Severity and Timing of Stunting in the First Two Years of Life Affect Performance on Cognitive Tests in Late Childhood[1,2]

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ABSTRACT Undernutrition in infancy and early childhood is thought to adversely affect cognitive development, although evidence of lasting effects is not well established. With the use of data from the Cebu Longitudinal Health and Nutrition Study, we assesshere the relationship between stunting in the first 2 y of life and later cognitive development, focusing on the significance of severity, timing and persistence of early stunting. The sample included > 2000 Filipino children administered a cognitive ability test at ages 8 and 11 y. Stunting status was determined on the basis of anthropometric data collected prospectively between birth and age 2 y. Children stunted between birth and age 2 y had significantly lower test scores than nonstunted children, especially when stunting was severe. The shortfall in test scores among children stunted in the first 2 y was strongly related to reduced schooling, which was the result of a substantial delay in initial enrollment as well as higher absenteeism and repetition of school years among stunted children. Interactions between stunting and schooling were not significant, indicating that stunted and nonstunted children benefitted similarly from additional schooling. After multivariate adjustment, severe stunting at age 2 y remained significantly associated with later deficits in cognitive ability. The timing of stunting was also related to test performance, largely because children stunted very early also tended to be severely stunted (χ^2 $P = 0.000$). Deficits in children's scores were smaller at age 11 y than at age 8 y, suggesting that adverse effects may decline over time. Results emphasize the need to prevent early stunting and to provide adequate schooling to disadvantaged children. J. Nutr. 129: 1555–1562, 1999.

KEY WORDS: • *developing countries* • *stunting* • *children* • *cognition* • *schooling*

Undernutrition in infancy and early childhood has adverse effects on children's cognitive and behavioral development, through mechanisms that are still not fully understood (see recent reviews by Grantham-McGregor 1995, Levitsky and Strupp 1995, Wachs 1995). Although many studies have documented a relationship between early malnutrition and concurrent performance on various tests of mental ability, it remains uncertain whether the cognitive effects of early nutritional insults persist into late childhood or adolescence (Grantham-McGregor 1995, Wachs 1995). Lasting effects are likely to be manifested as poor performance in school, and may have long-term implications for well-being. This paper analyzes the relationship between stunting and cognitive development in a cohort of Filipino children, focusing on several dimensions of the relationship in which current knowledge is limited.

The primary goal of this paper is to assess whether *moderate or severe stunting* in the first 2 y is associated with poor performance on cognitive tests in late childhood. Evidence of an adverse relationship is fairly strong, albeit inconsistent, for severe stunting (Grantham-McGregor 1995); a link between more moderate undernutrition and poor cognitive development is even less certain (Wachs 1995). A related objective is to evaluate the importance of the *persistence of early stunting* for cognitive development in late childhood. At present, it is not known whether the cognitive deficits associated with undernutrition are limited to children who remain persistently stunted from infancy into late childhood, or whether deficits are also found among children who later experience catch-up growth (i.e., those who are no longer stunted) (Wachs 1995).

The final dimension of stunting that will be assessed is the influence of *timing*. Little is known about the importance of age of onset of malnutrition for cognitive development (Grantham-McGregor 1995). Intervention research does not suggest that there is a "critical period" in early infancy; interventions initiated as late as 42 mo appear to be effective for improving cognitive outcomes (Pollitt et al. 1995, Pollitt 1996). In the absence of interventions, however, children who first become stunted very early in infancy may be at greater risk of adverse outcomes than those who become stunted later in life.

Because stunting usually takes place in the context of

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[2] The Cebu Longitudinal Health and Nutrition Survey is a collaborative project with the Office of Population Studies of the University of San Carlos. Data collection for the follow-up surveys was supported by grants from The World Bank and The Asian Development Bank.

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TABLE 1

Severity, timing and persistence of stunting in the first 2 years of life (The Cebu Longitudinal Health and Nutrition Study)[1]

	All children			Children stunted at age 2 y			Children not stunted at age 2 y		
	HAZ[2]								
		Age, *y*			Age, *y*			Age, *y*	
Stunting status	*n*	2	8	*n*	2	8	*n*	2	8
Entire sample	2131	−2.41 (1.08)	−2.01 (0.97)	1345	−3.04 (0.77)	−2.42 (0.81)	786	−1.33 (0.54)	−1.31 (0.79)
Stratified by									
1. Severity of stunting, age 2 y									
Moderate (HAZ < −2 to ≥ −3)	760	−2.50 (0.28)	−2.15 (0.72)	760	−2.50 (0.28)	−2.15 (0.72)	—	—	
Severe (HAZ < −3)	585	−3.75 (0.61)	−2.77 (0.79)	585	−3.75 (0.61)	−2.77 (0.79)	—	—	
2. Timing of 1st incidence of stunting									
1–6 mo	336	−3.44 (1.01)	−2.77 (0.88)	315	−3.57 (0.89)	−2.83 (0.84)	21	−1.53 (0.55)	−1.65 (0.64)
7–12 mo	535	−3.02 (0.78)	−2.49 (0.77)	484	−3.16 (0.69)	−2.57 (0.71)	51	−1.74 (0.22)	−1.69 (0.89)
12–18 mo	422	−2.59 (0.65)	−2.07 (0.71)	342	−2.80 (0.51)	−2.15 (0.72)	80	−1.69 (0.30)	−1.72 (0.58)
18–24 mo	251	−2.25 (0.35)	−1.84 (0.65)	204	−2.36 (0.26)	−1.85 (0.65)	47	−1.75 (0.22)	−1.81 (0.64)
Never stunted through age 2 y	587	−1.20 (0.55)	−1.16 (0.78)	—	—	—	587	−1.20 (0.55)	−1.16 (0.78)
3. Persistence of early stunting									
Persistent (stunted 0–2 and 8 y)	1013	−3.10 (0.85)	−2.77 (0.60)	1013	−3.10 (0.85)	−2.77 (0.60)	—	—	
Catchup (stunted 0–2 y only)	531	−2.43 (0.68)	−1.48 (0.48)	531	−2.43 (0.68)	−1.48 (0.48)	—	—	
Late (stunted at 8 y only)	80	−1.57 (0.33)	−2.31 (0.26)	—	—		80	−1.57 (0.33)	−2.31 (0.26)
Never stunted (0–2 and 8 y)	507	−1.14 (0.55)	−0.98 (0.67)	—	—		507	−1.14 (0.55)	−0.98 (0.67)

