Whitepaper on the BoneXpert Adult Height Prediction method, version 3.0

1 Summary

The BoneXpert online Adult Height Predictor, www.BoneXpert.com/ahp underwent a major update on 12 Feb 2021 to version 3.0. This whitepaper gives the clinical background for the update, including its development and validation.

The main improvements in version 3 are:

a) The Caucasian model has been extended down to bone age 2 years, and a validation study from Johannesburg has been introduced.

b) The Asian model has been revised based on a new Japanese longitudinal study and it has been extended down to bone age 5 years.

c) A new African model has been added, developed and validated on a longitudinal study from Johannesburg.

d) All models are based on bone age from BoneXpert version 3 which is using 21 bones in the hand, and the accuracy has thereby been improved.

These new developments will be published in two forthcoming articles – this whitepaper gives a summary.

2 Background

The first version of the BoneXpert AHP model was developed in 2009 [1]. It was validated in normal Danish children [2], in normal French children [3], and in German children with idiopathic short stature [4]. It was based on bone age determined by BoneXpert version 2, which is using 13 bones. An extensive review of the method was presented in [2] available as pdf here: pdf.

In September 2019, version 3 of the BoneXpert bone age method was released [5]. This bone age is based on 21 bones: 5 metacarpals, 14 phalanges, radius and ulna, rather than just 13, and it is was designed agree more closely with manual rating by means of using a very large training set containing 30000 images.

The new AHP version 3 is based on several longitudinal studies, all analysed with this version 3 of BoneXpert bone age.

3 The Caucasian Model

The Caucasian AHP model was extended down to bone age 2 by adding **the Paris longitudinal study** [3], including 98 children born in 1955, with known adult height and followed with X-rays at ages 1, 1.5, 2, 3, 4, 5 and 6 years.

The model performance is shown in Figure 1.

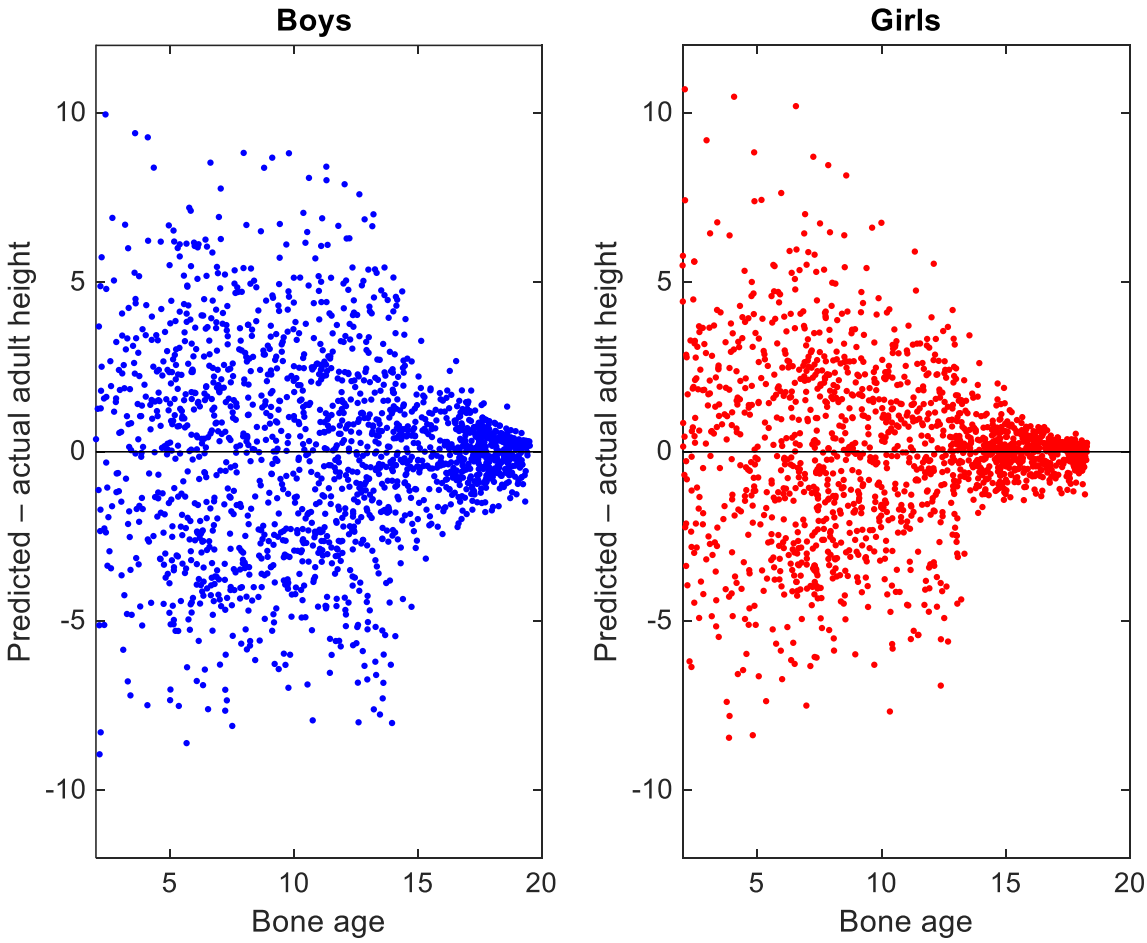

Figure 1: Accuracy of the extended Caucasian model

The Root Mean Square error (RMSE) in the prediction of the adult height varies with bone age as shown in Figure 2.

