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Long-term effects of child nutritional status on the accumulation of health human capital

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A B S T R A C T

Research on the impact of childhood nutrition on adult health and human capital has been extensively studied in developed countries, but research in China on this topic is limited. Nowadays, for children's nutritional status, while significant progress has been made in addressing childhood undernutrition in China, regional disparities persist, conversely, the prevalence of childhood overweight continues to rise. For adults' health human capital, the burden of chronic non-communicable diseases among Chinese residents is gradually increasing, over 50% of Chinese residents are overweight or obese, with obesity being one of the risk factors for other chronic diseases. Therefore, this study uses national representative data from 1991 to 2015 China Health and Nutrition Survey (CHNS), matched with individual information from their childhood, to examine the relationship between childhood nutrition and adult health human capital. Based on the two-way fixed effects models and logit models, the study finds that childhood nutrition status measured by height-for-age z score (HAZ) significantly and continuously has been influencing adult health human capital measured by height, BMI, self-rated health (SRH), whether have been sick in last four weeks (SH). BMI-for-age z score (BMIZ) significantly and continuously influence adult health human capital measured by BMI, blood pressure, and perceived stress (PS). Among that, this study places special emphasis on the long-lasting effects of late childhood and adolescence (ages exceeding 6) on the progressive height accumulation and sustained presence of elevated blood pressure. In conclusion, reducing childhood overweight and promoting linear growth and development throughout the whole childhood can reduce the future burden of disease on the nation.

1. Introduction

The early nutritional status has been substantiated by epidemiologists and health economists to be a significant determinant of health human capital across the entire life course (Abiona, 2017; Adair et al., 2013; Alderman, 2006; Almond & Currie, 2011; Barker, 1990, 2007; Black et al., 2007; Case et al., 2005; Case & Paxson, 2010; Deng & Lindeboom, 2022; Hoddinott et al., 2013; Islam et al., 2015; Skogen & Øverland, 2012; Victora et al., 2008; Wang et al., 2016). According to the latest definition (World Health Organization (WHO), 2021a), child malnutrition outcomes encompass not only undernutrition like stunting, wasting and underweight caused by protein and energy deficiencies, but also includes overnutrition like overweight and obesity stemming from excessive and uneven energy intake. However, the classic focus of early research has separated undernutrition and overnutrition in childhood, which has been recognized as a nutritional challenge for countries at different levels of economic development (Popkin et al., 2020; Wells et al., 2020). Presently, children in low- and middle-income countries are facing a dual challenge of nutritional status, known as double burden malnutrition (DBM), where both undernutrition and overnutrition coexist (Black et al., 2013; Caleyachetty et al., 2018; Nugent et al., 2020; Hawkes et al., 2020, WHO, 2021a). Despite overweight has received considerable attention in developed nations, it remains as a form of hidden malnutrition in developing nations. In certain cultural settings, it is even perceived as a sign of good health or a symbol of successful child rearing. Thus, the issue of child undernutrition remains unresolved, but there is a concerning rise in the number of overweight children due to shifting dietary patterns and lack of physical activity. Disparities in health and nutritional status during childhood are highly persistent throughout the whole life course.

Theoretically, the link between childhood nutritional status and health human capital can be traced back to fetal origins adult disease (FOAD) and developmental origins of health and disease (DOHaD) (Barker, 1990, 2007; Gillman, 2005; Gluckman et al., 2008; Godfrey &

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Barker, 2000; Hanson & Gluckman, 2014; Low et al., 2011; Skogen & Øverland, 2012; Uauy et al., 2011). Early epidemiologists have provided substantial evidence that child malnutrition outcomes in the first 1000 days of life have a programmatic impact on child growth and development, which in turn contributes to increased risk of non-communicable disease like elevated blood pressure, diabetes, and metabolic disease in adulthood (Victora et al., 2008; Reilly & Kelly, 2011; Fall, 2013). On the one hand, the mechanism of the effects of child undernutrition is intrauterine restriction due to maternal deficiencies during pregnancy, which is largely responsible for low birth weight in the first two years of life, during which persistent nutritional deficiencies can impair glucose homeostasis, insulin secretion, and lead to insulin resistance and other endocrinopathies (Barker, 1997; Black et al., 2013; Drake & Walker, 2004; Soliman et al., 2021). On the other hand, children with intrauterine growth restriction and low birth weight who subsequently receive adequate nutrition during the catch-up period are likely to increase the likelihood of obesity in school-age period (Saavedra & Prentice, 2022). In this process, programmatic impact reduces metabolism and increases susceptibility to adiposity in the middle of the body, accompanied by a reduction in fat oxidation and energy expenditure, and therefore are more likely to cause lean deficit. The persistence of such effects can contribute to obesity in adulthood, as well as the likelihood of developing chronic cardiovascular diseases such as hypertension and diabetes (Huang et al., 2010; Prendergast & Humphrey, 2014; Shrestha & Copenhaver, 2015; Mwene-Batu et al., 2021; Soliman et al., 2021; Victora et al., 2008).

Likewise, early nutrition and lifestyle have been demonstrated to explain the developmental origins of obesity, and childhood obesity is primarily attributed to intergenerational effects resulting from maternal obesity (Baran et al., 2020; Black et al., 2013; Brands et al., 2014; Eriksson et al., 2014; Mameli et al., 2016). Maternal overnutrition, manifested in higher maternal pre-pregnancy body mass index and relative weight gain during pregnancy, can similarly program children's metabolic and endocrine development during the critical period of plasticity, resulting in higher birth weight (Chandrasekaran & Neal-Perry, 2017). Literature research has consistently reached a unanimous conclusion that high birth weight is linked to a heightened risk of overweight, diabetes, high blood pressure and cancer (Victora et al., 2008; Adair et al., 2013; Zhang et al., 2013; Fall, 2013). In addition, the accelerated weight gain experienced during the initial two years of life, as a result of programming effects, similarly influences the insulin growth metabolic pathways (Brands et al., 2014). In comparison, when comparing the long-term effects between undernutrition and overweight, both conditions elevate the risk of disease occurrence. Nevertheless, an overlooked long-term impact of childhood overweight is its correlation with psychological well-being. Obese children are more susceptible to experiencing symptoms of psychological depression in comparison to their peers, with gender disparities suggesting that girls face a heightened risk (Gallagher et al., 2023; Martinson & Vasunilashorn, 2016; Sanderson et al., 2011).

Currently, most of empirical studies on the long-term effects of childhood nutrition primarily concentrate on the accumulation of human capital in a comprehensive way, which includes cognitive abilities, educational attainment, socioeconomic status, and single health dimensions. In this case, numerous studies have used natural experiments to explore the long-term effects on adulthood of child malnutrition caused by exogenous shocks such as famine in different countries (Arage et al., 2021, 2022; Black et al., 2007; Chen & Zhou, 2007; Dercon & Porter, 2014; Huang et al., 2010; Meng & Qian, 2009), natural disasters (Abiona, 2017; Caruso & Miller, 2015; Hoddinott & Kinsey, 2001; Rosales-Rueda, 2018; Tang & Di, 2022). In addition, early interventions and nutrition programs, such as Guatemala's 1969–1977 program to improve children's protein intake (Hoddinott et al., 2013), China's Student Nutrition Improvement Program (Fang & Zhu, 2022), and other birth cohort follow-up studies in developing countries have reached the consistent conclusion that undernutrition in childhood has significant effects on individuals' anthropometric measures, cognition, education, labor market performance, socioeconomic status and health in adulthood (Abiona, 2017; Almond & Currie, 2010; Case & Paxson, 2010; Currie & Vogl, 2013; Koshy et al., 2022; Soni et al., 2021).