[1] Values are means (SD).
[2] Abbreviations used: HAZ, height-for-age Z-score.

multiple psychosocial disadvantages, differences in the educational and socioeconomic resources available to stunted and nonstunted children must be taken into account to determine whether there is evidence of an independent association between undernutrition and cognitive development. Schooling is likely to be particularly important because more time in school is strongly associated with higher scores on cognitive tests (Ceci 1991). Stunted children tend to come from poor families and are likely to have lower quantities and poorer quality of schooling than nonstunted children. Accordingly, an additional objective is to estimate the confounding effect of schooling and other aspects of the broader socioeconomic environment on the relationship between stunting and intellectual development.

The issues to be addressed may be summarized in the following questions: *1*) Is moderate or severe stunting in the first 2 y of life associated with performance on cognitive tests in late childhood? *2*) Do the timing and persistence of stunting influence the severity of any effects? *3*) Is there a meaningful association between early stunting and later cognitive ability after controlling for the confounding effects of schooling and other psychosocial factors?

Stunting, a measure of linear growth retardation, is a nonspecific indicator of chronic undernutrition. Consequently, in interpreting this analysis, it is important to keep in mind that stunting may be an indicator of a broad range of insults (individually or in combination), having such diverse origins as prenatal undernutrition, postnatal deficiencies of energy or specific nutrients, infection or illness, and inadequate attention or affection from care givers. Each of these has also been hypothesized as a possible cause of poor cognitive development in children (Brown and Pollitt 1996, Connally and Kvalsvig 1993, Pollitt 1996, Zeitlin 1996). The objective of this paper is to advance understanding of the implications of the severity, timing and persistence of early stunting from multiple causes for later cognitive development, rather than to isolate effects of specific risk factors.

SUBJECTS AND METHODS

The Cebu Longitudinal Health and Nutrition Survey (CLHNS)[4] is a community-based, prospective study of a 1-y birth cohort in the area surrounding the second largest and fastest growing city of The Philippines. Anthropometric and dietary data were collected bimonthly on children during the first 2 y of life. Subsequent follow-up surveys took place in 1991–1992 and 1994–1995 when the children were 8 and 11 y. The sample for this analysis includes >2000 children for whom cognitive test scores and anthropometry at ages 2, 8 and

[4] Abbreviations used: CI, confidence interval; CLHNS, Cebu Longitudinal Health and Nutrition Survey; HAZ, height-for-age Z-score; SES, socioeconomic status.

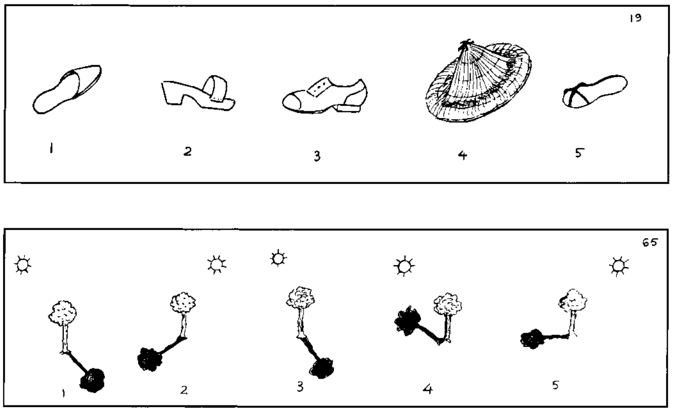

FIGURE 1 Illustrative questions from the Phillippines Non-Verbal Intelligence Test. The test comprises a series of 100 cards which increase in difficulty. Children were asked: *Which one of the 5 items is different?*

11 y are available (**Table 1**). A total of 2131 children had complete data on stunting at age 2 y and test scores at age 8 y; 2048 (96%) of these children also had test scores at age 11 y.

The CLHNS was designed to be representative of births in metropolitan Cebu in 1983–1984, rather than the population of Metro Cebu per se. Consequently, the survey has a slightly higher prevalence of households with low income and fairly low education than we would expect for Metro Cebu as a whole. As a result, the CLHNS may have a high prevalence of health conditions associated with poverty; however, this should not affect the validity of associations between socioeconomic factors or stunting with children's test performance. Additional details on the sampling strategy and survey design have been published previously (Adair et al. 1993, The Cebu Study Team 1991).

Cognitive ability. The Philippines Non-Verbal Intelligence Test, a cognitive test designed to assess fluid ability (i.e., analytic or reasoning skills), was administered at both follow-up rounds (Guthrie et al. 1977). The test comprises a series of 100 cards, each of which contains drawings of five objects. The objects depicted are culturally appropriate for the Philippines and include simple geometric shapes, local farm animals and familiar activities of daily life such as washing clothing. On each card, one object differs from the others in a meaningful way; children are asked to indicate which of the five is different. Time limits were not given for responding to each item. Difficulty increases as children advance through the test. Typical cards from early in the series are shown in **Figure 1**.

