Physical Growth and Nonverbal Intelligence: Associations in Zambia

Sascha Hein, PhD1, Jodi Reich, PhD1,2, Philip E. Thuma, MD3, and Elena L. Grigorenko, PhD1,4

Objective To investigate normative developmental body mass index (BMI) trajectories and associations of physical growth indicators—height, weight, head circumference (HC), and BMI—with nonverbal intelligence in an understudied population of children from sub-Saharan Africa.

Study design A sample of 3981 students (50.8% male), grades 3-7, with a mean age of 12.75 years was recruited from 34 rural Zambian schools. Children with low scores on vision and hearing screenings were excluded. Height, weight, and HC were measured, and nonverbal intelligence was assessed using the Universal Nonverbal Intelligence Test, Symbolic Memory subtest and Kaufman Assessment Battery for Children, Second Edition, Triangles subtest.

Results Students in higher grades had a higher BMI over and above the effect of age. Girls had a marginally higher BMI, although that for both boys and girls was approximately 1 SD below the international Centers for Disease Control and Prevention and World Health Organization norms. When controlling for the effect of age, nonverbal intelligence showed small but significant positive relationships with HC ($r = 0.17$) and BMI ($r = 0.11$). HC and BMI accounted for 1.9% of the variance in nonverbal intelligence, over and above the contribution of grade and sex.

Conclusion BMI-for-age growth curves of Zambian children follow observed worldwide developmental trajectories. The positive relationships between BMI and intelligence underscore the importance of providing adequate nutritional and physical growth opportunities for children worldwide and in sub-Saharan Africa in particular. Directions for future studies are discussed with regard to maximizing the cognitive potential of all rural African children. (J Pediatr 2014;165:1017-23).

Physical health indicators, such as height, weight, body mass index (BMI), and head circumference (HC), have been linked to intellectual development.1-5 Correlations of height and intelligence have been found across broad age ranges, with mean intellectual performance increasing with height6 and smaller children scoring lower on academic achievement tests compared with their taller counterparts.7 Higher BMI has been linked to lower performance IQ8 and lower nonverbal reasoning.6 In contrast, in 5-year-old boys, BMI has been positively correlated with fluid intelligence, but negatively correlated with crystallized intelligence.9 HC is one of the most important anthropometric indicators (ie, nutrition and brain volume index) associated with intellectual performance,2,4,10 notwithstanding the associations of developmental disorders and microcephaly and macrocephaly.11

Most of the published research on developmental indices is from high-income countries. Comparatively less is known about these indicators in low-income countries. Reports from both suggest that inadequate physical growth represents a constant source of childhood underachievement. Worldwide, the largest percentage of young children living in poverty, a factor tied to underachievement and undergrowth, is in sub-Saharan Africa (54.3% of children aged <5 years).12 A recent report described BMI trends in more than 9 million people in nearly 200 countries.13 Contrary to the overall global trends toward increasing BMI and rates of obesity, in parts of Africa the trends are toward low and decreasing BMI, suggesting that many people are underweight. As in much of the relevant literature, African countries were underrepresented in this research.13 In particular, Zambia was not included. Few studies of child nutrition have been completed in Zambia. Available data indicate worse nutritional status in children compared with adults,14 as well as more underweight children in underprivileged communities.15 Here we describe the connections between health and cognition in a large cross-sectional rural sample of students. The results provide a descriptive statement that emphasizes indicators of general health and explores their relationships with nonverbal intelligence.

Methods

A total of 4609 children were approached for participation in the Bala Bbala Project (bala bbala means “read the word” in Chitonga), a large-scale Institutional Review Board–approved (UNZA BREC #003-08-09) study of the manifestation, prevalence, and etiology of specific reading disabilities in rural Zambia.16 After screening and enrollment, the following children were excluded from this analysis: those with missing data for BMI, intelligence, or HC; those age >19 years (ie, the upper age limit of

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>BMI</td>
<td>Body mass index</td>
</tr>
<tr>
<td>HC</td>
<td>Head circumference</td>
</tr>
<tr>
<td>UNIT-SM</td>
<td>Universal Nonverbal Intelligence Test, Symbolic Memory subtest</td>
</tr>
</tbody>
</table>