The Bayley Pinneau model extends down to bone age 7. Here we see that it is possible to extend adult height prediction down to 2 years for girls without suffering a major loss in accuracy. For boys, the accuracy becomes significantly worse below 2.5 years of bone age. This extension has clinical value because today many children are treated for growth disorders already from the age of 2.

We define a **standard accuracy measure** of an AHP method as the RMSE in the bone age interval 10-15 years for boys, and 8-13 years for girls. These intervals are indicated in Figure 2, and the standard accuracy is presented in Table 1.

Table 1: Standard Accuracy of AHP models in cm, averaged over the bone age range 10-15 y and 8-13 years for boys and girls, respectively.
The average birth year and the mean population heights of each study are indicated.

Study	Ethnicity	Population height		RMS error		
		Boys	Girls	Boys	Girls	Both sexes
Europe 1955	Caucasian	178	165	3.0	2.5	2.8
Johannesburg 1990		178	165	3.0	2.6	2.8
Japan 1975	Asian	170	157	2.6	2.3	2.5
Johannesburg 1990	African	171	159	3.0	3.0	3.0

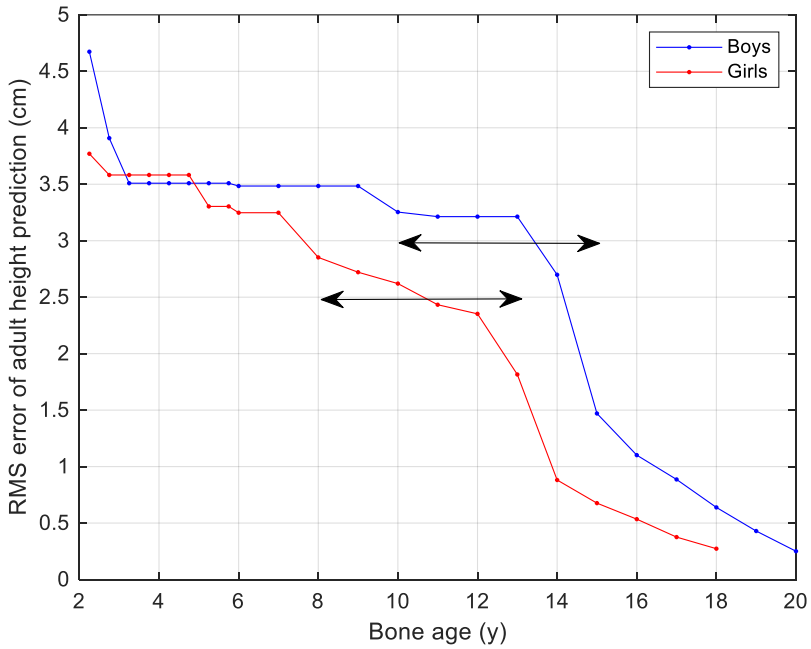

Figure 2: RMS error of the Caucasian model – the standard accuracy is computed as the average over the intervals indicated by the double arrows.

The Caucasian model was validated on **the Birth-to-20 study** of healthy black and white children born in Johannesburg in 1990. Figure 2 shows the performance on the 138 white children. The standard accuracy, presented in table 1, is similar to what was observed in the European children. It is a strong validation that the model developed on children born in Europe in 1955 performs so well on Caucasian subjects born 35 years later in a different continent.

