International Journal of Sport Studies for Health

Journal Homepage

Validation of A Somatic Maturity Prediction Model in North America and Development of Original Japanese Model with Ogi Growth Study

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A r t i c l e I n f o

Article type:
Original Paper

How to cite this article:
Tsuji, K., Tsuchiya, Y., Hirano, Y., & Ochi, E. (2024). Validation of A Somatic Maturity Prediction Model in North America and Development of Original Japanese Model with Ogi Growth Study. *International Journal of Sport Studies for Health*, *7*(1), 36-44.
http://dx.doi.org/10.61838/kman.intjssh.7.1.5

A B S T R A C T

Objective: While peak height velocity age (PHVA) forecasting models exist for Westerners, there are no equations that target the Japanese. This study aimed to analyze the suitability of Canadian equations model using data from a large-scale study of Japanese participants to verify their applicability (study 1) and to create model equations that are optimal for Japanese participants by multiple regression analysis using the same data (study 2).

Methods and Materials: In Study 1, 3,211 and 2,611 data points from boys and girls, respectively, were used to analyze the fit of Asian data to the sex-specific regression equations developed by Mirwald et al. (2002) and Moore et al. (2015). The participants were used in Study 2 to create an optimal maturity prediction model for the Japanese population, and the applicability of the model was verified. In addition, to verify the external validity of the Maturity prediction model, the data were randomly divided for analysis and for validation prior to the creation of the model equation.

Results: The results of Study 1 revealed that previous prediction models were underestimated PHVA for Japanese individuals of both males and females at younger ages and overestimated PHVA at older ages. Thus, it is suggested that the Moore model might not be suitable for the Japanese population. However, by using Study 2, we confirmed that our PHVA prediction model was suitable.

Conclusions: The development of a predictive model suitable for the Japanese population through this study may assist in the establishment of optimal training prescriptions and environments during the growth and development period.

Keywords: *Maturation, maturity offset, peak height velocity age, adolescence, development.*

Article history:
Received 10 November 2023
Revised 23 November 2023
Accepted 14 December 2023
Published online 01 January 2024

1. Introduction

Ensuring that childhood exercise programs are optimized for children's stage of development in terms of load, volume, duration, and activity type is critical to their acquisition of proficient motor skills (1, 2). However, training loses its effectiveness when its contents are excessive or inappropriate for the child's growth, and even increase the risk of sport-related injuries (3). This is why exercise instruction in children's sports settings is typically divided into chronological age and grade levels. However, emerging evidence suggests that such programs should additionally be customized at an individual level given the presence of numerous differences between children in terms of morphological and physiological parameters in the course of growth and development (4-9).

While a child's level of maturity can be precisely evaluated using techniques such as X-ray morphometry (10, 11), the invasiveness of such methods makes them particularly difficult to implement in younger populations. Efforts have been made to predict peak height velocity age (PHVA) based on chronological age and morphological data such as height using maturity offset (MO)-based methods (7). In one pioneering study, Mirwald et al. (12) developed sex-specific regression equations to predict child maturity ("Mirward model") based on data from Caucasian Canadian children, the study population of the Saskatchewan Pediatric Bone Mineral Accrual Study (PBMAS), and validated the models' accuracy using the data of Canadian children from the Saskatchewan Growth and Development Study (SGDS) and Belgian twin children from the Leuven Longitudinal Twin Study (LLTS). More recently, some of the same researchers created new model equations based on the same PBMAS data ("Moore model") (13); the models were calibrated using the data of Canadian children from the Healthy Bones Study III (HBS-III) and British children from the Harpenden Growth Study (HGS). However, it has been suggested that PHVA may differ between Japanese and Westerners (14), and the validity of the Moore model to Japanese population is unclear.

