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Longitudinal Principal Components Analysis of Patterns and Predictors of Growth in Guatemalan Children

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ABSTRACT Longitudinal principal components (LPC) analysis was used to assess growth patterns in children from rural Guatemala in order to determine if this methodology could provide additional information regarding correlates of growth compared to more traditionally used methods based on attained size and increments. LPC analysis reduces measures at many points in time into a few parameters. However, LPC analysis requires complete data, and many cases may be lost due to missing values. Thus the potentially greater sensitivity of LPC analysis should be weighed against the reduced power resulting from smaller sample sizes. Component indices representing centile level and centile shift, attained size, and 3 to 36 month increments of growth in length and weight were used as the dependent variables in multiple regression models in order to examine the effects of environmental variables, such as home dietary intake, supplementation, and prevalence of diarrhea on growth. Regardless of which growth index, i.e., attained size, incremental change, or principal component, was used, regression results were similar; higher nutritional intakes were generally associated with greater and more rapid growth from birth to age 3 years. The possible advantages of LPC analysis over more traditional methods were not great; therefore, LPC analysis is not recommended as the method of choice in this population.

This research explores the usefulness of longitudinal principal components (LPC) analysis in understanding the correlates of growth in a population of a developing country, and compares these results with more traditional growth indices, attained size and increments, generally used in this type of research. Traditional methods used in growth research, particularly in the context of developing countries, have generally entailed the use of outcome measures such as attained size at the end of the age interval of interest (e.g., height at 3 years of age) or the increment of growth over this time period (e.g., height at 3 years minus length at birth). By virtue of being simple, these approaches are understandable to a wide range of audiences, including clinicians and public health personnel. However, neither of these methods takes full advantage of the longitudinal nature of growth data, since they directly incorporate only one or two points in time. Attained size provides information about a child's relative status at the end of the interval, but provides little information about how he or she got there. Although increments can shed some light on growth patterns, much information is still lost if the interval under consideration either is large or is a period during which growth velocity changes markedly. In addition, measurement error for increments may be large relative to interindividual variability (Martorell et al., 1975), whereas measurement error for components should be less by definition (Berkey and Kent, 1983).

LPC analysis has been used effectively to summarize and characterize certain growth patterns in height and weight in children from developed countries (Berkey and Kent, 1983; Cronk and Reed, 1981; Cronk et al.,

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1982). In each case, analyses yielded a first component that lent itself to interpretation as a "size" or "centile level" component and a second component that seemed to characterize a "centile shift." In other words, individuals with the highest positive scores on the first component were larger children; those with extreme scores for the second component tended to cross centiles upward (positive scores) or downward (negative scores) during the age interval at a relatively faster rate than their peers. Although these first and second components are not directly comparable to attained size and increments, respectively, they do appear to be similar in some important respects. Attained size is a general measure of a child's centile level. In addition, if a child's second component, or centile shift, is negative, one would generally expect his or her growth increment to be small over the given time period; if the child shifted centiles upward, a larger increment would be expected.

Most longitudinal studies experience at least some attrition resulting in missing data. If outcome measures such as attained size or increments are used to assess growth, relatively few cases may be lost to the analyses due to missing data points, given that the number of data points needed for these indices is only one or two, respectively. Principal components analysis, on the other hand, requires complete data. If any point in the given time interval is missing, the entire case is lost. Thus, whereas longitudinal principal components analysis may potentially be more sensitive than the traditional indices, in practice this sensitivity may be outweighed by the reduction in sample size.

Longitudinal data from birth to age 3 years from a nutrition intervention study conducted in rural Guatemala provided an ideal opportunity to investigate patterns of growth, since a number of adverse factors, including chronic undernutrition and high rates of infectious illness, are endemic to the areas studied. In addition, the beneficial effects of the nutritional supplementation on growth could be explored in light of these stresses.

MATERIALS AND METHODS

Sample

Data collected between January, 1969, and September, 1977, from a food supplementation experiment conducted by the Institute of Nutrition of Central America and Panama (INCAP) were used for these analyses (Martorell et al., 1982). This longitudinal study enrolled individuals from four poor Spanish-speaking villages in eastern Guatemala. Chronic protein-energy malnutrition was endemic in all villages, and rates of respiratory and gastrointestinal infection were high.

In two of the villages, pregnant and lactating mothers and their children up to the age of 7 years had access to a high-protein/high-energy supplement called "atole." It contained Incaparina (a commercial mixture of vegetable proteins available in Guatemala), dry skim milk, and sugar and provided 6.1 g protein and 91 kcal/100 ml. The other two villages received a low-energy cold liquid called "fresco," which contained flavoring agents, a small amount of sugar, and no protein and provided 33 kcal/100 ml. Beginning in 1971, both beverages contained similar concentrations of vitamins and minerals. The nutrient composition of the two supplements has been previously reported (Martorell et al., 1982). The supplement was provided at a fixed locale under the care of trained observers on a daily basis, with distribution twice per day, 7 days per week. Subjects were given supplement in 180 ml cups and were free to consume as much as they wished at each visit. Consumption of the supplement was measured to the nearest 10 ml. As reported in earlier publications (Martorell et al., 1979), about 10 kcal of supplement displaced 1 kcal of the home dietary intake. This level of replacement is quite small and is more than compensated for by the supplement intake.

These analyses included all infants enrolled in the study from birth and whose 36 month examination had been completed by September, 1977. Measurements of recumbent length and weight were taken at 3 month intervals until 2 years of age and at 6 month intervals from 2 to 3 years of age using standard methods (Gordon et al., 1988). Recumbent length was measured to the nearest millimeter using a standard measuring table, and weight was taken to the nearest 0.01 kg using a beam balance scale. Technical intraobserver errors estimated during quality control sessions were 0.42 cm for supine length and 0.29 kg for weight (Martorell et al., 1975).