Children's cognitive test scores at age 11 y were strongly correlated with scores on English (reading comprehension) and Mathematics achievement tests, which were also administered at age 11 y (Pearson's $r = 0.65$ for Mathematics and 0.61 for English scores). These correlations are very similar to those reported elsewhere for IQ and achievement test scores (Smith et al. 1995), including correlations in a cohort of 11- to 13-y old Filipino girls in which the Otis Lennon Mental Abilities Test was used to measure IQ (Watkins and Astilla 1980).

The psychologists who developed the cognitive test did not develop age-specific norms, recommending instead that the test should be used for within-sample comparative purposes (Guthrie et al. 1977). We generated standardized scores (Z-scores) for the cognitive scores at each age, which allowed us to compare the extent to which the scores of stunted children deviated at each point in time from those of nonstunted children. There was greater variability in the earlier scores, although mean scores were 17 points higher at age 11 y than at age 8 y. A single SD represented 12.5 points on the raw scale score (maximum = 100) at age 8 y, and 11.6 points at age 11 y.

Stunting status. Four measures of stunting status were used to assess the presence or absence of any early stunting, the severity of early stunting, the timing of incidence and the persistence of stunting into late childhood. Previously published work has shown that the prevalence of stunting increases cumulatively with increasing age in the CLHNS, peaking at age 2 y (Adair and Guilkey 1997). The presence of early stunting was defined as a height-for-age Z-score (HAZ) at age 2 y of <-2 based on the World Health Organization reference data. Severe early stunting was defined as HAZ <-3; moderate stunting as HAZ <-2 and ≥ -3. For the analysis of timing of stunting, children were grouped into 6-mo intervals according to the time interval between birth and age 2 y when they first became stunted. In constructing the first interval, stunting status at birth was excluded, because of its low prevalence (5%), and because most children stunted at birth experienced rapid growth spurts, recovering from stunting in the 1st mo of postnatal life. Finally, to assess the importance of persistent stunting, we classified children on the basis of their stunting status in the first 2 y, as well as at age 8 y. Children stunted both at or before age 2 y and at age 8 y (48%) were classified as "persistent"; those stunted at or before age 2 y but not age 8 y (25%) were labeled as the "catch-up" or recovery group; and those stunted at neither age 2 y nor age 8 y (24%) were classified as "neither." A small number of children (4%) stunted for the first time after age 2 y were classified as "late incident."

Schooling. Level of schooling was represented by the highest grade achieved when the cognitive test was taken. Because 32% of children in the sample repeated at least one grade (often as a result of excessive absenteeism or after dropping out temporarily), alternative measures such as total months in school and age at first enrollment were less meaningful as indicators of children's cumulative exposure to formal education.

Data analysis. Mean test scores were calculated for children classified by stunting status; differences in scores were assessed using *t* tests (to compare two groups) or chi-square tests (for three or more groups). Linear regression was used to assess the relationship between early stunting and test performance. The effect of adjusting for schooling and other covariates was estimated by running a series of models as follows: crude, schooling adjusted and multivariate adjusted. The basic model was as follows:

$$\text{Test score} = \beta_0 + \beta_{1i}[\text{stunting status}] + \beta_{2i}[\text{schooling}] + \beta_j C_j$$

where C_j represents a vector of confounding variables, described below. The coefficient for stunting status in these models represented the mean difference in the scores of stunted children relative to nonstunted children, adjusted for other variables in the model. Results are presented as coefficients and 95% confidence intervals (CI). Separate models were run for each cognitive score at ages 8 and 11 y. Dummy variables represent any stunting at age 2 y (model 1), severity of stunting at age 2 (model 2), timing of stunting incidence (model 3) and persistence of stunting from the first 2 y through age 8 y (model 4). In addition to main effects, interactions between stunting status variables and schooling were assessed to determine whether the effect of schooling appeared to differ among stunted vs. nonstunted children. All analysis was conducted with the use of software from Stata (1997).

To account for differences in educational, health and social resources that might confound the relationship between stunting and test performance, we adjusted for several indices of socioeconomic status (SES). These included household income quartile, highest grade completed by mother and father, and type of settlement in which household resides (urban squatter or rural remote, for example). These variables represented SES during infancy and were therefore concurrent with the stunting variables under study. Numerous studies suggest that the early environment is particularly relevant for cognitive development later in childhood (Brooks-Gunn and Duncan 1997). Multivariate models also adjusted for change in household income quartile over time (an indicator of SES mobility), parity (used as an indicator of birth order), number of younger siblings (to control for resource allocation among additional dependents), maternal height (to account for inherited stature), percentage of fat in the diet at age 8 y (an index of dietary quality) and sex of the child. A dummy variable indicating whether the child was in the care of the mother was also included. Interactions between stunting and several covariates were tested to ensure that there were no meaningful differences in the effect of stunting on the performance of children with vs. without key characteristics that would warrant the presentation of stratified rather than summary results.