The present study had two objectives: 1) to analyze the suitability of the Mirward and Moore models and verify their applicability to Japanese boys and girls using a historical dataset from a 13-year large-scale study of 4,560 individuals (11,256 data points) conducted in Ogi City, Saga Prefecture, Japan; and 2) to develop model equations optimized for Japanese boys and girls by means of multiple regression analysis of the Ogi dataset. The study hypotheses were that the Mirward and Moore models would not adequately predict PHVA for the Japanese boys and girls, and the PHVA prediction models thus created based on the Ogi dataset would be more appropriate for the Japanese boys and girls.

2. Materials and Methods

Our study was conducted using the Ogi data donated to the National Science Museum in Japan. The database included data (4,560 individuals, 11,256 data points) on children and adolescents born between 1963 and 1978 and measured between 1979 and 1992. The study was approved by the Ethics Committee of the Graduate School of Sport and Health Studies at Hosei University (ID: 2022-11).

2.1 Study 1

Study 1, as done by Mirwald et al. (12), age at measurement was expressed in years since PHVA and the difference was defined as the biological MO. Data were extracted from a sample that included data from an approximate age of 13 years (3,211 data) for boys and 11 years (2,611 data) for girls. From the extracted samples, the period of greatest increase in height per year for everyone was calculated as the peak growth rate, followed by the median age in that interval. MO was then calculated for all samples by subtracting PHVA from the age at the time of measurement. In addition, similar to Mirwald et al. (12) and Moore et al. (13), we created the following 15 independent variables. Leg length (= height - sitting height), BMI (= weight / height2), age x height, age x weight, age x sitting height, age x leg length, leg length x sitting height, weight / height ratio, sitting height / height ratio, leg length / height ratio, and leg length / sitting height ratio. Predicted MO (pred MO) was calculated by fitting everyone's data at the time of measurement to the variables used in a model developed to predict MO in Canadians. The prediction accuracy was verified by analyzing the difference between the measured and predicted MOs for each individual.

2.2 Study 2

In Study 2, we used data from the Ogi Growth Study to create an optimal MO prediction model for the Japanese population and to test its applicability; we also separated data for validation. (Boys: analysis, 2,211; validation; 1,000. Girls: analysis, 2,611; validation, 1,611.) A sex-specific MO prediction model was constructed using the data divided for analysis, and the prediction accuracy was verified by analyzing the difference between everyone's MO and the pred MO calculated by the MO prediction model. We then applied the newly constructed MO prediction model to the data divided for validation and verified its validity.

Because of the nature of the multiple regression analysis and the possibility of including many variables in the constructed model, a simplified model was created using only the age and height data, and the validity of the model was verified in the same manner as in the aforementioned method.

2.3 Statistical analysis

All statistical analyses were performed using R (version 4.2.0; R Core Team, 2022). In Study 1, predicted (theoretical) MO was calculated by inputting the relevant Ogi dataset into each of the four model equations under consideration, that is, Mirwald boy's and girl's equations (12) and Moore boy's and girl's equations (13). For each model, the strength of the association between measured (actual) and predicted MOs was evaluated using Pearson's product-moment correlation analysis, while agreement and systematic error between measured and predicted MOs were evaluated using Bland-Altman analysis. In Study 2, Japanese-optimized MO prediction models were developed by means of multiple regression analysis. Sex-specific regression equations were created by stepwise selection of the 15 independent predictors (variables) mentioned above based on the analysis dataset of the corresponding sex. These equations validity was evaluated by comparing their predicted MO with respect to measured MO by means of Pearson's correlation analysis and Bland-Altman analysis, separately, for boys and girls. Finally, simplified regression models dependent only on age and height were created and tested in the same manner.

3. Results

The age, height, weight, sitting height, leg length, BMI, and mean values of PHVA and MO (minimum and maximum ranges) for each individual are shown in Table 1 for boys and girls.

Table 1. Age, height, weight, sitting height, leg length, body mass index, PHVA, and maturity offset of the participants.