Growth indices

Standardized factor scores from the LPC analyses, attained size at 36 months, and increments of growth from 3 to 36 months (e.g., length at 36 months minus length at 3 months) in length and weight were used to summarize growth patterns. As with standard principal components analysis, the central purpose of LPC analysis is to reduce a data set with many variables to a smaller set of variables (principal components) that summarizes the most important information in the original data. Scores for these principal components can be computed for each subject and used in further analyses. In the specific case of LPC analysis, information about patterns of growth for a single anthropometric variable measured at various points in time is summarized in the principal component scores.

LPC analysis requires a complete data set for each individual. Because missing observations at 15 and 21 months were considerably more frequent, only data for 3, 6, 9, 12, 18, 24, 30, and 36 months were used. Linear interpolation was used to estimate missing values for individuals with one missing length and/or weight value between 6 and 30 months of age. Those with two or more missing values or with values missing at the beginning or end of the age series (i.e., 3 or 36 months) were excluded from the analysis.

The SAS Princomp program (principal factoring without iteration or rotation) was used for the analyses (SAS, 1987). Two separate analyses, one for recumbent length and one for weight, were conducted. Because the component loadings did not differ by gender, analyses for genders combined are presented.

Independent variables

The effects of environmental variables, including supplement intake (SUPP), home dietary intake (HDIET), and prevalence of diarrhea (PDIAR), on growth were analyzed by means of multiple regression. Each variable was constructed to represent the experience of the child over the full age interval from 3 months to 3 years. For example, average daily energy intake of supplement (kcal/day) (SUPP) was computed for the 3 years of observation. Because of extreme collinearity between kilocalories of energy and grams of protein in the supplement, the latter was not used in this analysis. In addition, high collinearity was evident between SUPP and maternal supplement intake during lactation. Therefore, maternal intake of supplement was also excluded from the analysis. All possible interactions were considered and significant interactions were included in the final models.

Birth weight (BW) and gestational age (GAGE) were used as covariates in the analyses because some low-birth-weight and premature infants were included in the sample. In addition, the inclusion of these variables served as a control for the effects of maternal supplementation during pregnancy. BW was measured in grams within 24 hr of birth using a beam balance scale. GAGE was determined prospectively as weeks from mother's last menstrual period.

Home dietary intakes and illness histories were collected through frequent home visits. Average energy intake (kcal/day) from the home diet (HDIET) was estimated from 24-hr recall surveys taken at 3-month intervals from 15 to 36 months. Enumerators interviewed mothers in the home every 2 weeks regarding morbidity symptoms in their children. The percentage of days on which the child experienced diarrheal infection during the first 3 years of life was used as an indicator of morbidity (PDIAR).

RESULTS

Longitudinal principal components

The sample included in the LPC analysis represented 45% of 1,053 children who participated in the study from birth to age 3 years (n = 478, 230 from fresco and 248 from atole villages). If attained size at 3 years had been used to assess growth, the study sample would have consisted of 880 (84% greater). For 3–36 month increments, the sample size would have been 507 (6% greater).

Retention of components was based on whether a biological interpretation of the component was possible and on statistical criteria. Although eigenvalues were less than 1.0 (a commonly used retention criteria) for the second components, they were easily interpretable and added important information (Cronk and Reed, 1981).

Table 1 presents eigenvalues, percent of variation explained, and eigenvector loadings for the LPC analyses for each of the anthropometric variables. Two components each for length and weight were retained. For length, the two components (PCHT1 and PCHT2) explained 82.4% and 9.1% of the variation, respectively, and, for weight, the two components (PCWT1 and PCWT2) explained 78.6% and 11.2% of the variation, respectively. For the two first components (PCHT1 and PCWT1), loadings were similar at each age

TABLE 1. Eigenvalues, percent variation explained, and age-specific eigenvector loadings for longitudinal principal components analysis of length and weight from 3 to 36 months of age (n = 478)[1]

	PCHT1	PCHT2	PCWT1	PCWT2
Eigenvalue	6.59	0.73	6.29	0.90
percent variation	82.42	9.09	78.56	11.24
Age (months)				
3	0.306	−0.602	0.314	−0.486
6	0.350	−0.398	0.351	−0.425
9	0.367	−0.203	0.366	−0.287
12	0.369	−0.111	0.369	−0.158
18	0.365	0.141	0.368	0.152
24	0.365	0.296	0.359	0.363
30	0.353	0.387	0.350	0.424
36	0.349	0.410	0.349	0.375

[1]PCHT1, PCWT1 = first components for length and weight; PCHT2, PCWT2 = second components for length and weight.

interval (about 0.30–0.39); for the second components (PCHT2 and PCWT2), loadings generally increased across the entire age range from relatively high negative values to relatively high positive values.

The patterns of growth represented by the components are most easily illustrated by the growth curves of children with extreme scores on these components. Figures 1 and 2 show average curves of growth for children in the upper and lower 5% (n = 24 in each tail) of the distribution for PCHT1 and PCHT2 scores, respectively. It should be noted that the children at the extremes of the first component are not necessarily those at the extremes of the second component, as the components are orthogonal to each other. Figure 1 suggests that PCHT1 is a "centile level" component. Relative to other children, those with extreme positive scores on this component are taller and those with extreme negative scores are smaller. PCWT1 is also a "centile level" component for weight. PCHT2 appears to be a "centile shift" component (Fig. 2). Those with high positive scores on PCHT2 have moved from a relatively lower to a relatively higher centile level; i.e., they experienced faster than normal growth velocity for length during a given age interval. Those with extreme negative scores have crossed centiles downwards; i.e., relative to others in this sample, they exhibited worse linear growth velocity throughout the age interval. PCWT2 exhibits the same pattern as PCHT2.

Table 2 presents mean length and weight values for attained size at 36 months and for growth increments for those individuals who fell in the upper and lower 5% of the first and second principal components distributions. For attained size, the first component distribution was used to calculate the "upper" and "lower" categories; for growth increments, the distribution of the second component was used. Those children in the upper 5% of the distribution for PC1 had much higher mean lengths and weights at 36 months of age than those children who fell in the lower 5% of the distribution. In addition, the upper 5% of the distribution of PC2, the "centile shift" component, experienced larger increments of growth between 3 and 36 months than the lower 5%.