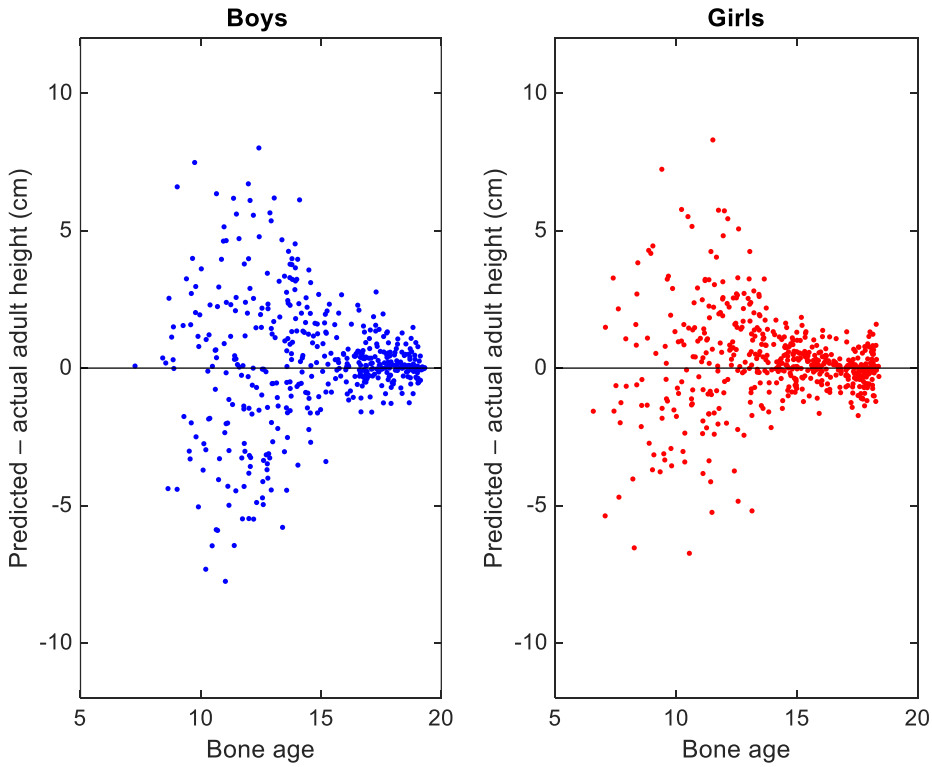

Figure 3: Accuracy of the extended Caucasian model on white subjects from South Africa

This AHP model can be applied to subjects from Caucasian populations with different mean population heights because the model takes the population height explicitly into account. Thus, the model developed on middle-European children can be used in Northern Europe by taking the 3 cm taller population there into account. Likewise, in Southern Europe it can adjust to the 3 cm lower population height. The magnitude of this effect can be estimated easily by switching between the Caucasian populations in the online AHP.

4 The Asian Model

The Asian model was developed based on **the longitudinal Ogi study** of 367 healthy children born on average in 1975 in Northern Japan. Figure 4 shows the application of the Caucasian model on these subjects – the model has been adjusted to the lower population height in Japan, but despite this, the model overestimates the adult height as indicated by the black curves. The Asian model was formed by subtracting this bias, resulting in the performance in Figure 5 and in Table 1, which also lists the population heights.

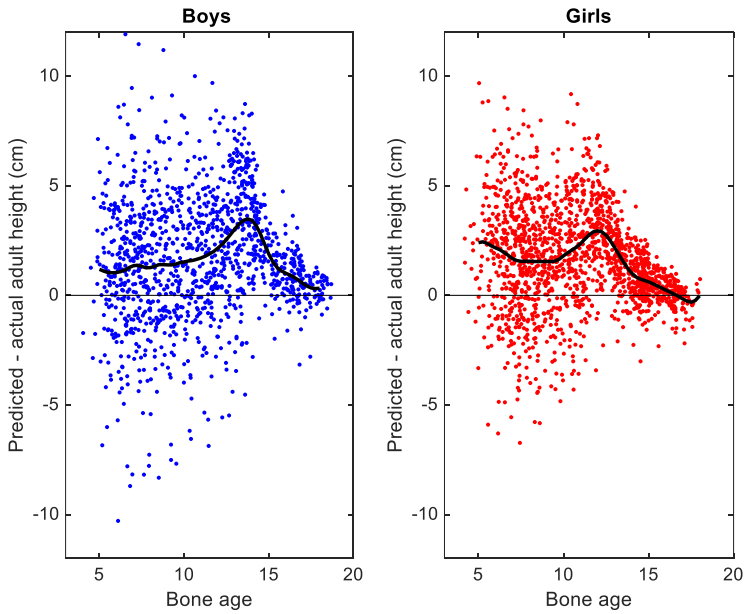

Figure 4: Using the Caucasian AHP model on Japanese children.
The model overestimates the adult height as indicated by the black curves.

