Preschool Stunting, Adolescent Migration, Catch-Up Growth, and Adult Height in Young Senegalese Men and Women of Rural Origin

Aminata Ndiaye Coly, Jacqueline Milet, Aldiouma Diallo, Tofèné Ndiaye, Eric Bénéfice, François Simondon, Salimata Wâde, and Kirsten B. Simondon

Abstract

Available data on the long-term consequences of preschool stunting are scarce and conflicting. The objective of this study was to assess the amount of catch-up growth from preschool stunting and the effect of migration (change in environment) during adolescence. A cohort study from preschool age (1–5 y) to adulthood (18–23 y) was conducted among 2874 subjects born in a rural area of Senegal. The subjects were divided into 3 groups of preschool stunting: none, mild, and marked, with height-for-age Z-scores of $>-1$, $-2$ to $-1$, and $<-2$, respectively. At follow-up, the history of migration was recalled. Mean height was 161.3 cm for girls and 174.0 cm for boys ($\geq 20$ y). Stunted subjects remained smaller than the others: the age-adjusted height deficit between the 2 extreme categories was 6.6 and 9.0 cm in girls and boys, respectively. However, their height increment from early childhood to adulthood differed (69.3, 70.5, and 72.0 cm, $P = 0.0001$, and 78.9, 80.0, and 80.3 cm, $P < 0.01$, for nonstunted, mildly stunted, and markedly stunted girls and boys, respectively). The duration of labor migration to the city was associated with height increment in girls only in a nonlinear relation (adjusted means: 67.2, 69.3, 67.4, and 67.7 cm for 4 groups of increasing duration, $P < 0.01$). In conclusion, Senegalese children caught up in height prior to adulthood, with the adult means $-2$ cm below the WHO/NCHS reference. However, this global catch-up did not reduce height differences between formerly stunted and nonstunted children to any greater extent and it was not enhanced by labor migration. J. Nutr. 136: 2412–2420, 2006.

Introduction

Preschool stunting has multiple consequences in terms of the nutritional status and health of young adults (1). It would appear that final height is a key element because it is a sensitive indicator of socioeconomic environment and health (2). Indeed, small adults have low economic productivity and small women are at increased risk of suffering from complications during delivery and of producing small offspring with low birth weight. Thus, stunting constitutes a handicap throughout the life cycle (3).

The hypothesis that stunted children under 5 y of age become small adults has been accepted for a long time. Data from a rural area in Gambia showed that, for the population as a whole, height deficits, compared with U.K. reference data, were established in early childhood and remained for life (4). In Guatemala, the height increment from 3 y of age to adulthood was not influenced by the degree of stunting, i.e., there was no catch-up growth (5). In Senegal, data from a longitudinal study showed a persistence of height deficits in boys from 10 to 17 y, but there was a tendency toward catch-up growth among malnourished girls in the oldest age groups (6,7).

In Kenya, a cross-sectional study compared urban children living in a privileged environment to rural children from a poor environment (8). Mean height was much lower in the rural sample during childhood, but the difference disappeared at 18 y for boys and 17 y for girls. In a birth-to-maturity cohort study in rural India, boys had not caught up from preschool stunting by the age of 18 y (9), but a partial catch-up was achieved later (10).

Studies that demonstrate catch-up growth have 3 main common characteristics: catch-up is partial and late, and occurs despite the fact that subjects remained in the environment in which the deficit was established (7,8,10). This led us to hypothesize that a substantial improvement in living conditions by migration may improve catch-up in height status.

In sub-Saharan Africa, rural areas are characterized by high levels of stunting among children <5 y of age (11), whereas adult heights are often only slightly below international references (2). This suggests that catch-up growth tends to occur during adolescence (12,13). In Senegal, rural adolescents and young adults are strongly attracted to urban migration for reasons of labor or emancipation, and labor migration of adolescents is an important strategy for diversifying rural family incomes (14). In the city, migrants are confronted with changes

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2 To whom correspondence should be addressed. E-mail: kirsten@ird.fr or amincolle@caramail.com.
in food habits and physical activity that have an impact on their nutritional status and growth (15,16).

Hence, this study aims to assess the degree of catch-up growth in adolescents and young adults according to their degree of stunting in early childhood (1–5 y), and to test the relation between rural-to-urban migration and catch-up growth by using migration as a marker of change in the environment. The cohort was partly the same as that included in the above-mentioned study of Senegalese adolescents (7), and our hypotheses were that partial catch-up occurs at the end of adolescence in stunted children of both sexes and that living in the city enhances the chances of catch-up growth through better nutrition.

Subjects and Methods

The Niakhar study area is located 150 km east of the capital city, Dakar. It is a rural area with a Sahelian climate and 2 distinct seasons: a dry season from October to June and a rainy season from July to September. The population is ethnically homogeneous with >96% Serers. The main activity is agriculture, with peanuts, millet, and sorghum as the main crops. Livestock breeding is also practiced (17).

The area has been subject to demographic surveillance since 1963, with a systematic registration of dates of birth, migration in and out of the area, and death. The population consists of ~30,000 people, 65% of whom are <25 y of age (18). Life-expectancy is increasing, and mortality for children <5 y of age is decreasing [253% between 1984 and 1991 (19)]; nonetheless, living conditions remain precarious. Electricity, refrigerators, and indoor tap water are unknown, and wood is used for cooking.