Within multiple complex impact pathways, childhood malnutrition outcomes can potentially impact the long-term outcomes of adult education, labor outcomes and socioeconomic status through its influence on the accumulation of health human capital. Empirical studies have demonstrated a strong direct correlation between childhood nutritional status and adult health outcomes (Arage et al., 2021; Cui et al., 2020; Mwene-Batu et al., 2021; Yao & Zhang, 2023). Anthropometric information like height, body mass index (BMI), blood pressure, is basically utilized in the literature as the assessment of health human capital. Initially, many studies have primarily utilized adult height as an indicator of the health human capital. Height is considered an ultimate manifestation of early childhood nutritional investment, reflecting the combined influences of socioeconomic conditions within the family and exposure to infectious diseases (Alderman, 2006; Arage et al., 2022; Black et al., 2007; Portrait et al., 2017). Because of the persistence of the effects of child malnutrition outcomes, this long-term effect is more intuitive in terms of cumulative growth and development. Also, the cumulative growth and development of height is influenced by genes and the environment (Victora et al., 2008). A series of natural experimental studies have consistently concluded that children with famine experiences exhibit significantly shorter stature than their counterparts (Chen & Zhou, 2007; Currie & Vogl, 2013; Dercon & Porter, 2014; Stein et al., 2013). Cumulative effects persist beyond adolescence, resulting in lower height and less schooling in adulthood (Adair et al., 2013). Short stature, together with lower educational attainment, is accompanied by lower labor productivity ultimately resulting in lower earnings and poorer socioeconomic status for children who have suffered stunting (Abiona, 2017; Case et al., 2005; Dercon & Porter, 2014; Hoddinott et al., 2013).

Moreover, a large body of research has demonstrated that there is a strong trajectory between childhood nutrition status and adult BMI, overweight, and cardiometabolic morbidity (Fan et al., 2012; Reilly & Kelly, 2011; Singh et al., 2008). Meanwhile, BMI is a common and powerful predictor of cardiovascular health or diabetes. Among the nutritional status, drawing from longitudinal data collected in five low-income countries, a study has provided evidence of a noteworthy correlation between high birth weights and a higher probability of having a BMI exceeding 25 in adulthood (Adair et al., 2013). Additionally, a comprehensive review of the literature has highlighted the enduring health consequences of childhood obesity, finding that individuals with a history of obesity during childhood are more prone to sustained obesity in adulthood, thereby increasing their vulnerability to cardiovascular risk factors (Arage et al., 2021; Frithioff-Bøjsøe et al., 2022; Fung, 2009; Liu et al., 2017; Reilly, 2003; Simmonds et al., 2016; Smith et al., 2012).

Studies of famine exposure during the window of childhood growth and development have concluded that famine exposure during early life is significantly associated with elevated systolic and diastolic blood pressure, and increased hyperglycemia (Huang et al., 2010; Hult et al., 2010; Wang et al., 2012, 2016). Other similar studies have tracked the effects of undernutrition evaluated by wasting, stunting, or severe acute malnutrition on blood pressure during adolescence in subjects aged 2–5 years, the results being negatively associated blood pressure in the subsequent follow-up (Asiki et al., 2019; Mwene-Batu et al., 2021). In contrast, studies linking birth status, such as pre-term, term, and post-term, to blood pressure and blood glucose in adulthood have not found significant differences (Stein et al., 2013).

Furthermore, self-reported health (SRH) and the occurrence of related diseases in the past four weeks serve as objective indicators to measure health human capital. SRH is highly correlated with other health indicators and provides a comprehensive picture of a person's health status. Case et al., (2005) found that SRH at aged 33 and 42 was highly correlated with respondents' reports of having a chronic illness and their reports of disability and hospitalization. Recently, Deshpande and Ramachandran (2022) also found that adolescents' own health was consistent with their SRH.

Although existing research has reached a consensus on the impact of childhood nutrition on long-term physical health, the link between childhood nutrition and mental health remains limited, especially in developing countries. Several studies have demonstrated a positive correlation between childhood nutrition and adult mental disorders, overall negative emotional indices, and depression by investigating exogenous environmental factors or nutritional supplementation interventions (Smith, 2009; Huang et al., 2013; Adhvaryu et al., 2014; Fang & Zhu, 2022). This phenomenon may be attributed to the potential explanatory role of early-life nutritional supplementation in facilitating brain and neural development. While, in the context of overweight, the consistent presence of overweight from childhood to adulthood or a notable weight gain during adulthood is linked to a heightened susceptibility to experiencing depression or other mood-related disorders in later adulthood (Gallagher et al., 2023; Martinson & Vasunilashorn, 2016; Sanderson et al., 2011).

In the current context, China is facing a significant nutritional transition challenge concerning childhood nutrition and health, with the coexistence of undernutrition and overnutrition. While the prevalence of childhood undernutrition has decreased from 1991 to 2015 to 6.1% (United Nations Children's Fund et al., 2021), regional disparities persist, with notably high rates of undernutrition observed in economically disadvantaged areas in the western region. Conversely, there has been a substantial increase in the nationwide prevalence of obesity and overweight among children aged 6–17, rising from 11.7% to 2.8% in 1991 to 25.2% and 10.1% in 2011, respectively (Jia et al., 2017). Among children below the age of six, there has been an upward trajectory in the prevalence of overweight, ascending from 6.5% to 8.4% between 2002 and 2012. Simultaneously, the prevalence of obesity also underwent an upward shift from 2.7% to 3.1% during the same time span (Peking University School of Public Health & United Nations Children's Fund (UNICEF), 2017). For adults' health, according to the China's Population Nutrition and Chronic Diseases Report 2020 (Chinese Centre for Disease Control and Prevention, 2022), over 50% of adult residents are now overweight or obese and increasing rise trend in body fat, which increase the risk suffering from chronic diseases. Specially, the average weight of male and female residents aged 18 and above was 69.6 kg and 59 kg, respectively, which represents an increase of 3.4 kg and 1.7 kg compared to the results released in 2015. Moreover, the average height of male and female residents aged 18 to 44 is 169.7 cm and 159 cm, which is 7.8 cm and 4.7 cm lower than that of developed countries, respectively, showing wide discrepancy. Furthermore, despite the increasing life expectancy in China, the burden of non-communicable diseases are growing, with rising rates of hypertension, type 2 diabetes, chronic obstructive pulmonary disease, and cancer. In detail, the prevalence of hypertension in residents aged 18 and above is 25%, and dyslipidemia is 40%. It is estimated that 82% of the disease burden in China is caused by non-communicable diseases. In addition to physical health, the importance of mental health has also been overlooked in China. According to recent estimates, the mental health issues of Chinese adults are becoming increasingly prominent. According to estimates from 2019, the prevalence of depression in China reached 2.1%, and the prevalence of anxiety disorders was 4.98%.

Given that FOAD and DOHaD emphasize the impact of early-life nutrition on the accumulation of health human capital, empirical research has provided ample evidence to support this link in some developed and developing countries where reliable and accessible data are obtainable (Case et al., 2005; Alderman, 2006; Smith, 2009; Case and Paxson., 2010; Case and Paxson., 2011; Mwene-Batu et al., 2020; Haywood & Pienaar, 2021). However, the relationship between childhood nutrition in China and adult health human capital has yet to be clearly studied. Considering the nutritional challenges faced by Chinese children, where both undernutrition and overnutrition coexist, coupled with the growing risk of chronic diseases in adults, the quantification of how childhood nutritional status affects the accumulation of health human capital in adulthood is of great significance in comprehending the dynamic health trajectory of individuals across their entire life span. Some studies on the long-term effects of nutritional status in China have focused on the effects of the 1959–1961 natural famine in China on human capital such as height, education, and socioeconomic status of children born during this period in adulthood. Nevertheless, the findings from these extreme nutritional shock scenarios may have limited relevance to the ongoing nutritional transition in China, where undernutrition and obesity coexist. Also, other studies have tracked the link between health inequalities and childhood malnutrition outcomes among elder people in China based on the recall of self-assessment method. In this scenario, it is essential to acknowledge that self-assessed retrospective health may result measurement errors, leading to potential biases in the estimation results. Furthermore, historical studies on great famine in China and long-term health tracking have predominantly centered around elderly populations, overlooking the significance of life stage of adult individuals, which is the transitional stage between childhood and old age. Understanding the health human capital of adults during this critical stage is paramount for comprehending its implications on individual labor productivity and socioeconomic contributions. Finally, the long-term health consequences of persistent childhood malnutrition can ultimately translate into economic costs for individuals and nations. These implications include reduced wages and productivity, as well as heightened burden on national healthcare expenditures, consequently impeding economic prosperity.

