



Geographic latitude and human height - Statistical analysis and case studies from China

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Abstract

Based on Chinese General Social Survey (CGSS) data, this paper selects ten variables, including height, gender, household registration, and age. Through the statistical analysis of 57,574 survey samples, this study finds that the average height of China's population has increased by more than 10 cm in the past 100 years. Among the findings, the data indicate the average height of men born after the 1990s is 11 cm taller than that of men born after the 1920s, which has now reached 173 cm, and that the height of women is 10.93 cm taller, averaging 163 cm. The average height of the Chinese population reflects significant differences in gender, region or province, urbanity and rurality, and nationality, among other variables. The average height of men and women gradually increases with the increase of geographical latitude. Some economically developed southern provinces approach the average height of the North. This paper predicts that the average height of the newborn population will continue to have inertial growth in the next 20 years, and the newborn male population will reach the World Health Organization's ideal height standard of 176.5 cm by 2030. The analysis suggests that geographic latitude and heredity are the determinants of body development. Geographical latitude difference is a super-variable for human mitochondria to regulate the proportion of heat outflow and ATP transformation. Historically, the population living in high-latitude areas of China migrates to economically developed low-latitude provinces such as Shanghai, Jiangsu, Zhejiang, and Guangdong, which is the main reason why the per capita height in these areas is significantly taller than that in other southern provinces.

Keywords Geographic latitude · Human height · Centennial variation · CGSS

Introduction

Individual height is one of the most apparent basic external characteristics of human beings, and it is also a common marker to describe and identify individual characteristics. People commonly believe that the average height of human

beings has gradually increased with evolution and social progress. However, more and more studies show that this is not the case. In Turkey, paleoanthropologists have found that the remains of humans seven or eight thousand years ago found in ancient sites, if restored, are much taller than the present Turks [1]. Jared Diamond, an American scholar, explains in his popular science masterpiece *Collapse: How Society Chooses Success or Failure* that the earliest human beings lived by hunting and collecting fruit and seeds in ancient times. Agriculture appeared about 10,000 years ago. With the popularization of agriculture, the source of human food has stabilized, the complexity of human structure has decreased, and human survival no longer depends on height to pick overhead fruit or the use of a tall body to deter prey. The requirement of social cooperation on the individual's ability to store and release energy is greatly reduced, so the height is gradually reduced [2]. A study from Oxford University in the UK also found that in the middle ages, the height of European men reached a peak of 173 cm and then

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began to decline, dropping to 167 cm before the industrial revolution and returning to 173 cm only a few decades ago.

In 2013, Max Roser et al. conducted a statistical study on the average height trend of 18 million adults born from 1896 to 1996 in 200 countries and regions worldwide (i.e., those who reached the age of 18 from 1914 to 2014). The results show that, globally, the average height of adult males born in 1996 has increased from 162 to 171 cm, while that of females has increased from 151 to 159 cm. Regardless of gender, those born post-1990 are 8–9 cm, or about 5%, taller than their ancestors 100 years ago [3]. The results of this cross-country comparison show that the average height of some groups in some countries has increased rapidly. For example, the average height of Iranian men has increased by 16.5 cm in the past 100 years. In 1914, the average height of Canadian women was 157.6 cm, and now, the average height of Canadian women is 163.9 cm, an increase of 6.3 cm. By contrast, South Korean women grew 20.2 cm. The average height of men and women in Japan is 170.8 cm and 158.3 cm, respectively, and the average height of South Koreans is 4 cm taller than the average height of the Japanese, measuring 174.9 cm and 162.3 cm, respectively (Bian Zhao, 2016) [4].

After investigation, as early as The Enlightenment, Montesquieu studied the influence of climate on individual body and character in his book *Discussing the Spirit of Law* and then extended the conclusion to the group's character and social and political system. Montesquieu believed that cold air could increase the elasticity of the ends of the fibers and help blood return to the heart from these ends. He hypothesized that the strength of the heart makes people more confident and more courageous, so the northern people's skin is coarse and thick, and their sensitivity to happiness is relatively low, so people appear to be plainer and bolder. He then theorized that hot air would have the opposite result; it would make the end of the fiber relax and elongate, reducing elasticity and strength. Therefore, Montesquieu conjectures, in hot climates, the mind is relatively depressed, the character is relatively cowardly, and the sensitivity to happiness is relatively high, so the inhabitants have a high crime rate and like to indulge their desires.

According to the available data, Li Ji (1896–1979) was the first scholar to study the height of the Chinese. In 1923, in his doctoral dissertation *The Constitution of Chinese Race* at Harvard University, Li Ji investigated and analyzed the height data of 5,081 Chinese, including 111 Chinese students and workers he investigated in the USA. The paper reported that the average height of Chinese people in the 1920s was 165 cm. In this study, he also found the heights of people in Guangdong, Yunnan, Guangxi, Hunan, Sichuan, Zhejiang, Hubei, and other provinces were shorter than the national average height. For example, the average height of men in Guangdong was 161.8 cm. In Jiangsu, Guizhou,

Gansu, Shanxi, Anhui, and other provinces, the average height was close to, or slightly taller than, the national average height. The average height of people from Jiangsu was 166.1 cm. People in Zhili (now Hebei), Shandong, Fujian, Henan, Jiangxi, Shaanxi, and other provinces were taller than the national average height. For example, the average height of people in Zhili was 169 cm. Li Ji, who drew the first height distribution map of China, believed that the height of people in Guangdong, Jiangsu, and Zhili could be compared with that of European Spaniards (162 cm), Finns (166.6 cm), and Danes (169.1 cm) and that the height of people gradually became taller from South to North [5].

