Economics and Human Biology 19 (2015) 258–264

Contents lists available at ScienceDirect

Economics and Human Biology

journal homepage: http://www.elsevier.com/locate/ehb

Socioeconomic development and secular trend in height in China

Xin-Nan Zong, Hui Li *, Hua-Hong Wu, Ya-Qin Zhang

Department of Growth and Development, Capital Institute of Pediatrics, No. 2 Yabao Road, Chaoyang District, Beijing 100020, China

ARTICLE INFO

Article history:
Received 2 April 2015
Received in revised form 6 August 2015
Accepted 14 September 2015
Available online 28 September 2015

Keywords:
Body height
Secular trend
Socioeconomic status
Pubertal maturity
Adolescents
China

ABSTRACT

The objective of this study was to examine the effect of socioeconomic development on secular trend in height among children and adolescents in China. Body height and spermarcheal/menarcheal ages were obtained from two periodic large-scale national representative surveys in China between 1975 and 2010. Chinese socioeconomic development indicators were obtained from the United Nations world population prospects. The effects of plausible determinants were assessed by partial least-squares regression. The average height of children and adolescents improved in tandem with socioeconomic development, without any tendency to plateau. The increment of height trend presented larger around puberty than earlier or later ages. The partial least-squares regressions with gross national income, life expectancy and spermarcheal/menarcheal age accounted for increment of height trend from 88.3% to 98.3% for males and from 82.9% to 97.3% for females in adolescence. Further, through the analysis of the variable importance for projection, the contributions of gross national income and life expectancy on height increment were confirmed to be significant in childhood and adolescence, and the contribution of spermarcheal/menarcheal age was superior to both of them in adolescence. We concluded that positive secular trend in height in China was significantly associated with socioeconomic status (GNI as indicator) and medical and health conditions (life expectancy as indicator). Earlier onset of spermarche and menarche proved to be an important role in larger increment of the trend over time of height at puberty for a population.

1. Introduction

Physical growth is a marker of the public health of the population as it changes over time (Tanner, 1992). Many theories link the secular trend to environmental factors and genomic/epigenetic factors (Mortier and Berghe, 2012; Schell et al., 2012). However, the most accepted explanation connects secular changes to socioeconomic conditions (Godina, 2013). Trends of increasing body size and accelerated growth tempo have been clearly documented since the mid-nineteenth century (Hauspie et al., 1997).

Body height is a powerful proxy for the physical growth of children and adolescents. The secular trend to increasing height has been occurring over long periods of time and in many cases continues to occur (Cole, 2003). One study from Japan showed larger increment of height trend around puberty than earlier or later ages (Takaishi, 1994), which presumably was the combined effects of a secular trend to increasing height and a secular trend to faster developmental tempo (Cole, 2000, 2003). This phenomenon of varying increments by age was also observed in other countries (Vignerová et al., 2006; Cardoso and Caninas, 2010; Schönbeck et al., 2013; Zong and Li, 2014).

* Corresponding author. Tel.: +86 10 85695553.
E-mail address: huiligrowth@163.com (H. Li).

http://dx.doi.org/10.1016/j.ehb.2015.09.006
1570-677X/

So far, however, no further evidence supported the aforementioned inference of the combined effects.

Previous studies described the associations between increasing height trend and socioeconomic status as well as medical and health conditions (Jacobs and Tassenaar, 2004; Inserm Collective Expert Report Center, 2007; Rashad, 2008; Kagawa et al., 2011), but they mostly were qualitative inference and few quantitatively examined their effects on increment of height trend. Most importantly, the role of pubertal maturity was usually not considered because of the lack of relevant data.

Over the past decades, China underwent great changes in its social economy and public health, which has been accompanied by positive trend in height and negative trend in age at onset of puberty (Zong et al., 2011; Chen and Ji, 2013; Zong and Li, 2014; Song et al., 2011a, 2011b). A natural experimental field for studying the effects of socioeconomic status, medical and health conditions as well as pubertal maturity on the increments of height trend in different ages has been emerging in China during this historical period. A battery of relevant data from Chinese sample was helpful to further explain why the height increments appeared larger around puberty than earlier or later.

