Nutrition in Early Life and the Fulfillment of Intellectual Potential[1,2]

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ABSTRACT The effects of early supplementary feeding on cognition are investigated using data collected during two periods in four Guatemalan villages. The first was the Institute of Nutrition of Central America and Panama (INCAP) longitudinal study from 1969 to 1977 and the second was a cross-sectional follow-up of former participants carried out in 1988–1989. The principal objective of these studies was to assess the differential effect of two dietary supplements, Atole containing 163 kcal/682 kJ and 11.5 g protein per cup or 180 mL and Fresco containing 59 kcal/247 kJ and 0 g protein per cup, that were given to mothers, infants and young children. Performance was assessed on a battery of psychoeducational and information processing tests that were administered during adolescence. Consistent differences between groups were observed on psychoeducational tests. Subjects receiving Atole scored significantly higher on tests of knowledge, numeracy, reading and vocabulary than those given Fresco. Atole ingestion also was associated with faster reaction time in information processing tasks. In addition, there were significant interactions between type of dietary supplement and socioeconomic status (SES) of subjects. In Atole villages, there were no differences in performance between subjects in the lowest and highest SES categories. On the other hand, performance in Fresco villages was best in the highest compared with the lowest SES group. After close scrutiny of alternative hypotheses, it is concluded that dietary changes produced by supplementation provide the strongest explanation for the test performance differences observed in the follow-up between subjects exposed to Atole and those exposed to Fresco supplementation. J. Nutr. 125: 1111S–1118S, 1995.

INDEXING KEY WORDS:

- *cognitive development*
- *intellectual achievement*
- *school achievement*
- *nutritional supplementation*

In addition to this one, there are at least six other studies on the effects of prenatal and early postnatal supplementary feeding on behavioral development. All test the hypothesis that protein-energy malnutrition in early life has adverse developmental consequences, but research designs and methods differ widely among them. One study conducted by Rush et al. (1980) restricted supplementation to pregnancy whereas other investigations involved prenatal as well as postnatal supplementation (Chávez and Martínez 1982, Waber et al. 1981). Work by Grantham-McGregor et al. (1990) and Husaini et al. (1991), on the other hand, focused exclusively on postnatal supplementation. Most reported results refer to the first 2 y of life. In general, nutritional interventions accounted for a small (~0.20 SD) but significant proportion of variability in performance among infants and toddlers on mental and motor developmental scales.

Some information about long-term effects of nutritional interventions on behavioral outcomes of older children are available from two follow-up studies (Hsueh and Meyer 1981, Super et al. 1991) but, unfortunately, the reports were limited to abstracts in conference proceedings. In the study by Super et al.

[1] Presented in the symposium on Nutrition in Early Childhood and its Long-term Functional Significance, FASEB, April 6, 1992, Anaheim, CA. Published as a supplement to The Journal of Nutrition. Guest editors for this supplement publication were Reynaldo Martorell, The Rollins School of Public Health of Emory University, Atlanta, GA and Nevin Scrimshaw, The United Nations University, Boston, MA.

[2] Data collection and analyses were supported by NIH grant HD22440 and by Pew Charitable Trusts grant 90-00210-000.

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0022-3166/95 $3.00

(1991) carried out in children (mean age = 6.74 y) from Bogotá, achievement was measured using a test that included reading readiness, arithmetic and basic knowledge. Statistically significant effects of treatment, accounting for ~8 mo of cognitive development, were observed in reading readiness, particularly among subjects whose mothers had strong psychological and social resources. In an earlier study in Taiwan, Hsueh and Meyer (1981) found that a nutrition supplement administered to Taiwanese mothers during pregnancy and lactation had no effect on an intelligence test administered to the offspring at 5 y of age.

