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Rapid Change in Height and Body Proportions of Maya American Children

B. BOGIN,[1]* P. SMITH,[2] A.B. ORDEN,[3] M.I. VARELA SILVA,[1] AND J. LOUCKY[4]
[1]*Department of Behavioral Sciences, University of Michigan-Dearborn, Dearborn, Michigan*
[2]*Department of Social Sciences, University of Michigan-Dearborn, Dearborn, Michigan*
[3]*Centro de Investigaciones en Genética Básica y Aplicada (CIGEBA)-Universidad Nacional de La Plata and Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Argentina.*
[4]*Department of Anthropology, Western Washington University, Bellingham, Washington*

ABSTRACT Maya families from Guatemala migrated to the United States in record numbers from the late 1970s to the early 1990s. Births to Maya immigrant women have created a sizable number of Maya American children. The height and sitting height of 5 to 12 years children (n = 431) were measured in 1999 and 2000. Leg length was estimated and the sitting height ratio was calculated. These data were compared with a sample of Maya children living in Guatemala measured in 1998 (n = 1,347). Maya American children are currently 11.54 cm taller and 6.83 cm longer-legged, on average, than Maya children living in Guatemala. Consequently, the Maya Americans have a significantly lower average sitting height ratio (i.e., relatively longer legs in proportion to length of the head and trunk) than do the Maya in Guatemala. These results add support to the hypothesis that both the height and body proportions of human populations are sensitive indicators of the quality of the environment for growth. Am. J. Hum. Biol. 14:753–761, 2002.

The purpose of this article is to report changes in the stature and body proportions of Maya American children and to test the hypothesis that human body proportions are sensitive indicators of the quality of the environment for growth. Anthropologists, human biologists, and economic historians use the average stature of a population as a sensitive indicator of the quality of life (Tanner, 1986; Komlos, 1994; Steckel, 1995; Bogin and Keep, 1999). There is less agreement about the use of body proportions in a similar manner. Some researchers suggest that genetic factors are relatively more important than environmental factors as determinants of body proportions (Malina et al., 1987; Martorell et al., 1988; Prathmanathan and Prakash, 1994; Yun et al., 1995; Cheng et al., 1996). To be sure, interindividual differences in proportions are under considerable genetic influence (Livshits et al., 2002). Less clear is the extent to which genetic and environmental variables influence population variation in body proportions (Bogin et al., 2001).

In support of strong genetic influence is a review of the literature by Eveleth and Tanner (1990, p. 186), who compared the body proportions of four geographic groups, African Americans, Australian Aborigines, Asians from Hong Kong, and Europeans from Bergen, Norway. Holding sitting height constant, the African American and Australian samples had the longest legs. The authors concluded that as the African Americans and Australians live under generally poorer environmental conditions than the Hong Kong and Bergen samples, the "... differences are certainly genetic in origin, for better environmental circumstances appear to produce relatively longer, not shorter legs."

Other researchers note that the quality of the nutritional and health environment impacts body proportions. Leitch (1951) was, perhaps, the first to propose that a ratio of leg length to total stature might be a good indicator of nutritional history and health. Noting the well-known cephalo-caudal gradient in growth, Leitch (p. 145) wrote that, "... it would be expected on general principles that children continu-

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*Correspondence to: Barry Bogin, Department of Behavioral Sciences, University of Michigan-Dearborn, Dearborn, MI 48128. E-mail: bbogin@umich.edu

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ously underfed would grow into underdeveloped adults... with normal or nearly normal size head, moderately retarded trunk and relatively short legs." Reviewing the literature available at the time, Leitch found that improved nutrition during infancy and childhood did indeed result in a greater increase in leg length than in total height or weight. Longer-legged children were also less susceptible to bronchitis, which was then a scourge of poorly fed children.

Many studies support Leitch's findings and hypothesis (Thomas and Duncan, 1954; Wolanski, 1979; Ramos Rodriguez, 1981, 1990; Tanner et al., 1982; Malina et al., 1985; Buschang et al., 1986; Dickinson et al., 1990; Gurri and Dickinson, 1990; Murgui et al., 1990; Bolzan et al., 1993; Wolanski et al., 1993; Siniarska, 1995; Wolanski, 1995; Jantz and Jantz 1999). In a recent article Frisancho et al. (2001) emphasized the environmental effects in a study that noted that leg length of Mexican Americans aged 2–17 years old was significantly associated with socioeconomic status of their families. Individuals from better-off families had significantly longer legs, but equal trunk length, compared with boys and girls from poorer families. Dangour (2001) reported similar findings for two tribes of Amerindian children living in Guyana. The tribes were both of low socioeconomic status, but differed markedly in quality of living conditions. Children in the tribe with better living conditions were taller than age-mates in the other tribe. The difference in stature was due almost entirely to differences in leg length, as there were no significant differences in sitting height between the tribes.