Some scholars have studied the changing trend of ancient Chinese height and think that the height of Chinese people in the Qin and Han Dynasties continued the basic trend since the Neolithic age, showing a basic trend of taller people in the North and shorter people in the South. During the Qin and Han Dynasties, the average height of adult males in the Yellow River Basin and the northern region was about 166–168 cm, and the average height of adult females was about 150–152 cm. The average height of male adults is about 161 cm, and that of female adults is about 150 cm. The average height of the population in the Shang and Zhou dynasties may be 2 cm or more lower than the average height in the Neolithic age [6]. Other scholars observed and measured the limb bones of adult bone specimens from Han, Tang, and Song tombs in Zhengzhou and calculated the average height of men and women in the three periods. They concluded that the average height of men in the Han, Tang, and Song Dynasties was 169.52 cm, 167.03 cm, and 164.49 cm, respectively, and the average height of women was 159.11 cm, 158.39 cm, and 156.17 cm, respectively. The average height of males and females was higher than that of females alone, and the difference was significant; over time, the height of men and women shows a downward trend [7].

The height change of the Chinese population has been a topic of study in the last 20 years. Based on the data collected from the national student physique surveys in 1985 and 2005, Xu Liang and Wang Fengxiao analyzed the height development, dynamic changes, and spatial distribution characteristics of 18-year-old students in China using a cluster analysis and GIS analysis tools. The results show that the height development of Chinese 18-year-old students is generally higher in the North and lower in the South, and the height development level fluctuates greatly. Among the findings, the researchers found the provinces with slow growth of young students in the North are concentrated in the northwest, while the provinces with slow growth of young students in the South are located in the more developed coastal areas in the East. The height level of students in neighboring provinces is similar, and the height is greatly affected by geography, natural environment, and other factors [8]. Liu Lu et al. used the height data of 10,451 Han people in cities measured in 31 regions in 22 provinces from

2009 to 2013. The statistical analysis results show that the height of adults is positively correlated with latitude [9]. Li Yonglan et al. used a similar method and larger sample data to compare and analyze the height and body ratio differences between northern Han and Southern Han. The results showed that, proportionally, the lower limbs in the northern Han were longer than those of the Southern Han, while the trunk was proportionally shorter than, or close to, that of the Southern Han [10].

. Other highly cited literature [11] includes research on athletes, which is published in sports academic journals. The research contents include the dynamic analysis of the height of Chinese men's volleyball league players, the comparative study of the height of CBA and American professional basketball league players, the analysis of the characteristics of the height of the world's top track and field athletes, the comparative analysis of the height of Chinese and foreign athletes, and the study of the height of athletes in different positions in the German World Cup.

In addition to studying the average height of the population and the height of athletes in different countries, a large number of studies abroad focus on the individual physiological and social effects of height differences. The taller the height, the longer the life span, the lower the risk of adverse pregnancy and cardiovascular and respiratory diseases, and the higher the risk of some cancers [12–19]. For the individual social impact of height difference, there is evidence that tall people have higher than average levels of education, higher income, and even higher social status [18, 20–22].

Through a review of the literature, we can see that the consensus of previous scholars is as follows: in the whole of human history, height is constantly fluctuating, and the trend is roughly U-shaped. For a long time, the average height of men has been higher than that of women all over the world. Before the industrial revolution, human height was in a downward trend. Since the industrial revolution, the average height has increased year by year. The turning points are different in different countries. Some studies have shown that Chinese people have grown taller in recent decades, but the statistical results are quite different. For example, Bian Zhai published a paper in 2016 saying that the height of 17-year-old Chinese people in 2002 was 3 cm taller than in 1992 and increased by 3 cm in ten years [23]. Large-scale studies abroad show that the average height of Chinese people has only increased by about 10 cm in the past 100 years [24]. There are different opinions on the reasons for the height difference.

Researchers are concerned with both genetic and environmental variables and generally tend to discuss the influence of height on factors such as economic status and social status. They think that the average height of the group with rich families or high social status is higher than that of the group with poor families or low social status.

The following are the study's problems, as determined by the aforesaid analysis:

- (1) How about the height of Chinese people?
- (2) What changes have taken place in the average height of Chinese people in the past 100 years?
- (3) What are the characteristics of per capita height distribution across the country?
- (4) What is the reason for the height change? What is the relationship between latitude and geography?

Compared with previous studies, there are two possible innovations in this study:

First, the sample size of this study is large, and the representativeness is slightly strong. As mentioned above, the first person to study the height of the Chinese was Dr. Li Ji. There were more than 5,000 people in the total sample, and the distribution was very uneven. Some provinces had too few samples, and the representativeness was insufficient. For example, there were only eight cases of human height in Guizhou Province, all of which were 166.6 cm tall. There were only ten cases of human height in Jiangxi Province, with an average height of 171.2 cm. In this sample, the height of adults in Guizhou and Jiangxi in the 1920s is obviously larger. Secondly, this study uses quantitative methods to analyze the impact of geographical latitude on the per capita height of a specific population, which is rare in the existing literature. Finally, this paper attempts to use an interdisciplinary perspective to explain the physiological mechanism and social reasons of China's per capita height and obtains a realistic solution to the research problem on the larger measurement granularity.

Empirical research

The data of this paper come from the comprehensive social survey of China, the Chinese General Social Survey, or CGSS for short. We combined the relevant variable data of six national sample surveys from CGSS 2008 to CGSS 2015, which supplied us with 57,574 valid samples. The sampling situation of each year is shown in Table 1. In addition to height, this paper also selected five variables, including gender, year of birth, nationality, province, and urbanity and rurality, for statistical calculation and comparative analysis.

In addition, geographic latitude is an important variable that affects individual height. Therefore, one of the explanatory variables is the geographic latitude of the provincial capital cities. The influence of geographic latitude on individual height was evaluated quantitatively. The results are as follows: general situation, inter-ethnic differences, and interprovincial comparison.

