



# Linear Growth between Early and Late Childhood and Cognitive Outcomes at 6-9 Years of Age

Ravi Prakash Upadhyay, MD<sup>1,2</sup>, Mari Hysing, PhD<sup>3</sup>, Sunita Taneja, PhD<sup>1</sup>, Ingrid Kvestad, PhD<sup>4</sup>, Nita Bhandari, PhD<sup>1</sup>, and Tor A. Strand, PhD<sup>2,5</sup>

**Objectives** To assess the extent to which linear growth beyond the early years of life determines later cognitive development.

**Study design** We revisited children from New Delhi, India, who had participated in a randomized controlled trial 6 years before and assessed neurodevelopment using standardized and validated psychometric tools (Wechsler Intelligence Scale for Children, 4th edition; Crichton Vocabulary Scales; and Neuropsychological test battery). The associations of change in height for age z scores between early (12-36 months) and late (6-9 years) childhood with cognitive outcomes at 6-9 years of age were explored using linear regression models, after adjustment for appropriate confounders.

**Results** Out of the 1000 North Indian children who were enrolled in the original study, 791 consented to participate in this follow-up. Height for age z scores in the first 2 years of life was significantly associated with both the Wechsler Intelligence Scale for Children-Crichton Vocabulary Scales (standardized  $\beta$  coefficient [ $\beta$ ], 0.15; 95% CI, 0.08-0.23), and the Neuropsychological test battery-II z-score ( $\beta$ , 0.09; 95% CI, 0.03-0.18) at 6-9 years of age. There were no significant associations between change in height for age z scores between early and later childhood and Wechsler Intelligence Scale for Children-Crichton Vocabulary Scales ( $\beta$ , -0.03; 95% CI, -0.11 to 0.04) or Neuropsychological test battery-II z-scores ( $\beta$ , -0.04; 95% CI, -0.12 to 0.06).

**Conclusions** Linear growth between early and late childhood is not associated with later cognitive outcomes. Our findings support the current practice of investing public health efforts to accelerate linear growth in the first 2-3 years of life. (*J Pediatr* 2020;225:214-21).

Brain development is substantial in the period from late gestation until the first 2-3 years of life.<sup>1,2</sup> Nutritional and other environmental insults during this period places the child at risk of linear growth deficits and subsequent long-lasting adverse effects on cognitive development.<sup>1-3</sup> Stunted growth is linked to delayed neurodevelopment and poor academic performance and improving linear growth in the first 2 years of life is associated with better developmental outcomes.<sup>4-7</sup> A meta-analysis of 68 studies from 29 low- and middle-income countries showed that each unit increase in height-for-age z-score (HAZ) for children  $\leq 2$  years of age was associated with a 0.22-SD increase in cognition at 5-11 years of age.<sup>4</sup> In children  $> 2$  years of age, the effect was less pronounced, and each unit increase in HAZ was associated with an increase of only 0.09-SD for the cognitive score.<sup>4</sup> It is worthwhile to note that, in this meta-analysis, the ability to adjust for important confounders such as socioeconomic status and child stimulation was limited. It is thought that growth failure and related cognitive deficits are difficult to reverse after the initial 2-3 years of age and, therefore, much of the resources are directed toward improving growth during this period.<sup>8,9</sup> It is important to explore if there is still an opportunity beyond this period when investments in improving linear growth can yield better results in terms of cognitive performance.

Recent studies suggest that a substantial recovery from early growth failure can take place.<sup>10-16</sup> However, it is not decisively understood if these improvements in growth are associated with improvements in cognitive capacities. Studies have assessed the effect of recovery from stunting on cognitive achievement in children and the evidence has been mixed.<sup>10,11,13,14,16</sup> These studies adjusted for socioeconomic variables, but did not take into account the child stimulation practices that might have distorted the direct effect of the linear growth improvement on cognitive abilities.<sup>17,18</sup> Current evidence, therefore, does not provide reliable guidance on the magnitude of improvement in developmental outcomes that could be expected as a result of

CVS	Crichton Vocabulary Scales
HAZ	Height-for-age z-scores
NEPSY-II	Neuropsychological test battery, 2nd edition
WISC-IV <sup>INDIA</sup>	Wechsler Intelligence Scale for Children, 4th edition (India)

From the <sup>1</sup>Centre for Health Research and Development, Society for Applied Studies, New Delhi, India; <sup>2</sup>Centre for International Health; <sup>3</sup>Department of Psychosocial Science, Faculty of Psychology, University of Bergen; <sup>4</sup>Regional Centre for Child and Youth Mental Health and Child Welfare, West, NORCE Norwegian Research Centre, Bergen; and <sup>5</sup>Department of Research, Inlandet Hospital Trust, Lillehammer, Norway

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accelerated growth after the first 2-3 years of age.<sup>19</sup> We conducted the current analysis to understand whether improvements in linear growth and/or change in stunting status between early and late childhood can lead to improved cognitive outcomes at ages 6-9 years, after adjustment for sociodemographic and child stimulation variables.