TABLE 2

Mean difference in the cognitive test Z-scores of stunted vs. nonstunted children in the first 2 years of life (The Cebu Longitudinal Health and Nutrition Study)[1]

	Age 8 y			Age 11 y		
Stunting Status	Unadjusted Coeff. (95% CI)	Adjusted for schooling[2] Coeff. (95% CI)	Multivariate adjusted[3] Coeff. (95% CI)	Unadjusted Coeff. (95% CI)	Adjusted for schooling Coeff. (95% CI)	Multivariate adjusted Coeff. (95% CI)
Stunting status, age 2 y (ref = not stunted, age 2 y)						
Stunted	−0.40 (−0.49,−0.32)	−0.27 (−0.35,−0.19)	−0.14 (−0.23,−0.05)	−0.31 (−0.39,−0.22)	−0.16 (−0.24,−0.08)	−0.05 (−0.13,0.04)
Severity of stunting, age 2 y (ref = not stunted, age 2 y)[4]						
Moderate	−0.25 (−0.34,−0.15)	−0.17 (−0.26,−0.08)	−0.06 (−0.16,0.03)	−0.16 (−0.26,−0.06)	−0.09 (−0.18,0.00)	0.01 (−0.08,0.11)
Severe	−0.61 (−0.71,−0.51)	−0.41 (−0.51,−0.31)	−0.20 (−0.31,−0.09)	−0.50 (−0.60,−0.39)	−0.27 (−0.37,−0.17)	−0.16 (−0.27,−0.05)
Timing of stunting incidence (ref = never stunted through age 2 y)						
1–6 mo	−0.60 (−0.74,−0.47)	−0.35 (−0.48,−0.23)	−0.10 (−0.24,0.03)	−0.47 (−0.61,−0.33)	−0.23 (−0.35,−0.10)	−0.08 (−0.22,0.05)
7–12 mo	−0.41 (−0.53,−0.29)	−0.26 (−0.37,−0.15)	−0.08 (−0.20,0.03)	−0.35 (−0.47,−0.23)	−0.16 (−0.27,−0.05)	−0.02 (−0.14,0.09)
13–18 mo	−0.30 (−0.42,−0.17)	−0.20 (−0.32,−0.08)	−0.06 (−0.18,0.06)	−0.29 (−0.42,−0.16)	−0.16 (−0.28,−0.04)	−0.03 (−0.15,0.09)
19–24 mo	−0.19 (−0.34,−0.04)	−0.15 (−0.29,−0.01)	−0.02 (−0.16,0.12)	−0.08 (−0.23,0.08)	−0.03 (−0.17,0.11)	0.09 (−0.05,0.23)
Persistence of early stunting (ref = never stunted, ages 0–2 or 8 y)						
Persistent	−0.51 (−0.62,−0.41)	−0.31 (−0.41,−0.22)	−0.11 (−0.22,−0.00)	−0.44 (−0.54,−0.33)	−0.20 (−0.30,−0.10)	−0.04 (−0.15,0.07)
Catchup	−0.24 (−0.36,−0.12)	−0.15 (−0.26,−0.04)	−0.05 (−0.16,0.07)	−0.24 (−0.36,−0.12)	−0.15 (−0.26,−0.04)	−0.05 (−0.16,0.06)
Late incident	−0.17 (−0.28,−0.05)	−0.07 (−0.18,0.03)	−0.05 (−0.16,0.06)	−0.21 (−0.33,−0.10)	−0.13 (−0.23,−0.02)	−0.10 (−0.20,0.01)

[1] Abbreviations used: Coeff, coefficients from linear regression models in which cognitive test Z-score is the dependent variable; coefficients represent the mean deficit in test Z-score relative to the reference group; 95% CI, 95% confidence interval; Ref, reference group; HAZ, height-for-age Z-score.

[2] Adjusted for schooling, using highest grade achieved by child to date.

[3] Multivariate-adjusted models, which include highest grade achieved by child to date, mothers and father's age at birth, mother's parity at birth of this child, highest grade completed by mother and by father, baseline household income quartile, change in income quartile between surveys, type of settlement (urban congested, rural remote, etc.), number of younger siblings in the home, child's residence in home of caretaker other than his/her mother, maternal height, birth weight, sex of the child, percentage of fat in diet, spouse present/absent at baseline, as well as other stunting variables shown.

[4] Definitions used for stunting severity and persistence. Severity of stunting: moderate = HAZ < −2 to ≥ −3; severe = HAZ < −3. Persistence of stunting: persistent = stunted ages 0–2 y and at age 8y; catch-up = stunted ages 0–2 y but not at age 8y; late incidence = stunted at age 8 y but not ages 0–2 y; never stunted = not stunted ages 0–2 y nor at age 8 y.

Additional models were run to assess whether other variables might modify the association between stunting and cognitive development, including the following: *1*) stratified by type of school (public vs. private, a proxy for school quality); *2*) excluding children not enrolled in school; and *3*) excluding children in the highest and lowest grade categories in which the number of children was sometimes small. Because mathematics draws on skills likely to be acquired in school, the inclusion of mathematics problems on the cognitive test may have overstated the importance of schooling relative to other factors. Models were therefore rerun using scores on the subset of questions that excluded the 18 mathematics problems. Models were also run after excluding children within ±0.2 SD of numbers used to define stunting status to ensure that results were not sensitive to the cutpoints selected. In all cases, results were very similar to those reported here.

The Heckman method (Heckman 1979), a standard econometric technique for evaluating selectivity bias, was used to confirm that coefficients were not biased by loss to follow-up or missing data. In addition, to ensure that attrition between the 1991 and 1994 rounds did not affect findings, models for cognitive test performance at age 8 y were reestimated after restricting the sample to the subset of children with data available for age 11 y. Both strategies indicated that there was no bias.

RESULTS

Severity, timing and persistence of stunting. The prevalence of early stunting was high, with 63% of children in the sample stunted at age 2 y (Table 1). Of these, 43% were severely stunted. Children stunted very early in infancy were more likely to be severely stunted than those stunted later on. There was a dose-response relationship between the timing (age at first onset) and severity of stunting, i.e., the mean HAZ at age 2 y increased from −3.44 among children stunted in the first 6 mo of infancy, to −2.25 to those stunted between 18 and 24 mo.

