Geographical differences in the effects of age and height at peak height velocity on final body height: An analysis of a population-based cross-sectional growth curve in Japan

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Background. The aim of this study was to elucidate the effect of geographical differences in the age at peak height velocity (APHV) and height at peak height velocity (HPHV) on final height, at a prefectural level, and to evaluate the current average height status of 47 prefectures in Japan.

Methods. We elucidated the association between the geographical differences in a prefectural-level cross-sectional population-based infancy-childhood-puberty (ICP) growth curve, derived from prefectural mean height data (age: 5-17 years, 2006-2013), APHV and HPHV, for final height.

Results. The correlation between the APHV and final height was very weak; however, the results of a multiple regression analysis showed that the final height of each prefecture can be accurately predicted based on the APHV and HPHV. This result showed that the earlier the APHV and higher the HPHV, the higher the final height. An earlier APHV reduced the height gain in the puberty component; however, this did not reduce the final height.

Discussion. From the perspective of the average value of each prefecture, in the present situation, the effect of an earlier APHV in increasing the amount of growth of the childhood component exceeded its effect in reducing the growth of the puberty component. In short, the final height of the prefectures depends on how large the height growth is in the early stages of childhood. However, the HPHV tended to be region-specific, and it is unlikely that it can increase the average height in this population in the future.

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Abstract

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Introduction

In recent years, it has been reported that the increase in the prevalence of childhood obesity has led to an acceleration in sexual maturation (Burt & McCartney, 2010; Yokoya & Higuchi, 2014; Wang, 2002). Several studies have reported that precocious puberty leads to reduced pubertal height gain, and exerts a negative effect on the final height (Limony, Kozieł & Friger, 2015; Pinhas-Hamiel et al., 2017; Ibáñez et al., 2000).

Whereas, over the past few decades, puberty has been setting in earlier worldwide, and this is accompanied by an improvement in the physique of children (Delemarre-van de Waal, 2005; Karlberg, 2002). Several studies have reported that earlier growth has a positive or neutral effect on final height (Yousefi et al., 2013; Bourguignon, 1988; Vizmanos et al., 2001).

Generally, there is an inverse compensatory phenomenon between height at pubertal onset, the intensity and duration of pubertal growth, the effect of making a stock before puberty and the effect of making a growth during puberty act complementarily (Karlberg, 2002; Vizmanos et al., 2001). These phenomena complicate the performance of analyses at the individual or population levels, and make it difficult to elucidate the effect of pubertal timing on final height.

To address the aforementioned issue, some researchers mathematically described that both age and height at the onset of the puberty were correlated to final height (Limony, Kozieł & Friger, 2015; Karlberg et al., 2003). They reported that, in spite of the weak correlation between age at the onset of puberty and final height, the correlation became strong when the parameter "height at the onset of puberty" was included in the regression analysis. Using this correlation, they compared the effect of age and height at the onset of puberty on final height.

In this study, we created a prefectural-level, population-based, cross-sectional growth curve using School Health Examination Survey data, in Japan (Ministry of Education, Culture Sports, Science and Technology; School Health Examination Survey Database), and assessed the geographical differences in pubertal timing and growth rate. Specifically, we observed the effect of the geographical differences in the age at peak height velocity (APHV) and height at peak height velocity (HPHV), on final height.

In general, cross-sectional growth curves reflect individual growth poorly, because of the "phase difference effect," in which the averaging of measurements obtained from different individuals smoothes and displaces the growth peak (Tanner, Whitehouse & Takaishi, 1966). However, population-based, cross-sectional analyses depend on data from large sample sizes and have a robustness in analysis, and provide evidence in typical and normal cases. The aim of this study is to elucidate the effect of geographical differences in the APHV and HPHV on final height, at a prefectural level, and evaluate the current average height status, in Japan.

Materials & Methods

Study area

This was an ecological study conducted using prefecture-level data on Japanese youth and children. Figure S1 shows a map of the 47 prefectures in Japan. Japan is a long, thin archipelago, with its longest axis oriented from the north to the south. Each prefecture was given a number corresponding to the information presented in Table S1.

Population-based, cross-sectional infancy-childhood-puberty growth curve

Prefecture-level height data of Japanese children were collected from the School Health Examination Surveys carried out from 2006–2013, and data were categorized by sex and age (5–17 years) for each of the 47 prefectures in Japan. A stratified two-stage sampling method was used to survey physical conditions. The physical condition survey of 2008 covered approximately 7,800 schools and included approximately 700,000 students. Sample size and original profiles are included in this database (Ministry of Education, Culture Sports, Science and Technology; School Health Examination Survey Database). In addition, prefecture-level birth height data were collected from the Vital Statistics in JAPAN, which was obtained from 2006–2013 by the Ministry of Health, Labour and Welfare (Ministry of Health, Labour and welfare; Vital Statistics in JAPAN database).

The infancy-childhood-puberty (ICP) growth model was applied to the mean height data of each year and prefecture (birth and 5–17 years, 2006–2013).