Although complete data were available for growth and supplement intake (SUPP) for 478 children, only 243 children had complete data for the other independent variables used in the regression analyses. Loss of cases was due primarily to incomplete data for home diet (HDIET) and birth weight (BW) (e.g., 136 individuals were lacking data on home diet; 74 cases were lacking data for birth weight. Because longitudinal information is required for analyses of the correlates of growth, the final sample sizes are similar for the various growth indices. If the sample chosen for the regression models had been based on attained size as the dependent variable, the sample size would have been 273, for the 3–36 month increments 246. All subsequent analyses refer to the LPC subsample of 243 cases so that the sensitivity of the various dependent variables can be compared within a given sample size.

Correlations between centile level components and attained size at 36 months (i.e., PCHT1 vs. HT36 and PCWT1 vs. WT36) were high (Table 3), and correlations of these first components with the increments of growth (HTINC and WTINC) were much

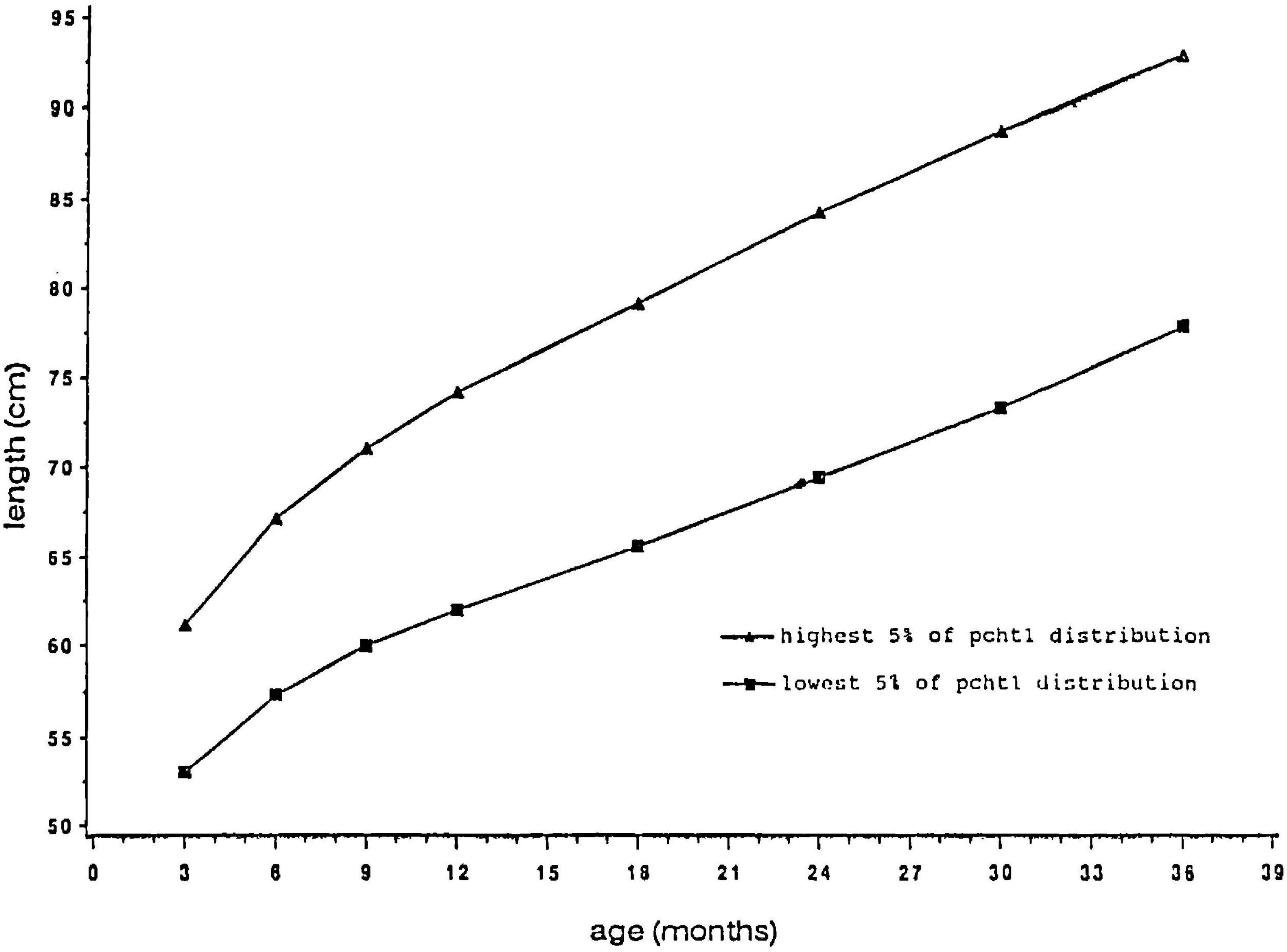

Fig. 1. Length curves for children who fall in the upper and lower 5% of the PCHT1 factor score distribution.