	Boys	Girls
Age (y)	12.7 (7.1 to 18.9)	12.4 (7.1 to 18.1)
Height (cm)	148.9 (108.9 to 189.4)	144.4 (107.8 to 170.4)
Weight (kg)	43.4 (16.0 to 108.0)	39.5 (16.5 to 84.0)
Sitting height (cm)	80.6 (59.5 to 100.4)	78.6 (61.0 to 94.8)
Leg length (cm)	69.2 (46.3 to 93.3)	65.8 (45.8 to 84.6)
Body mass index	18.6 (13.1 to 38.3)	18.5 (12.4 to 36.4)
PHVA (y)	13.0 (10.5 to 15.9)	10.9 (7.6 to 14.5)
Maturity offset (y)	-0.24 (-8.41 to 7.44)	1.42 (-7.44 to 10.39)

3.1 Study 1

Figure 1 summarize the performance of the sex-specific models by Mirward et al. (12) and Moore et al. (13), respectively, with the Ogi dataset. For boys, there was a significant correlation between actual and predicted MOs as estimated by the Mirward boy's equation (Figure 1A; r=0.955, p<0.001). Bland-Altman analysis showed that this model tended to underestimate each individual's MO at younger ages and overestimate it at older ages (Figure 1B). Similarly, there was a significant correlation between actual and predicted MOs as estimated by the Moore boy's equation (Figure 1C; r=0.952, p<0.001), and Bland-Altman analysis showed that this model underestimated each individual's MO at younger ages and overestimate it at older ages (Figure 1D).