This model divides growth, mathematically, into the following three partly superimposed components:

Infancy component (0-3 years). This component is characterized by restricted growth, and the growth rate is linear with height. It is represented by the modified exponential curve:

$$H_1 = a_1 - b_1 e^{-c_1 t} \qquad (1)$$

where t stands for age.

Childhood component (from 3 years to the onset of puberty). A simple second-degree polynomial function fits the growth during this period:

$$H_2 = -a_2t^2 + b_2t + c_2 \qquad (2)$$

Puberty component (after the onset of puberty). The contribution of pubertal growth spurt to final height can be modelled using a logistic function:

$$H_3 = \frac{a_3}{1 + e^{c_3 - b_3t}} \qquad (3)$$

Here, a_1, b_1, c_1, a_2, b_2, c_2, a_3, b_3, c_3 are parameters, which are estimated from the growth data. The mean height for each age is calculated using $H = H_1 + H_2 + H_3$ (Karlberg et al., 2003; Karlberg et al., 1987a; Karlberg et al., 1987b; Karlberg, 1987; Karlberg, Albertsson-Wikland, 1988; Karlberg, 1989; Ellermeijer & Heck, 2002).

To fit the data, first, a search was started for a second-degree polynomial function that fits the height between 3 and 10 years well, and reaches its maximum at 20 years, when height growth usually stops. However, in our study, the birth height and height data of only children older than 5 years were available; therefore, the fitting of the data with the childhood component was performed with data from 5- to 10-year-old children. Furthermore, fitting of the data with the childhood component for girls was performed with data of 5- to 9-year-old children, because Japanese girls generally mature faster than girls in Europe and the US (Matsuo, 1993). In addition, a search was performed for a second-degree polynomial function for females that reached its maximum at the age of 17 years. The growth rate of the puberty component was very small with the setting that reached its maximum at 20 years. The childhood component was calculated using data of children who were a year old. After the subtraction of the extrapolated values of the childhood component from the observed values, before and after the component, two additional components were extracted and modelled. A modified exponential regression model and logistic model were applied for these two periods (Ellermeijer & Heck, 2002). In our study, the birth height and height data of only children over the age of 5 years were obtained; therefore, the fitting of the data for the infant component was done with the birth height and height data of 5 to 8-year-old children. The fitting of the data of the pubertal component was done with the data of children who were less than 17 years old. Therefore, for some data of the infant and puberty components, meaningful coefficients of the growth curves were not obtained.

In our study, only data of youth less than 17 years were obtained; therefore, the final height was obtained from the growth curve, at the age of 17 years.

Peak height velocity (PHV) was detected from the height velocity curve, obtained by differentiating the growth curve (distance curve) numerically, using a computer program (He & Karlberg, 2001). The age at peak height velocity (APHV) and height at peak height velocity (HPHV) were also obtained from a comparison of the growth curve and the height velocity curve.

Figure 1 shows the fitting of the ICP growth curve (distance curve) and height velocity curve, in boys in the Hokkaido prefecture, as an example.

The root mean square error (RMSE) was calculated from the mean height data at each year (birth and 5–17 years, 2006–2013) and by fitting (estimated) data in each prefecture. The RMSEs in each prefecture were 0.39–0.56 cm for boys and 0.53–0.92 cm for girls. The standard deviations of height in the 8-year study period (2006-2013), in adolescents in each prefecture, were 0.36–0.62 cm for boys and 0.28–0.71 cm for girls. Therefore, the error caused by fitting was considered small. The coefficients of each component and prefecture, APHV, PHV, HPHV and final height are listed in Table S1.

Data analysis

Data analysis to test for the correlations was performed using the coefficients of the ICP growth curves, PHV, APHV, HPHV and final height. The relationship between APHV and HPHV for final height was further analyzed by performing multiple linear regression analysis to identify the significant predictors of final height. All statistical analyses were performed using R version 3.4.1 (R Foundation for Statistical Computing, 2017).

Results

Figure 2 maps the APHV, HPHV, and final height in Japanese males, and Figure 3 maps the APHV, HPHV, and final height in Japanese females. The final height tended to be higher in the northern areas of the country, for both sexes. The distributions of the HPHV and final height were similar. The distributions of the APHV and PHV were not similar to that of final height.

Table 1 shows the basic statistics of the PHV, APHV, HPHV, and final height. The maximum APHV values were observed in Kyoto (males) and Kanagawa (females), and the minimum APHV values were observed in Akita (males) and Aomori (females). The maximum HPHV values were observed in Kyoto (males) and Kanagawa (females), and the minimum heights were observed in

Okinawa, in both sexes. The maximum final heights were observed in Akita, and the minimum final heights were observed in Okinawa, in both sexes.