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the Centers for Disease Control and Prevention and World Health Organization BMI norms); and those with vision poorer than 20/30 in both eyes or hearing loss of >40 dB for at least 1 of the assessed frequencies (ie, 1000, 2000, and 4000 Hz) in both ears. A total of 628 children were excluded based on these criteria (Figure 1; available at www.jpeds.com). Table I (available at www.jpeds.com) present characteristics for the initial, excluded, and final samples. The final sample comprised 3981 students (50.8% male), grades 3-7, from 34 schools, with a mean age of 12.75 ± 2.03 years. The wide age range (7.40-18.78 years; mode, 14; median, 12.71) is typical in rural Zambia, where students often miss years of schooling because of financial difficulties or household responsibilities, or repeat grades because of absenteeism. The Universal Nonverbal Intelligence Test, Symbolic Memory subtest (UNIT-SM) and Kaufman Assessment Battery for Children, Second Edition, Triangles subtest (KABC-II-T) were administered to assess nonverbal intelligence (ie, memory and simultaneous visual processing, respectively). These tests were chosen because they use manipulative materials thought to be as engaging as possible for children not familiar with Western testing modes. The UNIT-SM uses nonverbal instructions and comprises 30 items (Cronbach α = 0.82) that require students to reproduce an array of 1-6 images of people from memory. The KABC-II-T comprises 27 items (Cronbach α = 0.86) that require students to use physical foam and plastic shapes, mainly triangles, to reproduce images. Summed scores were computed and submitted to a principal components analysis (oblimin rotation) to extract factor scores from a 1-component solution (65.48% of variance explained) for further analyses. A stadiometer, scale, and measuring tape were used to measure height, weight, and HC of barefoot uniformed children. BMI was calculated as weight in kilograms divided by height in meters squared. Once written informed consent was obtained from each subject’s parent or guardian, trained research assistants individually administered the assessments and were monitored during data collection. The data collectors were not informed of the study hypotheses, group status (ie, at risk/not at risk for specific reading disabilities), or results. Assessments were performed in the local language, Chitonga.

Results

Zambian age expectations are based on school entry age (7 years for first grade). In this sample, the exact norm (eg, 9 or 10 years in grade 3) was achieved by approximately 50% of students in each grade (grade 3, 63.3%; grade 4, 52.5%; grade 5, 50.4%; grade 6, 51.1%; grade 7, 44.8%). The mean age for each grade was 10.49 years for grade 3, 11.76 years for grade 4, 12.86 years for grade 5, 13.95 years for grade 6, and 15.02 years for grade 7. The age–grade correlation was relatively high (Spearman rank-order correlation coefficient, ρ = 0.79; P < .001).

Table I presents descriptive statistics for the main study variables. Boys had larger HC (Mboys = 52.87, SD = 1.82; Mgirls = 52.62, SD = 1.98; t[3979] = 4.13; P < .001), whereas girls had higher weight (Mboys = 33.81, SD = 7.83; Mgirls = 34.53, SD = 8.69; t[3979] = −2.73; P < .01) and marginally higher BMI (Mboys = 16.09, SD = 2.07; Mgirls = 16.28, SD = 2.51; t[3979] = −2.51; P < .05). There was no significant height difference by sex. To show the BMI value distribution, we used R to fit a generalized additive model for location scale and shape to the data, with age as an explanatory variable and assuming a Box-Cox distribution (Figure 2). As expected, these curves follow worldwide developmental trajectories, at least in the range of −2 to +2 SD below and above the mean. However, both boys and girls had comparatively lower BMI; for instance, in girls, BMI up to age 16 years is approximately 1 SD below global norms.