To summarize this brief review of the literature, Norgan (1998) presents evidence that leg length, head shape, and other aspects of body shape are determined by a complex interaction between environmental and genetic factors. This study attempts to understand more precisely the role of these factors.

MATERIALS AND METHODS

Since 1992 we have studied the growth of Maya children living in the United States (Bogin, 1995; Bogin and Loucky, 1997; Bogin et al., 2001). These children are the offspring of Maya adults who emigrated from Guatemala, mostly firom the late 1970s to the early 1990s. All of the adult Maya refugees were born in Guatemala and prior to migration most lived in rural villages in the Q'anjob'al-speaking language area (northwest Guatemala highlands). We include here data for the height of children measured in 1992, called the USA-1992 sample (n = 211, sitting height was not measured in 1992). About 50% of the children in the 1992 sample were born in the US and the remainder were born in Guatemala or Mexico. All had lived for years in the US and there was no significant difference in height between those born in the different countries.

A new study of the growth of Maya children in the US was carried out in 1999 and 2000. This new sample is called USA-2000. The height, weight, and sitting height of 458 Maya American boys and girls 2–16 years of age were measured. Age was verified from school records in Indiantown, Florida, or from interviews with parents and close relatives in Los Angeles. Age in years and decimals of the year were calculated by subtracting the child's birth date from the measurement date. There were too few individuals younger than 5.00 years or older than 12.99 years for statistical analysis. Thus, the analysis is limited to 431 Maya American children, 5.00–12.99 years (204 boys and 227 girls). Of the 431 subjects, 93% were born in the US.

The USA-2000 sample includes children living in Indiantown, Florida (a rural community, n = 329), and Los Angeles, California (n = 102). The history of these communities and the biocultural environment of the refugees have been reported in detail elsewhere (Ashbranner and Conklin, 1986; Burns, 1989, 1993; Loucky, 1993, 1996; Bogin, 1995; Bogin and Loucky, 1997).

In Florida, adult Maya work as day laborers in agriculture, landscaping, construction, childcare, or in other informal sector jobs. Some Maya work as teacher aids, nursing aids, or have opened small businesses such as grocery stores. Still, almost all of the Maya families in Indiantown are of low SES by US standards. All of the Maya American children in the sample qualify for free breakfast and lunch programs at the schools they attend. In Los Angeles, most of the Maya over the age of 15 toil for 50 or more hours a week doing low-wage manual sewing work in the sweatshops of the garment district (Loucky, 1993). A few Maya have established their own sewing shops and some are beginning to work as paraprofessionals (such as nursing aides), as community development officers, or as skilled workers (hairdresser, electronic technicians). Based on ethnographic work in Los Angeles, it is clear that the Maya families are comparable in SES to the Maya families of Indiantown, i.e., of generally low SES, with many families below the US poverty line.

For comparison, a sample of Guatemalan Maya schoolchildren (n = 1,347), measured in 1998 by an anthropometric team from Spain (Luis Rios of the Universidad Autónoma de Madrid kindly supplied these data), is also considered. The Guatemala Maya sample is referred to as GUATE-1998. Birth dates and ages of these children were verified from school records of birth certificates and personal identification cards. These children lived in the rural agricultural and fishing communities of La Unión, Simajuleu, Yulba, San Juan, San Bartolomé, and Cantón Dolores. These Maya communities are of very low SES. Furthermore, basic human services, such as health care, safe drinking water, and supplementary food programs for women, infants, and children, are either very limited or totally absent. The growth status of these children shows evidence of negative effects from moderate undernutrition and infectious disease. This is not surprising, as the entire nation of Guatemala suffered a major economic crisis in the late 1980s to mid-1990s. This crisis lead to sharp declines in food availability and a steep rise in food prices. The economic and nutritional problems were exacerbated by a cholera epidemic in the 1990s (Bogin and Keep, 1999).

Thus, the Maya American samples, although of low SES for the US, live under much more favorable conditions for growth and development than do the Maya sample in Guatemala. The Maya American children benefit from safe drinking water, medical screening at the schools, medical care in their communities, and supplementary feeding programs. The parents of the Maya American children were able to capitalize on the economic prosperity in the US of the 1990s via relatively steady employment. Their wages afforded them a higher quality of material and social lifestyle than is available to most Maya families in rural Guatemala.