This study will focus on the impact of childhood nutrition in China on the accumulation of health human capital in adulthood. The contributions of this study are as follows: health is an important component of human capital, and research on the impact of childhood health on human capital has mostly focused on outcomes such as education, income or other outcomes in adulthood. Only a few studies have measured health human capital and have only focused on one dimension, ignoring the multidimensional nature of health human capital. Therefore, this study not only includes objective physical health, but also subjective health and mental health to comprehensively measure health human capital. What is more, empirical literature has focused on the long-term effects of child undernutrition, neglecting the long-lasting impacts of child overweight that accompany rapid economic development in most developing countries, this study will fill this gap. In addition, regarding the long-term development of children's nutritional status, most research has focused on the critical windows of growth, while the potential catch-up process during the later stages of childhood and its impact on adult health have been largely understudied. The study population of this research includes children aged 18 years and below, and age is categorized into 6 years and below, and above 6 years to explore the impact of early-life and later-life nutrition outcomes on adult health human capital. Finally, in recent years, the Chinese government has implemented the "China Healthy Lifestyles for All" Action Plan (2017–2025) and Healthy China 2030. The findings of this study can provide reference significance for policy development. The nutritional status during childhood is closely related to adult health. In order to improve the quality of life in adulthood, more attention should be paid to childhood health. From another perspective, investment in children's nutrition is being promoted as a strategy for economic development.

2. Methods

2.1. Data source

This study uses the data of the China Health and Nutrition Survey (CHNS), a representative survey carried out by the Chinese Centre for Disease Control and Prevention's Institute of Nutrition and Food Safety in partnership with the University of North Carolina Population Centre in the USA. Since its initial wave in 1989, this database has been updated every two to four years. To date, has conducted a total of 10 waves of data collection, with the most recently available data extending up to the year 2015. However, the data from the 2018 CHNS survey has not been released to the public yet due to disruptions caused by the COVID-19 pandemic. To ensure the data's current relevance for this research, the study employs an unbalanced panel data spanning 9 waves of the CHNS, coving the years 1991, 1993, 1997, 2000, 2004, 2006, 2009, 2011, and 2015. The initial survey conducted in 1989 is excluded from the analysis due to a substantial number of missing values.

The CHNS uses a three-stage stratified random sample approach and considers the regional distribution of China's diverse dietary patterns and economic development levels. Firstly, the survey identified counties and municipal areas within each province based on their location and economic development. Next, townships or street-based communities were randomly chosen from these areas. Finally, households were selected from the chosen townships or communities based on the previous two stages of sampling. During the initial eight rounds of sampling, a total of nine provinces or autonomous regions were chosen, including Liaoning, Jiangsu, Shandong, Henan, Hubei, Hunan, Guangxi, Guizhou, and Heilongjiang. In the subsequent ninth round conducted in 2011, three municipalities, namely Beijing, Shanghai, and Chongqing, were additionally included in the sample. In addition, the CHNS database provides an abundance of demographic data, along with relevant social, economic, and nutritional data, making it well-suited to meet the data requirements of this study.

This study selected the sample of adults aged over 18 years in the latest wave, and matched their childhood-related information according to their ID in the database from previous waves. Total 638 individuals were repeatedly surveyed in the nine waves, among these, around 24.45% of the samples were tracked in two or three consecutive survey periods, while the remaining samples were followed for four or more survey periods. Since it is necessary to control for parental and family characteristics, after matching the childhood and adulthood information, the family ID and parental information were matched. After removing individuals with missing key information in both adulthood and childhood, therefore, the final sample size is 1612. In the regression equation that used blood pressure to measure health human capital, there were missing values for blood pressure in some individual samples, resulting in a sample size of 1165.

2.2. Outcome variables

In health economics, Grossman (1972) was the first to conceptualize health human capital, which considers an individual's health status at a certain point in life as a capital stock. The health acquired by individuals in their early stages through genetic inheritance can be regarded as their initial health endowment. Health stock, over time, undergoes a gradual devaluation with age, but it can also be enhanced through investments. Thus, considering the dynamic nature of health human capital and the sustained influence of childhood early health endowment, the nutritional and health status during childhood will have long-lasting effects on the accumulation of health human capital in adulthood.

When it comes to measurement, precisely assessing health human capital for individuals poses difficulties since there is a dearth of universally acknowledged indicators with standardized criteria. Moreover, the varying perspectives on the relevance and significance of diverse health indicators within the context of human capital measurement add to the complexity of the task. In empirical research, a range of indicators, including height, BMI, obesity, SRH, disease occurrence, blood pressure, are frequently employed to assess individual health. Drawing from prior literature, this study classifies the measurement of health human capital into distinct dimensions: objective health, subjective health, mental health.

First, height and BMI are commonly used objective anthropometric measurements in the literature (Adair et al., 2013; Alderman, 2006; Liu et al., 2017; Stein et al., 2013). Throughout the data collection phase of the CHNS, the survey team, comprised of skilled professionals, performed height and weight measurements on the participants. Two measurements were obtained from each respondent, and the average of these values was adopted for further analysis. Consistent with the guidelines for adults (WHO), 2021b), the BMI was determined by dividing an individual's weight (measured in kilograms) by the square of their height (measured in meters). Additionally, the following blood pressure measurements were taken by professional healthcare workers using standardized and calibrated mercury sphygmomanometers. Participants were instructed to remain seated, and measurements were taken at 30-s intervals, with three readings obtained and averaged. Systolic blood pressure (SBP) and diastolic blood pressure (DBP) are commonly used as predictors of future cardiovascular health. The normal range for SBP is between 90 and 139 mmHg, while the normal range for DBP is between 60 and 89 mmHg.

Next, SRH and short-term health (SH) are the indicators to evaluate the subjective health. SRH is a powerful predictor of mortality, disability, chronic disease, health-related behaviors, and healthcare utilization. In addition, it goes beyond merely assessing the presence or absence of disease and provides a comprehensive evaluation of one's overall quality of life (Hill et al., 2005). In the CHNS study, the question regarding SRH was "Compared to others your age, what would you say your health? Answers were divided into four categories including poor, fair, good, or very good. Regarding short-term health, the CHNS questionnaire includes specific questions like, "In the past four weeks, have you had any illnesses or injuries? Do you have any chronic or acute illnesses?" The response options are "yes" and "no." No is coded as 0, yes is coded as 1. Therefore, whether have been sick in the last four weeks is the disease condition in SH.

Finally, the Perceived Stress Scale 14 (PSS-14) is used in CHNS to measure the level of stress perception in adults aged 18 and over, which is also an indicator of psychological health in this study. PSS-14 is a professional scale used to assess the level of psychological and physiological stress and discomfort individuals experience after experiencing life events. PSS-14 consists of 7 positive and 7 negative questions, corresponding to a 5-point Likert scale ranging from "never" to "very often". For positive questions, the 5-point Likert scale is assigned values of 4, 3, 2, 1, and 0, respectively. Conversely, for negative questions, the 5-point Likert scale is assigned values of 0, 1, 2, 3, and 4, respectively. The answers obtained are summed up, with scores ranging from 0 to 56. The higher the score, the greater the level of stress perceived by the individual in daily life. As there is no recognized cut-off point for the PSS-14 scale, this study uses the average value of 32 as the cut-off point for stress perception. When an individual's perceived stress value is greater than or equal to 32, it is assigned a value of 1 and defined as a high level of stress perception. When an individual's perceived stress value is less than 32, it is assigned a value of 0 and defined as a lower level of stress perception.

2.3. Explanatory variables

The explanatory variables in this study are the nutritional status during childhood. Therefore, we used heigh-for-age z score (HAZ) and BMI-for-age z score (BMIZ), based on WHO Growth Standards 2007, as the two main indicators to measure undernutrition and overnutrition during childhood. HAZ and BMIZ serve as objective metrics for evaluating chronic undernutrition and overweight in children. These indicators were calculated using the STATA function "zanthro" based on height (cm), weight (kg), sex, and age during childhood. The measurement of height and weight followed the protocols utilized for adult assessments, administered by skilled healthcare professionals during the health examination procedure. The z scores range from −5 to 5, and z scores >5 or z scores < -5 are excluded from the analysis. In addition, binary variables for stunting and obesity during childhood are included in the regression models for height and BMI, respectively. A child with HAZ below two standard deviations (HAZ < median -2SD) is regarded as to be stunted (WHO, 2007). Similarity, a child with BMI-for-age z score over one standard deviation (BMIZ > median 1SD) are considered as at the risk of overweight (de Onis & Lobstein, 2010).