Table 1 Sampling in each survey year

Survey years	2008	2010	2011	2012	2013	2015	Total
Number of samples	6000	11783	5620	11765	11438	10968	57574

General survey of Chinese height

The number of cases was 57,574, with an average age of 48 years and a median age of 47 years. They were all over 18 years old at the time of the investigation. Regardless of age, urbanity or rurality, ethnic groups, or provinces, the average height of males was 169.60 cm, while the average height of females was 158.88 cm. The gender difference was significant ($P < 0.000$).

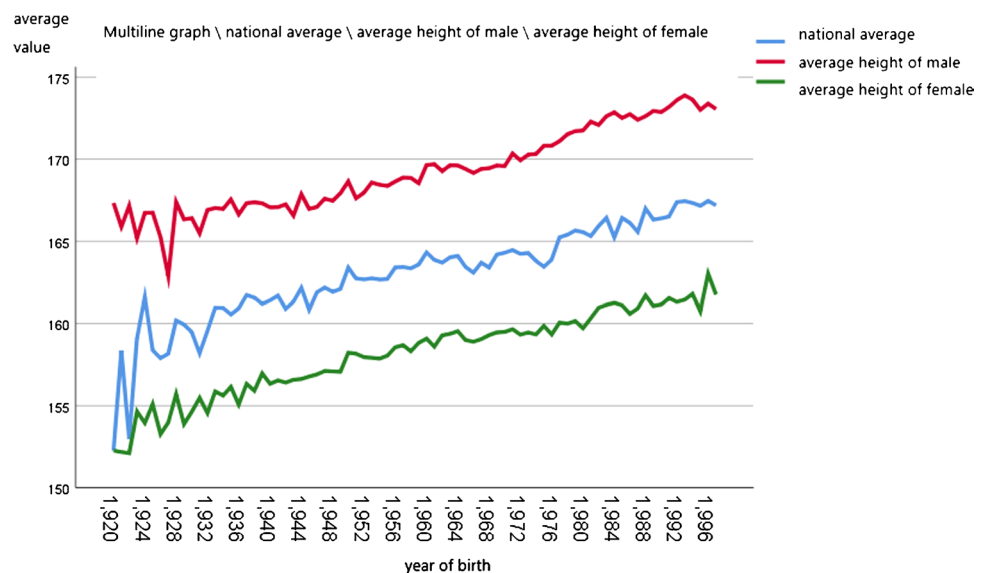
In the sample, in the past 100 years, the largest male was born in 1993, with an average height of 173.89 cm, and the smallest was born in 1927, with an average height of 162.88 cm, with a maximum increase of 11 cm (Fig. 1). The oldest age group was born in 1996, with an average height of 163.04 cm. The youngest age group was born in 1922, with an average height of 152.11 cm, with a maximum increase of 10.93 cm. A large data study from all over the world shows that the average height of an adult male born in 1996 is 171 cm in the world and 173.4 cm in China. The average height of men and women on the Chinese mainland is 171.8 cm (ninety-third in the world) and 159.7 cm (eighty-seventh in the world), with an increase in 11 cm and 10 cm, respectively, in the past 100 years [24]. The conclusion of this study is basically confirmed in our statistics. As for the height gap between men and women, the survey statistics from the 1930s showed that the height gap between men and women in China was 8 cm [25]. However, according to our calculation, the height gap between men and women was between 13 and 15 cm from the tenth to the twentieth

century, with the largest gap reaching 24 cm. The gap narrowed to around 10 cm from the 1940s to the 1960s. After the 1970s, there seems to be a trend of steadily widening the gap. The height gap between men and women born in the early 1990s was more than 12 cm again in many years.

According to the latest data, the global average height of men is 171 cm, and that of women is 159 cm [24]. Globally, the average height of women is about 12 cm shorter than that of men. The height gap between men and women is prevalent around the world. The gap in Macedonia is the largest; men are usually 18.5 cm taller than women. Gambia has the smallest gap, with an average difference of only 4.5 cm. In every country in the world, men are taller than women on average. The relative difference between men and women ranges from 2–3% to 12%. On average, men are 7% taller than women. Regionally, sub-Saharan Africa has the smallest difference in average height between men and women; in many countries, it is below the global average of 7%.

Men are taller than women, and this conclusion is true in all countries in the world. When did this high differentiation happen? What is the difference between boys' and girls' growth in childhood? Studies have shown that both sexes grow rapidly in the first six months of life, and the growth rate gradually declines in the next few years. Boys and girls are about twice as tall as their height at birth at the age of 3 or 4, but the boys are still slightly taller. At the age of 8, the growth rate of boys begins to slow down. At the age of 9, the average height of girls is taller than that of boys. At the age of 11, girls are usually more than 2 cm taller than

Fig. 1 Average height of population in different birth years in China



boys. At this point, though, the growth rate of girls begins to slow down, and the growth rate of boys begins to accelerate again. Around the age of 13, the average height of boys overtakes the height of girls again. Girls tend to stop growing a few years earlier than boys and reach their final adult height around the age of 16. The height of boys peaks around the age of 18. At this stage, they are on average 13 cm taller than girls.

National comparison of Chinese height

The sample includes 56 ethnic groups in China. The proportions of Han, Mongolian, Manchu, Hui, Tibetan, Zhuang, and Uygur in the sample are 91.8%, 0.3%, 0.9%, 1.9%, 0.2%, 1.2%, and 0.3% respectively. The calculation results of sample number, average height, and standard deviation are shown in Table 2.