In the Guatemalan study reported here, an assessment is made of the differential impact of the nutritional supplements on functional outcomes designed to be relevant to the local context. The outcomes were measured more than 10 years after the administration of the supplements was discontinued. The study design called for two villages to receive a high energy, high protein supplement called Atole and two to receive a low calorie supplement devoid of protein called Fresco. Data for this paper were collected as part of the Institute of Nutrition of Central America and Panama (INCAP) longitudinal study from 1969 to 1977 and the follow-up study carried out in 1988 and 1989 (Martorell et al. 1995).

Detailed results about the effects of early supplementary feeding on performance are provided in a separate publication[4] for a wide range of psychoeducational tests measured in adolescents and young adults (Pollitt et al. 1993). A summary of these results is given here to provide a more complete presentation of the follow-up results, with emphasis on selected outcome measures that reflect distinct cognitive domains. The analyses focus on performance differences between treatment groups (i.e., Atole and Fresco) and on the interactive effects of type of supplement with social and economic characteristics.

MATERIALS AND METHODS

Design of the study

The study villages. Four villages were included in the study; at baseline, two had populations of ~900 each and two were smaller, ~500 people each. Within each pair, assignment to Atole or Fresco supplementation was random (Martorell et al. 1995). The villages are located in the Department of El Progreso, a dry mountainous area northeast of Guatemala City. The temperature ranges from 14 to 38°C, with the rainy season occurring from June to October.

[4] Available from the Nestle Foundation, P.O. Box 581, 4 Place de le Gare, 1001 Lausanne, Switzerland.

Throughout the course of the studies, from 1969 to 1989, the primary source of income for most villagers was agriculture. The majority of the children's fathers made their living as wage laborers, tenant farmers or small land owners. No one in any of the villages reported being a large landholder. Few adult males reported being skilled tradesmen or merchants. Women infrequently reported having an occupation outside the home. Adult literacy rates continue to be low but have improved over time. Literacy among mothers increased from 30 to 60%, whereas, among fathers, rates increased from 46 to 67% from 1969 to 1989.

Subjects. At the time of the initial study in 1969 potential subjects were all children ≤ 7 y old living in the villages (i.e., all those born since 1962). In addition, all children who moved into the villages during the course of the project and all children born in the villages from January 1, 1969 through February 28, 1977 were also potential study participants.

Subjects born between 1962 and 1965 were excluded from the behavioral assessments to lower costs and to focus on the children exposed to supplement at younger ages. The analysis reported here focuses on those subjects exposed to the nutrition treatment during the prenatal period and the first 2 y of life. This is a period of accelerated brain growth and is perhaps the time when development of the brain is most sensitive to the effects of nutrition. The critical period of exposure to supplementation is expanded to 3 y of age in analyses of physical growth data (Haas et al. 1995, Rivera et al. 1995) because of evidence of continued but declining effects of supplement intake on growth rates between 24 and 36 mo of age (Schroeder et al. 1995). All subjects selected in this paper were born between 1970 and 1974 and ranged in age from 13 to 19 y at the time of the follow-up study. The sample was comprised of 636 subjects, divided almost equally among Atole and Fresco villages.

Experimental intervention

The Atole supplement was a warm, thick, brown, sweet drink, similar to corn gruels given to children in rural Guatemala. It contained 11.5 g of protein and 163 kcal/682 kJ of energy per cup (180 mL). The Fresco supplement was a cool, clear, sweet drink like KoolAid™, also similar to common village drinks. It contained no protein but it had 59 kcal/247 kJ per cup, approximately one third the energy of the Atole. Both supplements were fortified with vitamins and minerals. At the time the longitudinal study began, it was assumed that the energy concentration of Fresco was insufficient to have a developmental effect. The supplements were available at a central feeding station 7 d/wk to every resident of the village twice daily (1000 and 1400 h). Ingestion was recorded only for

target subjects, that is, pregnant and lactating women and children up to age seven. Because consumption was ad libitum, attendance at the feeding centers, after controlling for consumption, was used in the analyses to control for factors associated with supplement participation. Additional details are given in Martorell et al. (1995).

Socioeconomic indicators. Three socioeconomic variables are included in the analyses as potential confounders: house quality, maternal education and father's occupation. Data for each of these three variables were derived from census data obtained in 1987.