2.4. Covariates

Taking potential possible confounding into consideration, this study also controls individuals' demographic characteristics that influence the health stock in adulthood, such as age, gender, ethnicity, schooling, average monthly income, diet health, personal health behaviors, place of residence. In addition, this study also controls family background and parents' characteristic that may simultaneously affect the nutrition status of childhood and thus affect the formation of health human capital in adulthood. To be specific, the average annual household per capita income in childhood, mother's education level, the nutritional status of parents, parents' height, mother's occupation, household size, 3-day average protein intake in childhood are also included (Alderman, 2006; Hoddinott et al., 2013).

2.5. Statistical analyses

To investigate the long-term effects of child nutritional status on health human capital during adulthood, this study employs two statistical models, the two-way fixed effects model and the logit model, based on the panel data and the nature of the outcome variables. The two-way fixed effects model is utilized to analyze continuous outcome variables such as height, BMI, and blood pressure, while taking into account time and province-level effects as control variables. The utilization of the two-way fixed effects model helps to mitigate endogeneity concerns caused by variables that remain constant over time. For categorical variables, the logit model is used for binary variables, including perceived pressure and the presence of sickness in the last four weeks. Additionally, the ordinal logit model is applied to multi-categorical variables, such as self-reported health. The coefficients and predicted probabilities for higher pressure, recent sickness, and poorer health are reported separately for both the logit and ordinal models. As the logit regression might not accurately reflect marginal effects through coefficient values and odds ratios, average marginal effects were included to assess the incremental change in outcomes variables when the HAZ or BMIZ increased by one unit, respectively.

Specially, due to the different potential pathways of the long-term effects of childhood undernutrition and overnutrition, in the regression models, it employs fixed effects models to examine how childhood stunting (measured by HAZ and binary variables whether this child is stunted) impacts adult height, with a focus on two age groups: under 6 years and 6 years and above. The outcomes of this analysis are presented in Table 2. In the context of BMI, the study explores different indicators, HAZ, BMIZ, and binary variables including the presence of stunting and overweight. Separate models are utilized to assess the coefficient differences for childhood undernutrition and overnutrition concerning adult BMI. The results are detailed in Table 3. For blood pressure analysis, the models incorporate HAZ, BMIZ, and binary variables indicating overweight for participants under 6 years and 6 years and above. The estimated outcomes are presented in Table 4. Furthermore, the study examines SRH by comparing the probability differences in SRH levels associated with HAZ and BMIZ. The marginal probability results are also reported. All the analysis are shown in Table 5 and Table 6. SH and perceived stress were analyzed separately by fitting models with HAZ and BMIZ as the main explanatory variables. The marginal probability results are also reported. The estimated results for these analyses are presented in Table 7 and Table 8. All the analyses employed the STATA 17.0 version.

Table 1
Descriptive analysis results of the long-term impacts of child nutritional status on health human capital.

Variables (N = 1612)	Mean (S.D.)	Frequency (N) Min	Percentage (%) Max
Children's age	11.38 (4.68)	1	18
1 ~ 6		303	18.8
7 ~ 11		441	27.36
12 ~ 18		868	53.85
Gender			
Male		1227	76.12
Female		385	23.88
Child's Height	139. (25.24)	70	184.5
Child's Weight	36.42 (15.91)	8	93
HAZ	−0.722 (1.132)	−4.813	4.024
BMIZ	−0.3 (1.121)	−4.343	4.28
Stunting			
Yes		181	11.23
No		1431	88.77
Overweight			
Yes		183	11.35
No		1429	88.65
Nationality			
Han		1402	86.97
Minority		210	13.03
3-day Protein intake	59.30 (22.52)	16.96	127.44
Adult age	28.98 (5.71)	18	43
Adult height	167.4 (7.43)	148	185
Adult weight	65.29 (12.25)	36	114
BMI	23.17 (3.31)	16.66	32.92
Perceived pressure	32.95 (5.61)	16	52
Higher		890	55.21
Lower		722	44.79
SBP (N = 1165)	117.6 (12.7)	90	180.7
DBP (N = 1165)	77.39 (9.685)	46	120.7
Self-reported health			
Very Good		246	15.26
Good		807	50.06
General		531	32.94
Poor		28	1.74
Been sick or injured in the past four weeks			
No		1489	92.37
Yes		123	7.63
Wage per month (thousand)	2.65 (1.29)	0	8
Adult education level/ schooling	11.01 (3.00)		
Primary		123	7.63
Low middle school		567	35.17
Upper middle school		261	16.19
Vocational		278	17.25
College and above		383	23.76
Medical insurance			
Yes		1572	97.52
No		40	2.48
Drinking			
Yes		723	45
No		889	55
Smoking			
Yes		678	42.06
No		934	57.94
Diet health	21.10 (4.49)	1	37
Household annual per capita income adult (thousand)	22.5 (23.5)	0	158.6

(continued on next page)

Table 1 (*continued*)

Variables (N = 1612)	Mean (S. D.)	Frequency (N) Min	Percentage (%) Max
Family size in adulthood	4.98 (1.74)	2	10
Family size in childhood	4.44 (1.20)	3	11
Mother's height	154.95 (5.32)	141.7	167.2
Paternal height	165.59 (5.74)	150.4	180
Maternal BMI	22.48 (2.89)	16.02	33.33
Paternal BMI	22.34 (2.73)	15.75	33.46
Maternal education/ schooling	6.19 (3.84)	0	17
Maternal occupation status			
Yes		1350	83.75
No		262	16.25
Sleeping duration	8.00 (0.89)	5	13
Watching TV			
Yes		1348	83.62
No		264	16.38
Video games			
Yes		205	12.72
No		1407	87.28
Region			
East coastal area		296	18.36
Central area		575	35.67
West area		564	34.99
North-east area		177	10.98
Residence			
Urban		533	33.06
Rural		1079	66.94

3. Results

3.1. Descriptive analysis

In the descriptive analysis, categorical variables are described using frequency and percentage, whereas continuous variables are summarized with mean, maximum, minimum, and standard deviation (SD). Table 1 presents the distribution of all characteristics during childhood and adulthood. In this study, childhood is defined according to the United Nations standards, which includes individuals aged 18 or below. Based on the matched information, the mean and standard deviation of age during childhood are 11.38 ± 4.68. More than half of the children belonged to the age group of 12–18 years (53.85%), while 27.36% and 18.8% belonged to the age groups of 7–11 years and 1–6 years, respectively. The majority of the participants are male (76.12%) and Han ethnicity (86.97%). The mean and standard deviation of height during childhood are 139.5 ± 25.24, and the mean and standard deviation of weight are 36.42 ± 15.91. The mean and SD of HAZ, which measures undernutrition during childhood, were −0.722 ± 1.132, with a range from −4.813 to 4.024. The mean and SD of BMIZ, which measures overnutrition during childhood, were −0.3 ± 1.121, with a range from −4.343 to 4.28. During childhood, 11.23% and 11.35% of children were classified as having stunted growth and overweight, respectively.

The age range of the adult population in our sample is 18–43 years, with a mean age and SD of 29 ± 5.71. Objective measures of health indicate a minimum height of 145 cm and a maximum height of 185 cm, with an average height and SD of 167.4 ± 7.43. The weight range is 36 kg–114 kg, with an average weight and SD of 65.29 ± 12.25. The average BMI and SD are 23.17 ± 3.31. In terms of subjective health, approximately half of the individuals (50.06%) reported being in a good state of health, followed by about 32.94% reporting being in a general state of health. Only 15.26% of individuals reported being in a very good state of health, while 1.74% reported being in a poor state of health. Perceived stress was measured using the 14-item Perceived Stress Scale (PSS-14) in CHNS, with an average score and SD of 32.95 ± 5.61. The majority of individuals (55.21%) reported a high level of perceived stress, while approximately 44.79% reported a low level of perceived stress. Regarding disease status, approximately 7.63% of individuals reported experiencing illness in the past four weeks. In terms of predicting cardiovascular health, the SBP values in our sample range from 90 to 180.7, with an average SBP and SD of 117.6 ± 12.7. The DBP values range from 46 to 120.7, with an average DBP and SD of 77.39 ±

Table 2
The impacts of child nutritional status on height in adulthood.