Table 2 shows that the average height of Mongolian and Hui ethnic minorities is more than 164 cm, and that of Manchu and Uygur ethnic minorities is more than 165 cm, which is significantly different from that of Tibetan, Zhuang, and other southern ethnic minorities ($P < 0.000$). In a 2015 study by Song Yi, Hu Peijin, Zhang Bing, Ma Jun, and others, based on the data of the national student physique survey in 1985, 1995, 2000, 2005, and 2010, this paper analyzed the physical fitness of the Mongolian, Hui, Uygur, Zhuang, Korean, Tibetan, Miao, Buyi, Dong, Bai, Tujia, Hani, Dai, Lisu, WA, Naxi, and other nationalities. The characteristics, rules, and trends of 17-year-old students' height growth in 18 ethnic minorities of Tu and Qiang were statistically analyzed and predicted. In 2010, the average height of 17-year-old boys of 18 ethnic minorities was more than 162 cm, and that of 17-year-old boys of Hui, Mongolian, and Korean nationalities was more than 170 cm. The ethnic groups whose height increases by more than 2 cm every ten years are Hui and Dong, and the ethnic groups whose height increases by more than 1 cm every ten years are Korean, Tibetan, and Hani. The average height of 17-year-old girls is more than 150 cm, and there are 15 groups of minority girls growing in varying degrees. The growth rate every ten years is more than 1 cm for Hui nationality and Korean nationality, and there are nine minority nationalities such as Hui nationality, Korean nationality, and Dong nationality ($P < 0.05$). This study shows that, while the majority of

ethnic minority students in China have a long-term growth trend, the height growth of boys and girls in different ethnic groups is unbalanced [26]. The conclusion of this study supports the research results of Song Yi and others in 2015 and holds that the stature of ethnic groups who traditionally live in higher latitudes is significantly taller than that of ethnic groups who traditionally live in lower latitudes.

Provincial comparison of Chinese height

Among the 31 provinces in China, the largest sample is Henan women, with more than 1600 participants, and the smallest sample is Tibetan women, with 39 participants. Table 3 shows the sample number, height per capita, and ranking of 31 provinces (autonomous regions and municipalities) by height.

Note: the list of "geographic latitude" shows the geographic latitude values of provincial capitals or central regions

The table shows that the top ten provinces of male height are Tianjin, Shanghai, Beijing, Liaoning, Hebei, Shanxi, Shandong, Xinjiang, Ningxia, and Jilin. Except for Shanghai, which is ranked second with 172.2 cm, the rest are from the North. The top ten provinces with the same height for women are Ningxia, Qinghai, Tianjin, Liaoning, Xinjiang, Shanxi, Shandong, Henan, Hebei, and Shanghai. It can be seen that Liaoning, Shanxi, and Shandong are the same in height ranking, ranking fourth, sixth, and seventh, while the other provinces are not in the same order.

Jiangxi, Guizhou, Sichuan, Hunan, Guangxi, Chongqing, Yunnan, and Tibet are the top eight provinces in male height; there are slight differences in the ranking of women, but all of them are southern provinces without exception. The tallest height belongs to males in Tianjin, at 173 cm, and the shortest belongs to males in Tibet, at 162 cm; the gap in height between males reaches 11.3 cm, and the gap in female heights reaches 6.51 cm.

In 1994, Chi Hua said in his research that, as early as 90 years ago in the 1930s, in terms of regional differences, according to geographical location, the height and weight of students in the northern provinces of China were larger than those in the southern provinces. There was a law of gradual decrease from North to South. This is basically consistent with our results [25].

Table 2 Comparison of height between different ethnicity groups

Ethnicity	Han	Hui	Zhuang	Manchu	Mongolian	Uygur	Tibetan	Others	No answer	Refuse to answer	Total
Number of samples	52848	1086	711	463	196	193	91	1914	20	52	57574
average value	163.88	164.36	160.28	165.35	164.23	165.61	159.87	159.27	160.65	149.67	163.69
standard deviation	11.054	12.691	9.709	11.08	8.018	7.724	20.746	17.104	10.158	45.748	11.45

Table 3 The average height of men and women in each province and the ranking of provinces

	Province	Male		National ranking	Province	Female		Geographic latitude
		Number of samples	Average height			Number of samples	Average height	
1	Tianjin	842	173.39	1	Ningxia	313	162.18	38.78
2	Shanghai	1220	172.2	2	Qinghai	228	161.18	37.03
3	Beijing	1368	171.91	3	Tianjin	929	161.06	39.22
4	Liaoning	990	171.6	4	Liaoning	1074	160.88	42.33
5	Hebei	776	171.49	5	Xinjiang	173	160.74	44.28
6	Shanxi	756	171.41	6	Shanxi	729	160.32	38.45
7	Shandong	1513	171.3	7	Shandong	1472	159.97	38.05
8	Xinjiang	207	171.21	8	Henan	1619	159.81	35.27
9	Ningxia	201	171.15	9	Hebei	943	159.76	38.05
10	Jilin	1231	170.96	10	Shanghai	1253	159.74	31.38
11	Heilongjiang	1433	170.74	11	Jilin	1346	159.53	44.47
12	Jiangsu	1249	170.68	12	Inner Mongolia	293	159.45	40.8
13	Qinghai	269	170.13	13	Jiangsu	1339	159.34	32.07
14	Zhejiang	1085	170.05	14	Shaanxi	1093	159.27	34.45
15	Guangdong	1253	169.99	15	Gansu	521	159.21	36.05
16	Henan	1474	169.97	16	Beijing	1479	159.03	39.93
17	Gansu	524	169.78	17	Heilongjiang	1526	158.39	46.33
18	Inner Mongolia	286	169.67	18	Guangdong	1281	158.25	23.27
19	Shaanxi	1036	168.87	19	Zhejiang	1250	158.24	30.47
20	Hainan	50	168.72	20	Hubei	1585	158.18	30.87
21	Fujian	749	168.5	21	Anhui	1141	158.09	32.43
22	Anhui	1104	168.49	22	Hainan	50	157.24	20.03
23	Hubei	1460	168.47	23	Fujian	664	156.69	26.13
24	Jiangxi	1198	166.53	24	Guizhou	795	156.2	27.08
25	Guizhou	699	166.51	25	Sichuan	1287	155.96	31.12
26	Sichuan	1299	165.85	26	Jiangxi	1276	155.81	29.13
27	Hunan	1061	165.69	27	Chongqing	782	155.61	29.95
28	Guangxi	1018	165.47	28	Tibet	39	155.36	30.08
29	Chongqing	684	164.71	29	Guangxi	954	155.36	23.4
30	Yunnan	969	164.59	30	Hunan	1177	155.34	28.35
31	Tibet	40	162.13	31	Yunnan	919	154.43	25.08
	Total	28044	169.31			29530	158.36	