The objective of this study was to quantitatively examine the associations between secular trend in height of children and adolescents and socioeconomic status and medical and health conditions in China over the past decades. We focused specifically the role of earlier onset of puberty on larger increment of height trend in adolescence.

2. Methods

2.1. Data procurement

2.1.1. Height data

Height (length under 3 years) data of children under 7 years are from the 1975, 1985, 1995 and 2005 rounds of the National Growth Survey of Children in the Nine Cities of China (NGSCNCC) (Zhang, 1977; Zhang and Huang, 1988; Li, 1998, 2008). The NGSCNCC used randomized cluster sampling according to the requirements of age intervals, children under 3 years in community as a minimum cluster unit, and children over 3 years (including 3 years) in kindergarten as a unit through the child health care system established in 1970s. Healthy children from birth to 7 years are divided into 22 age groups: newborn to 3 days, monthly for 1–6 months, bi-monthly for 6–12 months, tri-monthly for 12–24 months, half-yearly for 2–6 years, and yearly for 6–7 years. The “1 month-” group included data of those who were aged from 1 month to 1 day less than 2 months. Likewise, the “2 year-” group was a group with the age ranging from 2 years to 1 day less than 2 years and 6 months. The sample size was 150–200 for each sex-age subgroup in each area (urban/rural) of each city. The height was taken to the nearest 0.1 cm as supine length on an examining table for children under 3 and as standing height on stadiometer board with bare feet for children aged 3–6.

Height data of children and adolescents aged 7–18 are from the 1985, 1991, 1995, 2000, 2005 and 2010 rounds of the Chinese National Survey on Students’ Constitution and Health (CNSSCH) (CNSSCHA, 1988, 1993, 1996, 2002, 2007, 2012). The subjects are primary and secondary school students aged 7–18 years randomly selected from 30 of the 31 provinces of China by means of a multitage clustering process. In each of the provinces, the subjects were classified by gender and region (urban/rural), and each of the four groups consisted of equal numbers of individuals from three socioeconomic status classes (upper, middle and lower). Several primary and secondary schools were randomly selected from a list compiled by each area’s Educational Committee. A list of students from grades 1–12 was compiled, and a random selection of two or three classes (depending on their size) was made from each grade level. The age groups were divided yearly by the empirical interval and following criteria of “low limit”, for example, “7 years-” represented the children aged 7.0–7.9 years. Metal column height measuring stands (each 200 cm with 0.1 cm precision) were used to measure stature without shoes on.

The two series of the NGSCNCC and CNSSCH were nationally representative samples in describing secular trends of physical growth of Chinese children and adolescents. Sample sizes at each examination period for these two surveys were shown in Table 1. The protocol of this study was reviewed and approved by the Ethics Committees of the Capital Institute of Paediatrics.

2.1.2. Socioeconomic data

The development indicators for China were obtained from the 2012 Revision of the World Population Prospects (Department of Economic and Social Affairs of the United Nations, 2013). They included gross national income (GNI) and consumer price index (CPI) between 1970 and 2012.

2.1.3. Life expectancy data

Captured as the representative of medical and health conditions, life expectancy at birth for male and female for China between 1970 and 2012 were obtained from the 2012 Revision of the World Population Prospects.

2.1.4. Ages on spermarche and menarche

Captured as the proxy of pubertal maturity, the ages on spermarche and menarche calculated by probit analysis

Table 1
Sample sizes at each examination period in the two series of Chinese national surveys, 1975–2010.

Year	Males	Females	Total
NGSCNCC (aged 0–6)			
1975	93,267	89,810	183,077
1985	76,460	76,454	152,914
1995	78,891	78,473	157,364
2005	69,551	69,224	138,775
CNSSCHA (aged 7–18)			
1985	205,100	204,846	409,946
1991	70,568	70,047	140,615
1995	104,771	104,630	209,401
2000	108,301	108,362	216,663
2005	117,680	116,741	234,421
2010	107,687	107,632	215,319

were also obtained from the 1985, 1991, 1995, 2000, 2005 and 2010 rounds of the CNSSCH, which have been simultaneously collected (by self-report, occurring or not by the survey date) with the indicators of physical growth. The ages on spermarche and menarche were estimated by probit analyses in each examination period.

