

## Relationship between physical growth and motor development in the WHO Child Growth Standards

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### Abstract

**Aim:** To examine relationships among physical growth indicators and ages of achievement of six gross motor milestones in the WHO Child Growth Standards population. **Methods:** Gross motor development assessments were performed longitudinally on the 816 children included in the WHO Child Growth Standards. Six milestones (sitting without support, hands-and-knees crawling, standing with assistance, walking with assistance, standing alone, walking alone) were assessed monthly from 4 until 12 mo of age and bimonthly thereafter until children could walk alone or reached 24 mo. Failure time models were used 1) to examine associations between specified ages of motor milestone achievement and attained growth z scores and 2) to quantify these relationships as delays or accelerations in ages of milestone achievement. **Results:** Statistically significant associations were noted between ages of achievement of sitting without support and attained weight-for-age, weight-for-length and BMI-for-age z scores. An increase of one unit z score in these indicators was associated with 3 to 6 d acceleration in the respective achievement age. Statistically significant associations also were noted between various milestone achievement ages and growth when 3- or 6-mo and birth length-for-age z scores were entered jointly in the failure time models. In these analyses, one unit z-score increase in length-for-age was associated with 1 to 3 d delay in the respective achievement age.

**Conclusion:** Sporadic, significant associations were observed between gross motor development and some physical growth indicators, but these were quantitatively of limited practical significance. These results suggest that, in healthy populations, the attainment of these six gross motor milestones is largely independent of variations in physical growth.

**Key Words:** *Childhood growth, gross motor milestones, growth standards, young child development*

### Introduction

The WHO Child Growth Standards include descriptions of the physical growth and ages of achievement of universally recognized gross motor milestones in healthy infants and children throughout the world. The sample used to construct the growth standards consists of a sub-sample of children included in the WHO Multicentre Growth Reference Study (MGRS). The MGRS adopted a “prescriptive” approach designed to describe how children *should* grow rather than *how* children grew at a particular time and place. In so doing, it broadened the definition of health to include the adoption of several practices associated with healthy outcomes, e.g. breastfeeding and non-smoking. The rationale for the MGRS and its design and protocol are described in detail elsewhere [1,2].

The second unique feature of the MGRS was its inclusion of children from six of the world’s major regions, i.e. Brazil (South America), Ghana (Africa), India (Asia), Norway (Europe), Oman (the Middle East) and the USA (North America). This design feature tested the assumption that growth in infancy and early childhood is very similar among diverse ethnic groups when conditions that do not constrain growth are met [3,4]. The MGRS also offered the possibility to assess the heterogeneity/similarity in gross motor development across distinct cultural groups and environments. It demonstrated that, although some differences were observed in the ages of gross motor milestone achievement among study sites, they were not consistent and likely reflected diverse culture-specific care practices rather than inherent biological differences [5].

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The longitudinal and simultaneous assessments of physical growth and gross motor development also provided an opportunity to examine associations between physical growth and gross motor development in healthy children. Studies are published demonstrating the effects of diverse diseases and conditions on motor development [6–9], links between motor delays and various forms of general and specific under-nutrition [10–16], positive links between motor development and exclusive breastfeeding [17], and improved linear growth in undernourished children who undergo nutritional rehabilitation coupled with a physical activity regimen rather than only nutritional rehabilitation [18,19]. Published assessments of associations between physical growth and motor milestone achievement among well-nourished, healthy children are fewer (e.g. [17]), and to our knowledge none has a sample as large or as diverse as that of the WHO Child Growth Standards.

The objective of this paper is to examine relationships among attained weight-for-age, length-for-age, body mass index (BMI)-for-age, and weight-for-length z scores and ages of achievement of specified gross motor milestones in the growth standards' sample of healthy breastfed infants and young children who enjoyed living conditions that did not constrain linear growth.

## Methods

### *Study design*

The rationale, planning, design and methods of the MGRS, including its motor development component and site-specific protocol implementation, are described in detail elsewhere [1,2,20]. Briefly, in five of the six MGRS sites, i.e. Ghana, India, Norway, Oman and the USA, gross motor development assessments were performed longitudinally beginning at 4 mo of age on subjects enrolled in the MGRS longitudinal component. Motor development assessments were not performed in Brazil because most of this site's longitudinal sample was older than 4 mo when motor development was added to the MGRS protocol. Six distinct gross motor milestones were assessed: sitting without support, hands-and-knees crawling, standing with assistance, walking with assistance, standing alone and walking alone. These were selected because they are considered universal, fundamental to the acquisition of self-sufficient locomotion, and simple to test and evaluate. All milestones were assessed using standardized testing procedures and criteria [20], and were performed by study staff monthly from 4 until 12 mo of age and bimonthly thereafter until children could walk alone or reached 24 mo of age. Training and standardization

procedures were similar among sites. The criteria used to document the attainment of the six milestones were applied with equally high levels of reliability among observers within a site, among milestones within a site, and among sites across milestones [21]. No fixed milestone sequence was assumed, and all milestones were assessed at each visit.