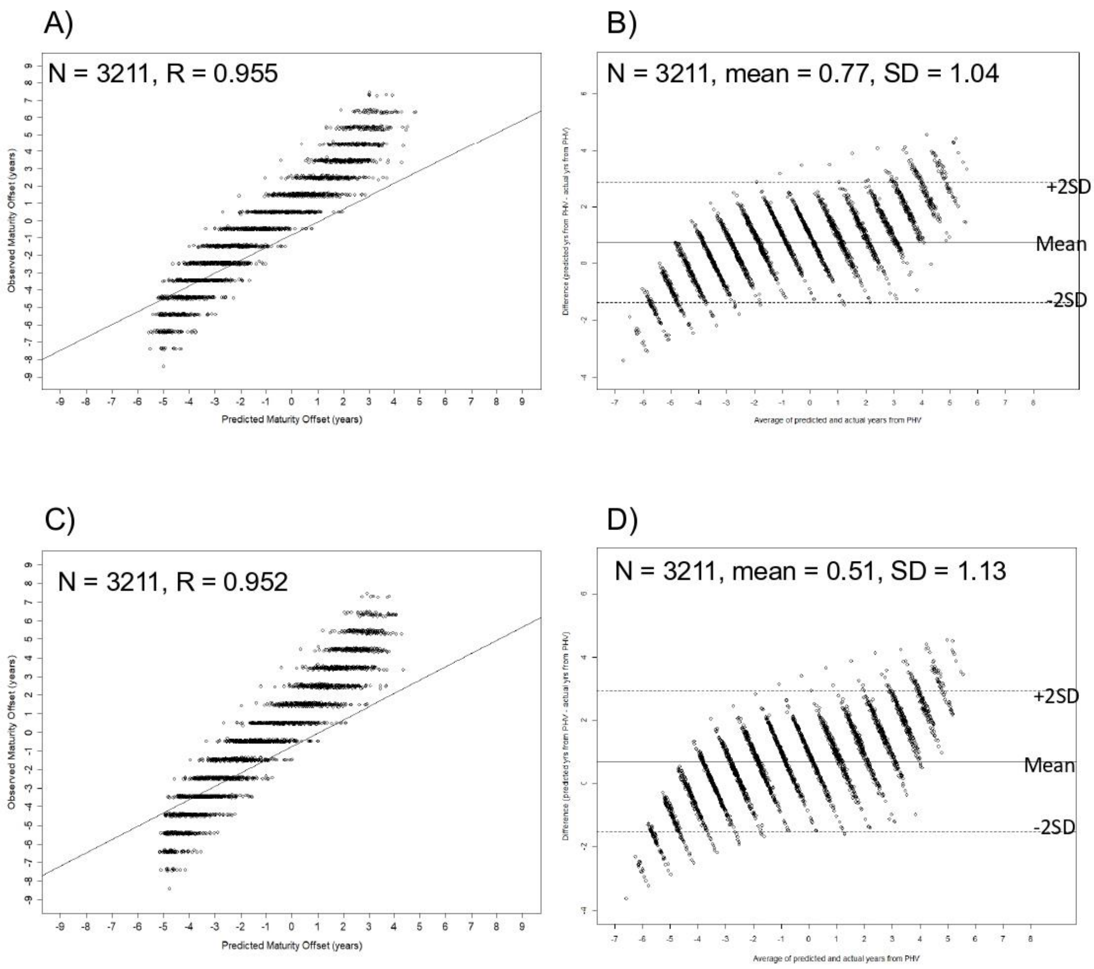

Figure 1. Calibration curves (observed vs predicted) and Bland Altman procedure in boys for Mirwald model (A and B) and Moore model (C and D).

For girls, there was a significant correlation between actual and predicted MOs as estimated by the Mirward girl's equation (Figure 2A; r=0.934, p<0.001). Bland-Altman analysis showed that this model tended to underestimate each individual's MO at younger ages and overestimated it at older ages (Figure 2B). Similarly, there was a significant correlation between actual and predicted MOs as estimated by the Moore girl's equation (Figure 2C; r=0.934, p<0.001), and Bland-Altman analysis showed that this model underestimated each individual's MO at younger ages and overestimated it at older ages (Figure 2D).