2.2. Data analysis

We calculated average height (length) increment for each sex-age subgroup for children aged 0–6 between 1975 and 2005 and for children and adolescents aged 7–18 between 1985 and 2010 per decade. We examined the associations between height at each sex-age subgroup and GNI per capita, life expectancy at birth by calculating Pearson's correlation coefficients (r) at the population level through the examination periods. The statistical relationship between height trend and earlier onset on spermarche and menarche was also considered in adolescence.

To comprehensively examine the associations between height trend and GNI, life expectancy and spermarcheal/menarcheal ages, we compared several statistical model, such as principal component regression, partial least-squares (PLS) regression, general linear model, generalized additive model. Finally, the PLS model, which was especially suitable for small sample size and multicollinearity, was selected as unified approach for each sex-age subgroup. Before the construction of the PLS, GNI per capita was adjusted by CPI for a fairer comparison for annual economic data, the moving average of which was calculated for the purpose of eliminating abnormal fluctuations as the average of each year and its two neighbours, for example the moving average for 2005 was the average of 2004, 2005, and 2006, and then log-transformed GNI was taken for the purpose of linear relationship with height trend. Moving average of life expectancy was also calculated as the average of each year and its two neighbours. The PLS Procedure in SAS software was used to generate the models of all subgroups. Percent variation accounted for by PLS factors for model effects and dependent variables (equivalent to R-square) were used to evaluate the goodness of the fitted models.

Variable importance for projection (VIP) was calculated based on the PLS model and used to determine the effects and contribution rates of GNI, life expectancy, and the ages on spermarche and menarche. Suppose there are dependent variable for y and explanatory variables for $x_1, x_2, \ldots, x_k$, the VIP for the explanatory variable of j is given by

$$\mathrm{VIP}_j = \sqrt{\frac{k}{\sum_{h=1}^{m} r^2(y, c_h)} \sum_{h=1}^{m} r^2(y, c_h) w_{hj}{}^2}$$

where x_h is the principal component of explanatory variables extracted from the PLS model, r is the correlation coefficient between dependent variable and principal component, representing the explanatory power of principal component on y, x_{hj} is the weight of explanatory variable on the principal component (Zhang and Feng, 2012). Wold suggested the importance of variable with more than 0.8 was considered a significant contribution on dependent variable (Wold, 1995).

All analyses were undertaken using SAS 9.2 (SAS Institute, Cary, United States of America).

3. Results

3.1. Trend in height

The average height of children and adolescents increased steadily between 1975 and 2010, without any tendency to plateau (Fig. 1). The increment of the height trend was more pronounced at puberty than at earlier or later ages, e.g. an increase of 3.8 cm per decade in 12-year-old males and 3.0 cm per decade in 11-year-old females relative to 1.3 cm in males and 0.8 cm in females at 18 years old (Fig. 2).

Average height (length) increment for each sex-age subgroup was calculated for children aged 0–6 between 1975 and 2005 per decade according to NGSCNCC and for children and adolescents aged 7–18 between 1985 and 2010 per decade according to CNSSCH.

3.2. Trends in GNI and life expectancy

Fig. 3 portrayed socioeconomic changes in China between 1975 and 2010. GNI per capita increased from 163 to 4414 US dollars during the period. Life expectancy at birth improved from 64 to 74 years old for males and from 67 to 76 years old for females over the same period.

3.3. Trends in spermarcheal and menarcheal ages

According to the series of the CNSSCH, Chinese adolescents have been reaching puberty earlier and earlier between 1985 and 2010, such as 0.25 year earlier per decade in spermarcheal age and 0.33 year per decade in the menarcheal (Fig. 2).