Measurements

The height and sitting height of each child were measured following standard procedures (Cameron, 1984). Two well-trained anthropometrists, who worked as a team to ensure accuracy and reliability, measured the Maya in the US. No formal test of reliability was conducted. Leg length was estimated by subtracting sitting height from stature. Relative leg length was estimated as the sitting height ratio [(sitting height/stature) × 100]. The sitting height ratio expresses the percent contribution of sitting height—the length of the head, neck, and trunk—to total stature (Martin et al., 1988). The sitting height ratio decreases with age, as the legs grow relatively faster than the head and trunk. In practice, this ratio is most often used as an indication of body proportion differences between individuals or populations.

Analysis

The USA-2000 data were initially analyzed for differences between boys and girls, and between the Los Angeles and Indiantown samples. There were no statistically significant differences by sex across the ages 5–12 years in the anthropometric variables. At ages 10–12 years, girls were, on average, taller than boys. The interest in this study, however, is not this well-known sex difference in height. Furthermore, we test the hypothesis about growth and environmental quality using z-scores, which standardize the raw measurements by age and sex. Hence, the data for boys and girls were combined in all subsequent analyses.

There were no significant differences between the Indiantown and Los Angeles groups (boys and girls combined) for height or leg length, but the two groups differed in sitting height (Indiantown mean = 69.83 cm; Los Angeles mean = 67.76 cm) and the sitting height ratio (Indiantown mean = 54.94; Los Angeles mean = 54.08). This probably reflects chance variation. For comparisons of body proportion with the GUATE-1998 sample, the Indiantown and Los Angles samples were combined into a single USA-2000 sample to increase sample size and allow focus on the hypothesis of environmental quality effects on stature and body proportions between Maya in Guatemala and in the US.

The data for height, sitting height, and sitting height ratio were standardized as z-score deviations from the 50th centile of the NHANES I and II reference data for the US (Frisancho, 1990). These reference data were chosen because they are a nationally representative sample for the US and are readily available to serve as a baseline for comparison with the Maya samples. The reference data for the total NHANES sample, which includes data for boys and girls of "White" (n = 35,931), "Black" (n = 7,125), and "other" (n = 718) ethnic groups, were used. Frisancho (1990) notes that these data were weighted by sample size according to the recommendations of the National Center for Health Statistics.

Multiple regression analysis was used to statistically assess the effects of the independent variables of AGE and GROUP (USA-1992, USA-2000, GUATE-1998) on each of the anthropometric dimensions (dependent variables). AGE was calculated as whole year groups; for example, AGE 5 includes children from 5.00–5.99 years old. The GROUP categories were organized into two bivariate dummy variables. The variable "USA-2000" was assigned the code "1" if a subject belonged to that group or "0" if not a member of that group. The variable "USA-1992" was assigned the code "1" if a subject belonged to that group or code "0" if not a member of that group. The Maya children in Guatemala (GUATE-1998) served as the reference group. The regression formula for height was specified as follows:

$$\text{height} = B_1 + B_2\text{AGE} + B_3\text{USA-2000} + B_4\text{USA-1992} + \varepsilon$$

The values of the B_3 and B_4 coefficients are the average difference in height between the USA-2000 or USA-1992 and GUATE-1998 samples, respectively. Similar regression formulas were used for sitting height, leg length, and the sitting height ratio, except that no term for the USA-1992 sample was included, as these variables were not measured in 1992. Between-group post-hoc comparisons by age were made by means of the "Tukey Honest Significant Difference for Unequal N."

RESULTS

Sample sizes by age and sex are given in Table 1 for the USA-1992, USA-2000, and GUATE-1998 cohorts. Means and standard deviations by sample and age for each anthropometric variable are given in Table 2. Figures 1–3 show the mean z-scores for height, sitting height, and the sitting height ratio for each sample of Maya children. The "0.00 line" represents the NHANES reference. Frisancho (1990) did not report reference data for leg length. The sitting height ratio, however, provides the essential information for leg length—lower ratios indicate relatively longer legs.