Table 2 shows the basic statistics of the coefficients of the ICP growth curves of each component for each prefecture. The coefficients correspond to formulae (1) to (3), as mentioned in the Methods. Due to a lack of data, not all the coefficients could be used for interpretation. The coefficient a_2 of the second-degree polynomial function controls the sharpness of the curvature of the childhood component. The minimum (i.e. most sharp) coefficient a_2 was observed in the Aomori prefecture, for both sexes. The coefficient a_3 denotes the amount of growth during puberty. The maximum a_3 was observed in Shimane (males) and Nagano (females), and the minimum a_3 was observed in Miyagi (males) and Aomori (females).

Table 3 shows the Pearson's correlation matrix between the coefficients of the ICP growth model, PHV, APHV, HPHV, and final height. Since, the coefficients a_2 and b_2 were proportional to each other, they were summarized. The APHV values were negatively correlated with the coefficients a_2 and b_2 (r=-0.36: males, -0.62: females). This suggests that the more vigorous the growth in childhood, the earlier the APHV. The APHV values were highly correlated with the coefficient a_3, in both sexes, and negatively correlated with b_3, c_3, and PHV. This suggests that the higher the APHV, the lower the growth in the puberty component, and, the higher the APHV, the higher the pubertal growth speed. A very weak correlation was found between APHV and final height, in both sexes (r=-0.05: males, 0.00: females). The HPHV values were highly correlated with final height, in both sexes (r=0.90: males, 0.85: females).

Table 4 shows the results of the multiple linear regression analysis performed to predict final height. The correlation between final height and both APHV and HPHV was very high in both sexes. The APHV was negatively correlated with final height, while the HPHV was positively correlated with the same. The magnitude of the standardized coefficient of the HPHV was more than twice that of the APHV.

Discussion

A very low correlation between APHV and final height was observed. However, the results of the multiple regression analysis showed that the final height of each prefecture could be accurately predicted through a combination of APHV and HPHV. The results also show that the lower the APHV and higher the HPHV, the higher the final height.

However, when the APHV was lower, the amount of growth of the puberty component decreased (Table 3). This seems to contradict the result of the multiple regression equation, in which the final height increased as the APHV increased.

Generally, in normal puberty, the intense growth during childhood advances the APHV and increases the PHV; however, the subsequent pubertal component becomes sluggish and the adolescent height gain reduces (He & Karlberg, 2001; Soliman et al., 2014; Holmgren et al., 2016). In this study, the APHV was negatively correlated with the coefficients of the curvature of the childhood component. In addition, APHV was negatively correlated with the coefficient of the curvature of the pubertal component (b_3 and c_3) and PHV, and positively correlated with the amount of growth of the puberty component (a_3) (Table 3). Conversely, in general, gradual growth during childhood delays the APHV, and the subsequent pubertal component becomes moderate; however, the adolescent height gain increases.

Currently, in the prefectures in Japan, the effect of earlier APHV in increasing the amount of growth of the childhood component exceeds its effect in reducing the growth of the puberty component. It is possible that, the earlier the APHV the higher the final height and lower the growth of the puberty component; this means that the amount of growth in the childhood component is dominant in terms of final height. In other words, the results of the multiple regression analysis suggest that the final height depends on how large the height growth is in the early stages of childhood.

One cause of the advance of the APHV is obesity (Burt & McCartney, 2010; Yokoya & Higuchi, 2014; Wang, 2002). In previously conducted population-based studies, in Japan, it was found that the APHV tends to be earlier in areas with a higher prevalence of obesity (Yokoya & Higuchi, 2014). In addition, obesity has been reported to advance the APHV and reduce the amount of growth in the pubertal components (He & Karlberg, 2001; Holmgren et al., 2016). Similarly, in this study, the amount of growth of the pubertal component decreased as the APHV advanced.

In general, obesity results in a temporary increase in height gain, in childhood, and subnormal growth in adolescence (He & Karlberg, 2001; Soliman et al., 2014); our study's results were in alignment with this finding. However, with regard to the final height, the results of this study suggest that the final height is unlikely to decrease due to obesity, in the future. The prevalence of obesity is on the rise, in Japanese children (Asia Pacific Cohort Studies Collaboration, 2007). However, it has not pathologically changed the average value of physique, at the prefecture level. Since peaking between 1997 and 2001, the height of Japanese youth has plateaued (Ministry of

Education, Culture Sports, Science and Technology). Based on these facts and under the present circumstances in Japan, it is unlikely that obesity has reduced the average final height, across prefectures. Additionally, the standardized coefficients of the APHV in the multiple regression were half of those of the HPHV. Even if the APHV is advanced by obesity, the increase in final height will be minimal.

However, despite the average height being at its highest ever, regional differences in height still remain in Japan. Children in the northern regions of Japan tend to be taller than those in the southern regions, and a geographical gradient exists (Figure 2 and 3). Although the existence of this phenomenon has been known for at least 50 years, the underlying mechanism remained unclear. After consideration of the nutritional improvement, economic growth, and migration during this period, this phenomenon was attributed to the result of environmental factors rather than nutritional or genetic factors (Yokoya, Shimizu & Higuch, 2012; Yokoya & Higuchi, 2016).