Migration within Senegal

In Niakhar, seasonal migration of adolescents and young people looking for work in the city mainly takes place during the dry season. Many return to the village during the period of field work (July–October) and thus live alternately in the city and the village; whereas older, more experienced subjects with higher incomes choose to remain in the city year around. Many girls return permanently to their village after marriage. Boys may also undertake other types of migration, such as labor migration to other rural areas with a longer rainy season than in Niakhar, rainy-season migration with livestock (transhumance), or schooling migration to towns with secondary-level educational facilities. These forms, however, are less frequent than urban migration for work.

Early-childhood survey

In 1983–84, infants and children up to 5 y of age were included in a large anthropometric study that compared the risk of death to a child’s nutritional status and the season of the year (20). Four surveys were conducted at 6 monthly intervals from May 1983 to November 1984. All children that were born between 1 January 1978 and 30 November 1984 and who were still living in the area at the onset of each round of surveys, were eligible. Surveys were conducted at a central location in each of the 30 villages, but absent subjects and their mothers were visited at home. Coverage was 86.5%. The remaining 912 children were either absent from their homes or their mothers did not consent to participate. Anthropometric measurements included weight, height, arm circumference, and tricipital and subscapular skinfolds, which were measured using standard methods. Length or height was measured using a tape measure to the nearest mm. Maternal anthropometric measurements, including height, were taken during the last 3 rounds of surveys only. During all rounds, mothers were provided with chloroquine and instructed on how to administer it if their children for malaria treatment. No nutritional intervention was conducted.

Follow-up study

All subjects eligible for the childhood study were also eligible for the late adolescence study. Subjects were visited at their last known address in the

Figure 1  Number of subjects included in childhood survey in rural Senegal in 1983–84, in a follow-up survey in 2001–02, and in analyses, with reasons for noninclusion.

Niakhar area from March to June 2001, and those who were present were included in the study upon obtaining informed consent. Whenever possible, information about subjects who had migrated (vital status and approximate current address) was obtained from their family members remaining in the area. A second survey of subjects who were absent during the dry season was conducted during the rainy season (August to September 2001).

Migrants were visited at the home of their guardian (i.e., a family member in charge) in Dakar (October to December 2001), Mbour and Fatick (February to March 2002), or Koumpentoum in eastern Senegal (May 2002). A few were visited at their working address.

Data collected

A closed questionnaire inquired about migration (place, date of onset and end date, and main activity during each migration), schooling (current or past, highest level reached), and current reported diseases. Females were also asked about current pregnancy, breastfeeding, and number of live-born children. Field workers were well trained and used detailed calendars of local events to enhance the precision of recalled dates. Two study teams of 3 persons/team were involved.

The study protocol was approved by the ethics committee of the Ministry of Health in Senegal, and subjects and their parents or guardians provided oral informed consent.

Anthropometric measurements

Anthropometric measurements were taken using recommended techniques (21), except that all lateral measurements were taken on the left side of the body. Height was measured to the nearest mm (using a Harpenden anthropometer, Siber-Hegner), as was the upper arm circumference. Tricipital and subscapular skinfolds were measured to the nearest 0.2 mm using Holtain calipers (Siber-Hegner). All these measurements were taken twice and the means were computed for analyses. Body weight was obtained in simple measure using an electronic balance (Téfaj) with a precision of 100 g.

Four different persons (measurers) took part in anthropometric data collection. Teams were frequently supervised, and measurements were
compared at the beginning and middle of the study period on 30 subjects. Between measurers 1 and 2, the standard error was 0.13 cm, 0.13 cm, 0.32 mm, and 0.22 mm, respectively, for height, arm and tricep circumference, and subcapular skinfolds (first assessment), compared with 0.11 cm, 0.06 cm, 0.34 mm, and 0.39 mm, respectively, between measurers 3 and 4.

Subjects
As of 28 February 2001, 1082 subjects died, whereas 5667 were eligible for the study. Among the latter, 3572 still lived in their village at least part of the year, and 2095 had moved out of the area. In total, 3977 subjects were included in the survey, 113 refused participation, and 1577 were not located in either Niakhar or urban areas (Fig. 1).

Sample
The procedure for selecting study subjects to be included in the analysis is illustrated in Figure 1. In the preschool study, coverage was 86.5% of eligible children. In the follow-up study of adolescents and youth, eligible subjects were those eligible for the preschool study, excluding those who died between 1984 and 2001, and coverage was 70.2% of the survivors. Finally, 52.3% of subjects eligible for the preschool surveys had complete data for both time periods (i.e., 62.3% of those who survived). Another 55 subjects were excluded from the analysis because of a handicap that was likely to alter the validity of anthropometric data and/or migration recall. These handicaps included severe poliomyelitis sequelae, bone fluorosis, and badly consolidated leg fractures (making upright position impossible or difficult), mental retardation, and deaf-dumb persons.