Results of the regression analysis and post-hoc tests of significance for the mean z-score values indicate that compared with

TABLE 1. Number of Maya children (boys and girls) by age for the combined Indiantown and Los Angeles samples measured in 1992 (USA-1992) and in 1999–2000 (USA-2000), and Guatemala (GUAT-1998) samples

	USA-1992		USA-2000		GUAT-1998	
Age, years	Boys	Girls	Boys	Girls	Boys	Girls
5	22	15	14	21	4	1
6	18	21	30	35	85	68
7	9	16	32	41	102	96
8	13	10	38	37	102	122
9	15	11	39	46	95	99
10	11	11	33	26	103	109
11	12	13	11	16	80	95
12	9	5	7	5	93	99
Totals	109	102	204	227	664	689
Grand total	211		431		1353	

In 1992 the number of Maya children measured in Indiantown and Los Angels were 100 and 111, respectively. In 1999–2000 the number of Maya children measured in Indiantown and Los Angeles were 329 and 102, respectively.

TABLE 2. Means (M) and standard deviations (SD) in Maya samples

	USA-1992		USA-2000		GUATE-1998	
Age, years	M	SD	M	SD	M	SD
Height						
5	111.3	6.1	111.5	6.0	102.2	2.8
6	113.2	4.4	115.8	4.7	105.0	5.3
7	118.5	6.6	119.7	5.4	109.3	5.8
8	124.1	5.6	126.5	6.1	116.1	5.7
9	131.0	7.2	133.1	7.5	120.6	7.0
10	133.7	7.1	137.7	7.2	125.1	6.2
11	138.1	8.4	142.5	5.6	129.8	7.0
12	139.7	4.1	147.1	7.4	134.7	7.2
Sitting height						
5	—	—	63.3	3.4	60.2	1.2
6	—	—	64.1	2.6	59.9	2.6
7	—	—	66.4	3.0	62.0	2.9
8	—	—	69.1	3.1	64.9	2.7
9	—	—	72.2	3.8	66.8	3.5
10	—	—	73.8	3.7	68.9	3.0
11	—	—	76.3	3.1	71.0	3.4
12	—	—	77.7	4.3	73.0	3.6
Leg length						
5	—	—	48.2	9.1	42.0	2.2
6	—	—	51.7	2.9	45.0	3.4
7	—	—	53.4	3.4	47.4	3.6
8	—	—	57.4	3.8	51.2	4.0
9	—	—	60.9	4.4	53.8	4.9
10	—	—	63.9	4.4	56.2	4.0
11	—	—	66.3	3.3	58.8	4.6
12	—	—	69.4	5.4	61.6	4.6
Sitting height ratio						
5	—	—	56.9	1.7	58.9	1.2
6	—	—	55.4	1.3	57.1	1.5
7	—	—	55.4	1.5	56.7	1.5
8	—	—	54.6	1.4	55.9	1.8
9	—	—	54.2	1.3	55.5	2.2
10	—	—	53.6	1.4	55.1	1.4
11	—	—	53.5	1.1	54.8	1.6
12	—	—	52.8	2.0	54.3	1.5

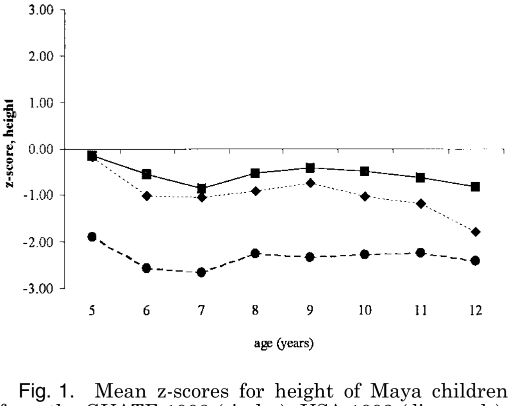

Fig. 1. Mean z-scores for height of Maya children from the GUATE-1998 (circles), USA-1992 (diamonds), and USA-2000 (squares) samples compared with the NHANES II reference means.

the NHANES reference, all of the Maya samples are shorter in stature and have relatively shorter legs. For sitting height, the GUATE-1998 sample is shorter than the NHANES reference, but the USA-2000 sample does not differ significantly from the reference at any age.