3.4. Associations between height and GNI, life expectancy, spermarcheal and menarcheal ages

The height trend of children and adolescents showed a close correlation with the trends of GNI and life expectancy over time. The correlation coefficients with GNI and life expectancy were approximately equal to 1 for children under 7 years. The correlation coefficients with GNI ranged from 0.87 to 0.97 and with life expectancy from 0.91 to 0.99 for adolescents aged 7–18 years. Additionally, for adolescents the correlation r of height and spermarcheal age ranged from −0.99 to −0.97 and the correlation r of height and menarcheal age ranged from −0.98 to −0.93.

3.5. Partial least-squares models

For children under 7, the PLS models with GNI and life expectancy, with one extracted factors, showed percent variations for model effects were 99.7% and for dependent variables varied from 94.7% to 99.9% for boys, and percent variations for model effects were 99.6% and for dependent variables varied from 96.5% to 99.9% for girls. For adolescents aged 7–18, the PLS models with GNI, life expectancy and spermarcheal/menarcheal age displayed percent variations for model effects were 96.9% for males

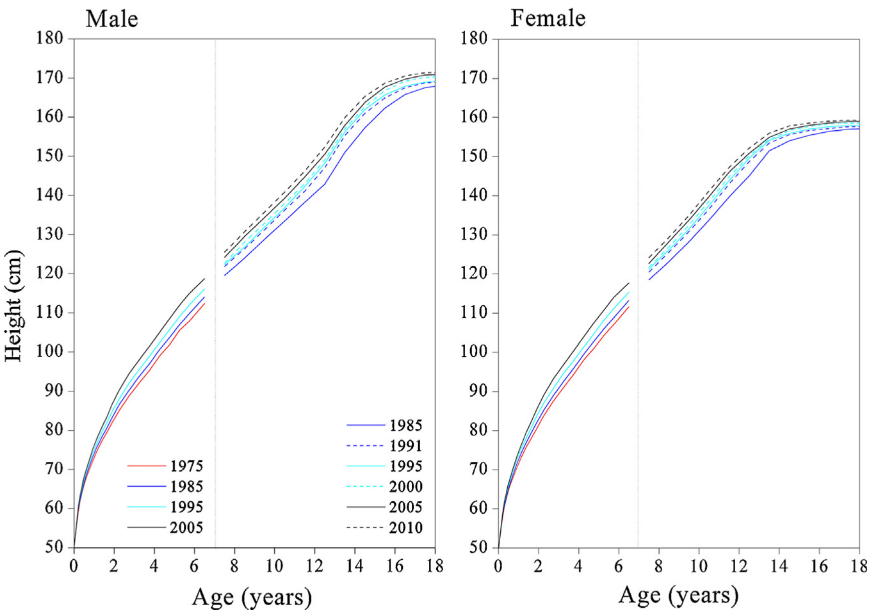

Fig. 1. Trends in mean measured height (length) of children and adolescents in China, 1975–2010. *Note.* Length, younger than 3 years; height, 3 years or older. Data sources: National Growth Survey of Children under 7 years in the Nine Cities of China and Chinese National Survey on Students Constitution and Health.

and 98.7% for females, and those for dependent variables varied from 88.3% to 98.3% for males and from 82.9% to 97.3% for females.

3.6. Variable importance for projection

For children under 7, the GNI and life expectancy importance for projection on height trend were confirmed to be significant, the VIP values of both were about 1.22 for males and females. For adolescents aged 7–18, the GNI importance for projection ranged from 0.97 to 0.98 for males and from 0.97 to 0.99 for females, which were slightly weaker than the life expectancy contribution from 0.98 to 1.02 for males and from 1.00 to 1.02 for females. The importance of spermarcheal age from 1.00 to 1.05 were superior to those of GNI and life expectancy for males