For the preschool surveys, children who were included in the study did not differ from their nonincluded counterparts in terms of sex ratio (49.4% and 49.3% in females in the 2 groups, respectively) or death rate from 1984 to 2001 (15.8 vs. 17.3%, P > 0.10). However, their age distribution differed, in that both infants and children aged >5 y were less represented (coverage was 66.9, 83.8, 91.4, 93.4, 95.2, 94.1, 95.6, and 66.7%, respectively, for children aged 0–5.9, 6–11.9, 12–19.3, 24–35.9, 36–47.9, 48–59.9, 60–65.9, and 66–72 mo as of 1 January 1985, P < 0.001). Included children were less likely to migrate out of the study area between 1984 and 2001 (29 vs. 43% for nonincluded counterparts, P < 0.001).

In the late adolescence survey, coverage did not differ between boys and girls (71.0 vs. 69.3%, P > 0.10), but was greater among younger subjects (74.5, 70.7, 71.5, 69.5, 70.4, 69.1, and 65.0% for age groups 0–11.9, 12–19.3, 24–35.9, 36–47.9, 48–59.9, and 60–72 mo as of 1 January 1985, P < 0.01). As expected, coverage was lower among subjects who migrated out of the study area before 2001 (46.0 vs. 84.6%, P < 0.0001); among migrants, early out-migration was associated with less likelihood of inclusion (26.8, 33.5, 56.6 and 59.0%, respectively, for out-migrations at 0–4, 5–9, 10–14, and ≥15 y of age, P < 0.001). Indeed, out-migrations before the age of 10 usually included the entire family, which made tracking these adolescents very difficult.

There was no difference in nutritional status at the preschool surveys between those who were included in the follow-up survey and those who were not, although they had survived, in terms of height-for-age (−1.04 ± 1.3 vs. −1.08 ± 1.4, P = 0.32), weight-for-age (−0.97 ± 1.2 vs. −0.95 ± 1.2, P = 0.57) or weight-for-height (−0.41 ± 0.99 vs. −0.36 ± 0.98, P = 0.09). Conversely, those who died between the preschool surveys and the follow-up survey had a lower mean preschool nutritional status than survivors (results not shown).

The analyses include a total of 2874 subjects with anthropometric data in both infancy and adulthood. Infants <1 y of age during the childhood surveys were excluded because they had not yet experienced, in full, the postnatal period of linear growth retardation. The prevalence of stunting was 2.7, 4.9, 10.9, and 13.0%, respectively, from 0–2.9, 3–5.9, 6–8.9, and 9–12 mo of age. In addition, the group of stunted infants was thought to include a large proportion of those who had suffered intrauterine growth retardation, a condition that makes recovery from stunting more uncertain (22).

Variables
Preschool height-for-age Z-scores (HAZ), weight-for-age Z-scores (WAZ) and weight-for-height Z-scores (WHZ) were computed using Anthro (CDC/WHO) according to the WHO/NCHS reference (23). Three categories of preschool stunting were defined: none, mild and marked, for HAZ > −1, −2 ≤ HAZ ≤ −1, and HAZ < −2, respectively. Adult “stunting” was defined for girls aged ≥18 and boys aged ≥20, as a height < −2 Z-scores of the NCHS reference at age 18 y (163.6 for boys and 151.8 cm for girls) because reference data are not available above that age.

BMI was computed as weight divided by squared height. Arm muscle circumference was computed as arm circumference − (π × tricipital skinfold) (24). The height increment was computed as the gain in height from childhood (1–5 y) to adulthood (18–23 y).

Four variables related to migration were considered: current place of residency (rural area, smaller towns, capital city), age at first migration out of the rural area of birth, number of migrations, and total duration of migration computed as the sum of durations of all migration episodes. The latter 3 variables were also computed for migrations to Dakar only.

Data on maternal schooling was extracted from the Niakhar area data base, and was missing for 28% of the sample.

Statistical analysis
Definition of catch-up. Several definitions exist for catch-up from preschool stunting. Indeed, a population may catch-up in comparison to an external reference population, such as the WHO/NCHS. Alternatively, the most stunted individuals in a malnourished population (with HAZ < −2) may catch-up, when compared with their less stunted counterparts living in the same population, in terms of either height or HAZ.

Regression to the mean. Regression to the mean is the tendency for a subject who had a variable measure below the mean on one occasion to have a measure closer to the mean on the next occasion, i.e., a positive increment over time. This occurs for 2 reasons in growth studies. The first reason is misclassification due to random measuring errors, i.e., an artifact, which is easily corrected by using 2 independent measures for initial grouping and computation of the increment. The second is the biological tendency of subjects with "abnormal" height to get closer to the mean over time. Both phenomena, therefore, suggest a possibility of catch-up for stunted subjects.

For most subjects included in the analysis (n = 2325), ≥2 preschool height measurements were available. These were chosen to test for a "regression toward the mean" effect in the analysis of height increments. Indeed, the last preschool height measurement was used to compute the height increment up to youth, and the next-to-last was used for the classification into 3 groups of preschool height for age. Thus, measuring errors in height increment and in degree of preschool stunting became uncorrelated.

Strategy of analysis. We first compared mean height in young adults and their height increment since preschool age according to the severity of preschool stunting (marked, mild, or none). Similar mean adult heights among stunting categories would indicate full catch-up, whereas a greater height increment of markedly stunted boys and girls, compared with their nonstunted counterparts, would indicate at least a partial catch-up. This analysis was first conducted on the entire sample, and thereafter on the restricted sample, with 2 preschool height measurements. For the latter sample, the difference in height increments among groups of degree of stunting was compared for each sex separately, according to the preschool height measurement used for classifying preschool stunting, i.e., the same measurement as that used for the height increment vs. an independent measurement.