## Methods

The current analyses use follow-up data from children who had previously participated in a randomized double-blind placebo-controlled trial on the effect of vitamin B<sub>12</sub> and/or folic acid supplementation on childhood infections and growth in New Delhi, India.<sup>20</sup> The primary trial had a sample size of 1000 children aged 6-30 months at enrolment. Children were recruited at age 6-30 months from low to middle socioeconomic class families living in New Delhi and randomly assigned to receive placebo, vitamin B<sub>12</sub>, folic acid, or vitamin B<sub>12</sub> and folic acid supplements for a period of 6 months.<sup>20</sup> The intervention was a lipid-based nutritional supplement prepared by Nutriset, Ltd (Malaunay, France). Children were supplemented with 1 spoon (5 g) if they were 6-11 months of age and 2 spoons (10 g) if they were ≥12 months of age. Each 10 g of the supplement (dose for children aged ≥12) contained 54.1 kcal total energy, 0.7 g of protein, and 3.3 g of fat. For the groups that were assigned to receive B vitamins, the supplement also contained 1.8 μg of vitamin B<sub>12</sub> or 150 mg of folic acid or both, constituting 2 recommended daily allowances.<sup>20</sup> In the follow-up study, an attempt was made to contact all the children in the primary trial. The study investigators were able to contact 798 children, and 791 consented to participate. The follow-up study aimed to examine the long-term effects of the 6-month supplementation of vitamin B<sub>12</sub> and/or folic acid in early childhood on cognition at age 6-9 years.<sup>21,22</sup> The primary trial (CTRI/2010/091/001090) as well as the follow-up study (CTRI/2016/11/007494) were registered at Clinical Trials Registry-India (CTRI). The follow-up study obtained approval from the ethics committee of Society for Applied Studies (India) and from the Norwegian Regional Committee for Medical and Health Research Ethics (REK WEST).

### Exposure and Outcomes

In the follow-up study, information was collected on socioeconomic status and child stimulation at home. The wealth of the family was determined by a wealth index created through a principal component analysis based on household assets. In the primary trial, trained field supervisors measured weight and length at the time of enrollment (ie, child age range of 6-30 months) and after 6 months of supplementation (ie, at age range of 12-36 months). Height, using a Seca 213 scale and reading to the nearest of 0.1cm; and weight, using Digitron scales to the nearest of 50 g, were also measured in the follow-up study (ie, at age range of 6-9 years) by trained and standardized study team members.

The cognitive assessments were conducted at the study clinic by trained psychologists. Ten percent of all assessments were double scored, attaining a kappa coefficient of agreement of >96%. Age appropriate psychometric assessment tools were used. Wechsler Intelligence Scale for Children 4th edition (India) (WISC-IV<sup>INDIA</sup>) was used to assess general intellectual ability (IQ). This version has Indian norms and is validated for the Indian population.<sup>23</sup> Seven subtests were conducted, and their scores were summed up to 3 index scores: the perceptual reasoning (block design, picture concept, matrix reasoning), processing speed (symbol search, letter-number sequences), and working memory (digit span, coding). Because verbal comprehension tests in the WISC-IV<sup>INDIA</sup> require English language skills, we substituted this component with Crichton Vocabulary Scales (CVS) to assess verbal skills.<sup>24</sup> The CVS has been translated to Hindi and has Indian norms providing a standard total score. We also included seven age-appropriate subtests from the Neuropsychological test battery, 2nd edition (NEPSY-II): inhibition, design fluency, word generation, visuomotor precision, manual motor sequences, affect recognition, and geometric puzzles.<sup>25</sup>

### Statistical Analyses

Mean ± SD or median (IQR) were calculated for continuous variables and proportions for categorical variables. HAZ were calculated based on the World Health Organization Child Growth Standards.<sup>26</sup> Scores on the cognitive tests were calculated based on the available norms. An IQ can be calculated from the four index scores in WISC-IV<sup>INDIA</sup>. Owing to the lack of the verbal comprehension index score, we calculated a combined WISC-IV<sup>INDIA</sup> and CVS z-score based on converted z-scores for the 3 index scores in the WISC-IV<sup>INDIA</sup> (the perceptual reasoning, processing speed, and working memory) and the total CVS score. We also calculated a combined NEPSY-II z-score based on converted z-scores in seven subtests.

For the analyses in the present study, we define “baseline” to denote measurements at the end of the primary trial (ie, at ages 12-36 months). To understand the association between the baseline HAZ score and cognitive scores at follow-up (ie, at ages 6-9 years), we performed a multivariable linear regression. We performed a purposive selection of covariates (socioeconomic, child characteristics and stimulation variables) for adjustment in the models based on the principles suggested by Hosmer and Lemeshow.<sup>27,28</sup> First, a univariate analysis was run with baseline HAZ score as the exposure and cognitive test scores as the outcome (model 1) and the resulting β-coefficient was noted. Thereafter, each of the covariates was added in the model, one by one, and the change in β-coefficient was noted. To improve the chances of retaining meaningful confounders, all covariates that brought ≥15% change in the β-coefficient were included in the multivariable model (model 2).<sup>28</sup> We estimated the interaction between baseline HAZ and age at baseline (categorized as ≤24 months and >24 months of age) for the neurodevelopmental outcomes. We conducted subgroup analyses with

children aged  $\leq 24$  months of age (model 3) and with children aged  $> 24$  months (model 4) to test whether HAZ scores in these subgroup of children are differentially associated with later neurodevelopment.