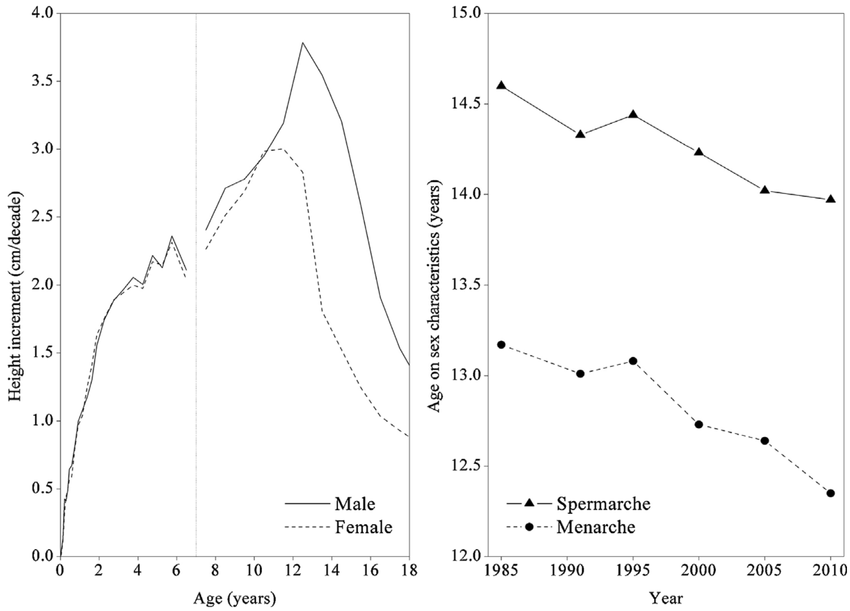

Fig. 2. Varying increment of the trend over time of height (length) per decade by sex and age, and trends in the ages on spermarche and menarche among children and adolescents in China, 1975–2010. *Note.* Length, younger than 3 years; height, 3 years or older. Data sources: National Growth Survey of Children under 7 years in the Nine Cities of China and Chinese National Survey on Students Constitution and Health.

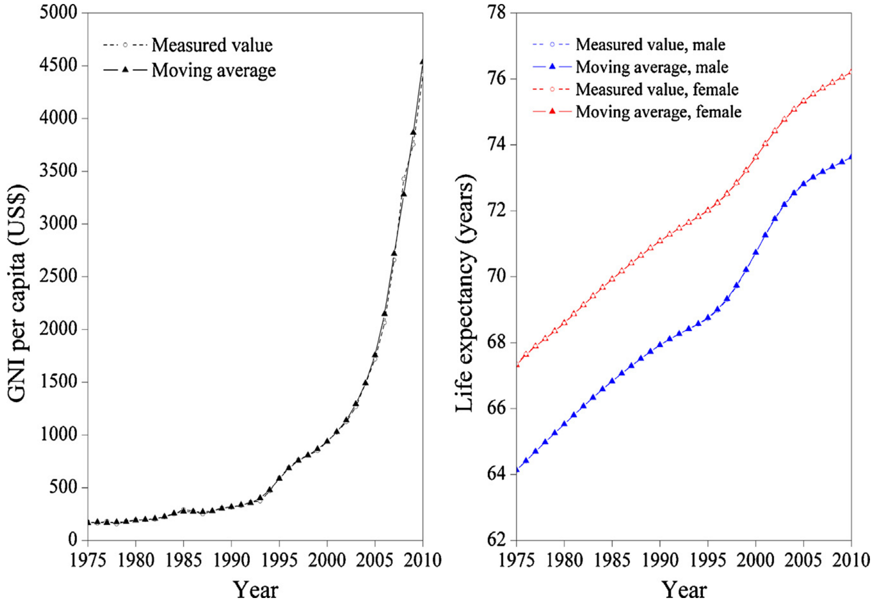

Fig. 3. Trends in GNI per capita and life expectancy at birth for measured value and moving averages in China, 1975–2010. *Note.* US $, United States dollars. Data sources: the development indicators for China from the 2012 Revision of the World Population Prospects.

and the importance of menarcheal from 0.99 to 1.03 also presented the superiority to both of them for females in adolescents. Further, the age on spermarche/menarche contributions fell sharply after puberty and became lower than the life expectancy at ages 18 (Fig. 4).