Second, we computed the increase in HAZ from preschool age to adulthood, for females and males separately, and compared the mean to the expected adult HAZ in the absence of catch-up, using the correlation between preschool and adult HAZ to adjust for regression to the mean (expected mean adult HAZ = r × mean preschool HAZ) as suggested by Cameron et al. (25).

Finally, we compared mean height at adulthood to that of the reference population, and computed the rate of adult stunting for all subjects pooled and by the degree of preschool stunting. The latter 2 methods define catch-up as a faster linear growth compared with the
Effect of urban migration for labor on catch-up growth. The height increment from early childhood to youth was studied in relation to total duration of migration to the city of Dakar. The effect of migration to Dakar on catch-up growth was examined using the restricted sample size with 2 preschool height measurements. Mean height increment (from the last preschool measure to adulthood) was compared among 4 groups of migration duration (i.e., no migration and 3 groups of increasing duration using tertiles as cut-off points) for boys and girls separately, and adjusting for age and preschool HAZ (measured at a previous round) using general linear modeling. Preschool HAZ was included in the model because the degree of stunting was a determinant of several migration characteristics (see results below). Migration to smaller towns was not considered in this analysis because the change in environment was expected to be minor compared with that for migrants living in Dakar.

Statistical tests and software. Data entry and quality control were performed using Dbase 4. All analyses were performed using SAS (SAS, version 8.1). Chi-square tests, chi-square tests with Mantel-Haenszel adjustment for category of age at follow-up, general linear regression, and ANOVA were used, as appropriate. Multiple comparisons among groups were made using the Student Newman Keuls test. Differences were considered significant at P < 0.05. Values in the text are means ± SD unless otherwise noted.

Results

At the follow-up survey, boys were taller and heavier than girls, but the latter had greater BMI, arm circumference and skinfold thickness (Table 1). More boys than girls had attended school, particularly secondary level of education, and 70% of girls and 50% of boys did not benefit from any schooling. Girls migrated more frequently than boys and at younger ages than boys. A few females had still not experienced menarche, whereas 10% were pregnant.

In childhood, mean HAZ was slightly greater for girls (Table 1). The prevalence of stunting was 27.6% (95% CI; 24.9, 29.3), with no difference between boys and girls. It varied by age, with the greatest prevalence during the second and third years of life (28.0, 43.0, 32.7, 34.1, 26.3, 21.9, and 23.0%, respectively, from 12–17.9, 18–23.9, 24–29.9, 30–35.9, 36–47.9, 48–59.9, and 60–72 mo, P < 0.0001).

In childhood, the age-adjusted height difference between the 2 extreme categories of stunting was 9.5 and 10.0 cm, respectively, for girls and boys.

Girls started migrating ~2 y earlier than boys (Table 1). Among the former, age at first migration was slightly higher for those who had attended school (14.0 vs. 13.5 y, P < 0.05), whereas the opposite was true for boys (15.8 vs. 16.7 y, P < 0.0001). For the latter, those with previous schooling had performed more migrations than those without any schooling (5.3 vs. 3.5, P < 0.0001). A larger proportion of males had attended secondary school, and schooling migration accounted for a larger proportion of all migrations among males. Indeed, secondary schooling is not available in this area.

Adult height and height increment since preschool age. For women, height did not vary between the ages of 18 and 23 y, whereas the height of men increased until age 20 y. However, height increased slightly up to 21 y for women (P = 0.05) and 22 y for men (Table 2). A severe delay in sexual maturation was noted for females: 6.9% of 18 to 19-y-olds were still premenarcheal. This proportion varied with the degree of preschool stunting (3.5, 5.5, and 11.2% for nonstunted, mildly stunted, and markedly stunted subjects, respectively, P < 0.05).

Women aged 18–23 y, and men aged 20–23 y, had height deficits of 2.4 and 2.8 cm, respectively, compared with the WHO/NCHS growth reference (161.3 vs. 163.7 cm for women and 174.0 vs. 176.8 cm for men), and their HAZ was −0.40 ± 1.00 and −0.46 ± 1.05, respectively. In both sexes and all age groups, markedly stunted subjects were smaller than mildly stunted subjects who, again, were smaller than nonstunted subjects (Figs. 2A, B). When adjusted for age, the height deficit between the extreme categories of stunting was 6.6 cm for females and 9.0 cm for males. These height differences were thus reduced by 2.9 cm for females and 1.0 cm for males, compared with early childhood.