Stunting was defined as a HAZ of  $< -2$ , based on the standard World Health Organization definition.<sup>26</sup> We created four categories of change in stunting status (ie, persistently stunted—stunted both at baseline and at follow-up, considered the reference), never stunted (not stunted at baseline and follow-up), recovered (stunted at baseline and not stunted at follow-up), and faltered (not stunted at baseline and stunted at follow-up). Distribution of sociodemographics, child characteristics, and stimulation variables were presented across the four categories of change in stunting status. Multivariable linear regression models were developed with change in stunting status as the exposure and cognitive test scores as the outcome. As described elsewhere in this article, we performed purposive selection of covariates for adjustment in the model. A univariate analysis was run with change in stunting status as the exposure and cognitive test scores as the outcome (model 1). All those covariates that brought a  $\geq 15\%$  change in the coefficient were included in the multivariable model (model 2).<sup>28</sup> We also explored the interaction between change in stunting status and baseline HAZ score. In the absence of a significant interaction, a third model was created where adjustment for baseline HAZ scores was also done (model 3). We performed similar analyses for change in HAZ scores (from baseline to follow-up) as the exposure and cognitive test scores as the outcome. We created stunting categories at baseline (ie, stunted and non-stunted among children aged 12-36 months) and ran a stratified analysis to explore the association of change in HAZ with cognitive score within each stratum. We performed generalized additive model analysis to generate perspective plots to visually present the relationship between baseline HAZ score, change in HAZ score and the cognitive z-scores.<sup>29</sup>

## Results

Of the 1000 children enrolled in the primary trial, 791 consented to participate in the follow-up study. Data on HAZ at both time points ie, at baseline and at follow-up were available for 773 children. The mean  $\pm$  SD follow-up period was  $5.95 \pm 0.24$  years and age of children at the time of follow-up assessments was  $7.83 \pm 0.65$  years (Table I). The mean  $\pm$  SDHAZ at baseline and at follow-up was  $-1.79 \pm 1.1$  and  $-1.02 \pm 0.98$ , respectively. Among the study subjects, 397 (51.4%) were males and majority belonged to Hindu families (83.2%). The characteristics of the children have been presented in Table I.

### Baseline HAZ and Cognitive Outcomes

Table II shows the association between baseline HAZ and cognitive outcomes. For the overall sample of children, baseline HAZ was significantly associated with the WISC-

**Table I. Baseline characteristics of the study children (n = 773)**

Variables	Total study population (n = 773)
<b>Sociodemographic characteristics</b>	
Annual family income (in USD)	2200 (1574-3930)
Religion	
Hindu	643 (83.2)
Muslim	111 (14.3)
Others (Jain/Sikh/Christian)	19 (2.5)
Social class*	
Scheduled caste/scheduled tribe	391 (50.6)
Other backward class	148 (19.1)
General class	234 (30.3)
Mother's age (in y)	31.5 $\pm$ 4.8
Mother's duration of schooling (in y)	7 (0-10)
Mother illiterate	206 (26.6)
Mother does not work outside home <sup>†</sup>	624 (82.1)
Father's duration of schooling (in y)	10 (7-12)
Father unemployed <sup>‡</sup>	30 (3.9)
Nuclear family	448 (58.0)
Number of living children in the family	
1	46 (6.0)
2-3	549 (71.0)
$\geq 4$	178 (23.0)
<b>Child characteristics</b>	
Male sex	397 (51.4)
Age at baseline (mo)	22.5 $\pm$ 7.1
Age of child at time of assessment (y)	7.83 $\pm$ 0.65
Follow-up period (y)	5.95 $\pm$ 0.24
HAZ score at baseline	-1.79 $\pm$ 1.1
HAZ score at follow-up	-1.02 $\pm$ 0.98
<b>Stimulation and learning opportunities</b>	
Child attends school	759 (98.2)
No. of hours/day child plays with other children	1 (1-2)
Child reads story books	153 (19.8)
Child pursues his/her hobby	13 (1.7)
Parents read story books to the child	235 (30.4)
Parents tell stories to the child	344 (44.5)
Parents regularly assist and follow-up with child's studies	673 (87.1)
Family has a fairly regular and predictable schedule for child	339 (43.9)

Data are presented as number (%), mean  $\pm$  SD or median (IQR).

\*General-groups that do not qualify for any of the positive discrimination schemes by Government of India. OBC is a term used by the Government of India to classify castes that are socially and educationally disadvantaged. SC/ST are official designations given to groups of historically disadvantaged indigenous people in India.

<sup>†</sup>Data not available for 13 mothers.

<sup>‡</sup>Data not available for 5 fathers.

CVS z-score ( $\beta$  coefficient [ $\beta$ ] 0.08; 95% CI, 0.02-0.14; n = 742), but not the NEPSY-II z-score ( $\beta$ , 0.04; 95% CI, -0.02 to 0.11; n = 741) in the adjusted model. In the subgroup analyses, baseline HAZ was significantly associated with both the WISC-CVS z-score ( $\beta$ , 0.15; 95% CI, 0.08-0.23; n = 447) and the NEPSY-II z-score ( $\beta$ , 0.09; 95% CI, 0.03-0.18; n = 441) among children whose HAZ was measured within 24 months of age. However, this association was not significant among children with baseline HAZ measured after 24 months of age. The interaction between baseline HAZ and age at baseline categories (ie,  $\leq 24$  months and  $> 24$  months of age) did not reach statistical significance for either the WISC-CVS ( $P = .36$ ) or the NEPSY-II z scores ( $P = .77$ ).