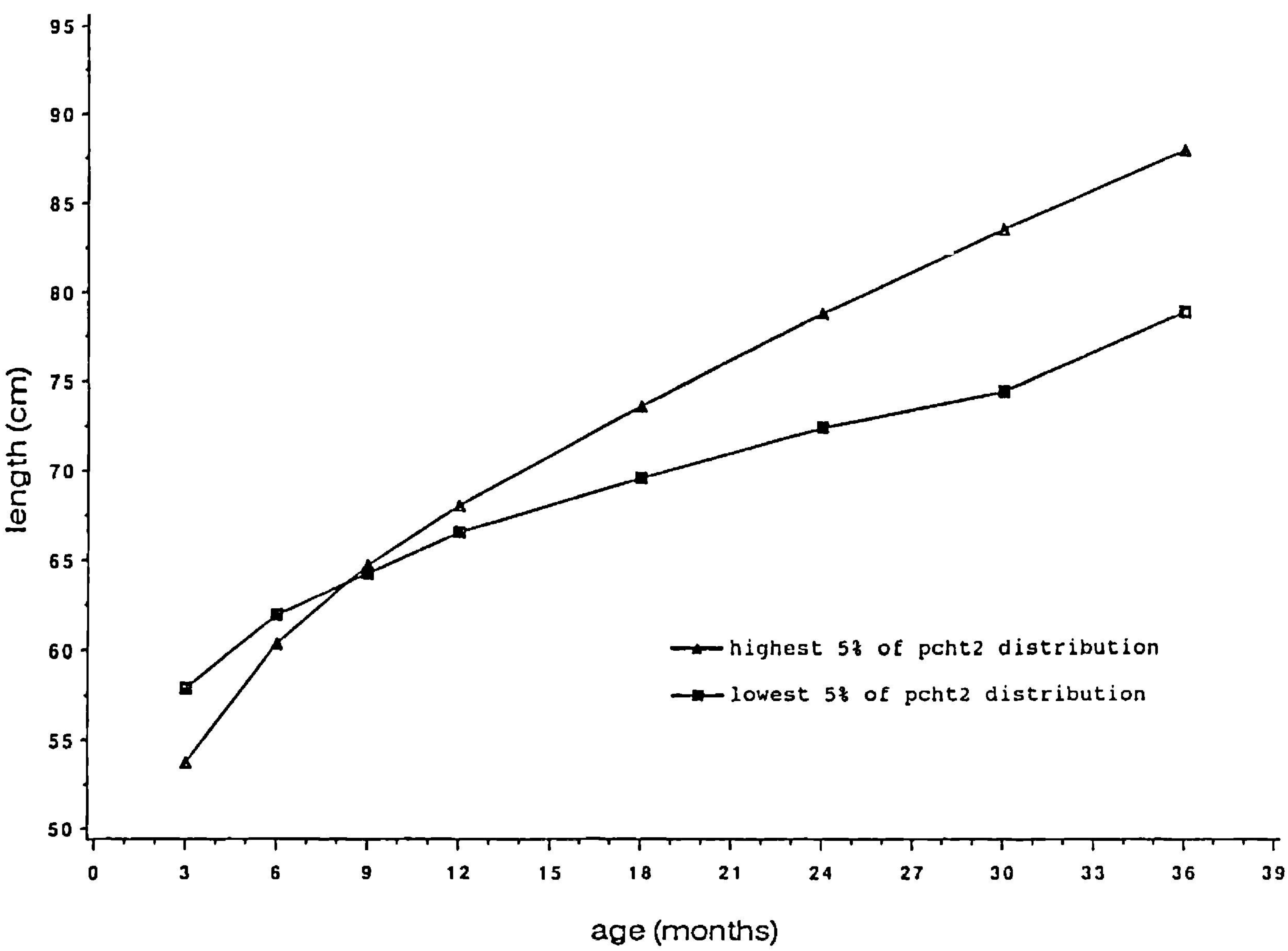

Fig. 2. Length curves for children who fall in the upper and lower 5% of the PCHT2 factor score distribution.

TABLE 2. Mean attained size and growth increments in length and weight by upper and lower 5% of the principal components distributions[1]

	Attained size[2]				Growth increment[2]			
	Lower		Upper		Lower		Upper	
Variable	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Length (cm)	77.67	3.25	92.57	1.59	21.07	3.12	34.32	1.82
Weight (kg)	9.72	0.71	14.42	1.16	5.03	0.94	8.35	0.95

[1]Lower and upper categories refer to the upper and lower 5% of the first principal component distribution, in the case of attained size, and the second principal component distribution, in the case of the growth increment. There are 24 individuals in each tail.
[2]Attained length and weight at 36 months of age and growth increment in length and weight from 3 to 36 months of age.

lower. The opposite was true for the second, or centile shift, components (PCHT2 and PCWT2), which had high correlations with their respective increments but low correlations with attained size (Table 3). This implies that the first principal components and attained size values are measuring similar constructs; the second components and growth increments appear to be similar in this regard. By design, the first and second components are uncorrelated. Similar results are obtained when the sample is stratified by supplement type and gender (not shown).

Means and standard deviations for the total regression sample and by supplement type for all anthropometric variables and for the independent variables are shown in Table 4. Atole villages had higher mean values than fresco villages for all growth indices. With the exception of gestational age and prevalence of diarrhea, all independent variables were also statistically different between supplement types (t test, $P < 0.05$). Differences in prevalence of diarrhea (PDIAR) between atole and fresco villages were tested with the Kruskal-Wallis nonparametric test since the distribution of this variable was highly skewed. There were 112 fresco subjects (62 boys and 50 girls) and 131 atole subjects (71 boys and 60 girls) in the regression sample. Few differences were apparent when descriptive statistics were stratified by gender, with the exception of slightly lower home dietary intakes for fresco females (about 60 kcal/per day less).

An estimate of the size of the supplementation effect is shown in Figures 3 and 4. The distribution of supplement calories was divided into tertiles and classified into "high" (90.8 to the maximum of 384.0 kcal/day), "medium" (20.9 to 90.7 kcal/day), and "low" (the minimum of 1.7 to 20.84 kcal/day) levels of intake. All growth indices, i.e., first and second principal components, attained size at 36 months, and increments from 3 to 36 months, for length and weight by level of supplementation were normalized for ease of presentation, and mean values by supplement level were calculated. Higher levels of supplement are generally associated with higher average values for both the length and weight indices, the only exception being PCWT2, which decreases from the low to medium supplement levels but increases from the medium to high levels. The differences in length and weight among supplement tertiles were all significant by one-way ANOVA ($P = 0.0001$), except for PCHT2, which was also significant ($P = 0.0004$).