Comparing Maya children living in the US to Maya living in Guatemala, both the USA-1992 and the USA-2000 are significantly taller at all ages than the GUATE-1998 (Fig 1). The USA-1992 and USA-2000 samples of Maya do not differ significantly in height at any age. However, there is an increasing disparity in height after age 9 years. The USA-2000 sample is significantly larger in sitting height than the GUATE-1998 sample at all ages except 5 years (Fig. 2). The USA-2000 sample has relatively longer legs (a significantly smaller sitting height ratio) than the GUATE-1998

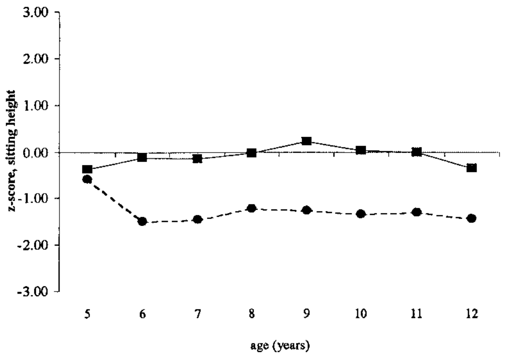

Fig. 2. Mean z-scores for sitting height of Maya children from the GUATE-1998 (circles) and USA-2000 (squares) samples compared with the NHANES II reference means.

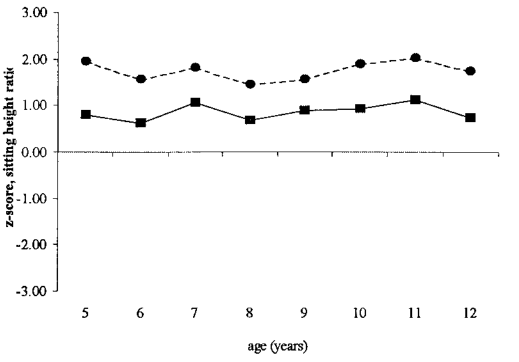

Fig. 3. Mean z-scores for sitting height ratio of Maya children from the GUATE-1998 (circles) and USA-2000 (squares) samples compared with the NHANES II reference means.

TABLE 3. Regression summary for the dependent variables height, sitting height, leg length and sitting height ratio

Height
R = 0.845 R^2 = 0.715 Adjusted R^2 = 0.714 F(3, 1984) = 1656.5 P < 0.000 Std. Error of estimate: 6.38

	Beta	St. Err. of beta	B	St. Err. of B	t(1984)	*p*-level
Intercpt			75.28	0.68	109.71	0.00
AGEC	0.84	0.01	4.98	0.07	67.85	0.00
USA2000	0.40	0.01	11.54	0.36	32.01	0.00

Sitting height
R = 0.797 R^2 = 0.636 Adjusted R^2 = 0.635 F(2,1777) = 1550.2 P < 0.000 Std. Error of estimate: 3.32

	Beta	St. Err. of beta	B	St. Err. of B	t(1777)	*p*-level
Intercpt			46.75	0.38	122.39	0.00
AGEC	0.79	0.02	2.21	0.04	53.85	0.00
USA2000	0.37	0.02	4.77	0.19	25.42	0.00

Leg length
R = 0.800 R^2 = 0.650 Adjusted R^2 = 0.640 F(2,1771) = 1571.6 P < 0.000 Std. Error of estimate: 4.27

	Beta	St. Err. of beta	B	St. Err. of B	t(1771)	*p*-level
Intercpt			27.89	0.50	56.39	0.00
AGEC	0.78	0.02	2.84	0.05	53.43	0.00
USA2000	0.41	0.01	6.83	0.24	28.19	0.00

Sitting height ratio
R = 0.464 R^2 = 0.215 Adjusted R^2 = 0.215 F(2,1771) = 243.06 P < 0.000 Std. Error of estimate: 1.92

	Beta	St. Err. of beta	B	St Err. of B	t(1771)	*p*-level
Intercpt			60.01	0.22	270.73	0.00
AGEC	−0.44	0.02	−0.49	0.02	−20.48	0.00
USA2000	−0.27	0.02	−1.35	0.11	−12.43	0.00

sample at all ages except 11 and 12 years (Fig. 3). The lack of statistical significance at these ages may be an artifact, as the absolute difference in the mean values is about equal to that at the other ages.

An important difference in body shape between the USA-2000 and GUATE-1998 samples is more precisely apparent in the regression analysis (Table 3). The regression coefficients ("B") indicate that the USA-1992 sample is, on average, 8.9 cm taller than the GUATE-1998 sample. For the USA-2000 sample, the height difference increases to an average of 11.54 cm. For sitting height, the GUATE-1998 sample averages 4.77 cm less than the USA-2000 sample, while for leg length the difference is 6.83 cm (59% of the total height difference). The average difference in sitting height ratio is −1.35 units. Based on these values, it is clear that the Maya living in Guatemala have a deficit in absolute and relative leg length that is greater than their deficit in sitting height. Stated another way, one effect of growing up in the US on the Maya American children is that they are significantly taller than Guatemala Maya children and the effect on leg length is absolutely greater than the effect on sitting height.