About one third (34%) of children stunted at or before age 2 y experienced catch-up growth (i.e., these children were no longer stunted at age 8 y). The likelihood of persistent stunting vs. catch-up by age 8 y was related to the severity of early stunting. Children with persistent stunting had a mean HAZ of −3.10 SD at age 2 y, vs. −2.43 SD among those with catch-up growth. Timing was also strongly associated with persistence. For example, among 336 children stunted in the first 6 mo, only 21 (6%) were no longer stunted at age 2 y. The correlation between timing and persistence was high (Spearman's $r = 0.76$). As is apparent from these data, children with very early stunting tended to have severe and persistent stunting, making it difficult to separate effects of timing from severity or persistence. Additional analysis of catch-up growth in this cohort has been reported elsewhere (Adair 1999).

Unadjusted models. Children stunted at age 2 y had significantly lower mean cognitive test scores than nonstunted children, with greater differences at age 8 y than at age 11 y (**Table 2**; model 1). There was a dose-response relationship between severity of stunting and cognitive scores (Table 2; model 2). At age 8 y, children with severe early stunting had

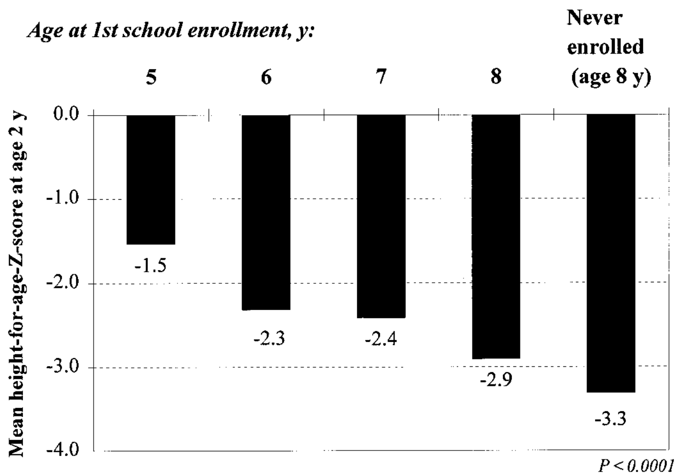

FIGURE 2 Filipino children stunted at age 2 y had delayed school enrollment (The Cebu Longitudinal Health and Nutritional Survey)

mean cognitive scores 0.61 SD below the mean for nonstunted children ($P < 0.000$). This was more than twice the shortfall in children with moderate stunting, whose mean scores were 0.25 SD lower than those of nonstunted children ($P < 0.001$). Again, deficits among children with either moderate or severe stunting were smaller at age 11 than at age 8 y. The discrepancy in scores was reduced over time because children stunted at age 2 y had relatively large improvements in scores compared with nonstunted children. Between age 8 y and age 11 y, the cognitive scores of children stunted at age 2 y improved by an average of 18.3 points, compared with 16.9 points among nonstunted children (t test $P < 0.003$).

The timing of stunting was also related to cognitive test scores (Table 2; model 3). As with severity, there was a dose-response effect of the timing of stunting. Compared with children never stunted in the first 2 y, the cognitive scores of children stunted in the first 6 mo of infancy were 0.60 SD lower at age 8 y, and 0.47 SD lower at age 11 y (adjusted for stunting in other 6-mo intervals, $P < 0.001$). In contrast, the shortfall in scores among children stunted later on, i.e., between 18 and 24 mo of age, was 0.19 SD at age 8 y, and 0.08 SD at age 11 y.

Children with persistent stunting through age 8 y had significantly lower cognitive test scores than children who were never stunted, as well as children with catch-up growth (Table 2; model 4). Children with catch-up growth also had significantly lower scores than those who were never stunted, although deficits were more moderate.

Relationship between stunting at age 2 y and schooling. Children stunted in the first 2 y of life tended to start school later than nonstunted children. Children who started school at age 5 or 6 y were substantially taller at age 2 y than children who started school only at age 7 or 8 y (**Fig. 2**). In addition, at age 11 y, children stunted at age 2 y were 3.0 (95% CI 1.5–5.8) times more likely to have dropped out of school in the past, 1.8 (1.4–2.2) times more likely to have repeated a grade and 1.2 (1.0–1.5) times more likely to have been absent in the month before the interview date. As a result, on average, stunted children had been in school for fewer months than nonstunted children at both age 8 y (11.7 vs. 13.6 mo, t test $P < 0.001$) and age 11 y (42.4 vs. 44.5 mo, t test $P < 0.001$).

As expected, more schooling (by any measure: months, grade, age at enrollment) was strongly associated with higher cognitive scores among both stunted and nonstunted children (**Fig. 3**). This association remained strong after controlling for SES and other covariates. Thus part of the apparent effect of stunting on cognitive scores was attributable to the lower level of schooling received by children stunted in early life.

Models adjusted for schooling. Adjusting for schooling substantially attenuated the deficits in cognitive scores associated with stunting in the first 2 y (Table 2, column 2). Despite this attenuation, the association between stunting at age 2 y and later cognitive scores remained significant. The dose-response relationship between the severity of early stunting and later cognitive ability also persisted after adjusting for schooling. As before, the deficit in cognitive test scores associated with stunting at age 2 was consistently smaller at age 11 y than at age 8 y, regardless of the severity of early stunting (Table 2, model 2). Similarly, the dose-response effect of the timing of stunting was attenuated in the schooling-adjusted models for cognition at both ages (Table 2, model 3). Deficits in cognitive scores associated with persistent stunting and early stunting with catch-up by age 8 y were also significant, albeit attenuated, after this adjustment (Table 2, model 4).