The current geographical differences in the body height may be caused by geographical differences in the photoperiodic environment, which could influence thyroid hormone activity (Yokoya, Shimizu & Higuch, 2012; Yokoya & Higuchi, 2016). This hypothesis is derived from the fact that the effect of recombinant human growth hormone (r-hGH) therapy varies with latitude (De Leonibus et al., 2016). In growth hormone therapy, in spite of the administration of a certain amount of r-hGH, the effect differs, by latitude. This may be due to the seasonal and regional differences in the activity of the thyroid hormones working synergistically with the growth hormones. The activity of thyroid hormones has seasonal and regional differences, and it fluctuates based on the day length. The distribution of the body height of Japanese children is very similar to that of the effective day length (day length, considering the light intensity) (Yokoya & Shimizu, 2011). Geographical differences in the body height of Japanese individuals may be caused by geographical differences in the effective day length (Yokoya, Shimizu & Higuch, 2012; Yokoya & Higuchi, 2016).

According to this theory, the regional differences in the HPHV values of Japanese children may be caused by differences in thyroid hormone activity, brought on by differences in the photoperiodic environment. Generally, thyroid hormones have a significant influence on the growth phase before puberty (Karlberg & Albertsson-Wikland, 1988). In this study, the regional differences in body height were predominantly expanded in the childhood component, and they persisted until the final height was achieved (Table 1). From the above data, it could be concluded that thyroid hormone activity is related to regional differences in body height.

The multiple regression analysis showed that the APHV and HPHV were statistically independent. This implies that the cause of the regional differences in the HPHV is independent of the regional differences in obesity and nutritional intake, which are considered to cause the regional differences in the APHV. In recent decades, the Japanese physique has improved significantly, and the APHV and HPHV were thought to have advanced in parallel. Improved nutrient intake may have played a major role in this. However, the current regional differences in the HPHV were likely caused by factors other than nutritional intake. In fact, the distributions of the prevalence rates of obesity and height do not coincide. In some prefectures, the prevalence of obesity is on the rise despite the people there being of short stature (Yokoya & Higuchi, 2014). It is unlikely that regional differences in height are caused by regional differences in nutritional intake.

If the geographical differences in body height are caused by geographical differences in day length, it can be concluded that the HPHV is region-specific. After peaking between 1997 and 2001, the height of Japanese youth, across prefectures, has remained at a highest-ever level (Ministry of Education, Culture Sports, Science and Technology). From these facts, it is unlikely that changes in the HPHV leads to an increase in the final height average, across prefectures.

Conclusions

The aim of this study was to elucidate the effect of geographical differences in the APHV and HPHV on final height, at a prefectural level, and to evaluate the current, average height status in the Japanese population. We found that the final height has increased, due to the earlier APHV and higher HPHV.

From the perspective of the average value of each prefecture, in the present situation, the effect of an earlier APHV in increasing the amount of growth of the childhood component exceeded its effect in reducing the growth of the puberty component. In short, final height is dependent on the height growth in the early stages of childhood.

Given the trends over the past several decades, the increase in the APHV may be attributed to the increase in the prevalence of obesity. However, the increase in final height due to this is considered to be minimal. While the final height, across prefectures, reached a plateau in 2001, geographical differences in body height still remain. There is a possibility that current regional differences in the HPHV are region-specific, and cannot be ignored. It is unlikely that increases in the HPHV will lead to increases in the final height.

In the future, it is necessary to conduct a detailed investigation of the influence of the APHV and HPHV on final height, by focusing on the regional differences in the prevalence of obesity or differences in growth, by era. While we focused on the APHV, in this study, research focusing on the onset of the pubertal growth spurt is required.

All ecological studies are potentially prone to ecological fallacy. Therefore, the findings of our study should be interpreted cautiously. Furthermore, cross-sectional studies have some limitations that may influence the results. Therefore, careful assessment of whether the findings of our study have the same physiological meaning as those of previously conducted longitudinal studies, based on individual-level data, is required. Despite the averaging of individual information, we found a clear association between APHV and HPHV, and final height, suggesting that some causes of the differences in the APHV or HPHV are region-specific (independent of individual differences) and persist, across prefectures. Identifying and tracing region-specific factors should be considered an essential public health priority (Maier et al., 2014).

Ethics

This study did not require ethics committee approval because all the data used were previously published.

Conflict of interest

The author declare that there are no conflicts of interest with regard to the publication of this paper

Supporting Information

Figure S1. Map of the 47 prefectures of Japan. Numbers correspond to the prefecture information presented in Tables S1 (Yokoya & Higuchi, 2014).

Table S1. Coefficients of the infancy-childhood-puberty growth curves, age at peak height velocity, peak height velocity, height at peak height velocity and final height in each component obtained for each prefecture.

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Figure Legends

Figure 1 Example of the fitting of the infancy-childhood-puberty growth curve.

The growth curve was estimated by infancy-childhood-puberty growth model fitting, using data on the birth height and the height of 5–17-year-old youth and children, from 2006 to 2013. This is an example of the boys in Hokkaido prefecture.