Multiple regression analyses

Multiple regressions of each of the growth indices on all of the independent variables, as well as a dummy variable indicating gender (GENDER: 0 = males, 1 = females), were

TABLE 3. Correlations between principal component, attained size, and growth increment indices for length (above diagonal) and weight (below diagonal) (n = 243)[1]

	Attained size (at 36 months)	Increment (3–36 months)	PC1 ("size")	PC2 ("shift")
Attained size (at 36 months)	—	0.77	0.89	0.33
Increment (3–36 months)	0.77	—	0.46	0.81
PC1 ("size")	0.87	0.42	—	−0.04
PC2 ("shift")	0.32	0.77	−0.07	—

[1]All correlations are significant at $P = 0.0001$, except correlations between principal components, which were not significant.

TABLE 4. Summary statistics for growth indices and independent variables by supplement type for cases with complete data[1]

Variable	Fresco (n = 112)		Atole (n = 131)		All villages (n = 243)	
	Mean[2]	SD	Mean[2]	SD	Mean	SD
Principal components						
PCHT1	−0.237	1.049	0.194	0.942	−0.005	1.014
PCHT2	−0.194	0.970	0.196	0.984	−0.016	0.995
PCWT1	−0.310	1.034	0.305	0.957	0.021	1.038
PCWT2	−0.195	1.136	0.201	0.911	−0.018	1.038
Attained size at 36 months						
HT36 (cm)	84.438	4.210	86.544	3.661	85.573	4.054
WT36 (kg)	11.407	1.263	12.272	1.267	11.873	1.335
Increments from 3 to 35 months						
HTINC (cm)	27.566	3.223	29.271	3.092	28.485	3.260
WTINC (kg)	6.233	1.063	6.810	1.037	6.544	1.086
Independent variables						
HDIET (kcal/day)	861.925	279.854	792.701	215.943	824.607	249.336
SUPP (kcal/day)	19.388	15.768	140.038	87.880	84.430	88.851
PDIAR (% days with diarrhea)	7.897	7.363	8.142	6.480	8.029	6.888
BW (kg)	2.999	0.468	3.153	0.483	3.082	0.482
GAGE (weeks)	38.946	3.040	39.489	2.862	39.239	2.952

[1]SUPP = energy from supplement, HDIET = energy from home diet, PDIAR = prevalence of diarrhea, BW = birth weight, GAGE = gestational age.
[2]All atole-fresco differences are statistically significant at $P < 0.05$, except for GAGE and PDIAR.

computed. The regression models presented in Table 5 show the effects of all independent variables on the patterns of growth in length represented by the various indices. Regression coefficients are reported in standardized form so that effects of the various correlates on growth could be compared within and between models. All possible interaction terms were considered, and the interaction between gender and home diet was included in the final models, since it was significant in 4 of the 8 models.

The independent variables explain about the same amount of variance in PCHT1 and HT36 (28 and 24%). HDIET, SUPP and BW all contributed significantly to both models in a consistently positive direction. GENDER was also positive and significant, indicating that girls are larger than boys. A significant negative interaction between GENDER and HDIET suggests that growth in males benefits more from increasing dietary calories than does growth in females.

Comparison of the PCHT2 and HTINC models also indicates significant regressions with about the same amount of variance explained (18 to 19%). However, the contributions of the independent variables varied somewhat. SUPP, GENDER, and GAGE were significant in both models, SUPP and GENDER in a positive direction and GAGE in a negative direction. The magnitude of the HDIET coefficient was four times greater in the HTINC model, causing it to have a significant positive effect, whereas it was not a contributor in the PCHT2 model. BW was a highly significant negative predictor of PCHT2, whereas it did not contribute to the HTINC model. A significant negative interaction was found between gender and home diet in the HTINC model, again suggesting that the growth velocity of males benefits more from larger dietary intake, although this interaction was not significant in the PCHT2 model.

The results of the multiple regression analyses for weight indicate that the set of independent variables explained the same amount of variance for PCWT1 as for WT36 (about 27–28%; Table 6). HDIET, SUPP, and BW were significant positive predictors for both models. GENDER and GAGE were not significant terms; however, there was a significant negative interaction between gender and home diet, particularly in the PCWT1 model, as was apparent in the PCHT1, HT36, and HTINC models.

The comparison of the PCWT2 and WTINC models reveals a 6% increase in the amount of variance explained by the independent variables in the WTINC model (16 vs. 10%), although both were highly significant regressions. SUPP and GAGE were significant predictors for both models, SUPP in a positive, and GAGE in a negative direction. HDIET had a significant positive effect