	Model 1	Model 2	Model 3	Model 4
Age	−0.0388 (−1.28)	−0.1108*** (−3.69)	0.1428 (0.84)	−0.1276*** (−2.92)
GENDER				
Female	−12.5581*** (-39.78)	−12.7205*** (-38.52)	−14.0138*** (-17.91)	−12.4365*** (-33.60)
male (reference)				
Nationality				
Minority	−1.6217*** (-4.20)	−1.6774*** (-4.22)	−3.0861*** (-2.88)	−1.4387*** (-3.36)
Han (reference)				
HAZ	1.6483*** (12.88)			
Stunting				
Yes		−2.8517*** (-7.04)	−2.2453* (-1.93)	−2.9749*** (-6.82)
No (reference)				
Schooling	0.0949** (2.15)	0.1377*** (2.99)	0.2419** (2.26)	0.1191** (2.33)
Average wage per month	−0.0719 (−0.81)	−0.0838 (−0.88)	0.0603 (0.26)	−0.0996 (−0.94)
Smoking				
Yes	0.3947 (1.46)	0.3331 (1.19)	−0.1646 (-0.26)	0.3882 (1.23)
No (reference)				
Drinking				
Yes	−0.0052 (-0.02)	0.0230 (0.08)	−0.7492 (-1.21)	0.1888 (0.60)
No (reference)				
Mother's height	0.1299*** (5.36)	0.1749*** (6.99)	0.2426*** (3.95)	0.1620*** (5.89)
Father's height	0.1586*** (7.14)	0.1985*** (8.45)	0.2478*** (4.72)	0.1921*** (7.28)
Mother's schooling	−0.0698** (−1.99)	−0.0737** (−2.01)	−0.0587 (−0.75)	−0.0837** (−1.99)
Mother's employment status				
Yes	−0.2333 (-0.74)	−0.0718 (-0.21)	−0.4923 (-0.52)	0.0101 (0.03)
No (reference)				
Household per capita income	−0.0000 (−0.01)	0.0043 (0.98)	0.0002 (0.02)	0.0046 (0.97)
Household size in childhood	−0.2436** (−2.51)	−0.2429** (−2.32)	−0.2781 (−1.54)	−0.2565** (−1.99)
Diet health	0.0586** (2.45)	0.0722*** (2.86)	0.0791 (1.29)	0.0646** (2.31)
Protein intake in childhood	−0.0052*** (−2.97)	−0.0023 (−1.26)	0.0006 (0.03)	−0.0024 (−1.32)
Residence				
Central area	−0.7232** (-2.09)	−0.6437* (-1.73)	0.5483 (0.69)	−0.8798** (-2.07)
West area	−1.3814*** (-3.64)	−1.6114*** (-3.93)	−0.7398 (-0.78)	−1.7802*** (-3.88)
North-east area	−0.2832 (-0.59)	0.2294 (0.45)	1.0521 (0.87)	0.0685 (0.12)
Fixed effects	Yes			
_cons	126.7366*** (23.79)	113.5363*** (20.23)	86.3036*** (6.52)	117.7126*** (18.78)
N	1612	1612	303	1309
R^2	0.6697	0.6365	0.7141	0.6220
adj. R^2	0.6643	0.6306	0.6916	0.6144

Note : T statistics in parentheses.*$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

Table 3
The results of impacts of child nutritional status on BMI in adulthood.

	Model 1	Model 2	Model 3	Model 4
BMIZ	0.6485*** (8.64)			
HAZ		0.3951*** (5.09)		
Stunting				
Yes			−0.6940***	
No (reference)			(-2.99)	
Overweight				1.2104*** (4.34)
Yes				
No (reference)				
Control Variables	Yes			
Fixed effects	Yes			
_cons	14.4681*** (9.70)	14.8404*** (9.68)	14.5730*** (9.49)	13.8844*** (9.03)
N	1612	1612	1612	1612
R^2	0.2189	0.1932	0.1830	0.1910
adj. R^2	0.2051	0.1789	0.1686	0.1767

Note: T statistics in parentheses. *p < 0.1, **p < 0.05, ***p < 0.01.

9.685.

The distribution of other control variables is as follows. Variables related to socio-economic status include education, monthly average income, insurance status, and residential area. The average years of education during adulthood and its SD are 11.01 ± 3. Around one-third of the sample have a low-middle level of education, followed by college and above at approximately 23.76%. The proportions of vocational education and high school education are similar, at 17.25% and 16.19%, respectively. The smallest proportion is individuals with primary school education, at approximately 7.63%. The average monthly income ranges from 0 to 8 thousand yuan, with an average monthly salary and SD of 2.65 ± 1.29. Almost all of the samples have insurance, with only 2.48% of individuals without insurance. The proportion of samples from the central and western regions is close, at 35.67% and 34.99%, respectively. The eastern region has 18.36% and the northeast region has 10.98%. The majority of the samples come from rural areas, accounting for approximately 66.94%, while urban areas account for approximately 33.06%.

Personal behaviors related to health, including smoking, drinking, sleep duration, TV watching, and sedentary activities such as playing video games, are also included. The proportion of smokers and drinkers is 42.06% and 45%, respectively. The average sleep duration and SD are 8 ± 0.89 h. Approximately 83.75% of individuals watch TV, and 12.72% play video games. Diet health is also assessed based on two dimensions, namely personal dietary knowledge and food preferences, with scores ranging from 1 to 37. A higher score indicates a healthier diet, and the mean and SD of diet health score are 21.1 ± 4.49, respectively.

Variables related to parents and family background are also controlled for. The average annual per capita income and SD of the family during childhood are 22.5 ± 23.5 (thousand) yuan. The average height and SD of the father and mother are 155 ± 5.32 and 166 ± 5.74 cm, respectively, and their average BMI and SD are 22.34 ± 2.73 and

Table 5
The coefficients and odds ratio of the impacts of child nutritional status on SRH in adulthood.

	Model 1	Model 2	Model 3	Model 4
	β	OR	β	OR
HAZ	−0.1338*** (−2.91)	0.875*** (0.04)		
BMIZ			−0.0976** (−2.01)	0.907** (0.041)
Controls Variables	**Yes**			
/cut1	−3.5605*** (−3.61)	0.028*** (0.026)	−3.6539*** (−3.72)	0.026*** (0.024)
/cut2	−1.0530 (−1.07)	0.349 (0.323)	−1.1517 (−1.18)	0.316 (0.292)
/cut3	2.4589** (2.44)	11.691*** (10.991)	2.3594** (2.35)	10.584** (9.93)
N	1612	1612	1612	1612
Pseudo R^2	0.0399	0.04	0.0388	0.039

Note: T statistics in parentheses in model 1 and model 3. *p < 0.1, **p < 0.05, ***p < 0.01. Standard errors in parentheses in model 2 and model 4. *p < 0.1, **p < 0.05, ***p < 0.01.

Table 6
Average marginal effects of child nutritional status on SRH in adulthood.

	(1)	(2)
	HAZ	BMIZ
Very good	0.016***	0.012**
Good	0.012***	0.009**
General	−0.026***	−0.019**
Poor	−0.002**	−0.002*
N	1612	1612
pseudo R^2	0.040	0.039

Note: *p < 0.1, **p < 0.05, ***p < 0.01.

Table 4
The results of impacts of child nutritional status on SBP and DBP in adulthood in adulthood.