Correlates of General Health Indicators

Pearson product-moment correlations (Pearson r) were conducted. Partial correlations were computed to control for the effect of age. The 4 health indicators studied were significantly related to age (r = 0.29 for HC, 0.42 for BMI, and 0.69 for both height and weight) and grade (r = 0.25 for HC, 0.23 for BMI, 0.29 for height, and 0.32 for weight). Although the magnitude of association decreased when controlling for age, grade remained positively related to BMI (r = 0.12), indicating that greater level of schooling is related to higher BMI beyond biological maturation. Moreover, girls showed marginally higher BMI, attributable to higher weight. Given these BMI correlates, a multivariate model was specified to examine differential effects of grade by sex. Sex, grade, and the interaction between them were independent variables in ANCOVA, with age as a covariate. This model explained a significant proportion of variance in HC (adjusted $R^2 = 0.11$), height (adjusted $R^2 = 0.53$), weight (adjusted $R^2 = 0.53$), and BMI (adjusted $R^2 = 0.21$). Similar to the correlational analysis, the results showed significant main effects of grade on the 4 health indicators. However, significant interactions between sex and grade indicate that HC ($F_{\text{Interaction}} = 9.40; P < .001$; partial $\eta^2 = 0.009$), weight ($F_{\text{Interaction}} = 8.94; P < .001$; partial $\eta^2 = 0.009$), and BMI ($F_{\text{Interaction}} = 15.68; P < .001$; partial $\eta^2 = 0.016$) increased differentially by sex across grades. Figure 3 displays age-adjusted means for health indicators as a function of grade and sex. Post hoc tests (P value adjustment using the Holm method) of differences in interaction means showed that girls in grades 3 and 4 had smaller HC than boys ($F = 25.97$, for grade 3, and $F = 21.38$, for grade 4; $P < .001$); however, the difference narrows after grade 5. Girls weighed significantly ($P < .001$) more than boys in grades 5 ($F = 17.33$), 6 ($F = 35.71$), and 7 ($F = 39.50$); however, weight did not differ between boys and girls in grades 3 and 4. The strongest effect size was found for BMI, with approximately 1.6% of the variance accounted for by the sex–grade interaction. The pattern of

Table I

<table>
<thead>
<tr>
<th>Grade</th>
<th>HC (cm)</th>
<th>Weight (kg)</th>
<th>BMI</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>52.5</td>
<td>17.0</td>
<td>12.0</td>
<td>&lt;.05</td>
</tr>
<tr>
<td>4</td>
<td>53.0</td>
<td>18.0</td>
<td>12.5</td>
<td>&lt;.01</td>
</tr>
<tr>
<td>5</td>
<td>54.0</td>
<td>19.0</td>
<td>13.0</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>6</td>
<td>55.0</td>
<td>20.0</td>
<td>13.5</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>7</td>
<td>56.0</td>
<td>21.0</td>
<td>14.0</td>
<td>&lt;.001</td>
</tr>
</tbody>
</table>
age-adjusted means showed higher BMI in boys than girls in grade 3, but no difference in grades 4 and 5 (Table II). The driving factor is the reverse pattern of BMI difference in grades 6 and 7. BMI increased for boys after grade 5, but the increase was more pronounced for girls. There were moderate BMI differences in grade 6 and larger differences in grade 7.

Predictors of Nonverbal Intelligence

Boys had slightly higher nonverbal intelligence scores compared with girls ($M_{\text{boys}} = 0.04, SD = 1.03$; $M_{\text{girls}} = -0.04, SD = 0.97; t(3979) = 2.52; P < .05$). For comparison, scaled scores (possible range, 1-19) were derived from published US norms for the UNIT-SM and KABC-II-T. For the UNIT-SM, scaled scores ranged from 1 to 15 ($M = 3.07, SD = 2.44$; median = 2), with a mode of 1 (42% of the sample). For the KABC-II-T, scaled scores were 1-12 ($M = 1.63, SD = 1.38$; median = 1), with a mode of 1 (72.3% of the sample). Both results indicate low average performance compared with US norms.