Because of the difficulty of obtaining direct measures of income in developing countries, a measure of house quality often is used as a proxy for social-environmental variables that affect cognitive growth and educational development (Johnston et al. 1987). Nine variables describing house quality were assessed: an overall rating of the type of house (1–4 scale), ownership of house (no = 0, yes = 1), number of rooms, type of floor (1–5), type of walls (1–7), type of roof (1–4), location of the kitchen (1–3), type of toilet (1–4) and number of household possessions (1–6). In all instances, higher scale scores reflected the higher quality of the dwelling. The measure used in these analyses was generated using factor analysis on the within-village standardized variables.

Maternal education consistently has been shown to be related positively to the cognitive development of the offspring (LeVine et al. 1991). In this case, informants reported both literacy (coded 0 = none, 1 = some) and the number of years of schooling completed successfully. The mean number of years of schooling for mothers was 2.1 y.

Occupational status is a carrier variable that may be associated with income, status in the community, availability of resources and family socialization practices. The indirect effects of parental occupation on the cognitive development of children are thought to occur through the earning capacity of the parent and the consequent resources for stimulation that it permits. Both mothers' and fathers' occupations were assessed; however, because only ~20% of women at follow-up reported having an occupation, mother's occupation was excluded from further analysis.

Data on 19 occupational categories were obtained and then subsequently collapsed into six categories for comparison with earlier census data from 1967; the original and recorded scales are highly correlated (r = 0.88). In preliminary analyses, the recorded scale demonstrated adequate linear properties and was used in all subsequent statistical calculations as an ordinal variable. A detailed description of the specific procedures used in the construction of these three variables and the related reliability and validity data have been reported elsewhere (Pollitt et al. 1993). The three variables were standardized within village and a composite score was constructed using the sum of the three scores.

Schooling variables. At the time of testing, all subjects had reached school age and most had received some schooling. Given the well-established relation between schooling and cognition (Ceci 1991), performance on psychoeducational tests was adjusted for schooling experience. This was particularly important for the assessment of treatment effects given that differences between Atole and Fresco villages on important schooling indicators (e.g., maternal and paternal education) favored Fresco villages before the intervention (Engle et al. 1992). Two schooling variables in the statistical analysis were the age the child started school and the maximum grade attained in primary school.

The psychological test battery

Two psychological test batteries were used in the follow-up study. One includes psychoeducational tests and the other includes information processing tasks. The psychoeducational test battery included tests of literacy, numeracy, general knowledge, two standardized educational achievement tests and the Raven's Progressive Matrices. The achievement tests were part of the Interamerican Series used extensively in Guatemala by faculty from the Universidad del Valle in Guatemala City (for a detailed description of the tests see Pollitt et al. 1993). The purpose of this battery was to acquire a measure of general abilities, aptitudes and achievements that are influenced heavily by experience, education and cultural upbringing.

Information processing. Tests of simple, choice and memory reaction time (RT) (Sternberg 1966) comprised the computerized battery of tests to assess information processing. In addition, a paired associate test was administered as part of this battery. The intent of the battery was to assess the efficiency with which an individual processes information by focusing on speed of response in elementary cognitive tasks. In addition to measures of RT from three tests, two of the RT tests (i.e., choice and memory) also yielded a performance score (i.e., number of errors). In general, between-subject variability in RT tests is not accounted for by schooling and cultural background, yet test performance still maintains a low level correlation (−0.10 to −0.30) with g, a general ability factor. Theoreticians presently claim that RT is a sensitive indicator of differences in brain function (Eysenck 1986, Jensen 1991, Vernon 1987).

Procedure. Each of the four villages was visited twice by a research team, once during the dry season and once during the rainy season. The teams were rotated and each team visited each village during one round of testing. The presence of the team in the village varied from 3 to 9 wk depending on village size.