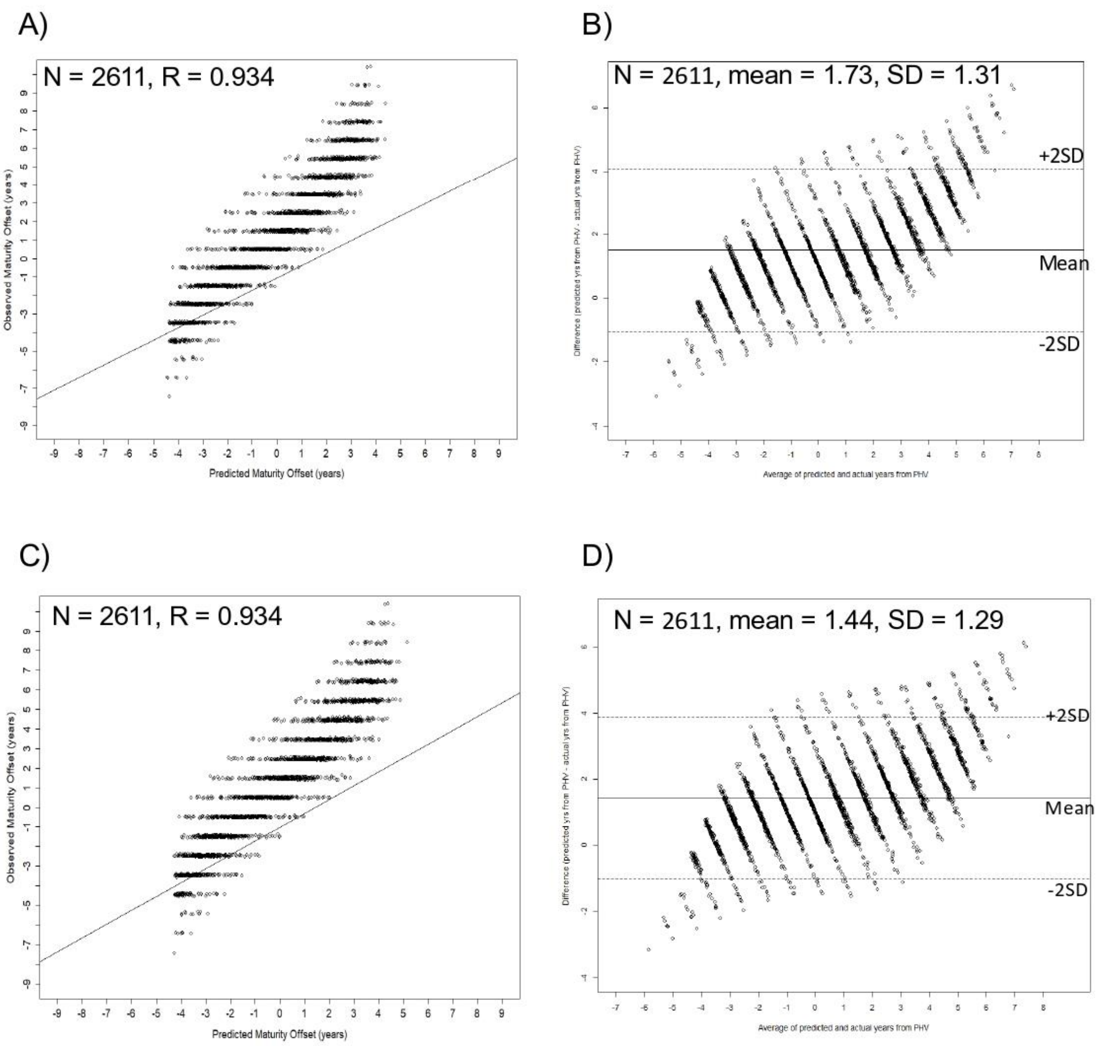

Figure 2. Calibration curves (observed vs predicted) and Bland Altman procedure in girls for the Mirwald model (A and B) and Moore model (C and D).

3.2 Study 2

Our predictive models for MO for boys and girls were developed using the respective sex's analysis data, and validated using its validation data. The following equation was derived by multiple regression analysis of the boy's analysis data (n=2,211).

Maturity Offset for boy's equation 1

$= 12.755 + (0.183 \times \text{age}) - (0.182 \times \text{height})$

$+ (0.502 \times \text{sitting height}) - (0.316 \times \text{weight}) + 0.00185 (\text{age} \times \text{height})$

$+ 0.00522 (\text{age} \times \text{weight}) + 0.428 (\text{weight/height} \times 100)$

$- 0.622 (\text{sitting height/height} \times 100)$

There was a significant correlation between predicted MO as calculated by Equation 1 and actual MO in the boy's analysis data ($r=0.959$, $p<0.001$), and Bland-Altman analysis revealed that its predictions were extremely accurate for both young and old PHVA (Figure 3A). When tested on the boy's validation data (n=1,000), there was a similarly strong correlation between predicted and measured MOs ($r=0.958$, $p<0.001$), as well as PHVA-independent accuracy in the results of Bland-Altman analysis (Figure 3B).

For comparative purposes, we also developed a simplified model for boys using the same approach, in which MO was calculated as a function of only the age and height. The following equation was derived by multiple regression analysis of the boys' analysis data (n=2,211).

Maturity Offset for boy's equation 2

$$= -16.416 + (0.778 \times \text{age}) + (0.0420 \times \text{height})$$

There was a significant correlation between predicted MO as calculated by Equation 2 and actual MO in the boy's analysis data (r=0.953, p<0.001), and Bland-Altman analysis revealed that its predictions were extremely accurate for both young and old PHVA, similar to the results for Equation 1 (Figure 3C). When tested on the boy's validation set (n=1,000), there was a similarly strong correlation between predicted and observed MO (r=0.953, p<0.001), as well as PHVA-independent accuracy in the results of Bland-Altman analysis (Figure 3D).

The following equation was derived by multiple regression analysis of the girl's analysis data (n=1,611).