No interaction between schooling and stunting. Interactions between schooling and each stunting status variable were included in the multivariate models; none were significant. The lack of a significant interaction indicates, as shown in Figure 3, that the effect of increased schooling on cognitive test scores was similar among stunted and nonstunted children.

Multivariate-adjusted models. Further adjustment for SES and other covariates considerably reduced the association between early stunting and later cognitive scores. Even after multivariate adjustment, stunting at age 2 y was associated with significant deficits in cognitive test Z-scores at age 8 y (−0.14 SD) (Table 2). By age 11 y, however, the shortfall in cognitive scores among children stunted at age 2 y was small and nonsignificant (−0.05 SD). Although moderate stunting at age 2 y was no longer associated with meaningful deficits in cognitive ability at either age 8 or 11 y, severe stunting at age 2 y was associated with significant deficits in cognitive test performance at both ages even after multivariate adjustment. In contrast, neither very early onset of stunting nor persistent stunting was associated with significant shortfalls in cognitive test performance by age 11 y in the multivariate models (Table 2).

Severity vs. timing or persistence of early stunting. To better evaluate the role of severity vs. the timing of incidence or persistence of early stunting, children were cross-classified

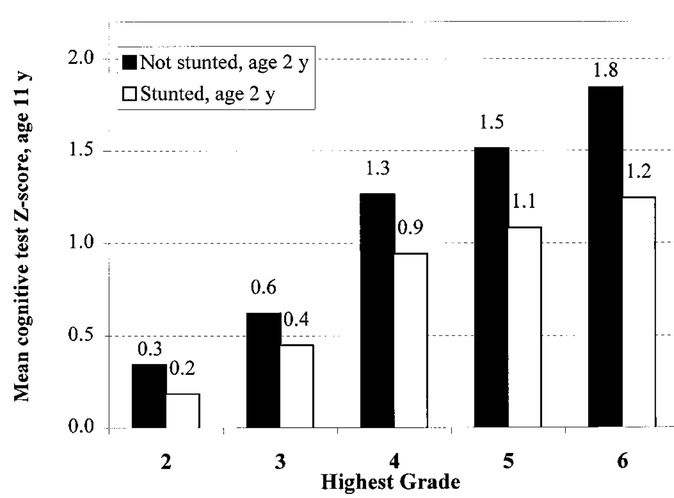

FIGURE 3 Schooling was associated with improved cognitive test scores regardless of stunting status at age 2 y (The Cebu Longitudinal Health and Nutritional Survey)

TABLE 3

Mean height-for-age among children cross-classified by severity and timing or persistence of early stunting (The Cebu Longitudinal Health and Nutrition Study)

		HAZ[1]			
		Age, *y*			
		2		8	
	n	Mean	SD	Mean	SD
Severity of early stunting × timing of incidence[2,3]					
Severe, incident 1–6 mo	226	−3.96	(0.73)	−3.05	(0.80)
Severe, incident 7–12 mo	257	−3.68	(0.51)	−2.75	(0.69)
Severe, incident 13–18 mo	100	−3.44	(0.34)	−2.22	(0.70)
Moderate, incident 1–6 mo	109	−2.38	(0.53)	−2.19	(0.73)
Moderate, incident 7–12 mo	278	−2.41	(0.41)	−2.25	(0.76)
Moderate, incident 13–18 mo	322	−2.32	(0.46)	−2.02	(0.71)
Moderate, incident 19–24 mo	249	−2.24	(0.34)	−1.84	(0.65)
Late incidence	80	−1.57	(0.33)	−2.31	(0.26)
Never stunted through age 8 y (ref)	507	−1.14	(0.55)	−0.98	(0.67)
Severity of early stunting × persistence of stunting					
Severe and persistent	497	−3.78	(0.63)	−2.98	(0.65)
Severe with catchup	88	−3.55	(0.49)	1.61	(0.39)
Moderate and persistent	516	−2.44	(0.38)	−2.58	(0.46)
Moderate with catchup	443	−2.21	(0.46)	−1.46	(0.49)
Late incidence	80	−1.57	(0.33)	−2.31	(0.26)
Never stunted through age 8 y (ref)	507	−1.14	(0.55)	−0.98	(0.67)

1 Abbreviations used: HAZ, height-for-age Z-score; Ref, reference group.

2 2 children with incident stunting at mo 20 and severe stunting at age 2 y were excluded.

3 Definitions used for stunting severity and persistence. Severity of stunting: moderate = HAZ < -2 to ≥ -3; severe = HAZ < -3. Persistence of stunting: persistent = stunted ages 0–2 y and at age 8 y; catchup = stunted ages 0–2 y but not at age 8y; late incidence = stunted at age 8 y but not ages 0–2 y; never stunted = not stunted ages 0–2 y nor at age 8 y.

based on both severity and timing and severity and persistence (see **Table 3**). Analysis using this cross-classification (see **Table 4**) suggested that the severity of early stunting was more important than either timing of incidence or persistence. Children with severe stunting had substantial deficits in cognitive scores regardless of the timing of incidence, whereas deficits among children with moderate stunting incident in any time interval were negligible. Similarly, children with severe early stunting had significant deficits in cognitive scores relative to children never stunted through age 8 y, regardless of whether they were persistently stunted or experienced catch-up growth.

Additional models. Models were also run to assess the association between stunting and performance on Mathematics and English achievement tests. Results were consistent with the findings for cognitive test performance, i.e., severity and very early onset of stunting were associated with substantial deficits in test scores. To further evaluate the importance of the timing of stunting, children were also classified on the basis of the prevalence of any stunting during each 6-mo interval. The results obtained using prevalent rather than incident stunting were similar. Supplementary analysis was also conducted to assess whether prenatal growth was associated with the cognitive scores. Neither stunting status at birth nor small size for gestational age was significantly associated with deficits in test scores. This could be attributable in part to the small proportion of children with these exposures in this sample.