Figure 2 Distribution map of the peak height velocity, age at peak height velocity, height at peak height velocity, and final height in boys.

Distribution map of the age at peak height velocity (APHV), height at peak height velocity (HPHV), and final height in each prefecture: (A) PHV (cm), (B) APHV (year), (C) HPHV (cm), and (D) Final height (cm). Distributions of the HPHV and final height are similar. The HPHV and final height of Japanese youth tend to be greater in the northern prefectures. The distributions of the APHV and final height do not match.

Figure 3 Distribution map of the peak height velocity, age at peak height velocity, height at peak height velocity, and final height in girls.

Distribution map of age at peak height velocity (APHV), height at peak height velocity (HPHV), and final height, in each prefecture: (A) PHV (cm), (B) APHV (year), (C) HPHV (cm), and (D) Final height (cm). Distributions of the HPHV and final height are similar. The HPHV and final height of Japanese youth tend to be greater in the northern prefectures. The distributions of the APHV and final height do not match.

Table 1 (on next page)

Basic statistics PHV, APHV, HPHA, and FH

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Table 1. Basic statistics PHV, APHV, HPHA, and FH

Boys	**PHV**	**APHV**	**HPHV**	**FH**
Maximum	8.72 (Okinawa)	12.11 (Kyoto)	153.0 (Kyoto)	172.5 (Akita)
Minimum	7.91 (Ibaraki)	11.74 (Akita)	150.3 (Okinawa)	169.9 (Okinawa)
Mean	8.24	11.97	152.2	171.4
Median	8.20	11.97	152.2	171.4
Girls				
Maximum	8.26 (Kochi)	10.20 (Kanagawa)	141.4 (Kanagawa)	159.5 (Akita)
Minimum	7.46 (Shizuoka)	9.84 (Aomori)	138.7 (Okinawa)	157.2 (Okinawa)
Mean	7.76	10.06	140.6	158.5
Median	7.72	10.09	140.6	158.5

PHV: Peak height velocity
APHV: Age at peak height velocity
HPHV: Height at peak height velocity
FH: Final height

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Table 2 (on next page)

Basic statistics of the coefficients of ICP growth model of each prefecture.

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1 **Table 2. Basic statistics of the coefficients of ICP growth model of each prefecture**

Boys	a_1	b_1	a_2	b_2	c_2	a_3	b_3	c_3
Maximum	79.91 (Iwate)	31.00 (Iwate)	0.2297 (Aomori)	9.19 (Aomori)	71.2 (Osaka)	13.26 (Shimane)	19.30 (Akita)	1.63 (Akita)
Minimum	78.74 (Miyazaki)	29.56 (Nagasaki)	0.2221 (Okinawa)	8.88 (Okinawa)	69.9 (Miyazaki)	11.73 (Miyagi)	16.74 (Ibaraki)	1.39 (Ibaraki)
Mean	79.36	30.29	0.2260	9.04	70.6	12.49	17.90	1.48
Median	79.37	30.25	0.2261	9.04	70.6	12.50	17.79	1.47
Girls								
Maximum	76.95 (Nagano)	28.31 (Wakayama)	0.3045 (Aomori)	10.35 (Aomori)	67.6 (Nagano)	7.84 (Nagano)	26.57 (Aomori)	2.69 (Aomori)
Minimum	74.7 (Okinawa)	26.51 (Miyazaki)	0.2874 (Nagano)	9.77 (Nagano)	65.0 (Okinawa)	5.64 (Aomori)	19.14 (Shizuoka)	1.87 (Shizuoka)
Mean	75.89	27.35	0.2957	10.06	66.3	6.93	21.64	2.13
Median	75.92	27.35	0.2954	10.04	66.3	6.93	21.37	2.12

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3 Coefficients a_1, a_2, c_2, a_3, b_3, c_3 correspond to formulae (1)–(3) in the text.

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Table 3 (on next page)

Correlation matrix between the coefficients of the ICP growth model, PHV, APHV, HPHV, and FH

Table 3. Correlation matrix between the coefficients of the ICP growth model, PHV, APHV, HPHV, and FH

	a_1	b_1	a_2 & b_2	c_2	a_3	b_3	c_3	**PHV**	**APHV**	**HPHV**	**FH**
a_1	1	0.75***	-0.63***	0.99***	0.51**	-0.21	-0.22	0.05	0.29	0.53**	0.37*
b_1	0.57***	1	-0.56***	0.76***	0.45**	-0.17	-0.19	0.06	0.25	0.34*	0.20
a_2&b_2	-0.03	-0.22	1	-0.74***	-0.80***	0.53**	0.55***	0.29	-0.62***	-0.02	0.34*
c_2	0.96***	0.61***	-0.28	1	0.59***	-0.28	-0.29*	-0.01	0.36*	0.46**	0.25
a_3	0.11	0.35*	-0.67***	0.29	1	-0.83***	-0.85***	-0.54**	0.83***	0.40*	0.06
b_3	-0.03	-0.04	0.31*	-0.12	-0.41**	1	1.00***	0.90***	-0.69***	-0.28	-0.07
c_3	0.00	-0.03	0.35*	-0.10	-0.49**	0.99***	1	0.89***	-0.74***	-0.30*	-0.06
PHV	0.09	0.20	0.11	0.05	-0.03	0.88***	0.87***	1	-0.55***	-0.13	0.04
APHV	-0.11	-0.02	-0.36*	-0.01	0.69***	-0.42**	-0.57***	-0.37*	1	0.48**	0.00
HPHV	0.41**	0.15	0.58***	0.25*	0.07	-0.03	-0.09	-0.03	0.35*	1	0.85***
FH	0.50**	0.22	0.73***	0.29*	-0.11	0.10	0.10	0.15	-0.05	0.90***	1