4. Discussion

China has succeeded in transforming itself from the country's planned economy into the free-market economy in 1978. Since then, sustained economic productivity has greatly increased food supply, average household income and personal expenditure on food. The height level of children and adolescents in China has significantly improved over this period and this improvement is more pronounced at puberty than at earlier or later ages. Trend analysis suggested the positive trend in Chinese children and adolescents may continue as China's economic development and urbanization process.

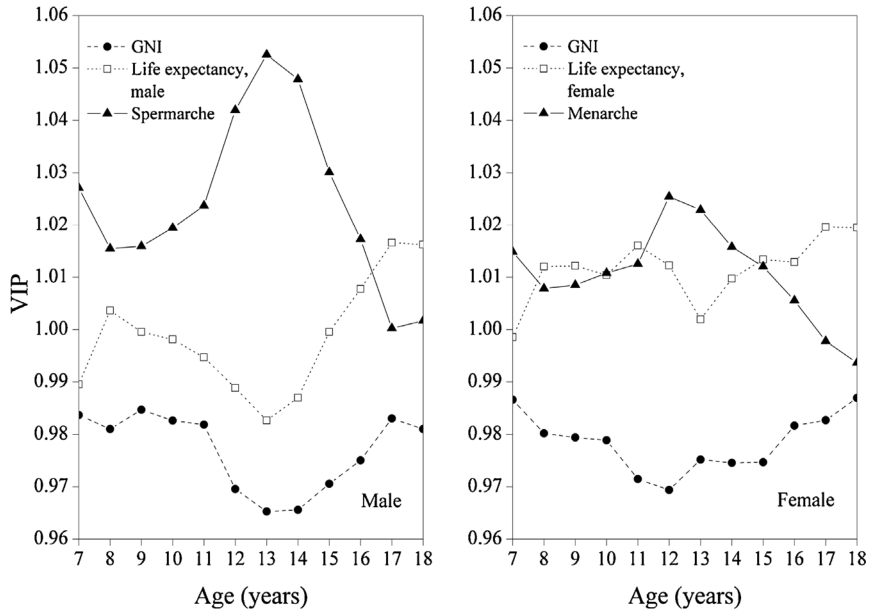

Fig. 4. VIP of GNI per capita, life expectancy at birth and the ages on spermarche and menarche on the height trend among adolescents aged 7–18, by sex and age.

Only using socioeconomic development may not well explain the difference of increment of the trend over time of height at different ages for a population. Synthetically considering socioeconomic status and medical and health conditions as well as pubertal maturity, by constructing an easily-understood multivariable model, we systematically analyzed their importance for projection on increment of height trend. In general, the PLS model generated good goodness of fit at almost all ages (except these groups under 3 months). The increment of height trend of children and adolescents were closely associated with GNI and life expectancy, at puberty also highly correlated with the ages on spermarche and menarche. The VIP values of GNI and life expectancy were far greater than 0.8 which was considered to be important force for the height trend. From a statistical perspective, the ages on spermarche/menarche played an important role in larger increment of the trend over time of height at puberty for a population and this effect was more pronounced in middle adolescence, especially for males. However, there is no doubt that the ages on spermarche and menarche were not causal relations with the height trend. Positive secular trend in height should mainly attribute to the improvement of socioeconomic status and medical and health conditions. An easy-to-understand example is the height of 12-year children in late surveys corresponding to the height of 13-year children in previous surveys due to a tendency towards earlier onset of sexual maturation.

By means of earlier onset of puberty, our study can clearly explain why most of increment of height trend at puberty does not continue into adulthood. It is important to note that earlier onset of puberty does not contribute to the "actual" height increment over time. To some extent, the effects of socioeconomic status and medical and health conditions should not be arbitrarily overestimated if large increment of height trend only occurred at puberty, which would be helpful to provide more accurate epidemiological evidence to check and optimize public health strategies for children's health and welfare. In addition, based on the PLS model, their net effects could be also estimated reasonably by subtracting the role of earlier puberty.