**Table II. Linear regression models for cognitive scores and baseline HAZ score**

Models	WISC-CVS z-score $\beta$ coefficient (95% CI)	NEPSY z-score $\beta$ coefficient (95% CI)
Model 1 (unadjusted model)		
Baseline HAZ score	0.27 (0.21 to 0.34); $P < .001$	0.19 (0.13 to 0.26); $P < .001$
Observations	751	750
Model 2 (multivariable model adjusted for covariates)*		
Baseline HAZ score	0.08 (0.02 to 0.14); $P = .006$	0.04 (−0.02 to 0.11)
Observations	742	741
Model 3 (multivariable model adjusted for covariates in subgroup of children with age at baseline $\leq 24$ mo)		
Baseline HAZ score	0.15 (0.08 to 0.23); $P < .001$	0.09 (0.03 to 0.18); $P = .039$
Observations	447	441
Model 4 (multivariable model adjusted for covariates in subgroup of children with age at baseline $> 24$ mo)		
Baseline HAZ score	−0.01 (−0.09 to 0.08)	−0.002 (−0.10 to 0.09)
Observations	295	300

Baseline HAZ denotes measurements at the end of the primary trial (ie, at child ages 12–36 months).

\*Adjusted for wealth quintile, number of living children in the family, mother's years of schooling, father's years of schooling, father's occupation, and intervention groups in the primary trial. The interaction between baseline HAZ and age at baseline categories (ie,  $\leq 24$  months and  $> 24$  months of age) was statistically nonsignificant for both WISC-CVS z scores ( $P = .36$ ) and NEPSY z scores ( $P = .77$ ).  $P$  values are provided against statistically significant effect sizes.

### Change in HAZ between Baseline and Follow-up and Cognitive Outcomes

The HAZ scores at baseline and at the follow-up assessment were strongly correlated ( $r = 0.74$ ) (Figure 1; available at [www.jpeds.com](http://www.jpeds.com)). There was also a moderate correlation between change in HAZ and baseline HAZ ( $r = -0.51$ ) (Figure 1). There was no interaction between change in HAZ and baseline HAZ/baseline stunting status for all the cognitive outcomes. Multivariable linear regression models did not show a significant association between change in HAZ scores and the WISC-CVS ( $\beta$ ,  $-0.03$ ; 95% CI,  $-0.11$  to  $0.04$ ) or the NEPSY-II z-scores ( $\beta$ ,  $-0.04$ ; 95% CI,  $-0.12$  to  $0.06$ ; Table III). Similar findings were observed in the subgroup analyses based on baseline stunting status. The perspective plot depicting the relation between baseline HAZ, change in HAZ and WISC-CVS z-score showed that WISC-CVS z-score increases with an increase in baseline HAZ whereas the change in HAZ did not affect the score (Figure 2). A similar observation was noted with the NEPSY-II z-score (Figure 2).

### Change in Stunting Categories and Cognitive Outcomes

Of the total 773 children included in the analysis, 13.1% were in the persistently stunted ( $n = 101$ ) category, 56.0% were in never stunted ( $n = 433$ ) category, 30.0% were in the recovered ( $n = 224$ ) category, and the remaining around 2% were in the faltered ( $n = 15$ ) category (Table IV; available at [www.jpeds.com](http://www.jpeds.com)). In the univariate linear regression, compared with children who were persistently stunted, those who recovered from stunting showed significantly higher WISC-CVS and NEPSY-II z-scores (Table III). However, in the model with adjustment for covariates, recovery from stunting was not associated with higher WISC-CVS z-score ( $\beta$ ,  $0.15$ ; 95% CI,  $-0.05$  to  $0.34$ ) and NEPSY-II z-score ( $\beta$ ,  $0.17$ ; 95% CI,  $-0.05$  to  $0.39$ ) when compared with children who were persistently stunted. The interaction between change in stunting categories and

baseline HAZ was not significant. Additional adjustment for baseline HAZ in the model yielded similar results ie, recovery from stunting was not associated with higher cognitive scores (Table III).

## Discussion

The current analysis was undertaken to elucidate whether improvement in linear growth beyond the initial 2–3 years of age is associated with higher cognitive outcomes in middle childhood in a follow-up study in North Indian children. We found that approximately two-thirds of the children stunted in early life (68.9%) recovered by late childhood, and linear growth in the first 2 years was associated with cognitive outcomes at 6–9 years of age, even after adjusting for potential confounders. We also observed that increments in HAZ score from early childhood to the late childhood were not associated with higher cognitive scores, thereby suggesting that improvements in linear growth beyond early childhood has limited effects for the cognitive performance in later childhood.