Lower triangle: Boys

Upper triangle: Girls

$^{***}p < 0.001$, $^{**}p < 0.005$, $^{*}p < 0.05$

Coefficients a_1, a_2, c_2, a_3, b_3, c_3 correspond to formulae (1)–(3) in the text.

PHV: Peak height velocity

APHV: Age at peak height velocity

HPHV: Height at peak height velocity

FH: Final height

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Table 4 (on next page)

Results of the multiple linear regression analysis

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Table 4. Results of the multiple linear regression analysis

	Beta	β	Regression coefficient	SE of the regression coefficient	t value	p value	Confidence interval of the regression coefficient (95%)	
Boys	Adjusted $r^2 = 0.973$							
Intercept			38.23	3.91	9.77	<0.0001	30.34	46.12
APHV	-0.43	0.03	-2.80	0.17	-16.27	<0.0001	-3.15	-2.46
HPHV	1.05	0.03	1.10	0.03	40.30	<0.0001	1.04	1.15
Girls	Adjusted $r^2 = 0.942$							
Intercept			33.26	5.03	6.62	<0.0001	23.13	43.39
APHV	-0.54	0.04	-3.07	0.23	-13.28	<0.0001	-3.54	-2.60
HPHV	1.11	0.04	1.11	0.04	27.29	<0.0001	1.03	1.19

APHV: Age at peak height velocity

HPHV: Height at peak height velocity

Beta: Standardized coefficient

β: Standard error

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Figure 1

Example of the fitting of the infancy-childhood-puberty growth curve.