The height increment from early childhood to adulthood was inversely associated with age at the time of the survey: means were lower for the oldest subjects because they had been older and thus taller in the preschool survey. It was greater among markedly stunted subjects than mildly and nonstunted preschoolers within the age range of 20–23 y for girls and 21–22 y

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**Table 1** Main characteristics of Senegalese men and women included in the analysis, at the preschool surveys (1–5 y) and at follow-up (18–23 y)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Females, n = 1456</th>
<th>Males, n = 1418</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>At preschool survey</td>
<td>3.4 ± 1.4&lt;sup&gt;1&lt;/sup&gt;</td>
<td>3.4 ± 1.4</td>
<td>NS&lt;sup&gt;2&lt;/sup&gt;</td>
</tr>
<tr>
<td>At follow-up survey</td>
<td>20.5 ± 1.6</td>
<td>20.4 ± 1.6</td>
<td>NS</td>
</tr>
<tr>
<td>Nutritional status at preschool survey</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HAZ</td>
<td>−1.30 ± 1.23</td>
<td>−1.40 ± 1.17</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>WAZ</td>
<td>−1.26 ± 1.16</td>
<td>−1.31 ± 1.17</td>
<td>NS</td>
</tr>
<tr>
<td>WHZ</td>
<td>−0.58 ± 1.05</td>
<td>−0.61 ± 1.09</td>
<td>NS</td>
</tr>
<tr>
<td>Anthropometry at follow-up</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Height, cm</td>
<td>161.3 ± 5.9</td>
<td>172.0 ± 7.8</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>56.2 ± 7.7</td>
<td>58.9 ± 8.8</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>BMI, kg/m²</td>
<td>21.6 ± 2.6</td>
<td>19.8 ± 2.0</td>
<td>&lt;0.0001</td>
</tr>
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<td>MUAC, cm</td>
<td>26.0 ± 2.5</td>
<td>25.6 ± 2.7</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>MAC, cm</td>
<td>20.7 ± 1.6</td>
<td>23.3 ± 2.6</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>TSF, mm</td>
<td>17.0 ± 7.6</td>
<td>7.4 ± 2.7</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>SSF, mm</td>
<td>12.6 ± 6.1</td>
<td>7.9 ± 2.3</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>School education, %</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>None</td>
<td>69.5</td>
<td>50.3</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Primary level</td>
<td>23.6</td>
<td>32.7</td>
<td></td>
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<tr>
<td>Secondary level</td>
<td>6.9</td>
<td>17.0</td>
<td></td>
</tr>
<tr>
<td>Still in school at follow-up, %</td>
<td>8.6</td>
<td>16.8</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Reproduction, %</td>
<td></td>
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</tr>
<tr>
<td>Postmenarcheal</td>
<td>97.2</td>
<td>—</td>
<td></td>
</tr>
<tr>
<td>Pregnancy</td>
<td>10.5</td>
<td>—</td>
<td></td>
</tr>
<tr>
<td>Migration out of study area&lt;sup&gt;3&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age at first migration, y</td>
<td>13.3 ± 3.3</td>
<td>16.5 ± 3.4</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Migrations, n</td>
<td>5.5 ± 3.3</td>
<td>3.2 ± 3.4</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Total migration duration, y</td>
<td>5.3 ± 3.6</td>
<td>2.2 ± 3.1</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Location at follow-up survey, %</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Rural area</td>
<td>66.0</td>
<td>76.6</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Smaller towns</td>
<td>15.0</td>
<td>15.2</td>
<td></td>
</tr>
<tr>
<td>Dakar</td>
<td>19.0</td>
<td>8.2</td>
<td></td>
</tr>
</tbody>
</table>

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1 Values are means ± SD.
2 NS, P ≥ 0.05.
3 Subjects who had never migrated were excluded (159 girls and 307 boys).
TABLE 2  Height of young Senegalese women and men at various ages

<table>
<thead>
<tr>
<th>Age, y</th>
<th>Females, n = 1456</th>
<th>Males, n = 1418</th>
</tr>
</thead>
<tbody>
<tr>
<td>18</td>
<td>160.5 ± 5.8</td>
<td>165.8 ± 4.6†</td>
</tr>
<tr>
<td>19</td>
<td>160.7 ± 6.1</td>
<td>170.5 ± 7.9†</td>
</tr>
<tr>
<td>20</td>
<td>161.3 ± 5.6</td>
<td>173.2 ± 7.8†</td>
</tr>
<tr>
<td>21</td>
<td>161.8 ± 6.2</td>
<td>172.8 ± 7.8‡</td>
</tr>
<tr>
<td>22</td>
<td>161.8 ± 5.8</td>
<td>174.7 ± 6.8†</td>
</tr>
<tr>
<td>23</td>
<td>161.6 ± 6.0</td>
<td>174.8 ± 6.8‡</td>
</tr>
<tr>
<td>P</td>
<td>0.05</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>All²</td>
<td>161.3 ± 5.9</td>
<td>172.0 ± 7.8</td>
</tr>
</tbody>
</table>

† Values are means ± SD. Means in a column with superscripts without a common letter differ, P < 0.05. ‡ Means were adjusted for age.

...for boys (Table 3). Adjusted for age, overall differences between extreme categories of stunting were 3.0 cm for girls and 1.5 cm for boys.

Within the restricted sample size with 2 preschool height measurements, the age-adjusted difference between extreme groups of stunting was slightly smaller when 2 different preschool height measures were used, instead of 1, i.e., 3.4 cm (P < 0.0001 for differences among the 3 groups) instead of 3.8 and 1.6 cm (P < 0.001) instead of 1.8, for girls and boys, respectively.