5. Limitations

Socioeconomic and medical and health related indicators are enormous, for the purpose of constructing a simplified model to uncover general characteristics of determinants of height trend, we captured GNI and life expectancy as their representatives, but in fact, some other indicators, such as gross domestic product and mortality rates for infants and under-5 children, can also be employed. The 1975 NSPGDC included 0–18-year-old children and adolescents, but those data at ages 7–18 lacked of good comparability with later data from the series of the CNSSCH due to the difference of settings. So we only used the single series of the CNSSCH for analyzing the height trend of adolescents aged 7–18 between 1985 and 2010. Socioeconomic data were not collected on the family situation of the individual children, but on population values of development indicators for the country in different periods. It may be a weakness to exactly correlate socioeconomic indicator with growth indicator, but seemed reasonable to explore the phenomenon of larger increment of height trend around puberty by means of a joint analysis of socioeconomic data and puberty maturity data.

6. Conclusions

This study further demonstrates the effects of socioeconomic status (GNI as indicator) and medical and health conditions (life expectancy as indicator) on positive secular trend in height in childhood and adolescence. Increment of height trend presented larger around puberty than earlier or later ages. Earlier onset of puberty does not contribute to the "actual" height increment over time, but proved to be an important role in larger increment of the trend of height in adolescence for a population. Our study implied the effects of socioeconomic status and medical and health conditions should not be arbitrarily overestimated if large increment of height trend only occurred at puberty and also provided an approach based on the PLS model to reasonably compare their net effects among different populations by subtracting the role of earlier puberty.

Conflict of interest statement

None declared.

Acknowledgments

This work was supported by the National Natural Science Foundation of China (No. 81302439).

We thank Prof. Zong-Han Zhu for his valuable comments on the design of this study.

References

Cardoso, H.F., Caninas, M., 2010. Secular trends in social class differences of height, weight and BMI of boys from two schools in Lisbon, Portugal (1910–2000). Econ. Hum. Biol. 8, 111–120.

Chen, T.J., Ji, C.Y., 2013. Secular change in stature of urban Chinese children and adolescents, 1985–2010. Biomed. Environ. Sci. 26, 13–22.

Chinese National Survey on Student's Constitution and Health Association (CNSSCHA), 1988. 1985 Researches on the Constitution and Health of the Chinese Students. People's Education Publishing, Beijing.

Chinese National Survey on Student's Constitution and Health Association (CNSSCHA), 1993. 1991 Reports on the Physical Fitness and Health Research of Chinese School Students. Beijing Science and Technology Publishing, Beijing.

Chinese National Survey on Student's Constitution and Health Association (CNSSCHA), 1996. 1995 Reports on the Physical Fitness and Health Research of Chinese School Students. Jilin Science and Technology Publishing, Changchun.

Chinese National Survey on Student's Constitution and Health Association (CNSSCHA), 2002. 2000 Reports on the Physical Fitness and Health Research of Chinese School Students. Higher Education Press, Beijing.

Chinese National Survey on Student's Constitution and Health Association (CNSSCHA), 2007. 2005 Reports on the Physical Fitness and Health Research of Chinese School Students. Higher Education Press, Beijing.

Chinese National Survey on Student's Constitution and Health Association (CNSSCHA), 2012. 2010 Reports on the Physical Fitness and Health Research of Chinese School Students. Higher Education Press, Beijing.

Cole, T.J., 2000. Secular trends in growth. Proc. Nutr. Soc. 59, 317–324.

Cole, T.J., 2003. The secular trend in human physical growth: a biological view. Econ. Hum. Biol. 1, 161–168.

Department of Economic and Social Affairs of the United Nations, 2013. World Population Prospects: The 2012 Revision. Comprehensive Tables, 1. United Nations, New York, NY, 〈http://esa.un.org/unpd/wpp/Documentation/pdf/WPP2012_Volume-I_Comprehensive-Tables.pdf〉 (accessed 27 February 2015).