DISCUSSION

The results of this analysis stress the need to prevent malnutrition in early childhood to improve cognitive development later in childhood. In this cohort of Filipino children, stunting in the first 2 y, particularly when severe, was strongly associated with cognitive test scores at ages 8 and 11 y. This finding is consistent with earlier research suggesting that short stature in early life is associated with poor cognitive development later in childhood (Grantham-McGregor et al. 1991, Martorell et al. 1992).

Stunting in the first 2 y was more strongly associated with cognitive test performance at age 8 y than at age 11 y, suggesting that the effects of early undernutrition on cognitive abilities may decline over time, even among severely stunted children. Gradual declines in the effects of early malnutrition on cognition have been reported previously, and suggest that the effects of early undernutrition may be largely a result of delay rather than permanently impaired mental development (Cravioto and Cravioto 1996, Pollitt 1996). Over time, schooling and other learning experiences may attenuate the effects of early undernutrition on cognition (Pollitt 1996).

Although each dimension of stunting in early life assessed in this paper was associated with children's test scores at age 8 y, only severe stunting appeared to have lasting effects at age 11 y; these effects were independent of differences in educational, socioeconomic and psychosocial resources. Several other studies have reported associations between severe malnutrition in early childhood and poor performance on tests of intellectual functioning in later childhood (Galler et al. 1983, Sigman et al. 1991), adolescence (Stoch and Smythe 1976) and adulthood (Grantham-McGregor 1995, Martorell et al. 1992). At present, few studies have investigated the long-term consequences of moderate stunting in infancy and early childhood (Wachs 1995). This study suggests that by age 11 y, direct effects of moderate undernutrition in early life on chil-

TABLE 4

Mean difference in cognitive test Z-scores among children cross-classified by severity and timing or persistence of early stunting (The Cebu Longitudinal Health and Nutrition Study)[1]

	Age 8 y				Age 11 y			
	Unadjusted		Multivariate-adjusted[2]		Unadjusted		Multivariate-adjusted	
	Coeff.	CI	Coeff.	CI	Coeff.	CI	Coeff.	CI
Severity of early stunting × timing of incidence[3,4]								
Severe, incident 1–6 mo	−0.79	(−0.94, −0.63)	−0.24	(−0.40, −0.09)	−0.65	(−0.81, −0.50)	−0.27	(−0.43, −0.11)
Severe, incident 7–12 mo	—		—		−0.57	(−0.72, −0.43)	−0.10	(−0.25,0.05)
Severe, incident 13–18 mo	−0.66	(−0.87, −0.45)	−0.26	(−0.45, −0.06)	−0.48	(−0.69, −0.27)	−0.14	(−0.34,0.06)
Moderate, incident 0–6 mo	−0.37	(−0.57, −0.17)	0.04	(−0.15,0.23)	−0.25	(−0.45, −0.05)	0.11	(−0.09,0.30)
Moderate, incident 7–12 mo	−0.30	(−0.44, −0.16)	−0.08	(−0.22,0.06)	−0.24	(−0.39, −0.10)	−0.02	(−0.16,0.12)
Moderate, incident 13–18 mo	−0.23	(−0.37, −0.10)	−0.02	(−0.15,0.12)	−0.30	(−0.43, −0.16)	−0.04	(−0.17,0.09)
Moderate, incident 19–24 mo	−0.23	(−0.37, −0.08)	−0.06	(−0.20,0.08)	−0.15	(−0.30, −0.00)	0.02	(−0.12,0.16)
Incident stunting at 8 y	−0.33	(−0.56, −0.11)	−0.10	(−0.31,0.11)	−0.42	(−0.65, −0.19)	−0.20	(−0.42,0.00)
Never stunted thru age 8 y (ref)	ref		ref		ref		ref	
Severity of stunting age 2 y × persistence of stunting through age 8 y								
Severe and persistent	−0.68	(−0.80, −0.56)	−0.19	(−0.32, −0.06)	−0.61	(−0.73, −0.49)	−0.17	(−0.29, −0.04)
Severe with catchup	−0.62	(−0.84, −0.40)	−0.25	(−0.47, −0.03)	−0.48	(−0.70, −0.26)	−0.20	(−0.41,0.01)
Moderate and persistent	−0.35	(−0.47, −0.24)	−0.06	(−0.18,0.06)	−0.28	(−0.21,0.01)	0.04	(−0.08,0.16)
Moderate with catchup	−0.17	(−0.29, −0.04)	−0.02	(−0.14,0.10)	−0.19	(−0.24, −0.01)	−0.04	(−0.16,0.08)
Incident stunting at 8 y	−0.33	(−0.56, −0.11)	−0.10	(−0.32,0.11)	−0.42	(−0.46, −0.04)	−0.20	(−0.41,0.01)
Never stunted thru age 8 y (ref)	ref		ref		ref		ref	

1 Abbreviations used: Coeff, coefficients from linear regression models in which cognitive test Z-score is the dependent variable; 95% CI, 95% confidence interval; coefficients represent the mean deficit in test Z-score relative to the reference group; Ref, reference group; HAZ, height-for-age Z-score.