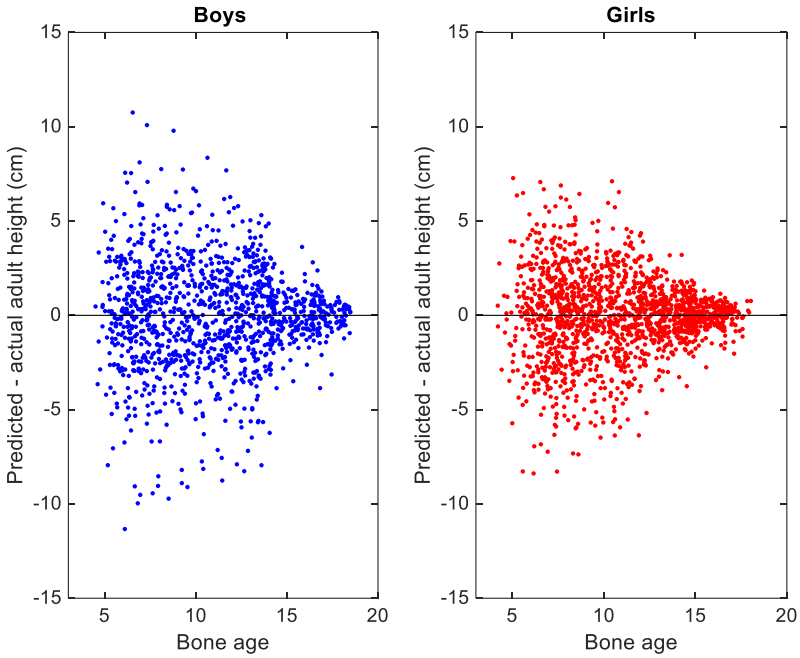

Figure 5: Performance of the new Asian AHP model on the Japanese children.

5 The African Model

The African model was developed based on the 363 black children of the Johannesburg study. Figure 6 shows the result of using the Caucasian model on these subjects, again adjusted to the lower population height. The model overestimates the adult height as indicated by the black curves i. The African model was formed by subtracting this bias, resulting in the performance in Figure 7.

Table 1 lists the standard accuracies which is worse than in the other population, perhaps due to the poorer living conditions.

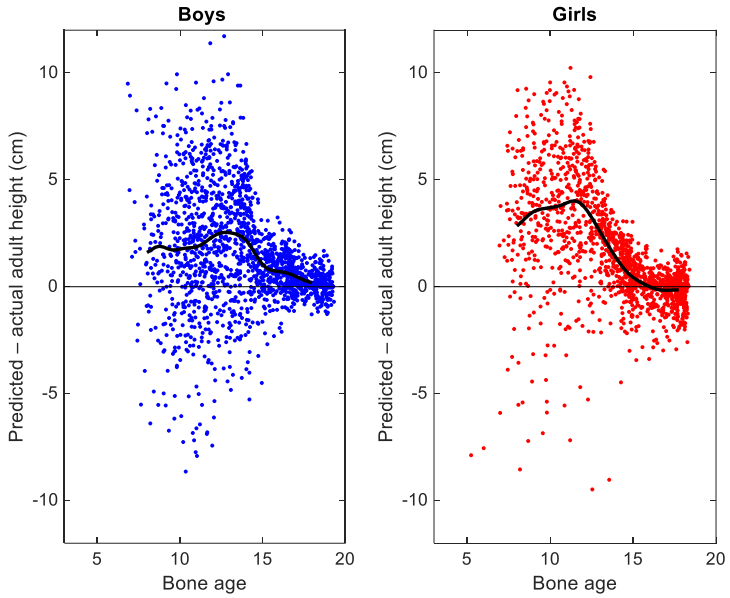

Figure 6: Using the Caucasian AHP model on black African children.

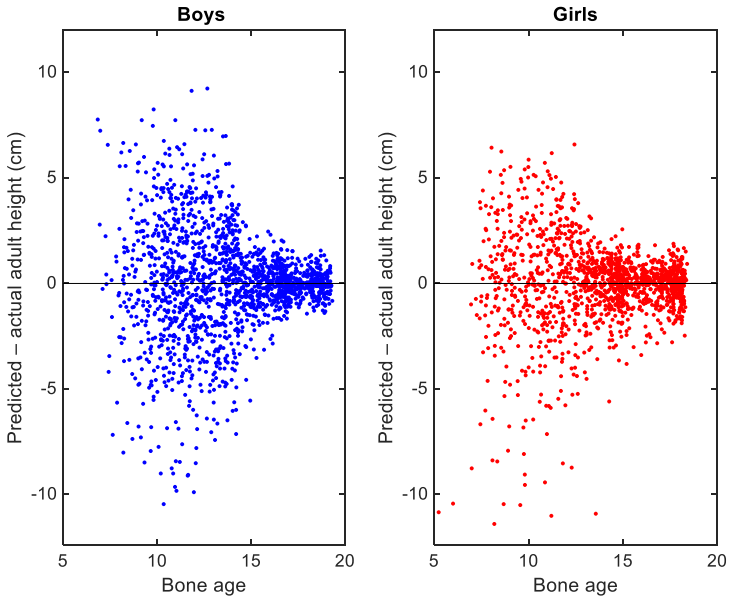

Figure 7 Performance of the new African AHP model on the black Johannesburg children

6 Bibliography

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