Godina, E., 2013. Secular trends. In: Hermanussen, M. (Ed.), Auxology—Studying Human Growth and Development. E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, pp. 138–139.
Hauspie, R.C., Vercauteren, M., Susanne, C., 1997. Secular changes in growth and maturation: an update. Acta Paediatr. Suppl. 423, 20–27.
Inserm Collective Expert Report Center, 2007. Growth and puberty secular trends. Environmental and Genetic Factors: A Collective Expert Report, ⟨http://www.ncbi.nlm.nih.gov/books/NBK10786/pdf/growth.pdf⟩ (accessed 27 February 2015).
Jacobs, J., Tassenaar, V., 2004. Height, income, and nutrition in the Netherlands: the second half of the 19th century. Econ. Hum. Biol. 2, 181–195.
Kagawa, M., Tahara, Y., Moji, K., Nakao, R., Aoyagi, K., Hills, A.P., 2011. Secular changes in growth among Japanese children over 100 years (1900–2000). Asia Pac. J. Clin. Nutr. 20, 180–189.
Coordinating Study Group of Nine Cities on the Physical Growth and Development of Children, 1998. In: Li, H. (Ed.), 1995 Researches on the National Growth Survey of Children Under 7 Years in the Nine Cities of China. Peking Union Medical College Publishing House, Beijing.
Coordinating Study Group of Nine Cities on the Physical Growth and Development of Children, 2008. In: Li, H. (Ed.), 2005 Researches on the National Growth Survey of Children Under 7 Years in the Nine Cities of China. People's Medical Publishing House, Beijing.
Mortier, G.R., Berghe, W.V., 2012. Genomics, epigenetics and growth. In: Cameron, N., Bogin, B. (Eds.), Human Growth and Development. second ed. Academic Press, London, pp. 153–171.
Rashad, I., 2008. Height, health, and income in the US, 1984–2005. Econ. Hum. Biol. 6, 108–126.
Schell, L.M., Knutson, K.L., Bailey, S., 2012. Environmental effects on growth. In: Cameron, N., Bogin, B. (Eds.), Human Growth and Development. second ed. Academic Press, London, pp. 245–286.
Schönbeck, Y., Talma, H., van Dommelen, P., Bakker, B., Buitendijk, S.E., HiraSing, R.A., et al., 2013. The world's tallest nation has stopped growing taller: the height of Dutch children from 1955 to 2009. Pediatr. Res. 73, 371–377.
Song, Y., Ma, J., Hu, P.J., Zhang, B., 2011a. Study of geographic distribution and 10 years' change of spermarche in Chinese boys of Han-group aged 11 to 18. Chin. J. Prev. Med. 45, 522–526.
Song, Y., Ma, J., Hu, P.J., Zhang, B., 2011b. Geographic distribution and secular trend of menarche in 9–18 year-old Chinese Han girls. Beijing Da Xue Xue Bao 43, 360–364.
Takaishi, M., 1994. Secular changes in growth of Japanese children. J. Pediatr. Endocrinol. 7, 163–173.
Tanner, J.M., 1992. Growth as a measure of the nutritional and hygienic status of a population. Horm. Res. 38 (Suppl. 1), 106–115.
Vignerová, J., Brabec, M., Bláha, P., 2006. Two centuries of growth among Czech children and youth. Econ. Hum. Biol. 4, 237–252.
Wold, S., 1995. PLS for multivariate linear modeling. In: van de Waterbeemd, H. (Ed.), Chemometric Methods in Molecular Design. Wiley-VCH Verlag, Weinheim, pp. 195–217.
Zhang, X., Huang, Z., 1988. The second national growth and development survey of children in China, 1985: children 0 to years. Ann. Hum. Biol. 15, 289–305.
Zhang, X., Institute of Pediatrics of Chinese Academy of Medical Sciences, 1977. Studies on physical development of children and adolescents in new Chinese. Chin. Med. J. (Engl.) 3, 364–372.
Zhang, Z., Feng, G.S., 2012. Application of variable importance for projection in the variables selection. Mod. Prev. Med. 39, 5813–5815.
Zong, X.N., Li, H., 2014. Physical growth of children and adolescents in China over the past 35 years. Bull. World Health Organ. 92, 555–564.
Zong, X.N., Li, H., Zhu, Z.H., 2011. Secular trends in height and weight for healthy Han children aged 0–7 years in China, 1975–2005. Am. J. Hum. Biol. 23, 209–215.