The z-scores analysis shows that a difference in body shape is also found for the Maya Americans compared with the NHANES reference sample. The Maya Americans are shorter in stature at all ages, and the difference is due entirely to shorter leg length, as the two groups are virtually equal in sitting height.

DISCUSSION

This study of Maya youth age 5–12 years supports the hypothesis that body proportion, especially leg length relative to stature, is a sensitive indicator of the quality of the environment. The Maya American samples are, in many ways, intermediate in quality of life between the very low SES Maya sample from Guatemala and the nationally representative sample of the NHANES. The Maya American children are intermediate in terms of stature. Given this, the increase in stature and the change in body proportions of the Maya Americans can be ascribed to improvements in the quality of life in the US. As noted earlier, improvements include safe drinking water, health care, and nutritional supplementation. Indeed, historical research supports this interpretation. Jantz and Jantz (1999) studied changes in longbone lengths and proportions from several large American skeletal collections. The life dates of the skeletons ranged from the years 1800 to 1970 and the samples included skeletons of men and women identified as ethnically Black and White. As expected, there was a general positive trend over time toward increased bone length for men and women of both ethnic groups. The more important finding was that the lower limb bones increased in length more than the upper limb bones, and the distal leg bones (tibia and fibula) increased in length at a faster rate than the the femur. Jantz and Jantz (1999) also noted that the overall increase in bone length was associated with improvements in the nutritional and health environments in which the people lived.

A reanalysis of the Carnegie Survey of Diet and Health in Britain, conducted from 1937–1939, shows that socioeconomic conditions affected leg length significantly more than they did trunk length in the children of the survey (Gunnell et al., 1998). A more recent survey in England in 1995–1996 finds that stature increased in the past 30 years and that the whole of the increase was in leg length and not sitting height (Dangour et al., 2002). The increase in leg length is believed to be large enough to warrant the creation of new reference curves for the British population. The increase in leg length was ascribed to the general rise in the standard of living.

The Maya Americans still have relatively shorter legs than the NHANES reference. This may reflect a genetic predisposition of the Maya to a more compact body shape than found in American Whites and Blacks of the NHANES sample. Alternatively, further improvements in the quality of life for future generations of Maya Americans may result in continued lengthening of the legs. Only additional research will definitively answer this question. Neverthless, no genetic explanation is needed to account for the rapid change in height and body proportion of the Maya American children. They are the offspring of Maya parents who migrated to the US within the last 20 years. This is too little time for any important genetic change between the parental and offspring generations. Indeed, the 8.9 cm average increase in stature of the Maya-1992 sample and the 11.54 increase of the USA-2000 sample over Maya in Guatemala are, perhaps, the largest such increases ever recorded for migrants (Boas, 1912; Bogin, 1988, 1999). A change in stature of this magnitude in less than one generation is unlikely to have any genetic basis. The change in stature is a testament to the dreadful conditions for growth that existed in Guatemala and Mexico prior to the arrival of the Maya migrants to the US.

Selective migration for healthier or taller Maya adults is not a likely factor either. The absence of phenotypic selective migration is shown in many studies of Mexican and Central American migrants to the United States (Bogin, 1988). The parents of the Maya American children were forced to flee Guatemala by civil war, economic crisis, and a cholera epidemic. These "push" factors forced all the residents of many rural Guatemalan villages to migrate, meaning that there was no selection for certain biological "types."

In a review of secular trends in human growth, Stinson (2000) finds that increases in leg length have been generally greater than trunk length. Because positive secular trends are ongoing in many populations, it is not known how worldwide variation in body proportions will change in the future. The specific ecological factors, such as specific nutrients, pathogens, meteorological conditions, or patterns of physical activity which influence the expression of body shape are not known. It is also not known how these ecological factors interact with the genome (Bogin et al., 2001). Accordingly, Stinson (2000) advocates the use of more sophisticated research to study the regulation of body proportions. This new research must make use of well-defined, bioculturally valid samples of people and the independent variables that may influence their body proportions.

This study of Maya children living in the US and in Guatemala is a step toward the type of research advocated by Stinson (2000). The migration of Maya refugees to the US breaks the cycle of extreme deprivation into which most Guatemalan Maya are born. In the US, Maya children and their families are still of low economic status, but the political economy of the US offers economic, nutritional, educational, and public health benefits unavailable to most Maya in Guatemala. This seems to result in the rapid increase of stature and change to a relatively longer-legged body shape.

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