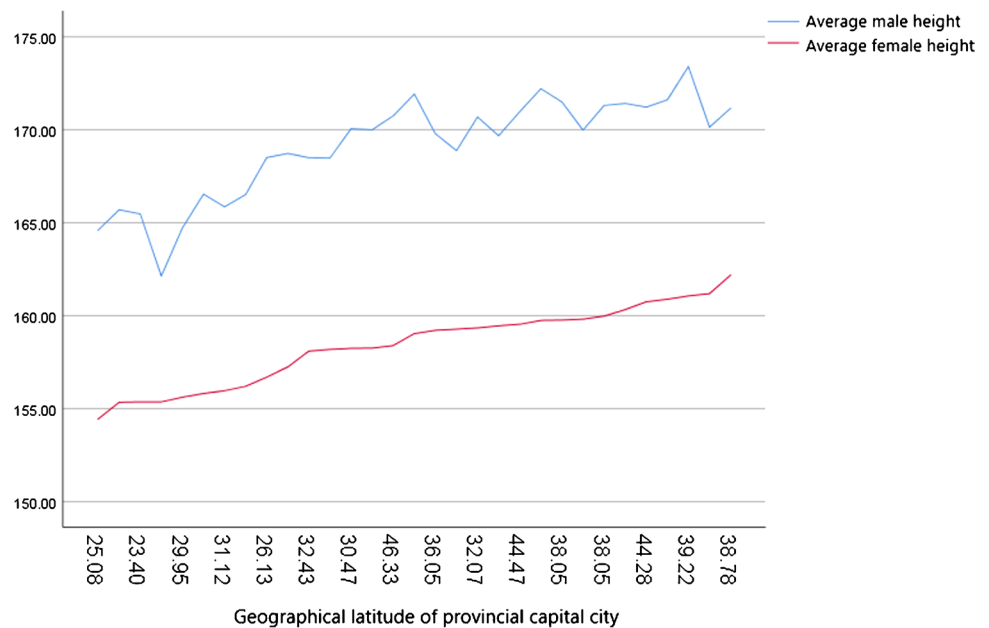
This conclusion is also applicable on an international scale. According to a British study [27], the top ten countries ranked by men's height in the world are the Netherlands, Belgium, Estonia, Latvia, Denmark, Bosnia and Herzegovina, Croatia, Serbia, Iceland, and the Czech Republic. The top ten countries ranked by women's height in the world are Latvia, the Netherlands, Estonia, the Czech Republic, Serbia, Slovakia, Denmark, Lithuania, Belarus, and Ukraine. These data reveal that, regardless of gender, the top ten countries, when ranked by average height, are all high-latitude European countries. According to the study, the shortest men in the world reside in East Timor, with an average height of 160 cm. The shortest women are found

in Guatemala, with an average height of 149.4 cm. It is no accident that the countries with the shortest average height of men and women are all in low-latitude countries. These findings support the conclusion that geographical environment, especially geographical latitude, determines the average height of a population to a certain extent.

In order to compare the changing trend of height with geographical latitude, we take the latitude of the central region of provincial capitals as the abscissa and the average height of men and women in each province as the ordinate to draw the line chart as follows.

The figure demonstrates that in the range between 25.08 and 38.78° North latitude, the height of both men and

Fig. 2 The changing trend of per capita height with geographical latitude of residence in China



women increased with the geographical latitude of their living area, showing an increasing trend (Fig. 2). The average height of females increased from 155 to 162 cm, while that of males increased from 165 to 172 cm. However, several exceptions, such as Jiangsu, Zhejiang, Guangdong, and Shanghai in low-latitude areas, do not support this inference. The reasons are discussed and analyzed in the following paragraph.

Why does latitude affect the average height of a population? In other words, what is the modern biological basis of the association between latitude and height? Modern biology provides a reasonable explanation from the functional analysis of human mitochondria. Modern biological studies have shown that human mitochondria are responsible for the production of ATP and heat. Specifically, there are two methods of proton excretion in the mitochondrial membrane. One method is to shock the ATPase protein motor to produce ATP; the other method, under the effect of concentration difference, does not impact the ATPase protein motor and protons flow out. The latter was originally designed to prevent free radicals from accumulating too much in cells and damaging other organelles, especially DNA in nuclei, so as to deal with the excretion mode evolved by the human body without ATP. In this way, the protons pumped into the cell membrane are wasted, but the side effect of this method is to generate heat. The proportion of ATP or heat produced by mitochondria is determined by the amount of food, temperature, and activity of the individual. People living in hot, low-latitude areas and people living in cold, high-latitude areas have different proportions of mitochondria to produce heat or ATP. In a hot environment, the body does not need too much heat, so the mitochondria of the population and their

offspring in low-latitude hot areas are used to converting a larger proportion of nutrition into ATP. However, because of the cold weather, the population and their offspring in high-latitude and cold regions have mitochondria that are bound to produce a lot of heat to maintain their body temperature and require roughly similar activity intensity to maintain their tribal life. In order to produce more heat, people in colder high-latitude regions and their descendants have to increase the amount of food they consume [28]. The essence of the regional and ethnic differences of human height is the latitude difference and energy consumption difference of their traditional living areas.