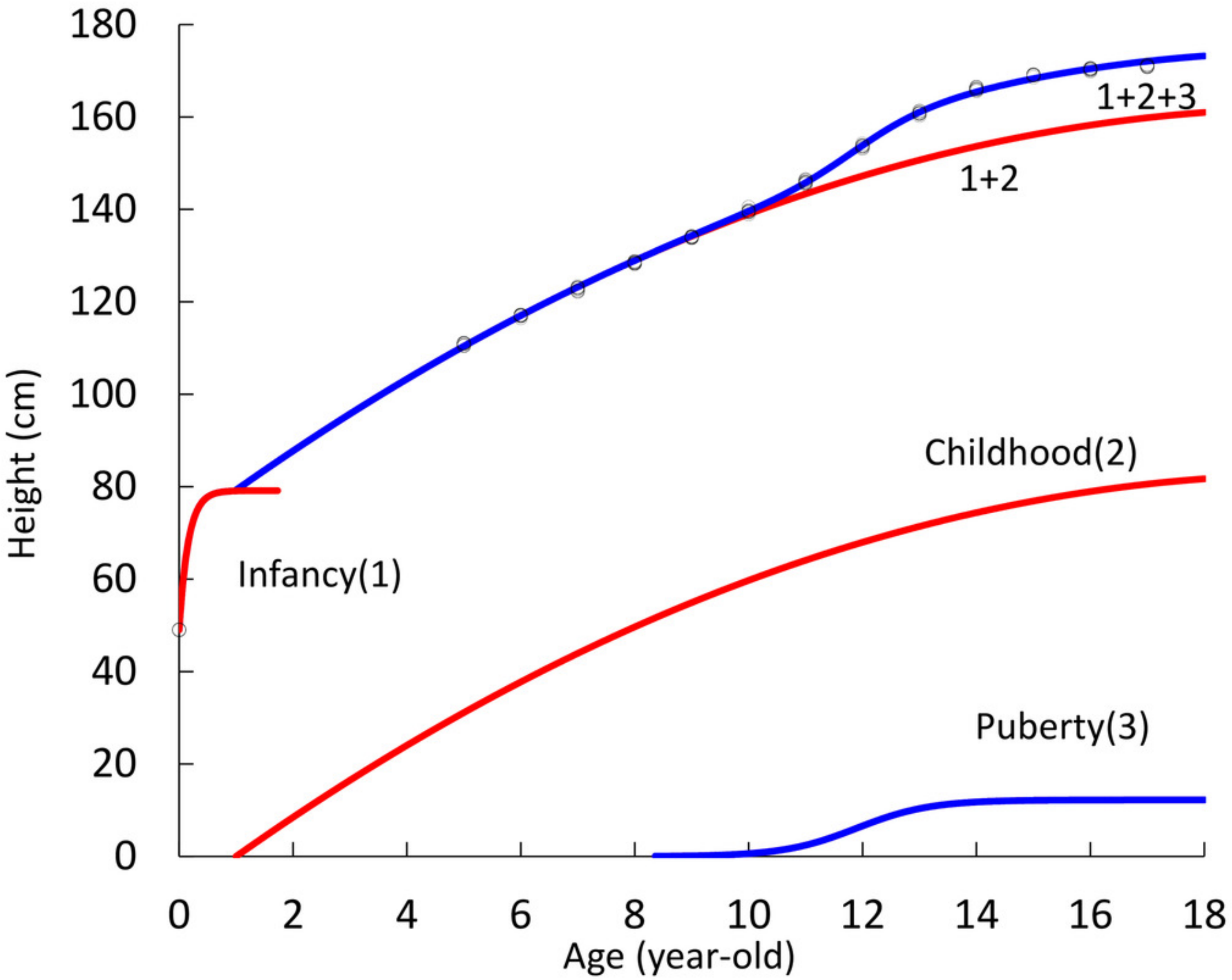

Figure 2

Distribution map of the peak height velocity, age at peak height velocity, height at peak height velocity, and final height in boys.