Our findings are in concordance with the recent meta-analysis that documented a positive association between linear growth in the first 2 years of life and cognitive development among children in low- and middle-income countries.<sup>4</sup> However, our findings contrast with studies that recovery from early stunting is associated with improved cognitive outcomes.<sup>10,13,30</sup> Similar to our analyses, these studies adjusted for socioeconomic indicators. However, unlike our analyses, they did not adjust for baseline HAZ, which might confound the observed effect of growth on cognitive development in late childhood. We have shown in our analyses that there is a moderate correlation between baseline HAZ and change in HAZ between early and later childhood. Therefore, baseline HAZ may be adjusted for in these models. In contrast, there is available literature suggesting the potential of bias when adjusting for baseline in analysis of change and further indicating that baseline adjustment substantially

**Table III. Linear regression models for cognitive scores with exposures as change in height for age z scores and change in stunting status between baseline (age 12-36 months) and follow-up (age 6-9 years)**

Models	WISC-CVS z-score $\beta$ coefficient (95% CI)	NEPSY z-score $\beta$ coefficient (95% CI)
Change in height for age z scores between baseline and follow-up		
Model 1 (Unadjusted model)		
Change in HAZ scores	-0.09 (-0.18 to 0.003)	-0.07 (-0.16 to 0.03)
Observations	751	750
Model 2 (multivariable model adjusted for covariates)*		
Change in HAZ scores	-0.03 (-0.11 to 0.04)	-0.04 (-0.12 to 0.06)
Observations	742	741
Model 3 (multivariable model adjusted for covariates and additionally for baseline HAZ)		
Change in HAZ scores	0.03 (-0.06 to 0.12)	0.002 (-0.09 to 0.10)
Observations	742	741
Model 4 (multivariable model adjusted for covariates; stratified by baseline stunting status)		
Nonstunted at baseline		
Change in HAZ scores	0.02 (-0.07 to 0.12)	0.07 (-0.04 to 0.18)
Observations	428	432
Stunted at baseline		
Change in HAZ scores	-0.07 (-0.23 to 0.09)	-0.15 (-0.32 to 0.02)
Observations	314	309
Change in stunting status on cognitive scores		
Model 1 (unadjusted model)		
Persistently stunted	Ref	Ref
Never stunted	0.65 (0.44 to 0.87); $P < .001$	0.55 (0.33 to 0.77); $P < .001$
Recovered	0.33 (0.09 to 0.56); $P = .004$	0.31 (0.07 to 0.55); $P = .004$
Faltered	-0.08 (-0.64 to 0.48)	-0.09 (-0.64 to 0.46)
Observations	751	750
Model 2 (multivariable model adjusted for covariates)*		
Persistently stunted	Ref	Ref
Never stunted	0.21 (0.02 to 0.40); $P = .020$	0.22 (0.01 to 0.43); $P = .031$
Recovered	0.15 (-0.05 to 0.34)	0.17 (-0.05 to 0.39)
Faltered	0.08 (-0.39 to 0.56)	0.11 (-0.40 to 0.62)
Observations	742	741
Model 3 (multivariable model adjusted for covariates and additionally for baseline HAZ)		
Persistently stunted	Ref	Ref
Never stunted	0.05 (-0.21 to 0.31)	0.21 (-0.08 to 0.51)
Recovered	0.09 (-0.11 to 0.30)	0.17 (-0.06 to 0.40)
Faltered	-0.08 (-0.58 to 0.43)	0.11 (-0.44 to 0.66)
Observations	742	741

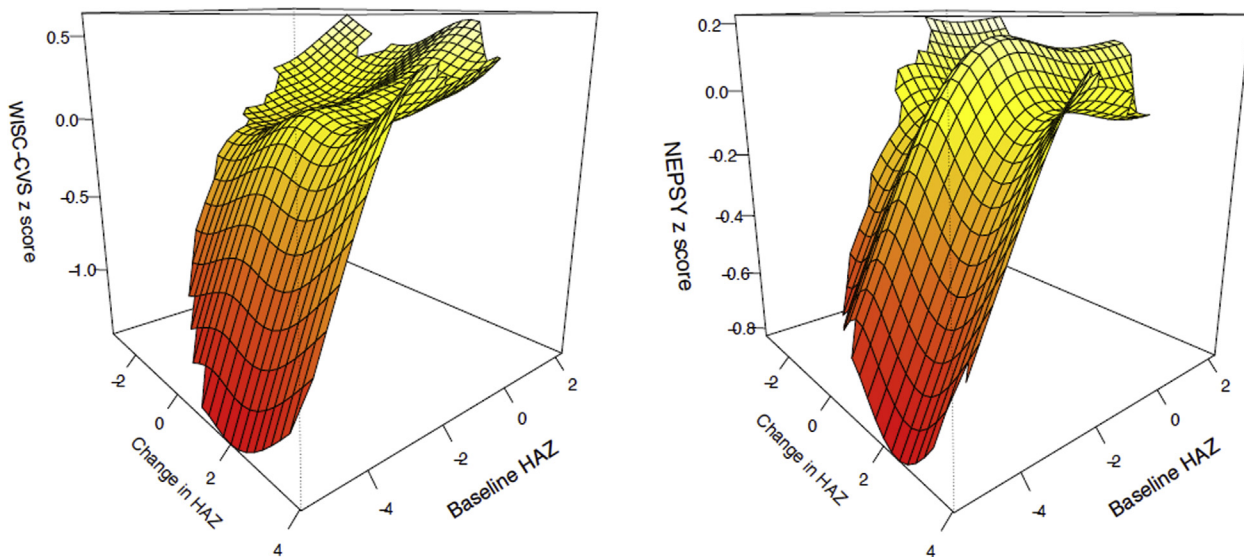
Baseline denotes child age 12-36 months and follow-up denotes child age 6-9 years.