Why is the average height of Shanghai, Jiangsu, Zhejiang, and Guangdong in relatively low latitudes taller than that in relatively high latitudes? In the past, some theorized that it was related to a healthy lifestyle, exercise, and balanced nutrition, which was suitable for economic development. This study suggests that it is related to the influx of immigrants from high latitudes. For the average height of a population, the role of the geographical environment, including temperature and latitude, is far underestimated. It may be more appropriate to take height as an indirect indicator of ethnic integration, North-South interaction, and population mobility. Why are inhabitants of Shanghai, Jiangsu, Guangdong, Zhejiang, and other southern provinces relatively tall per capita, even ahead of the traditionally taller provinces, such as Jilin, Inner Mongolia, and Xinjiang? We speculate that it is because a large number of northern immigrants from high latitudes have poured into these areas, which has increased the per capita height of these economically developed areas. According to the investigation, as the regions with the most immigration in China, the Pearl River Delta

and the Yangtze River Delta have been inundated with a large number of immigrants in the past 30 years, many of them coming from the North. The proportion of inter-marriage between people of the South and the North has increased, and the role of factors such as nutrition and health security cannot be underestimated.

Future prediction of Chinese height

Is there an upper limit for human height? In the past century, the height per capita in the world has increased significantly, but it is unbalanced among countries. The height per capita in some rich countries has stagnated, so it is reasonable to assume that there is an upper limit. According to a study in the journal “Frontiers in Physiology,” there are limits to human physiological conditions. The study was led by Jean Francois Toussaint, a professor at the University of Descartes in Paris. He and his team reviewed more than 160 studies over the past 120 years and found that human evolution has stabilized in the past 40 years, probably since 1980. “Despite our progress in nutrition, medicine, and science, these human characteristics are no longer growing,” said Professor Toussaint. This shows that modern society has let human beings reach their limits. For example, although more and more people can reach the limit, fewer and fewer people can break the record; fewer and fewer people break the life expectancy record, and fewer and fewer people break the sports record. Therefore, although we can still find that the statistics of per capita height are increasing, malnutrition, environmental pollution, climate change, the spread of diseases, and other factors in some areas may hinder human health and life expectancy [29]. A study published in the journal “Nature” confirmed that [30], in recent decades, the growth of height per capita in the Netherlands has come to an end, and studies tend to think that the Dutch have reached the largest height per capita. The study also speculates that changes in Dutch lifestyle in recent decades may be another reason. For example, it is easy to eat fast food now, which may lead to insufficient nutrition intake; a sedentary lifestyle and reduced energy consumption have led to an increase in overweight individuals and obesity. In addition, over the past decade, the high consumption of milk in the Netherlands has dropped from 63 liters per capita in 2000 to 60 liters in 2010 [31].

How much room is there for China’s per capita height growth? The use of 83 years of historical data from 1909 to 1997 establishes a time series model to predict the average height of the Chinese population born from 1998 to 2040. The figure is as follows.

According to the World Health Organization, the expected average height of healthy people is 163 cm for

women and 176.5 cm for men. At present, the average height of women in the world is 159.5 cm, while that of men is 171 cm, which is lower than the WHO’s expectation for healthy people. In this study, we calculated that the average height of the female population born in 1996 in China reached the expected average height of the healthy population, defined by the World Health Organization, for the first time, and that of the male population born after 1990 reached a height of 174 cm. While Chinese men were, on average, 3 cm taller than the average man, there is still a gap of 2.5 cm between expected and actual height, based on the World Health Organization’s expectation of the average height of the healthy population.

In order to save space, we only list the predicted average height of the newborn population from 2019 to 2040, as shown in Table 4. It can be seen from the table that the average height of men born in 2040 will reach 177.59cm, with a confidence interval of (173.85, 181.34), and the average height of women will reach 166.95cm, with a confidence interval of (159.99, 173.92). Other forecast results are shown in Table 4.

Observing the time series model, Fig. 3 shows that there is an apparent linear relationship between the height per capita and the year of birth. Therefore, this study also established a linear regression model of the height of Chinese men and women. The independent variable was the year of birth, the value range was [1926,1997], and the R^2 of the model was 0.938 and 0.947, respectively. The regression coefficients were 0.115 and 0.104, respectively, which indicated that the average increase in the height of the male population was 1.15 cm and that of the female population was 1.04 cm every ten years after birth since 1926.

From the model, there is no sign of change in the slope of the per capita height curve.

Conclusion and discussion

Conclusion

This study confirmed that the height of Chinese people has been steadily increasing in the past 100 years, and the average height of men is always higher than that of women. Among the newborn Chinese in the next 20 years, the average height of men will maintain inertial growth, and women may continue to maintain the current level of 1 cm increase every ten years. In 2030, the per capita height of newly born Chinese men will reach the ideal standard for height of the World Health Organization. The figure for northerners living in high-latitude provinces is significantly taller than that of southerners living in low-latitude provinces. Researchers at Imperial College in London gathered data on people’s

Table 4. Expected average adult height of newborn population in China from 2019 to 2040

Birth year	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Male	175.34	175.45	175.55	175.66	175.77	175.87	175.98	176.09	176.2	176.3	176.41	176.52	176.63	176.73	176.84	176.95	177.06	177.16	177.27	177.38	177.48	177.59
Female	164.48	164.6	164.71	164.83	164.95	165.07	165.19	165.3	165.42	165.54	165.66	165.78	165.89	166.01	166.13	166.25	166.37	166.48	166.6	166.72	166.84	166.95