### *Study sample*

The sample used for these analyses consisted of 816 children included in the generation of the physical growth standards [22]. By study site, the sample included 227 children from Ghana, 173 from India, 148 from Norway, 149 from Oman and 119 from the USA.

### *Statistical analyses*

*Ages of gross motor milestone achievement.* The MGRS design [2] did not permit the determination of exact ages of milestone achievement because subjects were not supervised daily by trained staff. "True" ages of milestone achievement were linked to intervals between the visit documenting the achievement of specific milestones and the most recent previous visit. Specific ages of achievement within designated intervals were assigned randomly based on the assumption that achievement ages were distributed uniformly within the interval [23].

Ages of milestone achievement were modelled using failure time analysis and either log-normal or log-logistic distributions, as appropriate. For the small percentages of children who were not observed by field staff to have achieved specific milestones (walking with assistance 0.6%; standing alone 2.1%; and walking alone 2.7%) by 24 mo, i.e. the visit date that terminated longitudinal follow-up, the ages of milestone achievement were right censored. For these same children, primary caretakers had reported that, by 24 mo, 80% walked with assistance, 94% stood alone and 55% walked alone. However, only the information reported by trained staff was used in estimating ages of achievement [23].

*Estimation of attained weight-for-age, length-for-age, weight-for-length and BMI-for-age at milestone achievement.* Z scores for attained weight-for-age, length-for-age, BMI-for-age and weight-for-length were based on the WHO Child Growth Standards [22]. Z scores corresponding to specific anthropometric measurements at ages of milestone achievement were estimated by linear interpolation of weight or length. Interpolations were bounded by the intervals used to assign ages of milestone achievement as described above. Z scores were calculated for interpolated weight and length values.

*Analyses of links among gross motor milestones and growth.* Failure time models were used to examine associations between assigned ages of achievement of gross motor milestones and attained growth z scores. Z scores for weight, length, BMI and weight-for-length at birth, 3 mo, 6 mo and at the ages of achievement of the gross motor milestones were added individually or jointly to "best-fitting" failure time models [23].

Associations were evaluated between z scores of attained anthropometric measurements at birth and ages of gross motor milestone achievement, and between z scores at birth and 3 mo (for the milestones sitting without support, hands-and-knees crawling and standing with assistance) or 6 mo (for the milestones walking with assistance, standing alone and walking alone) and ages of milestone achievement. These ages were selected arbitrarily to assess relationships among ages of milestone achievement and growth attained both at the age of achievement and at ages proximal to the attainment of the respective milestones.

Achievement ages were considered as failure times. The log-normal distribution provided the best fit for sitting without support and standing with assistance, and the log-logistic distribution the best fit for hands-and-knees crawling, walking with assistance, standing alone and walking alone. Failure time models were also used to quantify the relationships as delays or accelerations in ages (in days) of gross motor milestone achievement. Statistical significance was set at  $\alpha = 0.05$ .

## Results

Table I summarizes the statistical significance of associations between ages of achievement of the six gross motor milestones and weight-for-age, length-for-age, weight-for-length and BMI-for-age z scores at birth and/or at the ages of milestone achievement. Significant associations were observed only for sitting without support and limited to anthropometric indicators that included weight. Thus, associations were noted between ages of achievement of sitting without support and attained weight-for-age, weight-for-length and BMI-for-age z scores. The table also includes estimates of the increments (+) or decrements (–) in average ages of achievement (in days) per one unit z-score increase in the respective anthropometric indicator for which statistically significant associations were detected (see also Figure 1).

Table II summarizes associations between ages of achievement of the six gross motor milestones and weight-for-age, length-for-age, weight-for-length and BMI-for-age z scores at birth and/or at 3 mo for the milestones sitting without support, hands-and-knees crawling and standing with assistance, or birth and/or 6 mo for the milestones walking with assistance, standing alone and walking alone. Statistically significant associations were noted most often for sitting without support; however, unlike associations summarized in Table I, when z scores at birth and 3 or 6 mo were added jointly in the analytical model, statistically significant associations with length-for-age z scores were also noted for all milestones but walking

Table I. Associations between attained growth and ages of motor milestone achievement at birth and ages of milestone achievement.

