Letter to the Editor

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Relating weight growth trajectory to height and age

The paper by Dr Araújo and her colleagues [1] describes their quest to model the human weight growth trajectory as a function either of age or height. They had data on 719 children from the EPITeen study, with a mean of 16 measurements per child from birth to 21 years, and they modelled the serial weights as mixed effects models. For the mean curve they compared three alternative functions: polynomials, fractional polynomials (FP) and linear splines. Their conclusion was that weight is best predicted as a fractional polynomial in height.

As a conclusion this is not surprising. There is a strong allometric relationship between weight and height at all ages, such that for children of the same age, weight varies as a power of height, and the correlation between weight and height is around 0.7. [2] The optimal height power varies with age, and before age 5 it is around 2, corresponding to the body mass index (BMI), but it rises to 3 in puberty and then drops back to 2 in adulthood. [3] Thus at any particular age, height explains much of the variability in weight.

In addition mean height increases with age, so to an extent one's height predicts one's age. Combining the within-age and between-age components, it is inevitable that height is going to be better than age at predicting weight.

However, even ignoring height, the weight trajectory from birth to adult is complex in shape, with mean weight in boys increasing by a factor of 20 from birth to 20 years. [4] The weight velocity curve, i.e. the first derivative of the weight trajectory, shows two distinct peaks, in infancy and puberty, and they are the most obvious manifestations of the complex developmental changes that are taking place during childhood. Thus the relationship of weight to age is biologically important and not to be ignored.

Taken together, the logical conclusion is to model weight in terms both of height and age. But this leads back to the authors' research question: why did they want to predict the weight trajectory in the first place? What was the purpose?

The form of such a combined model would be as follows: a function to predict mean weight by age, combined with a function in height to model the deviation from mean age attributable to height in individuals. The form of these functions would be different: the

age function could be one of those considered by Araújo et al, i.e. polynomials or splines, but the height function could be simpler, just height^p where the power p is age-specific. Such a model is visualised in Figure 7 of Cole (1985).[5]

However there are problems with the functions used by Araújo et al. First, they are restricted – by choice – to 3 degrees of freedom, i.e. a cubic polynomial, an order 3 FP, and a linear spline with two internal knots. Figure 2 and Figure S5 show that all three curves fit the trajectory poorly, indicating that 3 degrees of freedom are insufficient to properly capture the curve's shape, however they are defined. It is also a shame that they did not consider cubic splines, which would avoid the disjunctions at the linear spline knots. And a third concern is that the two sexes were combined for this analysis, when their weight trajectories are known to be materially different in shape from puberty onwards.

To get an idea how many degrees of freedom are needed to properly model the weight trajectory from birth to adult, I fitted cubic spline models to data from the Berkeley Child Guidance Study,[6] 66 boys and 70 girls with a mean of 34 measurements per child from birth to age 21 (data available in my R CRAN *sitar* library). Fitting similar models to those of Araújo et al, with log(weight) predicted as a cubic spline in log(age + 1), and treating the data as cross-sectional (i.e. ignoring the repeated measures) the Bayes Information Criterion (BIC) was smallest with 9 degrees of freedom in girls and 10 in boys. Repeating the regression with log(height) gave 6 degrees of freedom in both sexes, and using the Akaike Information Criterion (AIC) gave larger values. Note that modelling the repeated measures, or using the larger sample of the EPITeen study, would have increased these values further. Thus 3 degrees of freedom are entirely inadequate to capture the subtleties of the weight trajectory.

A restricted model of weight trajectory also considered by the authors was a linear function in height^2, which gives residuals of weight adjusted for height^2, analogous to BMI. This model assumes that the index [weight | height^2] in individuals is constant through childhood, which of course it is not – mean BMI changes materially by age. Thus it is entirely unsurprising that the model fitted far worse than the age and height models. The Relative Squared Error (RSE, residual variance as a percentage of total variance) was 12.5% for BMI, as against 0.81% and 0.75% for the FPs in age and height.

In the Discussion the authors mention my SITAR growth curve model. This is also a mixed effects model in age, where the mean curve is fitted as a natural cubic spline, and the three random effects represent respectively the mean size, pubertal timing and pubertal intensity of each subject.[7] The authors say, incorrectly, that the model has only one independent variable and does not allow adjustment for other variables. In fact one

can include log(height) as a fixed effect for size, timing and/or intensity; including it as a size fixed effect works very well: the RSE is only 0.32% for Berkeley boys and 0.47% for girls, around half that for the authors' models. Here then is a model that predicts weight trajectory in terms of height and age in individuals.

References

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