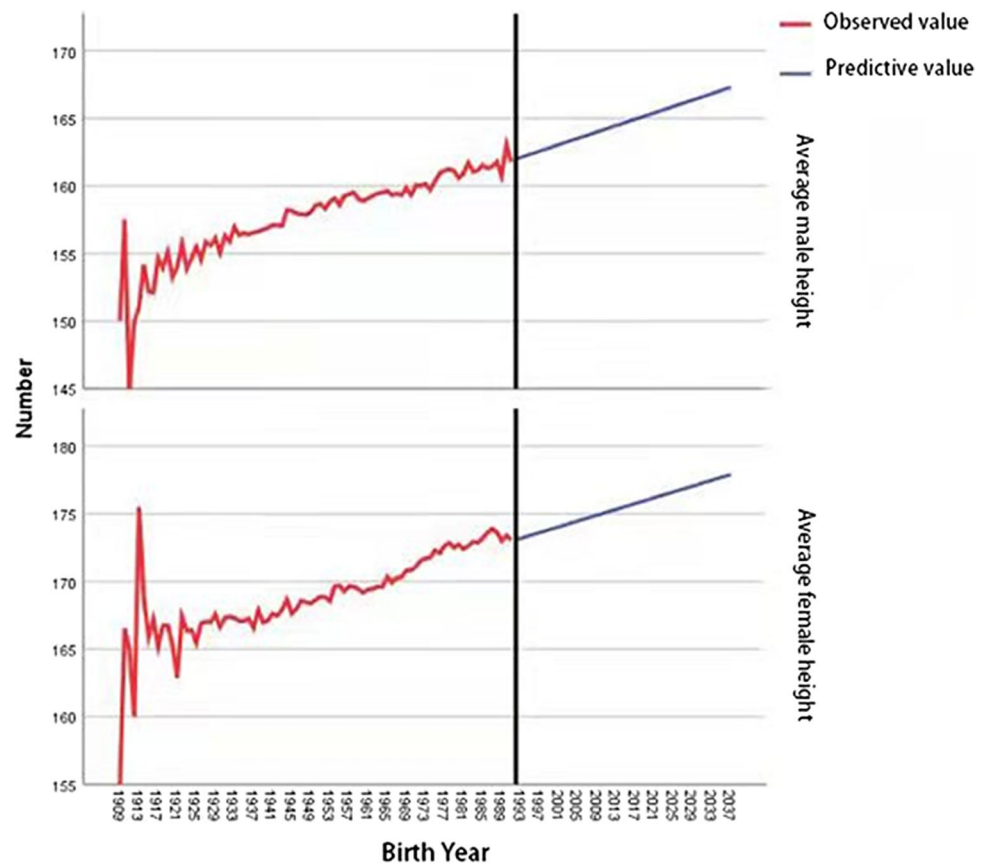
heights in 200 nations from 1914 to the present in order to compute the average height of people in these countries at the age of 18, when most people stop growing. In the last century, both men and women in China have grown 11 centimeters taller, according to the study [32]. This conclusion is supported by our calculations. The growth rate is above the medium level when compared to other countries throughout the world.

Discussion

Is height determined at birth or acquired? Through the study of identical twins, we can confirm that height is basically determined by heredity. In the late 1980s, scientists from the University of Minnesota analyzed the height data of twins in Minnesota and found that the height similarity between identical twins, whether they grew up together or not, was very high. If two children are not related by blood and grow up in the same family for some reason, their heights are similar to the similarity of heights between two strangers on the street. Researchers can even calculate that the genetic factor for height is about 80%. How to understand this figure? If you meet an adult man with a height of 190 cm in the USA, considering that the average height of an adult male in the USA is 178 cm, then the person’s height is 12 cm above the average. About 10 cm of this is due to the genetic contribution, and the remaining 20% is due to environmental impact. Therefore, the influence of genetic factors on height is significant. How significant is it? Science writer Wan Weigang has a very vivid metaphor; he said to imagine giving someone a brush and letting the person write a few words on rice paper. The calligraphy is likely to be very attractive. What about writing on a glass? Will the calligraphy on the glass look like it was written with a pen? No, it will still look like a brush but less attractive. In this case, the writing material plays an auxiliary role. Brush and paper seem to contribute to the beauty of calligraphy, but for calligraphy, the brush has the leading role. The conclusion that genetic factors significantly contribute to height was supported by a new study in 2018. In this study, scientists trained an algorithm using artificial intelligence methods combined with a large amount of genetic data, which it used to predict a person’s height [33]. In this study, the scientists did not investigate the parents’ heights, family economic status, living habits (such as drinking milk or not), or sports status.

The evidence presented here indicates that height is closely related to heredity. A large proportion of all height differences between people are determined by heredity. However, the proportion is not fixed. In the areas with large differences in lifestyle, the explanatory power of heredity on height will be smaller; conversely, where lifestyle differences are small, the effect of heredity on height will become more obvious. For example, British immigrants in the USA

Fig. 3 Time series model: predicting per capita height of newborn population based on 100-year historical data



have little change in lifestyle, so there is little difference in height between them. Among these people, the vast majority of height differences can be attributed to genetic factors. If the lifestyle changes a lot, then the height differences within populations will become evident. Guatemala, a Central American country, has an underdeveloped economy and low living standards. Many Guatemalans went to the USA to find jobs and live in the USA, and some even settled in the USA. Decades later, scientists compared the average height of Guatemalans living in the USA with those who did not leave and found that the former was a full 10 cm taller than the latter [34]. A similar situation occurred on the Korean Peninsula. The two countries on the Korean Peninsula share the same genetic lineage. Since the split in 1945, there has been a great difference in height per capita. The average height of South Korean men has increased by 3.8 cm, which is one of the largest growth rates in the world, while that of North Korean men of the same age has only increased by 0.8 cm. In a groundbreaking study on Japanese immigrants to Hawaii published in 1939, Harry Shapiro found that there was a significant difference in height between Japanese born in Hawaii and Japanese immigrants. In a similar study, Marcus Goldstein (1943) found that there were differences in height and other characteristics between Mexican immigrants, their children, and native Mexican children. Of

course, within a population, huge lifestyle differences can also lead to the expression of genetic genes. In the twentieth century India, for example, the caste of an individual had an important influence on his height. The average height of high caste members is 4.5 cm taller than that of low caste members. The former is more likely to obtain nutrition and health resources, and their lifestyles are quite different. Due to the caste inheritance of the population, genetic differences between caste groups are unlikely to explain this difference in height. For another example, Ayuda (2014) studied the relationship between socio-economic status and height of Spanish conscripts from 1850 to 1958 and found that literate conscripts are always taller than illiterate conscripts, by nearly 1 cm, while agricultural workers with less economic resources were shorter than high-quality non-manual workers by 3.6cm [35]. The basic idea here is that immigrants moving from poorer countries to richer countries may anticipate great changes among generations and that differences in lifestyles have a restrictive effect on genetic expression.