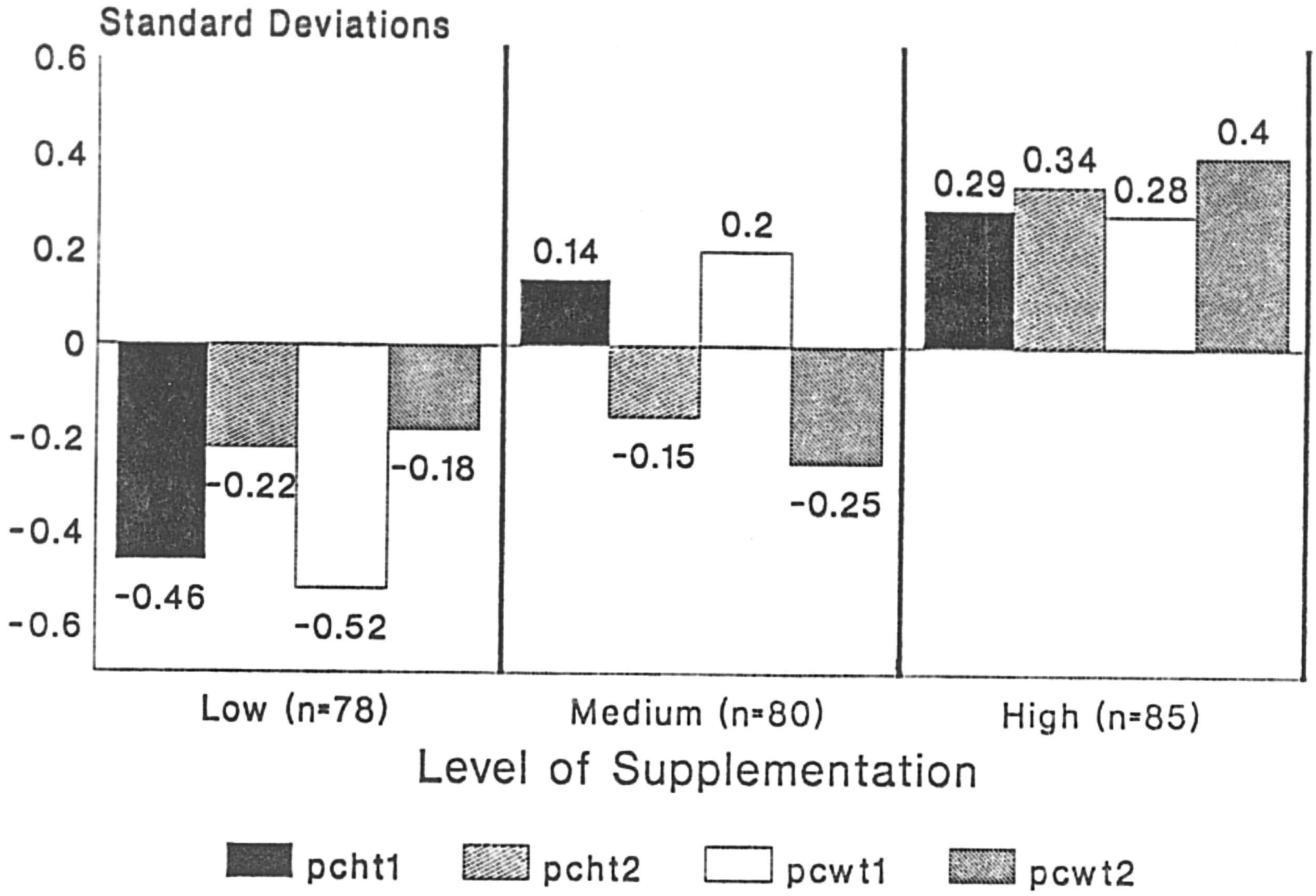

Fig. 3. Mean factor scores for principal components of growth in length (HT) and weight (WT) by level of supplementation.

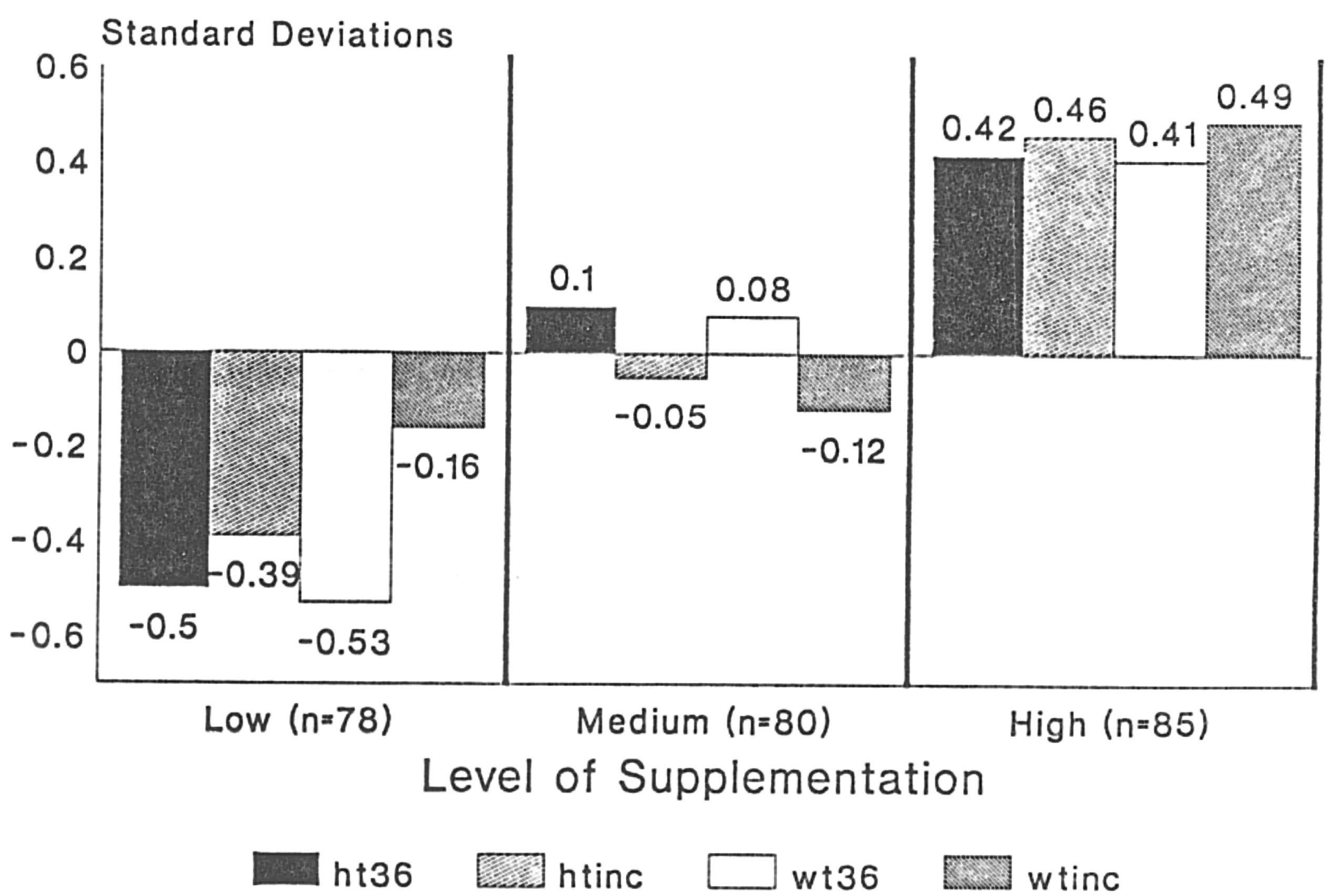

Fig. 4. Mean z scores for attained size at 36 months and 3–36 month increments (inc) of growth in length (ht) and weight (wt) by level of supplementation.