The prevalence of adult stunting was 5.2% among girls (18–23 y) and 6.7% among boys (≥20 y). Preschool stunting was a strong predictor of adult height status: the prevalence of adult stunting was 0.9, 1.1, and 15.8% among nonstunted, mildly stunted, and markedly stunted girls, respectively, (P < 10−4) and 0.5, 3.1, and 21.9% among the 3 categories of boys, respectively (P < 10−6). Thus, ~80% of subjects recovered from preschool stunting prior to adulthood.

The change in HAZ from preschool age to late adolescence was +0.86 ± 1.12, that is, +0.89 and +0.82 Z-scores for girls and boys, respectively (P > 0.10 for difference between sexes). It varied among groups of degree of preschool stunting (0.21, 0.90, and 1.79 Z-scores, and 0.31, 0.95, and 1.44 Z-scores, for girls and boys with no stunting, mild stunting, and marked stunting, respectively (P < 0.0001 for both)).

The correlations between HAZ in early childhood and in adulthood were 0.62 (P = 0.001) and 0.60 (P = 0.001) for girls ≥18 y and boys ≥20 y, respectively. The corresponding correlations for absolute height in childhood and adulthood were 0.46 (P = 0.001) and 0.49 (P = 0.001), respectively, for height correlations.

Preschool stunting, schooling and migration. Age at first migration was inversely associated with preschool height status in both sexes. In girls, the total duration of migration also varied according to the degree of preschool stunting: markedly stunted subjects tended to have the lowest durations (Table 4).

There was no association between stunting and school attendance in girls, but stunted boys were less likely to have reached secondary level, compared with other boys (P < 0.01). Maternal schooling was rare (~5%) and limited to primary level, but it was associated with a greater proportion of offspring with formal education: 44.0 and 32.0% with primary and secondary level, respectively, compared with 32.8 and 15.8%, respectively, for boys whose mother had no education (P < 0.01). However, there was no difference in preschool HAZ or degree of preschool stunting between children with educated and never-educated mothers (P > 0.20).

Migration in relation to the height increment. For girls, the mean height increment from early childhood to late adolescence varied with the total duration of migration to the city after adjusting for age and an independent measurement of preschool HAZ (Table 5). However, the relation was not linear; girls who never migrated to Dakar had increments similar to those of women who migrated for long durations, whereas those with a short duration of migration had the greatest increments. There was no relation between the height increment and age at first migration to Dakar (results not shown). Among boys, there was no association between the height increment and any of the migration variables. For both sexes, preschool HAZ was strongly and inversely correlated with height increment from childhood to late adolescence, but the association was strongest for girls (Table 5).

Discussion

This study examined linear catch-up growth following preschool stunting in rural West African children, and its relation to rural-to-urban migration for labor. When comparing children among groups of severity of preschool stunting, we found a rather limited catch-up of ~3 cm for females and 1.5 cm for males. Also, in contrast to our research hypothesis, a long duration of urban labor migration was not associated with greater linear catch-up.

The prevalence of preschool stunting (27.6%) in this population might seem modest but is far from trivial, given a mean maternal height of 160.7 cm. Indeed, in most Asian and Latin
American settings, mothers are considerably smaller, and small mothers constrain intra-uterine growth of their children independently of genetic growth potential. Therefore, maternal height is one of the main predictors of preschool stunting (26). The major strengths of this study lie in its large cohort of both males and females, together with a high follow-up rate (>70%) over a long time period. The demographic surveillance system greatly facilitated data collection in the rural area, whereas urban tracking of migrating subjects was quite cumbersome. Great care was taken to ensure high quality of anthropometric measurements: standardization sessions were organized regularly and high between-measurer and within-measurer agreements were obtained. The statistical phenomenon of regression toward the mean was controlled, and evidence of selective catch-up of the most stunted subjects persisted. The potential bias due to random errors in preschool height measurements was modest.

### Table 3: Characteristics of rural Senegalese women and men at the age of 18–23 y in relation to the degree of preschool stunting (1–5 y)

<table>
<thead>
<tr>
<th>Age in</th>
<th>Age in 2001–02, y</th>
<th>Degree of preschool stunting in females, n = 1456</th>
<th>Degree of preschool stunting in males, n = 1418</th>
</tr>
</thead>
<tbody>
<tr>
<td>18</td>
<td>1.4 ± 0.3</td>
<td>88.0 ± 5.4ab</td>
<td>81.0 ± 7.7ab</td>
</tr>
<tr>
<td>19</td>
<td>2.1 ± 0.5</td>
<td>79.5 ± 6.7</td>
<td>82.6 ± 7.7ab</td>
</tr>
<tr>
<td>20</td>
<td>3.1 ± 0.6</td>
<td>71.3 ± 7.1ab</td>
<td>75.1 ± 7.4ab</td>
</tr>
<tr>
<td>21</td>
<td>4.0 ± 0.6</td>
<td>63.2 ± 7.6ab</td>
<td>67.0 ± 7.8ab</td>
</tr>
<tr>
<td>22</td>
<td>4.8 ± 0.4</td>
<td>56.8 ± 6.0ab</td>
<td>64.3 ± 6.3ab</td>
</tr>
<tr>
<td>23</td>
<td>5.1 ± 0.4</td>
<td>57.0 ± 5.3ab</td>
<td>60.8 ± 6.9ab</td>
</tr>
<tr>
<td>All</td>
<td>3.4 ± 0.6</td>
<td>69.3 ± 12.1</td>
<td>72.0 ± 10.4</td>
</tr>
</tbody>
</table>

1 Values are means ± SD. Means in a row within a gender with superscripts without a common letter differ, P < 0.05.
2 Categories of stunting: none, HAZ > 1; mild, –2 < HAZ ≤ 1; marked, HAZ < –2.
3 NS, P ≥ 0.05.
4 The height increment was greater among the youngest subjects because they were also younger in 1983–84.
5 Height increments for all age groups pooled were adjusted for age (the prevalence of preschool stunting varied among age groups).