To reiterate, in a population with complete equality of nutrition and health resources, height distribution only reflects genetic variation. Unequal access to these resources in the population means better health and nutrition for the wealthier, so the richer tend to grow taller. Why is personal height so closely related to social and

economic development? How does nutrition affect the average height of people? Scientists believe that people convert a lot of nutrients stored in food into energy. The dietary energy intake from food must be balanced with energy consumption for maintaining metabolism and activities. Therefore, in an adverse environment with reduced energy consumption, children can experience growth retardation and sacrifice height growth rate to adapt to long-term low energy intake or malnutrition.

Inadequate dietary energy intake can lead to a lower average height in adults. On the other hand, the structure of energy, quality, and trace element content is also an important factor. Trace elements such as iron and zinc, which are essential for metabolism, are found in high amounts in meat. Therefore, a diet rich in animal-derived foods is likely to provide adequate micronutrients and amino acids. Headey's (2018) research on dietary patterns in low-income countries shows that there is a strong correlation between the consumption of animal-derived food and height [36]. For example, in Madagascar, animal protein accounts for 9.5% of energy intake, and the average height of males is 161.5 cm; in Botswana, where people get 12.5% of their calories from animal protein, the average height of males is 10 cm taller than that of a male from Madagascar. However, in high-income countries with high animal protein intake, Grasruber (2014) found that the ratio of high-quality animal protein (from dairy products, red meat, and fish) to low-quality plant protein (from wheat) can explain why the per capita height in some developed economies is lower than expected [37]. Take South Korea and the Netherlands; both countries have high HDI [38] (Over 0.9), but the Dutch are nearly 8 cm taller than the Koreans (182.5 cm vs. 175 cm), the difference coming from the ratio of animal and plant protein they consumed. The animal to plant protein ratio in the Netherlands is 2.16, while that in South Korea is only 0.69. Appropriate mixtures of plant-derived proteins, such as cereals, beans, or oilseeds, provide essential amino acids and micronutrients for growth. However, diets in low-income countries tend to rely on a single source of staple food. In Bangladesh, for example, more than 75% of the dietary energy comes from grains and cereals, 90% of which is rice. By contrast, grains and cereals account for less than a quarter of the dietary energy in the USA.

There are sufficient data to show that, with the increase of a country's per capita income level, the proportion of meat in the whole country's food consumption will also rise in a straight line. For example, from 1961 to 1971, when Japan's economy experienced rapid growth after World War II, the amount of animal protein consumed by the Japanese increased by 37%, and the consumption of plant protein fell by 3%. At the same time, through a study of more than 50 countries, high-income groups consumed much more fat,

protein, and calories from animal food than the low-income group.

In short, the difference in average height may be due to genes, environment, or, more likely, a combination of the two. Economic development will improve people's energy conversion efficiency and food structure. Whether a kind of food tastes good or not depends not on what it tastes like but on whether the food can effectively bring nutrition and ecological benefits to people in a specific environment. Human taste is not predetermined by culture and values but is closely related to the natural environment, climate, and mode of production. The key to the mystery of taste lies in the analysis of the revenue and expenditure benefits of nutrition and ecology [39]. In other words, people's preference for food taste is strongly influenced by cultural factors, and there is an economic law behind it, that is, whether it is cost-effective to eat. The foods that can nourish us in the most effective way tend to be more delicious. Therefore, the key to the mystery of taste is hidden in the analysis of the revenue and expenditure benefits of nutrition and ecology. Marvin Harris used most domesticated animals, insects, and even humans as examples. The less we pay for the same amount of nutritious food, the more suitable it will be for our stomach; conversely, the more paid for a food, the less delicious it is.

For all that, the role of lifestyle, nutritional structure, and other factors is still limited. The contrast between some international statistics is still very sharp. For example, the average height of men in Bosnia and Herzegovina is 181 cm, far taller than the global average height of 171 cm and even taller than the average height of 177 cm. This height cannot be explained by high living standards and high consumption of animal protein; its HDL is one of the lowest in Europe, with the consumption ratio of animal protein to plant protein only 0.33, compared to the Netherlands, with a ratio of 2.16. Under these circumstances, the reason must be genetic; congenital factors weigh more than acquired factors.

Research limitations

Accurate measurement of a person's height is a simple task, so we are sure that in the recorded data, the measurement error is relatively small. The limitation of this study is that, due to the large time span of the survey, the sample size distribution of each age group is not balanced, and the sample size in the early twentieth century and some years of the 1920s is small, so the representativeness is not strong [40]. Especially for the elderly residents, this study ignored the impact of survivorship bias [41]. Foreign research have demonstrated that tall persons in a

population live longer and are less likely to suffer from heart disease and stroke, as noted in the preceding literature review. Complications during and after birth are less probable among tall moms and their offspring [42]. That is to say, the number of people who survive may increase as we get older (Finucane et al., 2014) [43]. There is a possibility that the average age in the age group has been overestimated in this paper. Therefore, a reconsideration on the measurement may be needed in the future research.

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Data availability The data used to support the findings of this study are available from the corresponding author upon request.

Declarations

Conflict of interest The authors declare no competing interests.

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