Z scores based on the WHO Child Growth Standards	Sitting without support	Hands-and-knees crawling	Standing with assistance	Walking with assistance	Standing alone	Walking alone
<b>Weight-for-age</b>						
At birth (a)	×	×	×	×	×	×
At achievement (b)	√	×	×	×	×	×
(a) + (b)	×, √ <sup>a</sup>	×, ×	×, ×	×, ×	×, ×	×, ×
<b>Length-for-age</b>						
At birth (a)	×	×	×	×	×	×
At achievement (b)	×	×	×	×	×	×
(a) + (b)	×, ×	×, ×	×, ×	×, ×	×, ×	×, ×
<b>Weight-for-length</b>						
At birth (a)	×	×	×	×	×	×
At achievement (b)	√	×	×	×	×	×
(a) + (b)	×, √ <sup>b</sup>	×, ×	×, ×	×, ×	×, ×	×, ×
<b>BMI-for-age</b>						
At birth (a)	×	×	×	×	×	×
At achievement (b)	√	×	×	×	×	×
(a) + (b)	×, √ <sup>c</sup>	×, ×	×, ×	×, ×	×, ×	×, ×

√:  $p < 0.05$ ; ×:  $p > 0.05$ .

<sup>a</sup> One z-score increase in weight-for-age *reduces* the expected achievement age of sitting without support by approximately 3 d (2.9 d).

<sup>b</sup> One z-score increase in weight-for-length *reduces* the expected achievement age of sitting without support by approximately 5 d (5.1 d).

<sup>c</sup> One z-score increase in BMI-for-age *reduces* the expected achievement age of sitting without support by approximately 6 d (6.2 d).

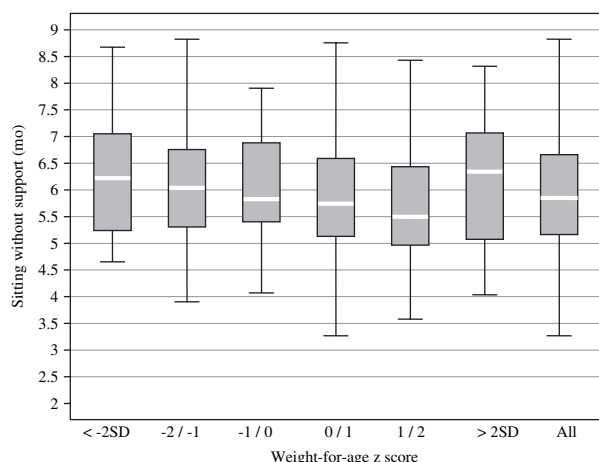


Figure 1. Ages of achievement of sitting without support for children grouped by weight-for-age z scores at achievement.<sup>a</sup>

<sup>a</sup>Horizontal bars within the respective boxes represent median ages of achievement, and the upper and lower boundaries for each box represent the 75th (P75) and 25th (P25) percentiles, respectively. The upper whisker is set at the sum of P75 and 1.5 times the difference between P75 and P25. The lower whisker is set at the difference between P25 and 1.5 times the difference between P75 and P25.

alone. The table also includes estimates of the increments (+) or decrements (–) in the average ages of achievement (in days) per one unit z-score increase in the respective anthropometric indicator for

statistically significant associations, e.g. one unit z-score increase in length-for-age was associated with 1 to 3 d delay in the respective achievement age.

## Discussion

These results indicate that associations between ages of gross motor milestone achievement and attained growth in healthy infants and toddlers are limited primarily to the milestone sitting without support. The exceptions to this generalization are statistically significant associations among length-for-age z scores at birth and at 3 mo of age and ages of achievement of sitting without support, hands-and-knees crawling and standing with assistance; and associations between length-for-age z scores at birth and at 6 mo and ages of achievement of walking with assistance and standing alone when these were entered jointly in failure time models. In each of those cases, however, significant associations were of limited practical significance (e.g. approximately 1 to 3 d delay in achievement ages for those milestones for which length-for-age was found to be related to ages of achievement). The increments/decrements in ages of milestone achievement associated with increments in z scores were small in both absolute terms and relative to the wide variability in the ages of milestone

Table II. Associations between attained growth and ages of motor milestone achievement at birth and 3 mo or 6 mo.