Nonverbal intelligence showed small but consistent positive relationships with the 4 health indicators after controlling for age. HC showed the highest correlation with nonverbal intelligence ($r = 0.17$); grade was positively related to nonverbal intelligence ($r = 0.28$), as was BMI ($r = 0.11$). ANCOVA (with age as a covariate) was used to examine whether the test score increase over grades was consistent across sex. A significant interaction indicated that the difference between boys and girls was not consistent across grades ($F_{\text{interaction}} = 2.83; P = .02$; partial $\eta^2 = 0.003$). Figure 3 displays the age-adjusted means for nonverbal intelligence as a function of grade and sex. Post hoc analyses (Table II) revealed that boys scored higher than girls only in grade 6.
Given the considerable correlations between nonverbal intelligence and HC and BMI, we examined whether these correlations explain a significant proportion of the nonverbal intelligence variance beyond sex and grade. We performed hierarchical linear regression with the nonverbal intelligence factor score as the dependent variable. Grade and sex were entered in block 1, and HC and BMI were entered in block 2. Age was not used as a covariate, to avoid multicollinearity and because ANCOVA showed no main age effect ($F = 0.10$) with grade as an independent variable in the same model. Grade and sex explained 18.2% of the variance ($F[2] = 443.08; P < .001$). HC and BMI explained an additional 1.9% of nonverbal intelligence variance, beyond grade and sex ($F[4] = 250.74, P < .001$; adjusted $R^2 = .201$; $\Delta R^2 = .019$; $F$ for $\Delta R^2 = 47.95, P < .001$). HC was a stronger predictor ($B = .07; SE B = 0.01; \beta = 0.13; P < .001; 95\% CI = 0.51, 0.82$) than BMI ($B = 0.02, SE B = 0.01; \beta = 0.05; P = .002; 95\% CI = 0.08, 0.35$), which indicates that with

**Figure 3.** Age-adjusted means of HC, BMI, height, weight, and nonverbal intelligence as a function of grade and sex. Estimates were derived from ANCOVA using sex, grade, and the interaction term between sex and grade as independent variables and age as a covariate.
grade and sex constant, for each unit HC and BMI increase, nonverbal intelligence increased by 0.07 unit and 0.02 unit, respectively.

The importance of adequate physical health is underscored by the finding that students with BMI 1-2 SD below average (derived from the standardized centiles; Figure 2) differed significantly in nonverbal intelligence from those with BMI at/above average (t[2138] = 3.17; P = .002; Cohen \( d = 0.37 \)). This difference is even more pronounced when BMI is 2-3 SD below average compared with at/above average (t[2138] = 3.17; P = .002; Cohen \( d = 0.37 \)).

### Discussion

In this study, we investigated the relationships between physical growth indicators and nonverbal intelligence in Zambia, a lower- to middle-income country, one of the 50 least developed globally, where most people live in poverty. Rural Zambian home life centers on agriculture. Maize and other cereals account for the majority of food consumption, with fruits and vegetables, but rarely meat, added as available. Schools, at least those in the study area, do not have cafeterias and cannot provide nutritious food. Such factors as underprivileged environments and inadequate diets have been linked to the high prevalence of underweight children in Zambia. Our present findings complement the limited data available from Zambia.

The developmental BMI-for-age trajectories in our participants followed the anticipated patterns; however, the Zambian context accounted for some unexpected differences. BMI was lowest for boys in grade 4 and then increased in grades 5-7. In the upper grades, BMI was higher for girls compared with boys. These unexpected results have cultural explanations. First, starting at around age 10-14 (the age range closest to grade 4), students have more household responsibilities that require more physical activity (eg, on family farms). Parents capitalize on their children’s emerging physical and cognitive capacities and assign more chores, requiring more time away from studies. It is believed that in some families, there is reason to keep more physically able (ie, stronger, heavier) boys at home and to send less physically able (ie, smaller, leaner) boys to school. The decrease in grade 4 could be due to heavier boys leaving school between grade 3 and grade 4. Second, at around age 10-15, girls are expected to have higher BMI owing to the onset of puberty.

The magnitude of associations between physical and cognitive indicators resembles the coefficients observed in high-income countries. Specifically, the age-adjusted relationships between HC and intelligence \((r \approx 0.17)\) and between height and weight and intelligence \((r \approx 0.13)\) are comparable with previously reported correlations. Unlike other studies that used normed BMI-for-age z-scores, we derived norms specific for this study. Although this approach is appropriate for exploring associations between physical growth and nonverbal intelligence, it precludes a direct comparison with other studies that use international references. An increasing number of reports have attempted to calculate national IQs and examine their correlates. On a country level, IQ has been found to be highly associated with educational achievement and real gross domestic product. Scores in countries of sub-Saharan Africa have been found to be approximately 2 SDs lower than those of other countries, mostly in fluid intelligence. In high-income countries, substantial gains in national IQ over time have been observed, known as the Flynn effect, attributed to improved nutrition. Similarly, the Raven matrices test performance gains in rural Kenyan children have been attributed to improved nutrition and health. In light of these findings, the associations between physical growth and nonverbal intelligence found here underscore the importance of adequate nutrition, which contributes to physical growth globally.