### Table 4: Characteristics of rural Senegalese women and men at the age of 18–23 y in relation to the degree of preschool stunting (1–5 y)

<table>
<thead>
<tr>
<th>Migrations to all destinations</th>
<th>Degree of preschool stunting in females, n = 1456</th>
<th>Degree of preschool stunting in males, n = 1418</th>
</tr>
</thead>
<tbody>
<tr>
<td>Any migration, P</td>
<td>99.0 ± 98.3</td>
<td>87.6 ± 82.1</td>
</tr>
<tr>
<td>Age at first migration, y</td>
<td>13.1 ± 2.8</td>
<td>16.1 ± 3.2</td>
</tr>
<tr>
<td>Number of migrations</td>
<td>5.7 ± 3.2</td>
<td>4.7 ± 3.4</td>
</tr>
<tr>
<td>Total duration of migration, y</td>
<td>5.3 ± 3.0</td>
<td>2.9 ± 3.1</td>
</tr>
</tbody>
</table>

1 Values of stunting: none, HAZ > 1; mild, –2 ≤ HAZ ≤ 1; marked, HAZ < –2. Values are (%) or means ± SD (adjusted for age).
2 P values with adjustment for age at follow-up study.
3 Maternal height data were missing for 220 girls and 229 boys (not collected during the first preschool round).
4 Subjects who had never migrated were excluded (i.e., 159 girls and 307 boys).
5 Subjects who had never migrated to Dakar were excluded (i.e., 238 girls and 784 boys).
6 Data were missing for 411 girls and 392 boys.
Continuous variables. 

$P = 0.0001$). This may be due to limited job 

$P = 0.0001$, 0.2. NS$2$

2nd tertile 67.4

$P = 0.0001$)

2nd tertile 67.7

Age at youth 3

Preschool HAZ$^d$ 3

<table>
<thead>
<tr>
<th>Variable</th>
<th>Grouping</th>
<th>Females</th>
<th>Males</th>
</tr>
</thead>
<tbody>
<tr>
<td>Migration duration$^1$</td>
<td>0</td>
<td>67.2</td>
<td>78.3</td>
</tr>
<tr>
<td></td>
<td>&lt;1st tertile</td>
<td>69.3</td>
<td>78.2</td>
</tr>
<tr>
<td></td>
<td>&lt;2nd tertile</td>
<td>67.4</td>
<td>78.5</td>
</tr>
<tr>
<td></td>
<td>=2nd tertile</td>
<td>67.7</td>
<td>77.6</td>
</tr>
<tr>
<td>Age at youth</td>
<td>3</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Preschool HAZ$^d$</td>
<td>3</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

1. Migration duration was a categorical variable in 4 classes: subjects who had never migrated to Dakar had a value of 0, and the remaining were divided into 3 classes based on sex-specific tertiles.

2. NS, $P = 0.05$.

3. Continuous variables.

4. Preschool height-for-age was computed from a height measurement independent of that used for the computation of height increment.

(2–4 mm) in analyses comparing catch-up growth among 3 

Several shortcomings limited the conclusions we were able to 

to early adolescence might prompt longer duration of migration 

 Among females. However, this hypothesis seems unlikely, insofar 

as girls who were tall in early childhood migrated earlier. A 

further limitation is that few data were available upon socio-

economic and other characteristics which may differ between 

girls migrating for short vs. long durations.

Recently, Cameron et al. (25) argued for the use of change in 

HAZ as the best indicator of linear catch-up, mainly because 

regression to the mean can be controlled using the correlation 

coefficient between HAZ at initial assessment and follow-up 

(25,27). According to this method, the expected HAZ in 

adolescence was $–0.78$ for girls and $–0.87$ for boys. Thus, 

observed mean adult HAZ ($–0.40$ for girls and $–0.46$ for boys) 

largely exceeded values expected from regression to the mean, 

which strongly suggests a “true” catch-up in height in this 

population relatively to the reference. Finally, if catch-up was 

defined as an adult HAZ above $–2$, then $~80%$ of stunted 

subjects achieved catch-up in this population.

Based on height increments, catch-up growth was better in 

girls than in boys. A previous study in this cohort, conducted 

during adolescence (11–17 y), had already shown some evidence 

of linear catch-up growth among the most stunted girls within 

the age group of 16–17 y [4–6 cm more than the nonstunted 

girls, $P < 0.05$ (7)]. We then hypothesized that the absence 

of catch-up among boys was due to the later pubertal growth spurt 

in males, but the present study suggests that Senegalese boys 

stunted in early childhood keep their height deficit relative to 

their nonstunted counterparts throughout life.