Z scores based on the WHO Child Growth Standards	Sitting without support	Hands-and-knees crawling	Standing with assistance	Walking with assistance	Standing alone	Walking alone
<b>Weight-for-age</b>						
At birth (a)	×	×	×	×	×	×
At age X mo (b) <sup>a</sup>	√	×	×	×	×	×
(a) + (b)	×,√ <sup>b</sup>	×,×	×,×	×,×	×,×	×,×
<b>Length-for-age</b>						
At birth (a)	×	×	×	×	×	×
At age X mo (b)	×	×	×	×	×	×
(a) + (b) <sup>c</sup>	√,×	√,×	√,√	√,√	×,√	×,×
<b>Weight-for-length</b>						
At birth (a)	×	×	×	×	×	×
At age X mo (b)	√	×	×	×	×	×
(a) + (b)	×,√ <sup>d</sup>	×,×	×,×	×,×	×,×	×,×
<b>BMI-for-age</b>						
At birth (a)	×	×	×	×	×	×
At age X mo (b)	√	×	×	×	×	×
(a) + (b)	×,√ <sup>e</sup>	×,×	×,×	×,×	×,×	×,×

√:  $p < 0.05$ ; ×:  $p > 0.05$

<sup>a</sup> Three months for milestones sitting without support, hands-and-knees crawling and standing with assistance; 6 mo for milestones walking with assistance, standing alone and walking alone.

<sup>b</sup> One z-score increase in weight-for-age at age 3 mo *reduces* the expected achievement age of sitting without support by approximately 4 d (3.5 d).

<sup>c</sup> One z-score increase in length-for-age (at birth and/or at age 3 mo) *extends* the expected achievement age of sitting without support, hands-and-knees crawling and standing with assistance by 1.4, 0.9 and 2.6 d, respectively. One z-score increase in length-for-age (at birth and/or at age 6 mo) *extends* the expected age of achievement for walking with assistance and standing alone by 2.1 and 1.5 d, respectively.

<sup>d</sup> One z-score increase in weight-for-length at age 3 mo *reduces* the expected achievement age of sitting without support by approximately 6 d (6.1 d).

<sup>e</sup> One z-score increase in BMI-for-age at age 3 mo *reduces* the expected achievement age of sitting without support by approximately 6 d (6.3 d).

achievement observed in the WHO Child Growth Standards population [23].

Relationships among anthropometric indicators and accelerations in ages of milestone achievement (related to weight-based indicators) or delays (related to length-for-age), even if small, appear to vary qualitatively in healthy populations with respect to specific motor milestones. This may reflect greater weight/length helping to sustain the balance and control necessary for sitting without support, whereas greater stature may not be advantageous with respect to mobility at later ages. Although these relationships are of inherent biological interest, their quantitative impact is likely to be of minimal practical significance in non-research settings.

These findings, coupled with published associations between motor development and states of under-nutrition [10–16] or the presence of specific diseases or conditions [6–9], suggest that observations of links between growth performance and motor development often signal past or ongoing stresses that should be evaluated and addressed. They also indicate that population-level motor development can be a robust functional indicator of various forms of stress during vulnerable developmental periods. Such population delays, however, must be assessed with care to determine possible influences of locally recommended care practices (see below).

The consistent achievement of gross motor milestones at later ages within normal “windows of achievement” likely has limited predictive value of good or bad outcomes in motor and other developmental domains for individuals within healthy populations [24,25]. The exceptions to this are infants in populations with severe deficits [26–28] such as those in special categories, e.g. extremely low-birthweight infants [29].

Equally importantly, there is no conclusive evidence in the literature that significant population-level motor delays are independently predictive of future functional delays or of other adverse outcomes (e.g. poorer cognitive performance or motor agility). For example, motor delays associated with under-nutrition may not be any more or any less predictive of other problems in subsequent development than direct measures of the severity of the co-existing under-nutrition. Motor delays thus may signal only the active impairment of normal development and not necessarily future impaired functional capacities [30]. There is ample evidence that regenerative, redundant and/or degenerative pathways often correct functional delays or may positively influence future attainment of motor capabilities [26,31,32]. Enabling regenerative, redundant and/or degenerative pathways, however, may require actively addressing under-nutrition or other aetiologies responsible for developmental delays.

It is also important to point out that consistent “delays” or “accelerations” in milestone achievement can occur among milestones that are especially susceptible to caretaker training [5]. There is no direct evidence that apparent milestone achievement delays or accelerations enabled by training have any functional significance beyond the specific milestone’s achievement. Nonetheless, the acceleration of motor skill acquisition may hasten the development of other functional domains through a child’s enhanced abilities to interact with the immediate environment [33,34]. Also, the accelerated attainment of certain skills may be of cultural value, e.g. field reports from Ghana in this study suggesting that mothers used several strategies to accelerate the ability of infants to sit without support so as to increase their time to attend to other tasks without having to carry the baby around [5].

In summary, growth and motor development are largely independent in healthy populations. Associations between motor development and attained growth parameters were restricted principally to sitting without support and were quantitatively of limited practical significance. Nonetheless, the universality of gross motor development and its reliable attainment within predictable age ranges among healthy populations have positive implications for using motor development standards to assess gross motor development in children at the population level and perhaps as an educational tool to reinforce the importance of development dimensions other than physical growth.

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