2 Multivariate-adjusted models, which include highest grade achieved by child to date, mothers and father's age at birth, mother's parity at birth of this child, highest grade completed by mother and by father, baseline household income quartile, change in income quartile between surveys, type of settlement (urban congested, rural remote, etc.), number of younger siblings in the home, child's residence in home of caretaker other than his/her mother, maternal height, birth weight, sex of the child, percentage of fat in diet, spouse present/absent at baseline, as well as other stunting variables shown.

3 Two children with incident stunting at mo 20 and severe stunting at age 2 y were excluded.

4 Definitions used for stunting severity and persistence. Severity of stunting: moderate = HAZ < −2 to ≥ −3; severe = HAZ < −3. Persistence of stunting: persistent = stunted ages 0–2 y and at age 8 y; catchup = stunted ages 0–2 y but not at age 8y; late incidence = stunted at age 8 y but not ages 0–2 y; never stunted = not stunted ages 0–2 y nor at age 8 y.

dren's intellectual development may not be independent of schooling and other socioeconomic and psychosocial factors.

Although the association between timing of stunting and cognitive test scores was not significant after multivariate adjustment, this study suggests that it is particularly important to prevent very early stunting to protect children's cognitive development. Early stunting is critical largely because it increases risk of severe, persistent stunting. i.e., 67% of children stunted in the first 6 mo were severely stunted at age 2 y, and another 26% were moderately stunted; 80% of children stunted by mo 6 remained stunted at age 8 y. As shown in Table 4, persistence appears to be less important for basic cognitive ability than the severity of early stunting and differences in educational, socioeconomic and psychosocial resources made available to stunted children. Children with severe early stunting had meaningful deficits in cognitive scores regardless of whether stunting persisted through age 8 y or children experienced catch-up growth.

As expected, reduced schooling was an important factor contributing to the poor intellectual development of children stunted in the first 2 y of life. After adjusting for schooling, associations between stunting in the first 2 y and later cognitive development were strongly attenuated. In this cohort, children stunted at age 2 y had a marked delay in initial school enrollment and were much more likely to experience absences and to drop out of school than nonstunted children. Deficiencies in educational flow may reflect poorer health. They may also be attributable to greater ability and motivation among higher SES parents to initiate and maintain children's schooling. Perhaps, as suggested by Brown and Pollitt (1996), parents may tend to enroll well-nourished children who appear more alert and ready for schooling earlier than children who seem small and poorly developed. Essentially, stunted children may be treated differently from nonstunted children because they are smaller and often appear younger than their age (Brown and Pollitt 1996). Differences in schooling experiences played an important role in explaining cognitive score deficits among moderately stunted children. Like children with severe early stunting, children with moderate stunting at age 2 y received significantly less schooling than nonstunted children (χ^2 P = 0.000). However, differences in schooling did not explain why moderate stunting was not associated with significant deficits in cognitive scores after multivariate adjustment. Coefficients for moderate stunting were not significant even after dropping schooling from multivariate models.

The absence of significant interactions between level of schooling and stunting in the first 2 y in models predicting cognitive scores indicates that the gains in basic cognitive ability associated with schooling exposure are similar for stunted and nonstunted children (Fig. 3). Earlier studies have also suggested that schooling may act as a buffer against the effects of poverty and malnutrition on intellectual development (Gorman and Pollitt 1996). Ensuring that children with early stunting receive schooling comparable in quantity and quality to that received by nonstunted children may help to improve their cognitive development.

Although schooling was associated with improved cognitive scores, adjusting for schooling did not eliminate the adverse effects of severe early stunting on cognitive or achievement test scores. This suggests that other mechanisms may be important. In addition to lower levels of schooling, chronic undernutrition (manifested in stunting) early in life may affect later intellectual development via deficiencies of nutrients such as vitamin B-6 or iron, which are vital for brain function (Guilarte et al. 1993, Pollitt 1997). In extreme cases, malnourished children may suffer from brain damage (Brown and Pollitt 1996, Grantham-McGregor 1995). As a result of their poor physical development, stunted children may also have delayed development of motor skills. This could affect their ability and interest in exploring their environment, delaying their intellectual development (Brown and Pollitt 1996, Grantham-McGregor 1995). Children who are persistently malnourished may have little energy to learn in the classroom (Brown and Pollitt 1996). Finally, a number of nondietary influences on child development exist, including parental attention and affection, as well as risk of infection or illness (Connally and Kvalsvig 1993, Monckeberg 1992).

This study suggests that optimizing healthy growth in early life is important for the intellectual development of children in developing countries. The study also makes it clear, however, that other aspects of children's early environment—most notably adequate schooling—are also critical. Although the association between stunting status and children's test scores was significant, stunting variables explained only 3–6% of the variance in these models (the R^2 varied depending on the outcome and stunting variables used). Incorporating schooling and other covariates increased the R^2 to nearly 40%. However, a substantial proportion of the variance remained unexplained by these models; we were unable to account for important factors such as inherited ability and differences in the quality of care and stimulation.

In summary, this analysis suggests that there may be a direct effect of severe chronic undernutrition in early life on cognitive development later in childhood, independent of psychosocial factors such as schooling and SES. It is unclear whether these deficits represent developmental delays that may persist into adolescence or adulthood, rather than permanent impairment. Children with severe stunting at age 2 y appeared to sustain these cognitive deficits through age 11 y, regardless of when they first became stunted. These deficits persisted even when children had recovered from early stunting. The fact that both moderately and severely stunted children received significantly less schooling than nonstunted children suggests that there are important *indirect* effects of chronic undernutrition; that is, the effect of early stunting is mediated in part through reduced schooling. Thus, although direct effects of moderate stunting on children's performance may not be significant, there may well be significant indirect effects mediated through changes in educational flow. Future research should focus on the indirect as well as the direct effects of children's nutritional status on cognitive development.

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