The mean age at menarche has been estimated at 16.1 y in 

this population, compared with 12.5 y among girls of African 

origin living in the U.S. (2). In the present sample, 6.9% of 

women <20 y had still not experienced menarche, and this 

proportion was larger for women stunted in early childhood. 

Also, in the WHO/NCHS reference, mean height of both girls 

and boys increase by 6 mm from 17 to 18 y of age (23). Thus, 

stricto sensu, all subjects in this study had not reached final 

height, especially men, who may well pursue linear growth 

beyond the age of 20. However, it seems unlikely that subjects 

stunted in early childhood could manage a substantial catch-up 

in height compared with their nonstunted counterparts after 

follow-up, given the limited amount of growth left.

In rural India, stunted girls also caught up to a much greater 

extent than boys, although none of them migrated during 

adolescence. Indeed, the height difference of 14.2 cm between 

the most and least stunted at age 5 y was reduced to 7.7 cm at 

age 18 y (28). Among males, the height difference was 14.8 cm at 

age 5 y vs. 9.7 cm at estimated final height (10). Therefore, these 

sex differences may be of biological origin.

Important sex differences existed for age at first labor migra-

tion, with girls starting to migrate several years earlier than boys 

(13.6 vs. 16.7 y, $P < 0.0001$). This may be due to limited job 

opportunities for male adolescents, but also to differences in 

schooling. The most stunted boys started secondary school mig-

ration later than other boys. This difference is probably explained 

in part by later enrollment of stunted children into primary school 

(29,30). In addition, in rural Guatemala and in the Philippines, 

preschool stunting had negative effects upon progress in school 

and intellectual achievement in young adults (1,30). Although mater-

nal schooling predicted the level of schooling in the offspring, it 

was not a confounder in the relation between preschool stunting 

and schooling, because preschool HAZ did not vary by maternal 

schooling. However, other factors may interact both with school-

ing and stunting in this population.

The main difficulty of this and similar studies lies in 

determining to what extent preschool height status is of genetic 

origin and to what extent it is due to undernutrition. Although 

variations among subpopulations with different growth poten-

tial were limited by the ethnic homogeneity of the present study 

population, it is clear that some of the height differences among 

the 3 groups of severity of preschool stunting could be explained 

by variations in genetic growth potential: in all populations,
including those free of childhood malnutrition, height during childhood is a strong predictor of adult height (24).

Therefore, a number of studies examine catch-up growth at the population level by comparing mean height of study subjects at various ages to an external reference population.

Using this approach, catch-up growth was partial in South Africa (31) and in Kenya (8), almost complete in Kenyan pastoralists (32) and in North American slaves of African origin (33), but it was absent in rural Gambia (4). In the present study, nearly complete catch-up was achieved at the population level, insofar as mean heights were only -2.5 cm below the NCHS reference for females aged 18–23 y and males aged 20–23 y. Also, the prevalence of stunting fell from 27% at ages 1–5 y to 6% in adulthood.

If partial catch-up growth is possible in stunted children, the mechanism remains to be clarified. Often, studies documenting catch-up growth also describe a delay in puberty which induce a prolongation of the growth period, thus providing an opportunity for stunted subjects to catch-up (34,35).

Conversely, a sudden improvement in living conditions, such as that experienced by third-world orphans adopted in Western countries, may hasten pubertal maturation and lead to extremely low final heights (36). It is commonly admitted that the 3-y decrease in age at menarche observed in European countries during the last centuries (37,38) is explained by the nutrition transition (2). Thus, it is possible that rural to urban migration in Senegal has similar effects on physical development and thereby reduces late growth. Indeed, in a previous study on a subsample of this cohort, i.e., female migrants aged 14–16 y, showed evidence of greater body mass index, subcutaneous fat, and more advanced sexual maturation than nonmigrants. Conversely, nonmigrants were taller by 1.6 cm in bivariate analyses (P < 0.05), and by 2.8 cm (P < 0.0001) if differences in sexual maturation were adjusted for, although they had similar heights at the age of 11–12 y, prior to migration (16).

Female migrants in Dakar work as maids in better-off urban households for an average of 10 h/d and eat the same food as their employer (16). Thus, fat and meat intakes are likely to be much greater than in the rural areas. Conversely, they have greater energy expenditures, more physical activity, and less sleep than their rural counterparts (15). Such living conditions may not be beneficial for linear growth.

Markedly stunted girls migrated nearly as often as other girls, but the duration of migration was lower, and thus each migration episode was shorter. It is possible that stunted girls were unable to sustain the requirements inherent in urban jobs for as long as other girls. In the village, female adolescents also have high work loads, but their mothers allow them to rest more often than do urban employers (15).

In conclusion, catch-up growth of children stunted at preschool age existed at the individual level, but differences in mean height were reduced by a modest 3 cm in girls and 1.5 cm in boys. At the population level, almost complete catch-up to the WHO/NCHS reference was achieved by the age of 20–22 y. There was no evidence that migration to urban areas might hasten puberty or delay sexual maturation, i.e., hastening the completion of sexual maturation and the end of the period of linear growth with possible negative consequences on adult height and fat-free mass. In addition, more information is needed upon the reversibility of functional outcomes of stunting (e.g., low muscle mass, obstetric complications, birth weight of offspring) in case of catch-up growth during adolescence.

Acknowledgments

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Literature Cited