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
	SBP	SBP	SBP	SBP	DBP	DBP	DBP	DBP
BMIZ	1.8476*** (5.23)				1.2489*** (4.90)			
HAZ		0.9309*** (2.61)				0.5099* (1.87)		
Overweight								
Yes			−5.3758	6.2607**			0.0874	3.1144*
No (reference)			(-1.07)	(2.40)			(0.03)	(1.95)
Controls	Yes							
Fixed effects	Yes							
_cons	79.6496*** (4.69)	95.3498*** (5.45)	109.0541 (2.54)	83.9459*** (4.18)	23.9365** (1.96)	33.1770*** (2.58)	5.3226 (0.15)	34.6087** (2.51)
N	1165	1165	222	943	1165	1165	222	943
R^2	0.1905	0.1560	0.2372	0.1778	0.2262	0.2121	0.2406	0.2231
adj. R^2	0.1581	0.1413	0.1355	0.1507	0.2057	0.1913	0.1394	0.1975

Note : T statistics in parentheses. *p < 0.1, **p < 0.05, ***p < 0.01.

Table 7
The impacts of child nutritional status on whether been sick in last four weeks (SH) and perceived stress (PS) in adulthood.

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
	SH	SH	SH	SH	PS	PS
	β	OR	β	OR	β	OR
HAZ	−0.6388*** (−2.83)	0.528*** (0.13)	0.0495 (0.42)	1.051 (0.113)		
BMIZ					0.1021** (2.12)	1.107** (0.053)
Control Variables	Yes					
_cons	−5.9041 (−1.50)	0.003 (0.014)	−0.9665 (−0.52)	0.38 (0.747)		
N	303	303	1309	1309	1612	1612
Pseudo R^2	0.162	0.162	0.077	0.077	0.04	0.04

Note: T statistics in parentheses in model 1, model 3 and model 5. *p < 0.1, **p < 0.05, ***p < 0.01. Standard errors in parentheses in model 2, model 4 and mode 6. *p < 0.1, **p < 0.05, ***p < 0.01.

Table 8
Average marginal effects of child nutritional status on whether been sick in last four weeks (SH) and perceived stress (PS) in adulthood.

	(1)	(2)	(3)
	SH	SH	PS
HAZ	−0.037***	0.003	
BMIZ			0.024**
N	303	1309	1612
pseudo R^2	0.162	0.077	0.040

Note: *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

22.48 ± 2.89, respectively. The average years of education and SD of the mother are 6.19 ± 3.84. The majority of mothers had a job, approximately 83.75%. The average number of family members and SD during childhood and adulthood are 4.98 ± 1.74 and 4.44 ± 1.20, respectively.

3.2. The regression results of child nutritional status on height in adulthood

Stating from Table 2, there are four models to associate children nutritional status with health human capital in adulthood. These models employ adult height as a proxy for health human capital. First, adult height, which represents the cumulative stock of health from childhood through adulthood, is highly correlated with early childhood nutritional status. Additionally, a taller height is associated with greater cognitive ability and physical fitness in the job market. Dichotomous variables for stunting and continuous variables HAZ are used to evaluate child nutritional status and regressed separately in model 1 and model 2. Furthermore, children aged 6 and under, and those aged over 6 are regressed in models 3 and 4 in order to evaluate the impact of the key developmental period and following catch-up period on height in adulthood.

Based on the estimated results of the models, both HAZ and stunting are significantly associated with height, while controlling for other height-related confounding variables. Model 1's findings indicate that, after controlling for other variables, childhood HAZ is significantly and positively associated with adult height. More precisely, for each unit increase in childhood HAZ, there is an average increase of 1.65 cm in adult height, with a statistically significant difference ($p < 0.01$). Model 2 provides further convincing evidence of the long-term consequences of childhood malnutrition by showing that adults who were stunted as children have considerably shorter heights (2.85 cm) than non-stunted adults ($p < 0.01$). In model 3, the long-term effect of early life (under 6 years of age) on height is significantly negatively correlated, but at the 10% significance level. Children over the age of 6 in model 4 who have stunting are substantially shorter in adulthood than children without stunting by around 2.97 cm ($p < 0.01$), even after adjusting for all other confounding variables. The noteworthy results highlight the significance of giving due consideration to the phase of catch-up growth in the later stages of childhood and adolescence.

3.3. The regression results of child nutritional status on BMI in adulthood

Table 3 features three models that investigate the relationship between childhood nutritional status and adult BMI, where adult BMI is used as an indicator of health human capital in adulthood. As a predictor of health risk, higher BMI levels are often associated with several chronic illnesses. In this study, BMI serves as a composite measure of adult health status. The study measures a child's nutritional status through several indicators, including BMIZ, HAZ, stunting, and overweight.

The model estimates, after adjusting for other BMI-related variables, show a statistically significant relationship between childhood BMIZ, HAZ, and stunting and adult BMI. Models 1 and 2 show that BMIZ and HAZ during childhood are strongly correlated with adult BMI ($p < 0.01$). To be precise, adult BMI in adulthood increases by 0.65 for every unit rise in BMIZ, and adult BMI increases by 0.40 for every unit rise in HAZ. Model 3 indicates that an adult's BMI is adversely correlated with whether they were stunted as children ($p < 0.01$). Stunted adults have a 0.69 lower BMI than adults who have experienced better growth development. Model 4 indicates that there is strong significant correlation between childhood obesity and adult BMIZ ($p < 0.01$). To be specific, individuals who are overweight during childhood have a mean BMI that is 1.21 higher than those who were not overweight. The findings highlight the persistent risks of childhood overweight.

3.4. The regression results of child nutritional status on blood pressure in adulthood

Following Table 4, there are four separate models to investigate the impact of child nutritional status on SBP (Model 1-Model 4) and DBP (Model 5-Model 8) in adulthood, respectively, without adjusted adult's BMI. Childhood BMIZ, HAZ, and overweight are included as explanatory variables to assess children's nutritional status. Previous research has demonstrated a significant correlation between childhood BMIZ and HAZ with adult cardiovascular health, as measured by systolic and diastolic blood pressure. In order to better understand the impact of critical developmental periods and subsequent catch-up periods on cardiovascular health, the study further examined the effect of childhood overweight on blood pressure in two age groups including aged 6 and under (Model 3 and Model 7), and over 6 years old (Model 4 and Model 8).

According to the regression results, both BMIZ and HAZ are significantly and positively related to SBP. Nonetheless, it is noteworthy that DBP displays a significant association exclusively with childhood BMIZ ($p < 0.01$). To be precise, an additional unit increase in BMIZ during childhood is associated with a 1.85 ($p < 0.01$) increase in SBP and a 1.25 ($p < 0.01$) increase in DBP during adulthood. A one unit increase in HAZ during childhood increases SBP by 0.93 ($p < 0.01$) in adulthood.

Children under the age of 6 do not show a significant correlation between overweight and adult systolic and diastolic blood pressure. However, for children above the age of 6, there is a notable positive correlation between overweight status and blood pressure in adulthood. Specifically, models 4 demonstrate that SBP are 6.26 ($p < 0.05$) higher in overweight adults compared to those who are not overweight after 6 years old.

After controlling for adult BMI (refer to supplementary materials for detailed results), a notable and consistent relationship between BMIZ and SBP was observed only among children aged 6 and above. Specifically, a one-unit rise in BMIZ was found to significantly correlate with a 0.84 increase in SBP ($p < 0.05$). Conversely, no significant associations were found between HAZ and both SBP and DBP.

3.5. The regression results of child nutritional status on SRH in adulthood

According to Table 5, two models are employed to investigate the relationship between a child's nutritional status and SRH in adulthood. However, because the models are non-linear as SRH is categorical and ordered, the findings are shown as coefficients (Models 1 and 3) and odds ratios (Models 2 and 4), respectively. SRH is a comprehensive assessment of an individual's health that takes into account their physical, mental, and social well-being. It is commonly utilized in the research of health economics since it is simple to measure and gather. This research divides SRH into four categories, poor, general, good, and very good. To assess children's nutritional status, the models include childhood HAZ and BMIZ as explanatory variables.

According to the estimation results in Table 5, the statistical result of HAZ and SRH is significantly negative with a coefficient value of −0.134 according to Model 1. This suggests that the likelihood of reporting poorer health as an adult decrease with higher childhood HAZ. While, in model 2, the odds of reporting poor health versus the combined general, good and very good are 0.875 lower, given that all of the other variables in the model are held constant. Similarly, in model 3, BMIZ is also significantly negative in relation to the poorer SRH, with a coefficient value of −0.098. This suggests that the higher the BMIZ, the less likely reports poorer health. Meanwhile, in model 4, the odds of reporting poor health versus the combined general, good and very good are 0.907 lower, given that all of the other variables in the model are held constant.

