukou	1.32***	(0.01)	1.36***	(0.01)	1.19*	(0.08)	1.16	(0.12)
Age	1.01***	(0.00)	1.01***	(0.00)	1.01**	(0.00)	1.01**	(0.00)
Female	1.04	(0.03)	1.03	(0.04)	1.06	(0.06)	1.07	(0.06)
Education (ref = illiterate)								
Literate without schooling			0.97	(0.04)	0.98	(0.05)	0.98	(0.05)
Primary school			1.01	(0.04)	0.98	(0.05)	0.98	(0.05)
Junior/secondary school or higher			0.90**	(0.03)	0.88*	(0.05)	0.88*	(0.05)
Per capita expenditure (ref = bottom tertile)								
Top tertile			1.00	(0.03)	0.98	(0.04)	0.98	(0.04)
Second tertile			1.01	(0.03)	0.99	(0.05)	0.99	(0.05)
Ever smoke					1.11*	(0.06)	1.11*	(0.06)
Drinking (ref = non-drinkers)								
Moderate drinkers					1.03	(0.06)	1.03	(0.06)
Heavy drinkers					0.97	(0.12)	0.96	(0.12)
Physical activities (ref = sedentary)								
Moderate physical activities					0.94	(0.04)	0.94	(0.04)
Vigorous physical activities					0.81***	(0.04)	0.82***	(0.04)
Community infrastructure (ref = least deficient)								
Somewhat deficient							1.14	(0.11)
Deficient							1.07	(0.11)
Most deficient							1.02	(0.10)
Community-level variance	0.05	(0.01)	0.05	(0.01)	0.10	(0.05)	0.09	(0.04)

Model 4 includes a category indicating respondents were missing on the community infrastructure variable

Significance: *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$

campaigns promoting physical activity and healthy lifestyle have been implemented in the last 10 years (Wang and Zhai 2013), it is a challenge to change people's habits and activity levels if they have been sedentary for years.

Our study suggests that higher education is a strong and independent protective factor against developing high biological risk. The effect of education persists after behavioral factors and community characteristics are accounted for. This could reflect more knowledge of health management and better access to higher-quality healthcare for highly educated older adults. We do not find a significant correlation between per capita expenditure and biological risk. This is consistent with some recent literature which has been skeptical about the links between financial measures of SES and health (Smith 2004). Smith (2004) suggests that economic circumstances during childhood might set the stage for the adult SES health gradient and have a bearing on health later in life.

One thing we should note is that we do not find sex differences in physiological dysregulation in China. In many countries, differences in physiological dysregulation between men and women are found that reflect their social roles and health behaviors (Crimmins 2015). The equality of dysregulation in this study may indicate relative similarity in life experiences for this cohort of Chinese men and women.

While the percentage of obese persons in China is still relatively low, many studies have shown a rapidly rising prevalence of overweight and obesity (Wang et al. 2007; Yang et al. 2008). Because of the well-known strong links between obesity and other cardiometabolic risks, the epidemic of obesity will become an increasing public health challenge in China.

One limitation of our study is that the study sample is reduced by initial non-response and non-participation in the blood sample collection. However, by applying the biomarker weight correcting for this non-response, our analytic sample is representative of middle-aged and older Chinese adults. Since Models 3 and Model 4 are based on the random half of the sample, we examined whether respondents who were asked the questions on physical activities differ from those who did not receive the questions. We find respondents who were excluded from Models 3 and 4 were not significantly different from those who were in the first two models, except that they were more likely to be in the top tertile of per capita expenditures; however, as given in Table 3, per capita expenditure is not significantly correlated with biological risk. Reassuringly, when we use the same half sample for Models 1 and 2, the results are similar to those shown.

Steps for further research deserve mention. Mechanisms behind the urban–rural differentials in biological risk need further exploration including how lifelong living environments might be a potential mediator of the differences we observe. In moving forward, taking advantage of the longitudinal design of CHARLS and a recent life history survey to better explore potential causal effects will provide a next step for this research. Our findings not only enhance our understanding of the health conditions in the older Chinese population and the challenges China is facing in maintaining a healthy population, but also indicate that improving education and promoting active lifestyles can help Chinese people reduce physiological dysregulation and achieve healthy aging.

Compliance with ethical standards

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

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