TABLE 1

Results of hierarchical regression analyses for vocabulary[1]

Step	Variables	R^2	F(eq.)	F-to-enter	β	Direction of effects favors
1	Sex	0.03	3.16*	0.01	−0.122	—
	Age			8.01**	3.290	Older subjects
	Attendance			1.48	−0.571	—
2	Socioeconomic status	0.11	10.66***	32.26***	1.168	Higher SES
3	Age at entry	0.21	14.25***	18.98***	−1.064	Younger subjects
	Maximum grade			19.17***	2.327	Higher grade
4	Treatment	0.26	16.20***	22.35***	3.930	Atole
5	Treatment by grade	0.30	15.13***	6.13**		
	Treatment by socioeconomic status			11.28***		

[1] Adapted from Pollitt et al. (1993).
* $P < 0.05$.
** $P < 0.01$.
*** $P < 0.001$.

In each community, two staff members recruited subjects and made appointments for testing. All testing was done in community houses rented by the project and adapted accordingly. In addition to psychological data, subjects were given several examinations, including medical and anthropometric assessments. They also were interviewed extensively about sociodemographic characteristics.

Analytical strategy. The data were analyzed using a hierarchical regression model. This approach permits the estimation of variance accounted for by treatment alone as well as the identification of differential effects of treatment that may be related to particular characteristics of the population. By including interactive terms in the model, it is possible to identify the potential indirect pathways through which supplement could also have affected the outcomes of concern.

All independent variables were standardized. Individual characteristics (sex, age at testing and attendance at the feeding center with consumption partialled out) were entered first, followed by the socioeconomic status (SES) composite (sum of mother's education, father's occupation and house quality factor score), and then the two school indicators (age at school entry, maximum grade attained) and finally the treatment variable (entered as a categorical (1/−1). In this way the percent of variance accounted for by the different predictors was estimated. In a subsequent step, two interaction terms were entered: treatment by SES and treatment by maximum grade. The results presented include the percent of variance accounted for at each step (R^2), and F values and regression coefficients for each variable in the step in which it was entered, controlling for all other variables entered before this step.

A three-way interaction term (treatment by SES by grade attained) also was entered into the model but the results of these analyses were nonsignificant and will not be presented. Similarly, treatment by gender terms were entered in preliminary analyses but also were nonsignificant and dropped from the final model.

RESULTS

Psychoeducational tests

Vocabulary. **Table 1** presents the results of the hierarchical regression analyses for the vocabulary test. In general, the results are in the predicted direction with older adolescents, subjects from higher SES families and those who entered school earlier and stayed in longer performing better on the measure of vocabulary. After controlling for all of these variables, the treatment contributed an additional 5% of the variance ($F = 22.35$, $P < 0.001$) in performance with Atole subjects performing significantly better ($b = 3.93$) than Fresco subjects.

When entered into the model, both interactive terms were significant and accounted for an additional 4% of the variance. In the case of the SES-by-treatment interaction, the slope for Atole subjects was nonsignificant whereas that for Fresco subjects was positive and significant ($b = 1.373$, $P < 0.001$). Although there was no relation between SES and performance in Atole villages, performance improved in Fresco villages with increasing SES level (**Fig. 1**). At lower ends of the SES distribution, subjects who received Atole supplements performed significantly better than those who received Fresco supplements; whereas at higher SES levels there were no differences between them.