Two factors limit the explanatory power of our results. We assessed nonverbal indicators of intelligence; however, other (ie, verbal) measures of acquired cultural knowledge (crystallized intelligence) might relate differently to grade (schooling) and physical growth, especially in the context of low BMI with different patterns for boys and girls across grades. Furthermore, only children attending school were assessed. Given that children in sub-Saharan African often lack school opportunities, and given that schooling has new demands for subsistence-farming families, whether the associations reported here generalize to children not in school remains to be examined.
Nonetheless, albeit with some limitations, this study makes what we believe to be an essential contribution to understanding both the presence and the magnitude of the associations between the physical-growth (BMI and HC) and cognitive (nonverbal intelligence) characteristics in lower-to middle-income countries. Although the accentuation of global initiatives has been systematically shifting toward improved access to and quality of education in low- and lower-middle-income countries, continued support of international antihunger initiatives as a foundation for compulsory and improved schooling remains critically important.

This research provides data on an understudied population, sub-Saharan children, about whom little is known and for whom there is no clear understanding of developmental trajectories. Given the large size of the rural sub-Saharan population (62.7% of the total population of sub-Saharan Africa in 2010) and the projected high population growth, urbanization, and youth surge formation in the near future, understanding the commonalities and specifics of their development compared with world peers is important. Beyond their underrepresentation in the world developmental literature, it is important to predict these children’s contribution to the global labor market and economy within the world’s changing demography.11,41

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References

Table I. Characteristics of the initial sample, excluded participants, and the final sample

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Initial (n = 4609)</th>
<th>Excluded (n = 628)</th>
<th>Final (n = 3981)</th>
<th>Difference</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>2341 (50.8)</td>
<td>318 (50.6)</td>
<td>2023 (50.8)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>2268 (49.2)</td>
<td>310 (49.4)</td>
<td>1958 (49.2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grade</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>943 (20.5)</td>
<td>150 (23.9)</td>
<td>793 (19.9)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>991 (21.5)</td>
<td>114 (18.2)</td>
<td>877 (22.0)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>931 (20.2)</td>
<td>143 (22.8)</td>
<td>788 (19.8)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>927 (20.1)</td>
<td>116 (18.5)</td>
<td>811 (20.4)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>817 (17.7)</td>
<td>105 (16.7)</td>
<td>712 (17.9)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>12.75 (2.07)</td>
<td>12.72 (2.35)</td>
<td>12.75 (2.03)</td>
<td>0.03 (764.71)</td>
<td>0.986</td>
</tr>
<tr>
<td>Height</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>144.39 (11.06)</td>
<td>144.38 (12.10)</td>
<td>144.39 (11.00)</td>
<td>0.03(266.97)</td>
<td>0.998</td>
</tr>
<tr>
<td>Weight</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>34.23 (8.33)</td>
<td>35.26 (9.13)</td>
<td>34.17 (8.27)</td>
<td>0.07(4243)</td>
<td>0.038</td>
</tr>
<tr>
<td>BMI</td>
<td>16.22 (2.33)</td>
<td>16.77 (2.71)</td>
<td>16.18 (2.30)</td>
<td>0.025 (260.23)</td>
<td>0.999</td>
</tr>
</tbody>
</table>

Percentages reflect within-group proportions. Descriptive statistics for nonverbal intelligence are not shown, because all children with missing data were excluded, resulting in the final sample of 3981 children for whom standardized scores (ie, M = 0, SD = 1) were derived. The Difference column reports values from independent-samples t-tests for continuous variables and \( \chi^2 \) tests for dichotomous variables to examine differences between the excluded participants and the final sample. P is the P-value for \( \chi^2 \) and t-test statistics (Bonferroni-adjusted \( \alpha \), 0.05/5 = 0.01). Although BMI was higher in the excluded sample compared with the final sample, this difference indicates a small effect (Cohen \( \delta = 0.23 \)); more importantly, BMI was comparable in the initial and final samples (Cohen \( \delta = 0.02 \)).