TABLE 5. Results of regressions of length indices[1] on independent variables

Regression stats	Dependent variables							
	PCHT1		HT36		PCHT2		HTINC	
Mean square	10.6443		146.6564		7.3558		74.0777	
M.S. error	0.7414		12.5537		0.7998		8.7358	
F value	14.3570		11.6820		9.1970		8.4800	
Prob. MS/MSE > F	0.0001		0.0001		0.0001		0.0001	
Adj. R^2	0.2787		0.2361		0.1917		0.1779	
	B[2]	SE	B	SE	B	SE	B	SE
HDIET	0.3248	0.0003	0.2936	0.0012	0.0412	0.0003	0.1917	0.0010
P value[3]	0.0001		0.0001		0.5964		0.0150	
SUPP	0.2902	0.0006	0.3694	0.0026	0.3077	0.0007	0.4097	0.0022
P value	0.0001		0.0001		0.0001		0.0001	
PDIAR	−0.0422	0.8149	−0.0832	3.3532	−0.0894	0.8464	−0.0984	2.7972
P value	0.4470		0.1453		0.1285		0.0972	
GENDER	0.4068	0.3888	0.4252	1.5997	0.4508	0.4038	0.5272	1.3345
P value	0.0345		0.0318		0.0269		0.0104	
BW	0.3051	0.1180	0.2136	0.4855	−0.2457	0.1225	−0.0700	0.4050
P value	0.0001		0.0003		0.0001		0.2431	
GAGE	0.0183	0.0194	−0.0651	0.0800	−0.1933	0.0202	−0.1669	0.0667
P value	0.7461		0.2649		0.0014		0.0062	
GENDER*HDIET	−0.5931	0.0005	−0.5450	0.0019	−0.2909	0.0005	−0.4984	0.0016
P value	0.0022		0.0061		0.1521		0.0154	

[1]PCHT1 = first principal component, HT36 = attained length at 36 months, PCHT2 = second principal component, HTINC = increment of growth in length from 3 to 36 months.
[2]Regression parameters are in standardized form.
[3]*P* value indicates the significance level of the given parameter in the regression model.

in the WTINC model only. GENDER had no significant main effect in either model; and there was no interaction between gender and home diet.

DISCUSSION

This research attempted to evaluate the usefulness of LPC analysis in understanding patterns of growth in a developing country under conditions of environmental stress and to compare the results with those using the more traditional indices of attained size and incremental growth. The four LPCs were chosen for analysis because the patterns of growth summarized by them were readily interpretable. LPC analyses of the same variables and age range in U.S. children yielded components with identical interpretation (Berkey and Kent, 1983; Cronk and Reed, 1981; Cronk et al., 1982). The pattern of growth of the Guatemalan children included in this analysis is congruent with that described in previous studies (Martorell et al., 1978, 1982) and follows that observed in children from many developing countries (Martorell and Habicht, 1986; Waterlow et al., 1980).

Although there were some differences between the various models, relationships between environmental variables and growth in Guatemalan children were generally as expected, regardless of which index was used to assess growth. Increased nutritional intake, particularly through supplementation, appears to help a child maintain his or her proper growth trajectory and may, in some cases, help to reduce the deleterious effects of other factors, such as high rates of infectious disease. Energy intake, particularly from supplementation (HDIET was not significant in the PC2 models for either length or weight), also appears to aid a child in catching up to his or her appropriate growth curve, resulting in a centile shift upwards.

Supplementation remains a significant predictor of length and weight, even after controlling for several potential confounders (Tables 5, 6). In addition, the fact that all villages were similar in 1968, prior to the initiation of the intervention program (Martorell et al., 1982) and that atole children were larger than fresco children subsequent to the intervention supports the notion that the relationship is true rather than spurious.

By comparing mean z scores across supplement levels in Figures 3 and 4, a general idea of the effect size of supplementation can be seen. In the case of PCHT1, for example,

TABLE 6. Results of regressions of weight indices[1] on independent variables

Regression stats	Dependent variables							
	PCWT1		WT36		PCWT2		WTINC	
Mean square	10.9861		18.7915		4.7289		7.4027	
M.S. error	0.7816		1.2752		0.9679		0.9934	
F value	14.0550		14.7360		4.8860		7.4520	
Prob. MS/MSE > F	0.0001		0.0001		0.0001		0.0001	
Adj. R^2	0.2741		0.2843		0.1010		0.1573	
	B[2]	SE	B	SE	B	SE	B	SE
HDIET	0.1959	0.0003	0.1865	0.0004	0.0683	0.0003	0.1709	0.0003
P value	0.0083		0.0113		0.4049		0.0321	
SUPP	0.2476	0.0007	0.3255	0.0008	0.3326	0.0007	0.3738	0.0007
P value	0.0001		0.0001		0.0001		0.0001	
PDIAR	−0.0862	0.8367	−0.0752	1.0687	−0.0574	0.9311	−0.0840	0.9433
P value	0.1221		0.1740		0.3541		0.1615	
GENDER	0.3517	0.3992	0.1996	0.5098	0.0882	0.4442	0.2428	0.4500
P value	0.0680		0.2959		0.6799		0.2414	
BW	0.3710	0.1211	0.3605	0.1547	−0.0738	0.1348	0.1179	0.1366
P value	0.0001		0.0001		0.2395		0.0528	
GAGE	0.0367	0.0200	−0.0441	0.0255	−0.1614	0.0222	−0.1400	0.0225
P value	0.5181		0.4343		0.0113		0.0230	
GENDER*HDIET	−0.5426	0.0005	−0.3537	0.0006	−0.0545	0.0005	−0.2673	0.0005
P value	0.0051		0.0646		0.7987		0.1974	

[1]PCWT1 = first principal component, WT36 = attained weight at 36 months, PCWT2 = second principal component, WTINC = increment of growth in weight from 3 to 36 months.
[2]Regression parameters are in standardized form.
[3]*P* value indicates the significance level of the given parameter in the regression model.

the lowest and highest supplementation levels are separated by 0.75 standard deviations in length, whereas the lowest and highest supplement levels for HT36 are 0.92 standard deviations apart. PCHT2 varies 0.52 standard deviations from low to high supplement levels; HTINC varies 0.85 standard deviations. Since the distributions of supplement intake for atole and fresco villages do not overlap very much, the majority of the "low" supplement category is composed of children who received fresco, and the "high" category is composed mostly of children who received atole.