Maturity Offset for girl's equation 1

$$= -26.900 - (0.261 \times \text{age}) - (0.208 \times \text{height})$$
$$+ (0.560 \times \text{sitting height}) - (0.545 \times \text{weight})$$
$$+ 0.00470\ (\text{age} \times \text{height}) + 0.00773\ (\text{age} \times \text{weight})$$
$$+ 0.721\ (\text{weight/height} \times 100) - 0.140\ (\text{sitting height/height} \times 100)$$
$$+ 0.176\ (\text{leg length/sitting height} \times 100)$$

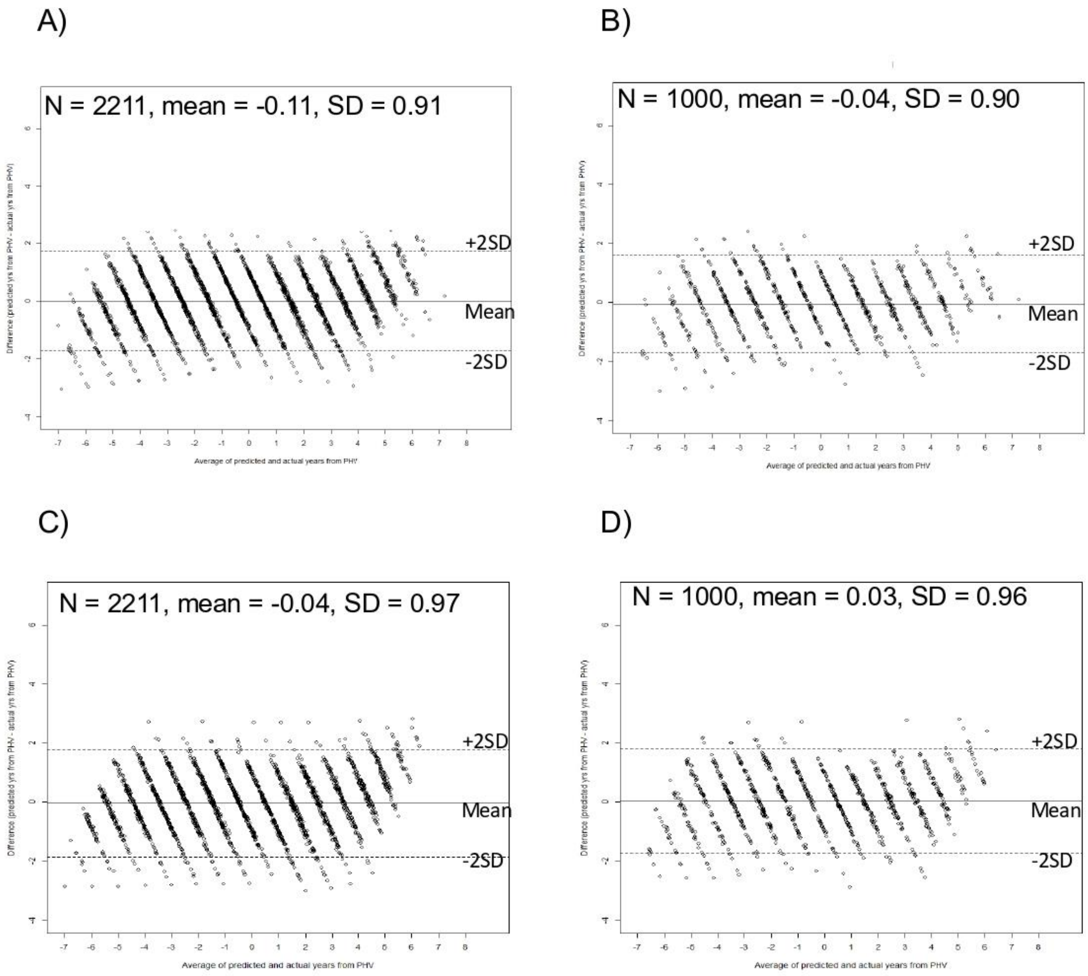

Figure 3. Bland Altman procedure for maturity offset of boys in the Maturity Offset for boy's equation 1 in analysis data (A) and verification data (B), and 2 in analysis data (C) and verification data (D). Maturity Offset for boy's equation 1= 12.755 + (0.183 × age) − (0.182 × height) + (0.502 × sitting height) − (0.316 × weight) + 0.00185 (age × height) + 0.00522 (age × weight) + 0.428 (weight/height × 100) − 0.622 (sitting height/height × 100). Maturity Offset for boy's equation 2 = −16.416 + (0.778 × age) + (0.0420 × height).