As the coefficients of the ordered logit regression are not able to give a clear picture of the effect of marginal changes in the explanatory variables on the explanatory variables. Therefore, based on Table 6, the table reports the marginal effects of HAZ and BMIZ on each category of SRH. The likelihood of being in very good health and good health increases by an average of 1.6% ($p < 0.01$) and 1.2% ($p < 0.01$) for each unit rise in HAZ, respectively. On the contrary, the likelihood of having general or poor SRH drops by 2.6% ($p < 0.01$) and 0.2% ($p < 0.05$) for each unit rise in HAZ, respectively. For each unit increase in BMIZ, the odds of being very good and good increases by 1.2% ($p < 0.05$) and 0.9% ($p < 0.05$) respectively. While, the odds of SRH being general and poor decreases by 1.9% ($p < 0.05$) and 0.2% ($p < 0.1$), respectively.

3.6. The regression results of child nutritional status on whether been sick in last four weeks and perceived stress in adulthood

Following Table 7, there are four models to investigate the impact of child nutritional status on whether been sick in last four weeks. Whether been sick in last four weeks is a kind of measurement of short-term health capital stock. Childhood HAZ is employed as an explanatory variable in the models to evaluate children's nutritional status. Because the explained variable is binary variable, the logit non-linear models are employed, the findings are shown as coefficients (Models 1 and 3) and odds ratios (Models 2 and 4), respectively. In addition, children aged 6 and under (model 1 and model 2), and over 6 (model 3 and model 4) are regressed separately in order to examine the influence of crucial developmental phases in life course.

The logit regression findings show that, the HAZ of children under the age of six has a significant association with whether been sick in the last four weeks in adulthood. It means that the odds of reporting having been sick in last four weeks are 0.528, given that all of the other variables in the model are held constant. It means that, children with higher HAZ in childhood are 47.2% less likely to be sick in the last four weeks. While, there is no statistical association between the HAZ of children over six and whether been sick in the last four weeks.

Additionally, the regression results (refer to supplementary materials for detailed results) for children aged 6 and younger shows that the likelihood of reporting sick in the last four weeks of adulthood increases with years of education ($p < 0.05$). Children aged 6 and elder who report being unwell in the previous four weeks are less likely to have higher average monthly income ($p < 0.05$), more years of maternal education ($p < 0.1$), health insurance ($p < 0.05$), and longer sleep duration ($p < 0.01$). Smokers ($p < 0.05$) and mother with higher maternal BMI ($p < 0.01$) are more likely to report having been sick in the previous four weeks.

Similarly, as perceived stress is categorized into two variables, higher stress and lower stress, a logit regression model is used, and the reported results in Table 7 include both coefficients and odds ratios. Childhood BMIZ is used as an explanatory variable to measure children's nutritional status. Previous studies have shown that childhood obesity is significantly associated with later psychological conditions due to teasing and bullying. Moreover, children who were overweight in childhood are more likely to be obese in adulthood and suffer from chronic diseases such as diabetes, which can increase psychological burden during the process. Based on the estimated results in Table 7, there is a significant relationship between childhood BMIZ and perceived stress in adulthood. Model 5 reports coefficient results, indicating a positive and significant relationship between childhood BMIZ and perceived stress in adulthood while controlling for other variables ($p < 0.05$). Model 6 reports odds ratio results, suggesting that children with higher BMIZ have a 10.7% increased probability of reporting higher perceived stress in adulthood.

The average marginal effect has been calculated using HAZ and BMIZ as an example in order to determine the impact of an additional unit of HAZ on whether been sick in last four weeks, and an additional unit of BMIZ on perceived stress. Specifically, for children under the age of 6, Table 8 shows that the likelihood of reporting an illness within four weeks decreases by 3.7% for every one unit of HAZ ($p < 0.01$). While, for every one-unit increase in childhood BMIZ, there is a 2.4% increase in the probability of reporting higher perceived stress in adulthood.

4. Discussion

This study associate child nutritional status under age of 18 with health human capital in adulthood by employing data of CHNS from 1991 to 2015. Using HAZ and BMIZ as two main indicators to evaluate children's malnutrition outcomes, the findings show that both undernutrition and overnutrition in childhood are significantly influence health human capital in adulthood. The primary contribution of this study lies in providing evidence on the persistent impact of childhood nutritional status, including early life and mid-to-late childhood, on health human capital in adulthood within the context of China's current nutritional transition stage. While previous extensive research has established links between childhood health and various adult health outcomes, most of the major studies have focused on the long-term effects of early critical period with exogenous shocks under natural experiments, such as famines, earthquakes, droughts, rainfall, natural disasters, Ramadan, and influenza. These extreme nutritional shocks have lasting effects on fetal growth and development during critical periods after birth, but the evidence of long-term effects under extreme nutritional shocks cannot fully explain the sustained impact of the current dual nutritional burden on health outcomes throughout an individual's life course.

Adult height is the one of the important anthropometric indicators of health human capital, which have significant impacts on individual health, labor productivity, earnings, marriage status, and next generation's development (Alderman, 2006; Himaz, 2018; Hoddinott et al., 2013). In this study, HAZ in childhood and stunting significantly explained the differences in adult height, consistent findings suggesting that childhood health can impact lifelong growth trajectories (Adair et al., 2013; Alderman, 2006; Arage et al., 2021; Case & Paxson, 2010; Hoddinott et al., 2013), in particular, this study highlights children who experienced stunting over 6 years old have a significant impact compared to their counterparts. The enduring influence of this crucial catch-up growth phase during late childhood and adolescence warrants thorough attention.

Previous research has mainly used natural experiments to focus on differences in height during pregnancy or infancy exposed to exogenous shocks and those who were not exposed, children exposed to exogenous shocks have a higher risk of being shorter in height (Arage et al., 2021, 2022; Chen & Zhou, 2007; Dercon & Porter, 2014; Meng & Qian, 2009; Portrait et al., 2017). In addition to natural shocks, similar studies have explored the associations between childhood severe malnutrition (Mwene-Batu et al., 2021), birth weight (Adair et al., 2013), preterm birth or small for gestational age (Stein et al., 2013), experiences of hunger during childhood (Cui et al., 2020; Deng & Lindeboom, 2022; Yao & Zhang, 2023). However, most of these studies have primarily focused on critical developmental periods in life on specific age-related self-reported health status, rather than objectively measuring the anthropometric nutritional status of children throughout their entire childhood. Moreover, this study also presents evidence suggesting that stunting occurring after 6 years of age has a more substantial impact on adult height than stunting before 6 years of age, highlighting the significance of the catch-up growth period in later childhood.

What is more, this study found that HAZ and BMIZ, as well as overweight, have significant positive and lasting effects on adult BMI. The longitudinal panel tracking data with individual biological information provided by CHNS has been instrumental in this study, enabling the demonstration of the persistent trajectory of the impact of childhood overweight on adult BMI. On the contrary, children who experienced stunting have a statistically significant negative impact on adult BMI. This may be explained by the mechanism through which undernutrition during childhood influences adult BMI is intricate and multifaceted. To date, the relationship between early undernutrition and adult BMI has not been consistently found in different country contexts and natural experiments, with some studies not finding a significant association (Arage et al., 2021; Stanner et al., 1997). However, a study that focused on the severity of famine exposure and the timing of exposure found that exposure to famine during fetal development is positively associated with adult BMI (Jiang et al., 2021). Similarly, a sample survey conducted in Qingdao, Shandong Province, China, which experienced a famine, all exposed periods including fetal period, infancy, childhood and adolesce have a significantly higher risk of obesity and maximum obesity compared to those who were not exposed (Liu et al., 2017). The inconsistent research findings could potentially be attributed to several factors. Firstly, the variation in adult BMI may be influenced by the severity and timing of famines experienced by different populations in various countries, as well as the environmental changes that occur following the famine. Secondly, demographic differences in sample like gender, or age, may also play a role in explaining the discrepancies, as previous studies have shown that women in older age are more likely than men to exhibit higher BMI after experiencing nutritional shocks in adulthood (Fung, 2009; Huang et al., 2010; Ravelli et al., 1999; Wang et al., 2009). In the present study, the lack of positive association between childhood stunting and higher BMI in adulthood may be due to the fact that the severity of undernutrition experienced during childhood in the sampled individuals does not match the extreme nutritional shocks observed in events like the great famine. Additionally, the sample distribution, with approximately 76% middle-age male participants, may also contribute to the inconsistent findings.