It is difficult to determine whether energy, or some other nutrient, caused the supplementation effect. Earlier analyses of these data suggested that energy and not protein supplementation was responsible for improvement in growth (Delgado et al., 1982; Martorell et al., 1979). Within the context of the present study, this issue cannot be properly evaluated, since the distribution of energy contributed by the two types of supplements (one containing protein and one no protein) overlap only at the lower ranges of intake of atole. Thus there is insufficient statistical power to separate the effect of protein from that of energy. However, supplement intake by mothers was such that the distribution of energy intake was similar in both village types, and Lechtig and coworkers (1975) were able to demonstrate that effects of prenatal supplementation on birth size were the same regardless of whether the energy was accompanied by protein. This strongly suggests that energy is more limiting than protein in the diets of women in this population.

Prevalence of diarrhea was in no instance significantly related to growth, although the direction of the coefficients was as expected (negative). A significant negative relationship between diarrheal disease and growth was found in fresco villages only in other analyses of these data (Martorell et al., 1990). Once relevant interactions were accounted for, gender of the child tended to have a positive effect on centile size and shift in length only, suggesting that girls were longer and grew faster than boys. Birth weight tended to have a positive effect on size attained at 3 years of age, suggesting that bigger babies become bigger children, and a negative effect on length velocity, indicating that normal children who are large at birth may experience some "catch down" growth (they will slow to a more normal rate after a period of particularly rapid growth), whereas children who are small at birth may be attempting to "catch up" to their normal growth trajectory (Tanner, 1986). Gestational age had no apparent effect on attained size at age 3 years; however, it was negatively associated with velocity in length and weight. Since longer gestational ages are associated with larger birth weights, this may again be explained by "catch down" growth experienced by the older and perhaps larger babies or catch up by babies of low gestational age.

Due to the significant gender interaction with home diet, gender specific regression models were also run (not shown). The magnitude and direction of the regression coefficients for the models for males only are strikingly similar to the models presented for the genders combined. Models for females, however, clarified the gender differences in the relationship of home dietary intake with growth. Home diet was not a significant contributor to overall size or velocity in length or weight; standardized regression coefficients were substantially smaller than in the combined models. Gestational age was not a significant predictor of centile shift in females in length or in weight as it is in males (regression coefficients are approximately half as large in absolute value). Birth weight also loses its significance due to a smaller coefficient in the model for HT36.

In comparing the specific models more closely, there appears to be little information gained when the first principal component is used as an index of overall size in length or weight as opposed to attained size at 36 months. Both indices were very highly correlated and resulted in almost identical regression models (Tables 5, 6). In addition, the magnitudes and directions of the effects of the independent variables were very similar regardless of the growth indicator.

Results for models involving centile shift in the second components vs. increments varied slightly more than the overall size comparisons, particularly for length. Again, the two indices were highly correlated but were not quite as highly correlated as the first components and attained size variables were. Although supplement intake was associated with an upward centile shift or larger growth increment in length and weight, the size of this effect differed by the index used (Figs. 3, 4). It is clear that the attained size and increment indices tend to be more sensitive to the effects of supplementation than the first and second component indices, respectively.

Home diet remained a significant main effect after controlling for the interaction with gender of the child in the HTINC model but was not significant in the PCHT2 model.

It may be that the second components and the increments are not measuring as much in common as the first components and attained size variables seem to be. This may be explained at least in part by the fact that, whereas one would expect the rank order of individuals based on their first component to be identical to the rank based on their attained size value, this is not completely true for the centile shift variables. Due to the increasing variation across centiles with age, an individual who tracks consistently along the 3rd percentile from 3 to 36 months would have a smaller increment of growth than a child who tracked consistently along the 90th percentile, but their factor scores for the second principal component would be similar since neither is crossing centiles.

Although many cases were lost to the LPC analysis in comparison to the use of attained size or increments to assess growth, similar numbers of cases remained for the regression analyses regardless of whether components, attained size, or increments were used as the dependent variables, due to missing data for the correlates of growth. It is clear that those children who were missing growth data were also more likely to be missing data for the independent variables as well. In other words, for this particular data set, when the relationship between growth and the environment is the issue of interest, available samples do not differ dramatically by type of growth index used.

LPC analysis may be quite valid for assessing growth and development in some circumstances. For example, principal components have frequently been used to assess relative body proportions or shape (Healy and Tanner, 1981) and for summarizing a large number of skinfold thicknesses into a relevant index of body fat distribution (Kaplowitz et al., 1987, 1988; Mueller and Wohlleb, 1981). In this study, however, principal components were used in a somewhat different application, i.e., to assess longitudinal growth in length and weight. The merits of this application were assessed relative to more standard measures of attained size and incremental growth. The findings are clear for both overall size or centile level and velocity or centile shift. Longitudinal principal components analysis did not aid significantly in increasing understanding of the correlates of growth in length or weight in Guatemalan children from birth to 3 years of age compared with the more commonly used indices of attained size or increments. There does not appear to be any overwhelming advantage of LPC analysis over more traditionally used methods. Therefore, LPC analysis is not recommended as the method of choice in this population.

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