There was a significant correlation between predicted MO as calculated by Equation 1 and actual MO in the girl's analysis data (r=0.940, p<0.001), and Bland-Altman analysis revealed that its predictions were extremely accurate for both young and old PHVA (Figure 4A). When tested on the girl's validation data (n=1,000), there was a similarly strong correlation between predicted and measured MOs (r=0.940, p<0.001), as well as PHVA-independent accuracy in the results of Bland-Altman analysis (Figure 4B).

For comparative purposes, we also developed a simplified model for girls using the same approach, in which MO was calculated as a function of only the age and height. The following equation was derived by multiple regression analysis of the girl's analysis data (n=1,611).

Maturity Offset for girl's equation 2

= −14.236 + (0.846 × age) + (0.0360 × height)

There was a significant correlation between predicted MO as calculated by Equation 2 and actual MO in the boy's analysis data (r=0.934, p<0.001), and Bland-Altman analysis revealed that its predictions were extremely accurate for both young and old PHVA, similar to the results for Equation 1 (Figure 4C). When tested on the boy's validation set (n=1,000), there was a similarly strong correlation between predicted and observed MO (r=0.937, p<0.001), as well as PHVA-independent accuracy in the results of Bland-Altman analysis (Figure 4D).

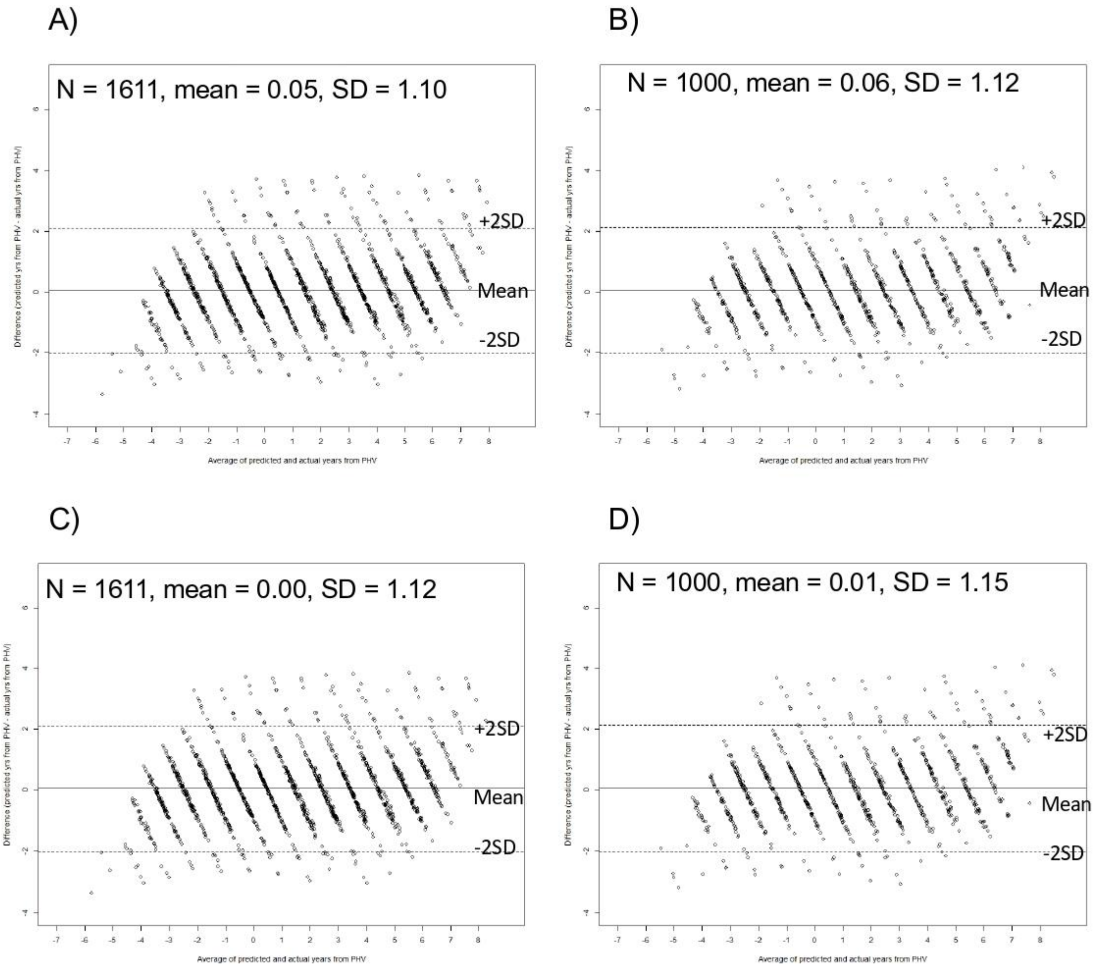

Figure 4. Bland Altman procedure for maturity offset of girls in the Maturity Offset for boy's equation 1 in analysis data (A) and verification data (B), and 2 in analysis data (C) and verification data (D). Maturity Offset for girl's equation 1 = −26.900 − (0.261 × age) − (0.208 × height) + (0.560 × sitting height) − (0.545 × weight) + 0.00470 (age × height) + 0.00773 (age × weight) + 0.721 (weight/height × 100) − 0.140 (sitting height/height ×100) + 0.176 (leg length/sitting height × 100). Maturity Offset for girl's equation 2 = −14.236 + (0.846 × age) + (0.0360 × height).

4. Discussion

The purpose of this study was to develop a prediction model for PHVA in the Japanese population. Study 1 calculated PHVA for the Japanese population using the prediction model from the previous study, and found that the younger age underpredicted PHVA and the older age overpredicted PHVA for each individual in both boys and girls. These results suggested that the Moore model for Canadians (Caucasians) may not be appropriate for the Japanese population. Therefore, we analyzed the results using the prediction model that we developed in Study 2, and for the first time ever, our study demonstrated a prediction model suitable for the Japanese population.