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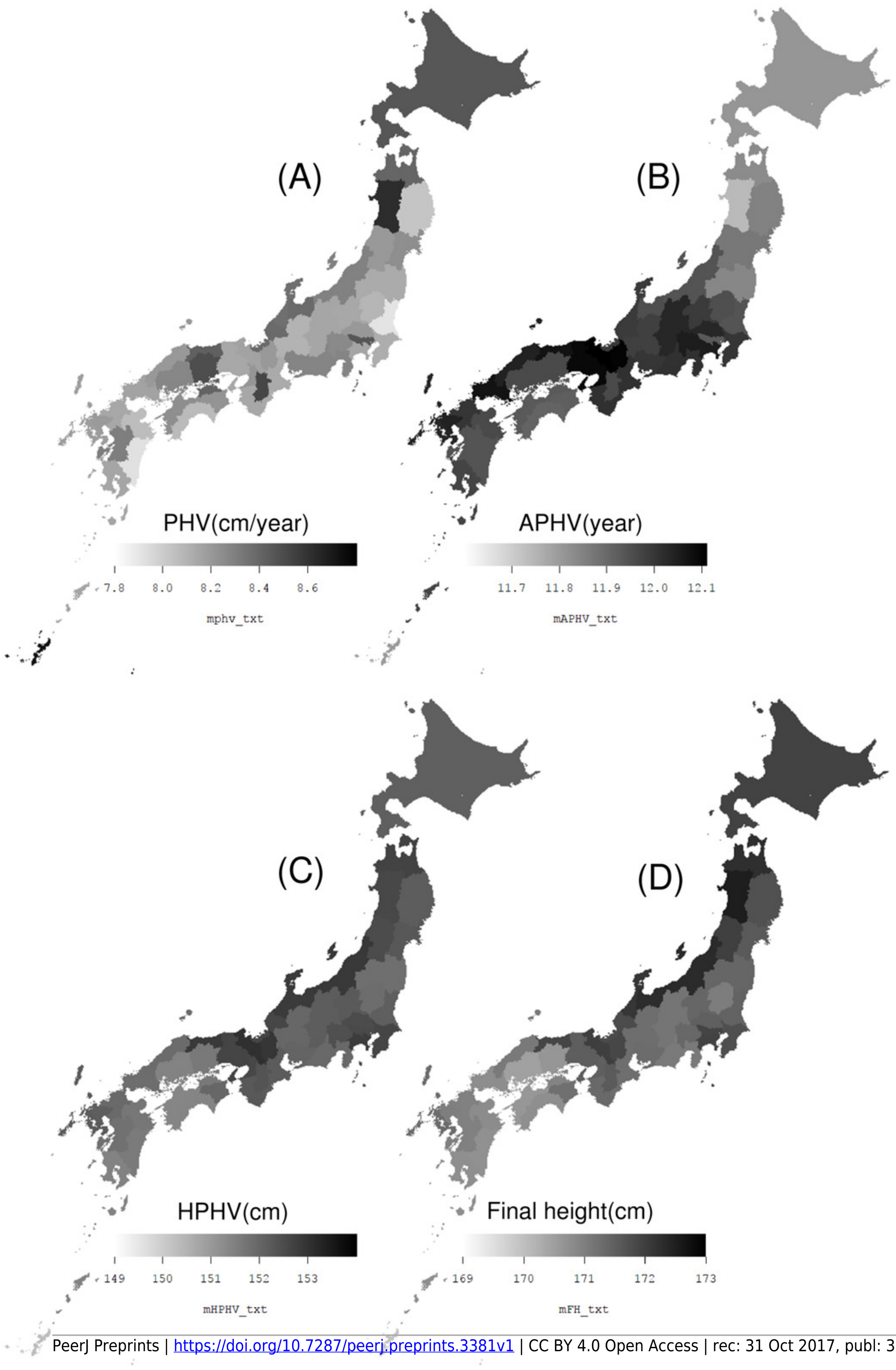
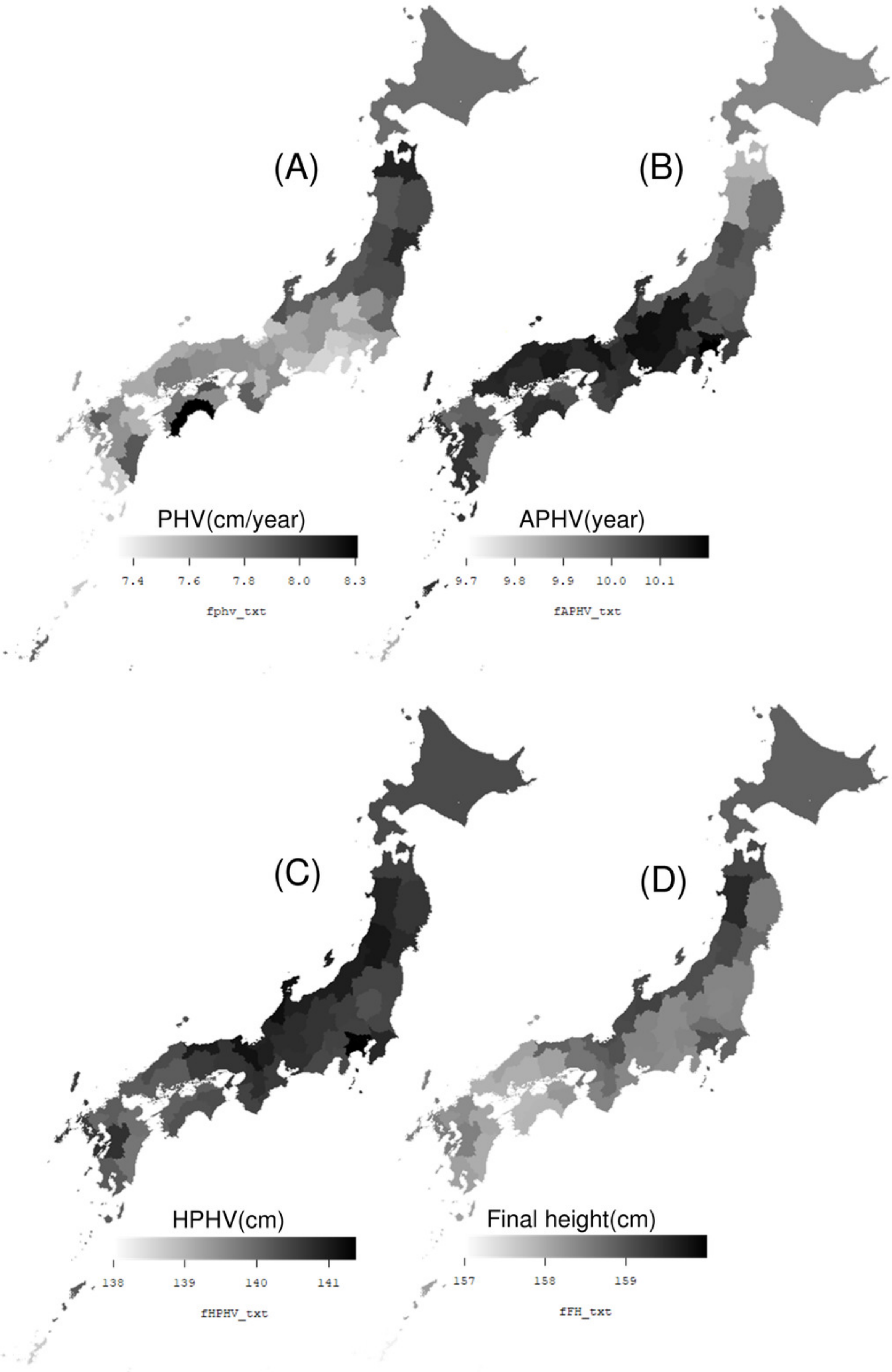

(A)
PHV(cm/year)
7.8 8.0 8.2 8.4 8.6
mphv_txt
(B)
APHV(year)
11.7 11.8 11.9 12.0 12.1
mAPHV_txt
(C)
HPHV(cm)
149 150 151 152 153
mHPHV_txt
(D)
Final height(cm)
169 170 171 172 173
mFH_txt

Figure 3

Distribution map of the peak height velocity, age at peak height velocity, height at peak height velocity, and final height in girls.


(A)
PHV(cm/year)
7.4 7.6 7.8 8.0 8.3
fphv_txt
(B)
APHV(year)
9.7 9.8 9.9 10.0 10.1
fAPHV_txt
(C)
HPHV(cm)
138 139 140 141
fHPHV_txt
(D)
Final height(cm)
157 158 159
fFH_txt