\*Adjusted for wealth quintile, number of living children in the family, mother's years of schooling, father's years of schooling, father's occupation, child schooling, and intervention groups in the primary trial;  $P$  value for interaction between change in HAZ (between baseline and follow-up) and baseline HAZ as well as baseline stunting status for WISC-CVS and NEPSY z-score not significant; Mean (SE) WISC-CVS z-scores were 0.20 (0.04), -0.55 (0.11), -0.13 (0.07), and -0.54 (0.18) for children belonging to the never stunted, persistently stunted, recovered from stunting, and faltered growth groups, respectively. The mean (SE) NEPSY-II z-scores were 0.16 (0.05), -0.46 (0.10), -0.09 (0.06), and -0.48 (0.17) for the 4 groups, respectively; the  $P$  value for interaction between change in stunting categories and baseline HAZ for WISC-CVS and NEPSY z scores not significant.  $P$  values are provided against statistically significant effect sizes.

alters the effect size.<sup>31</sup> Even in studies in which the baseline variable is measured before exposure and could be an important confounder (as in our study), adjustment for this baseline variable may introduce regression-to-the-mean bias.<sup>31</sup> We, therefore, chose to present the analyses with and without adjustment for baseline HAZ scores. In the regression models where we have adjusted for baseline HAZ, the possibility of a biased effect size cannot be ruled out. However, we noted similar findings that increments in HAZ scores from baseline till follow-up as well as recovery from stunting, regardless of whether we adjusted for baseline HAZ or not, were not associated with higher cognitive scores. This finding is visualized in the generalized additive model plots that indicate baseline HAZ, and not the change in HAZ scores, to be related to the outcome scores. Another reason for differences in findings, compared with previous studies, could be that our study measured outcomes related to neuropsychological and general abilities, whereas in other studies measures of school

performance (mathematical ability, reading ability and language) were the main outcomes.

Existing evidence supports that linear growth in the first 2 years of life is associated with concurrent and later childhood cognition.<sup>4,7,32-34</sup> The probable explanation could be that the etiology of poor growth and suboptimal neurodevelopment, such as insufficient nutrition; repeated infections and suboptimal care are similar during this period.<sup>35</sup> Although the literature on the associations between early linear growth and cognition is widespread, the literature on the association between catch-up growth after the first 2-3 years and subsequent cognitive development is scarce and conflicting. It is considered that the likelihood of catch-up growth, after the first 2-3 years of life is limited because children remain in environments that contribute to growth restriction.<sup>35</sup> We have shown through our analyses, however, that catch-up growth or recovery from stunting is possible and that 30% of the children in our study sample



**Figure 2.** Perspective plot showing the relation between baseline HAZ score, change in HAZ score from early to late childhood and WISC-CVS and NEPSY z-scores.

had recovered from stunting after approximately 6 years. This recovery in stunting status, however, did not lead to higher cognitive abilities of the children when they were in early school age.

Based on a published meta-analysis, we argue the possibility that the factors that affect linear growth and/or cognition in later childhood may either not be similar or they exert a differential effect on these 2 distinct yet related outcomes.<sup>36</sup> The meta-analysis showed that, in nutritional supplementation interventions, improvements in linear growth were associated with small improvements in child development, whereas nurturing and stimulation interventions had significant effects on child development but no effects on linear growth.<sup>36</sup> The review concluded that the determinants of linear growth and neurodevelopment are only partly shared and indicates that improved linear growth may not necessarily be associated with improved cognition. We found substantial attenuation in the association between change in stunting status and cognitive outcomes after adjustment for socioeconomic status, particularly the wealth index created through a principal component analysis.<sup>37</sup> However, we did not find any attenuation after adjustment for the child stimulation variables. Previous studies from India and Vietnam found that stimulation and nurturing environment at home attenuated the association between stunting and cognitive outcomes in children aged  $\leq 24$  months, but this effect was not observed in older preschool aged children.<sup>17,18</sup> The children in the current study were older (6-9 years of age), and our result suggest that they had limited sources of stimulation. Owing to limitations of the tool used, we were unable to assess the intensity of the stimulation. These factors might provide some explanation for the observed lack of attenuation effect of stimulation.

The quality of data collected was excellent with closely supervised collection of data on exposures and outcomes by trained and standardized study team members. To depict any nonlinear relationship between change in HAZ, baseline HAZ, and cognitive outcomes, we used a generalized additive model, which adds support to the findings of the study. Despite a long follow-up period ( $>5$  years), we were able to contact and assess approximately 80% of the children enrolled in early childhood. There was approximately a 20% attrition rate. The published article by our group from this follow-up study documented no differences in characteristics between the children who were included in the follow-up and who were not.<sup>22</sup> Therefore, the risk of bias owing to differential loss to follow-up is likely low in our current analysis.

There were some limitations of our analyses. First, growth measurements were available only at few time points, which limited our ability to determine the precise timing of growth improvements beyond the first 2-3 years of age. Second, we used a composite NEPSY-II score rather than scores from the different domains. NEPSY-II is a clinical tool to describe the function of individual domains and is not meant to be a description of global cognitive functioning.<sup>25</sup> As an a priori decision, we used a combined WISC-IV<sup>INDIA</sup> and CVS z-score based on converted z-scores for the 3 index scores in the WISC-IV<sup>INDIA</sup> and the total CVS score. This was done because the WISC-IV<sup>INDIA</sup> verbal comprehension tests required English language skills and CVS was available in Hindi with Indian norms. The ideal scenario would have been to use the WISC-IV<sup>INDIA</sup> without any changes; however, given the limitations, we believe the adopted methodology provided us with a measure closely reflecting the general ability index (ie, IQ). Third, we did not have reliable data on gestational age; therefore, we could not look at the

differential effect of catch-up growth on cognitive outcomes based on premature, small for gestational age, and term-appropriate for gestation age children. Fourth, we had a very small proportion of children in the faltered category ( $n = 15$  [1.9%]) and, accordingly, reliable insights could not be obtained for this subset of children.