Several models for predicting PHVA have been proposed, including the pioneering Mirward model (12) and its successor, the Moore model (13), which is a more accurate version reported by the same research group and does not require the sitting height data for calculation. However, the samples used to develop these models consisted entirely of Canadian Caucasians. In fact, it has been suggested that PHVA varies across racial groups; for example, Japanese children may reach PHVA about a year earlier than their Caucasian peers (14). In the first half of this work (Study 1), we tested the applicability of the Mirward and Moore models to Japanese youths. While these models did yield PHVA values that significantly correlated with the observed PHVA data, they tended to underestimate it in the younger age groups and overestimate in the older age groups, suggesting that the Mirward and Moore models may not be suitable for predicting PHVA in Japanese populations.

In the Study 2, we developed new predictive models intended to be optimal for Japanese children. Our equations successfully improved upon the performance of the Mirward and Moore models. In particular, the predictive model for boys was shown to be relevant. In other words, a slight gender difference was indicated in this study. The Moore model (13) also resulted in conspicuously higher prediction error for children in early or late maturity: approximately 2-3 times greater in boys and 6-7 times greater in girls. Our findings highlight the importance of considering sex differences in the maturity level in future studies on this research topic.

Acknowledgements

We extend our gratitude to all participants for their kind cooperation.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Author Contributions: Study concept and design: KT, and EO; analysis and interpretation of data: KT, YT, YH and EO; drafting of the manuscript: KT and YT; critical revision of the manuscript for important intellectual content: KT, YT, YH, and EO; statistical analysis: KT and YT.

Data Availability Statement

The dataset presented in the study is available on request from the corresponding author during submission or after publication. The data are not publicly available due to privacy.

Ethical Considerations

Informed consent was obtained from all individual participants included in the study and their parents. This study was approved by the Medical Ethics Committee of the Graduate School of Sport and Health Studies at Hosei University (ID: 2022-11).

Funding

There was no funding/support.

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