This study observed a significant positive association among BMIZ, HAZ and overweight with adult blood pressure. Especially, exposure to overweight at different times has a significant different impact on blood pressure. Overweight in children aged 6 years and older was found to significantly increase SBP and DBP without adjusting adult's BMI, while no significant effect of overweight on SBP and DBP was observed in children under 6 years of age. Even though after adjusting adult's BMI, children's BMIZ has a greater significant impact on SBP. Clinical and biological studies have long established that childhood overweight can lead to metabolic syndrome, which is one of the risk factors for cardiovascular diseases (Frithioff-Bøjsøe et al., 2022). However, early childhood overweight does not increase the risk of developing hypertension in adulthood; instead, it is the sustained overweight during middle childhood and adolescence that is associated with hypertension risk. Childhood overweight during the middle and later stages is indeed a worrisome and concerning challenge.

On the other hand, the relationship between early-life undernutrition and blood pressure has not reached a consensus across various studies. While most research indicates that exposure to undernutrition during early life, including the prenatal and infancy periods, increases the risk of hypertension in adulthood, there remains some inconsistency in the findings. For example, individuals who suffered from extreme malnutrition in childhood had an average blood pressure that was twice as high as those who were not exposed to malnutrition in adulthood (Mwene-Batu et al., 2021). Children exposed to famine during the Nigerian Civil War had an increase of 7 mmHg in SBP and 5 mmHg in DBP compared to the control group (Hult et al., 2010). However, a natural experiment on the effects of early-life intrauterine malnutrition during the Siege of Leningrad did not reveal a significant relationship with adult blood pressure (Stanner et al., 1997). Children conceived and born during the Siege of Leningrad are likely to have developed the thrifty phenotype hypothesis, which facilitated their adaptation to the harsh environment of malnutrition during infancy and childhood after birth (Calkins & Devaskar, 2011). Other studies have focused on the lack of association between preterm birth or small-for-gestational-age malnutrition and adult blood pressure (Stein et al., 2013).

The study's findings support previous research indicating a significant association between childhood nutrition indicators, such as HAZ and BMIZ, and self-rated health in adulthood. Specifically, higher HAZ and BMIZ during childhood are linked to better self-reported health outcomes later in life. Higher HAZ and BMIZ during childhood objectively indicate favorable growth and development, reflecting better physiological metabolism and development of various organs, which are similar with other studies' findings (Case et al., 2005; Wang et al., 2016). Interestingly, this study revealed a notable negative association between HAZ in children under 6 years old and recent health status, while no significant effect was observed for HAZ in children over 6 years old. These findings underscore the importance of early childhood chronic malnutrition in determining health outcomes in adulthood (Alderman, 2006). Consistent with other studies, evidence from research on the Ethiopian famine suggests that individuals exposed to famine conditions are more prone to illness, highlighting the vulnerability of disadvantaged populations (Dercon & Porter, 2014). Similarly, within the framework of the life course model, studies have investigated the regression of childhood, adulthood, and community-related factors on various health indicators in older age. The findings suggest a direct association between childhood circumstances and the cognitive, physical, and self-assessed health, as well as the mortality risk, in older adults. Conversely, the impact of adult socioeconomic conditions on the relationship between childhood circumstances and health outcomes in later life is minimal (Wen & Gu, 2011).

This study is one of the few research that establishes a connection between childhood BMIZ and perceived stress in adulthood. The assessment of stress in adults provides an indication of their exposure to various stressors, and it has been observed that both adult and childhood overweight are linked to the perception of stress (Papadopoulos & Brennan, 2015). However, most studies in this area have focused on parental perception of stress, early childhood psychological stress, and its impact on childhood obesity (Leppert et al., 2018), or the relationship between obesity measures represented by body mass index and mental health (McCrea et al., 2012). Regarding the positive relationship found in this study, children with higher BMIZ may experience body image insults and bullying, leading to dissatisfaction with their appearance and subsequently experiencing more psychological distress and stress in adulthood (Young-Hyman et al., 2003). Psychological research related to childhood obesity has shown that experiences such as peer victimization and weight-based teasing are contributing factors to the development of adolescent depression (Nemiary et al., 2012). Additionally, children with higher BMIZ may face social isolation and other social difficulties, which can affect their perceived stress in adulthood. Existing research, based on a life course perspective, has linked adverse childhood experiences to increased perceived stress in adulthood, providing indirect evidence of the lasting impact of early childhood experiences on perceived stress in adulthood (De Rubeis et al., 2023).

5. Conclusion

This study uses CHNS longitudinal data from 1991 to 2015, matched adult information with their childhood, to examine the relationship between childhood nutrition and adult health human capital. The study found that childhood nutrition significantly and continuously influenced adult health human capital measured by height, BMI, blood pressure, SRH, SH, and PS. The study found that differences in adult health can be traced back to childhood health status, and thus, childhood nutrition (no matter undernutrition and overnutrition) should be given more attention to promote the long-term development of a country's health human capital and its impact on economic growth. Particularly, stunting among children aged 6 and above has a lasting effect on adult height and short-term health. Both height and short-term health can contribute to a decrease in individual labor productivity and result in economic burdens to some extent. Consequently, apart from critical life stages, the nutritional well-being of school-age children aged 6 and above merits significant attention, increased investment, and heightened concern. Also, childhood overweight is a significant challenge in the current nutritional transition phase caused by rapid economic development in China. The study's results show persistent influence of child overweight on adult BMI, SBP, and perceived stress, which are all significant health threats facing China today. Reducing childhood obesity and promoting linear growth and development throughout childhood can reduce the future burden of disease on the nation.

The government should lead and coordinate multiple sectors, including various levels of government agencies, medical care, media, education, research institutions, and the market economy, to promote correct dietary habits and healthy personal lifestyles for families and individuals. For example, it is suggested that the government should take action to assist consumers in distinguishing between healthy and unhealthy food options. This can be accomplished by enforcing more rigorous regulations on food ingredient labeling in the market and including labels that indicate whether or not the product is recommended. Furthermore, the government has the option of imposing additional taxes on unhealthy food items, and placing restrictions on their advertisement. Additionally, the government can enhance the availability of public sports facilities in communities, schools, and workplaces to foster a culture of fitness for all. With regards to linear growth and development in children, it is suggested that the government should partner with relevant health authorities to advocate for the implementation of scientific family planning, to create a suitable prenatal environment for every child. Further, promoting breastfeeding post-birth, and continuously monitoring the growth and development of children until adulthood, is necessary. This is because most cases of child stunting in school-aged including middle childhood and adolescence are not promptly identified and given the appropriate attention by families, schools, and society.

Ethics statement

Before conducting interviews with participants for our study on ethical decision-making, the China Health and Nutrition Survey was ethically reviewed by the Institute of Nutrition and Health of the Chinese Centre for Disease Control and Prevention and all subjects signed an informed consent form prior to the survey, ensuring that they understood the purpose of the research, their rights as participants, and the voluntary nature of their involvement.

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Conflict of interest

Sa Li, Norashidah Mohamed Nor, Shivee Ranjanee Kaliappen affirm that they do not have any conflicts of interest to disclose.

Data availability

I have shared the link of the data.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ssmph.2023.101533.

Abbreviations

WHO	World Health Organization
DBM	Double Burden Malnutrition
FOAD	et al. origins adult disease
DOHaD	Developmental Origins of Health and Disease
BMI	Body Mass Index
CHNS	China Health and Nutrition Survey
HAZ	Height-for-age z score
BMIZ	BMI-for-age z score
PSS-14	Perceived Stress Scale 14
SD	Standard deviation
SBP	Systolic blood pressure
DBP	Diastolic blood pressure
SRH	Self-reported health
SH	whether been sick in last four weeks
PS	Perceived stress

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