Our findings support the current practice of investing public health efforts to accelerate linear growth in the first 2–3 years of life. Additionally, the findings seem to indicate that much of the effects of catch-up growth on cognitive outcomes are possibly through improvements in socioeconomic status, and considerations of a direct linkage of improved growth with cognitive outcomes should be made with caution. ■

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Reprint requests: Sunita Taneja, PhD, Centre for Health Research and Development, Society for Applied Studies, 45 Kalu Sarai, New Delhi-110016, India. E-mail: [sunita.taneja@sas.org.in](mailto:sunita.taneja@sas.org.in)

## Data Statement

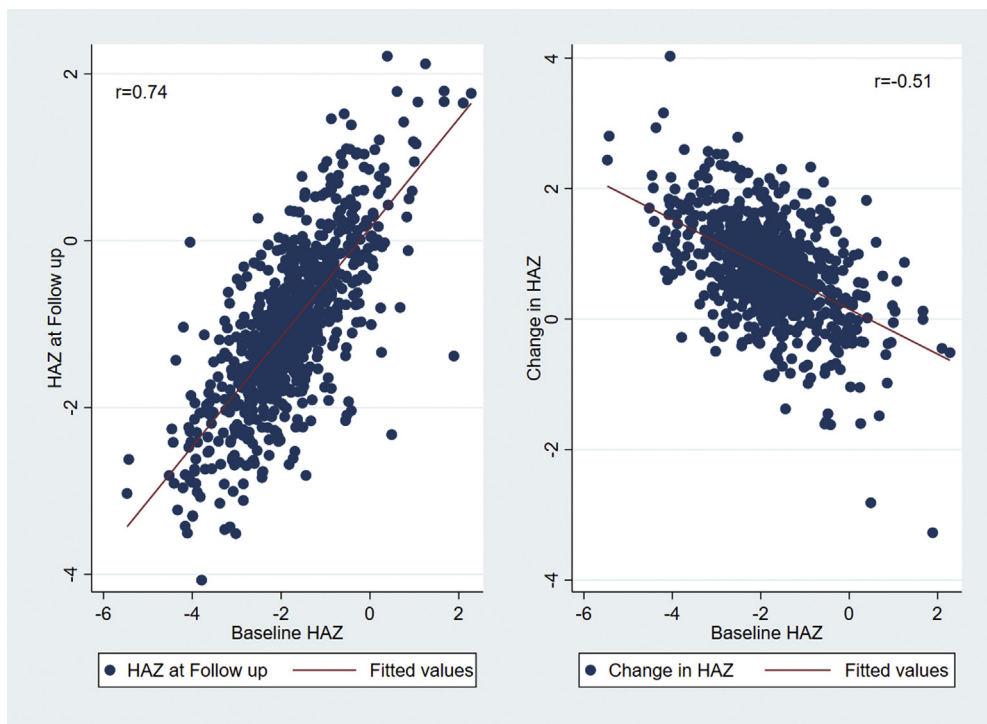
Data sharing statement available at [www.jpeds.com](http://www.jpeds.com).

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**Figure 1.** Scatter plot showing the correlation between baseline HAZ and HAZ at follow-up and change in HAZ between early and middle childhood.

**Table IV. Baseline characteristics of the study children by stunting categories (n = 773)**

Variables	Change in stunting status			
	Never stunted (n = 433)	Persistently stunted (n = 101)	Recovered (n = 224)	Faltered (n = 15)
<b>Sociodemographic characteristics</b>				
Wealth quintile*				
Poorest	56 (12.9)	35 (34.6)	52 (23.2)	5 (33.3)
Very poor	81 (18.7)	25 (24.8)	46 (20.5)	6 (40.0)
Poor	73 (16.9)	24 (23.8)	57 (25.5)	3 (20.0)
Less poor	99 (22.9)	13 (12.9)	45 (20.1)	0 (0.0)
Least poor	124 (28.6)	4 (3.9)	24 (10.7)	1 (6.7)
Religion				
Hindu	362 (83.6)	85 (84.2)	182 (81.3)	14 (93.3)
Muslim	58 (13.4)	15 (14.9)	37 (16.5)	1 (6.7)
Others (Jain/Sikh/Christian)	13 (3.0)	1 (0.9)	5 (2.2)	0 (0.0)
Social class* <sup>†</sup>				
Scheduled caste/scheduled tribe	187 (43.2)	63 (62.4)	129 (57.6)	12 (80.0)
Other backward class	86 (19.9)	17 (16.8)	43 (19.2)	2 (13.3)
General class	160 (36.9)	21 (20.8)	52 (23.2)	1 (6.7)
Mother's age in completed years	31.7 ± 4.7	31.2 ± 4.9	31.4 ± 5.1	30.7 ± 6.0
Mother's years of schooling*				
Median (IQR)	8 (3-12)	5 (0-8)	6 (0-9)	0 (0-5)
Mean ± SD	7.7 ± 5.3	4.7 ± 4.4	5.9 ± 4.4	1.8 ± 3.2
Mother's working status* <sup>‡</sup>				
Works outside home	74 (17.4)	26 (26.3)	31 (14.1)	5 (33.3)
Does not work outside home	352 (82.6)	73 (73.7)	189 (85.9)	10 (66.7)
Father's years of schooling*				
Median (IQR)	10 (8-12)	8 (5-10)	8 (5.5-10)	8 (5-9)
Mean ± SD	9.7 ± 4.1	7.1 ± 3.8	7.8 ± 4.2	6.9 ± 3.6
Father's occupation* <sup>§</sup>				
Government or private job	239 (55.6)	51 (51.0)	125 (55.8)	6 (42.9)
Daily wage earner	42 (9.8)	25 (25.0)	44 (19.6)	6 (42.9)
Self-employed	133 (30.9)	18 (18.0)	47 (21.0)	2 (14.2)
Unemployed	16 (3.7)	6 (6.0)	8 (3.6)	0 (0.0)
Type of family				
Nuclear	252 (58.2)	60 (59.4)	127 (56.7)	9 (60.0)
Joint	181 (41.8)	41 (40.6)	97 (43.3)	6 (40.0)
No. of living children in the family*				
1	34 (7.9)	5 (4.9)	6 (2.7)	1 (6.7)
2-3	321 (74.1)	59 (58.4)	159 (71.0)	10 (66.7)
≥4	78 (18.0)	37 (36.7)	59 (26.3)	4 (26.6)
Family has television at home	424 (97.9)	96 (95.1)	221 (98.7)	14 (93.3)
Family buys newspaper*	84 (19.4)	7 (6.9)	21 (9.4)	1 (6.7)
<b>Child characteristics</b>				
Sex				
Male	213 (49.2)	54 (53.5)	122 (54.5)	8 (53.3)
Female	220 (50.8)	47 (46.5)	102 (45.5)	7 (46.7)
Age at baseline (mo)*	22.4 ± 7.2	23.6 ± 6.9	22.7 ± 6.9	18.2 ± 6.2
Age of child at time of follow-up assessment (mo)*	94.0 ± 8.1	94.9 ± 7.6	93.9 ± 7.2	88.3 ± 6.6
Months of follow-up	71.6 ± 2.9	71.4 ± 3.3	71.3 ± 2.5	70.1 ± 2.3
HAZ score at baseline*	-1.06 ± 0.77	-3.25 ± 0.74	-2.57 ± 0.46	-1.28 ± 0.70
HAZ score at follow-up*	-0.46 ± 0.76	-2.56 ± 0.43	-1.31 ± 0.45	-2.29 ± 0.25
<b>Stimulation and learning opportunities</b>				
Child attends school*				
Yes and at a private school	285 (65.8)	44 (43.6)	129 (57.6)	5 (33.3)
Yes and at a government school	142 (32.8)	52 (51.5)	93 (41.5)	9 (60.0)
Does not attend school	6 (1.4)	5 (4.9)	2 (0.9)	1 (6.7)
No. of hours/day child plays with other children*				
Median (IQR)	1 (1-2)	1 (1-2)	1 (1-2)	2 (1-2)
Mean ± SD	1.28 ± 0.8	1.26 ± 0.8	1.34 ± 0.8	2.01 ± 1.7
Child reads story books	90 (20.8)	18 (18.0)	42 (18.8)	3 (20.0)
Child pursues his/her hobby	8 (1.9)	3 (2.9)	2 (0.9)	0 (0.0)
Parents read story books to the child*				
Yes (daily or on alternate days)	83 (19.2)	7 (7.0)	39 (17.4)	1 (6.7)
Yes (weekly or monthly)	66 (15.2)	10 (10.0)	27 (12.1)	2 (13.3)
Do not read story books	284 (65.6)	83 (83.0)	158 (70.5)	12 (80.0)
Parents tell stories to the child				
Yes (daily or on alternate days)	106 (24.5)	15 (14.8)	50 (22.3)	4 (26.7)

(continued)

Table IV. Continued

Variables	Change in stunting status			
	Never stunted (n = 433)	Persistently stunted (n = 101)	Recovered (n = 224)	Faltered (n = 15)
Yes (weekly or monthly)	102 (23.6)	24 (23.8)	41 (18.3)	2 (13.3)
Do not tell stories	225 (51.9)	62 (61.4)	133 (59.4)	9 (60.0)
Parents regularly assist and follow-up with child's studies*				
Yes (daily or on alternate days)	373 (86.1)	73 (73.0)	180 (80.4)	11 (78.6)
Yes (weekly or monthly)	17 (3.9)	8 (8.0)	11 (4.9)	0 (0.0)
Do not assist	43 (10.0)	19 (19.0)	33 (14.7)	3 (21.4)
Family has a fairly regular and predictable schedule for child*	202 (46.7)	41 (40.6)	94 (42.0)	2 (13.3)

Data are presented as number (%), mean  $\pm$  SD or median (IQR).

\*Difference in proportions/mean between the groups is statistically significant (ie,  $P < .05$ ).

†General is the group that does not qualify for any of the positive discrimination schemes by Government of India. OBC is a term used by the Government of India to classify castes that are socially and educationally disadvantaged. SC/ST are official designations given to groups of historically disadvantaged indigenous people in India.

‡Data are not available for 13 mothers.

§Data are not available for 5 fathers.