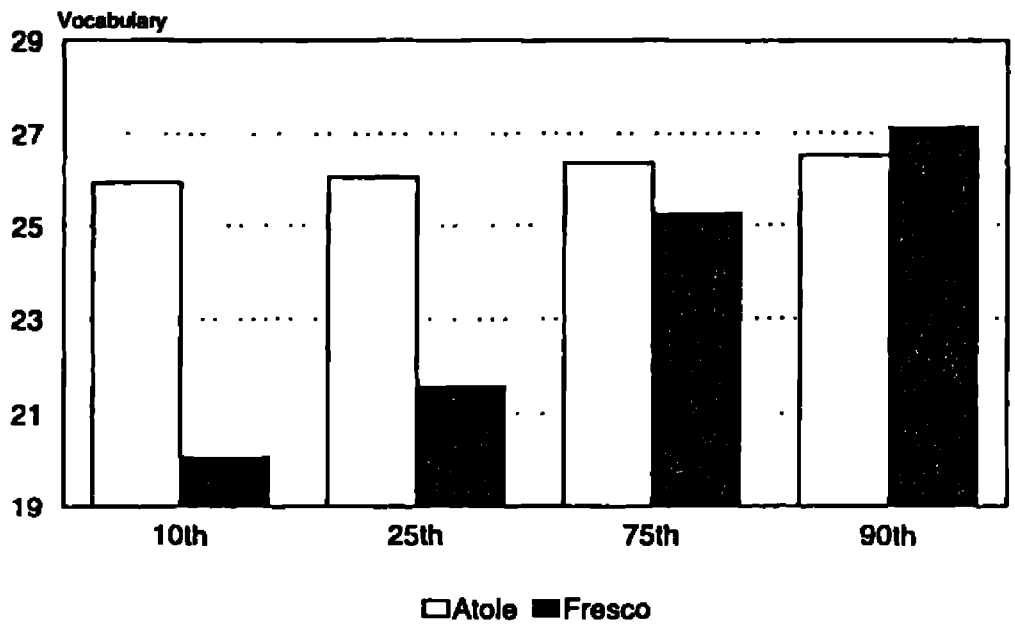

FIGURE 1 SES-by-treatment interactions for vocabulary.

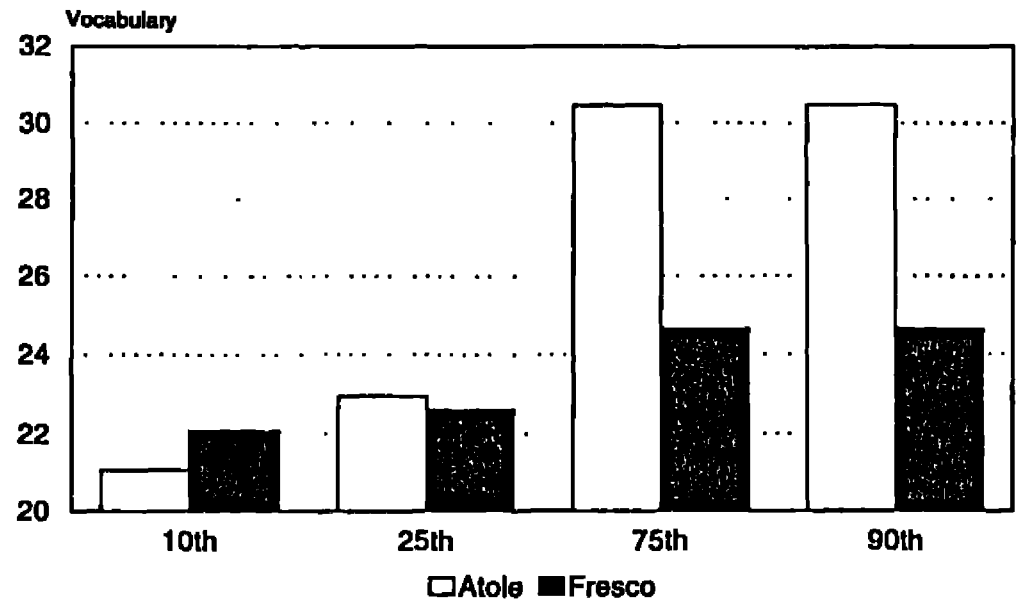

FIGURE 2 Maximum grade-by-treatment interaction for vocabulary.

The grade-by-treatment interaction showed a different pattern. The slope was positive and significant for Atole ($b = 3.861$, $P < 0.001$) but not for Fresco subjects. Differences between treatment groups increased with grade attained, such that children from Atole villages scored significantly higher than Fresco children at the upper ends of the grade distribution (**Fig. 2**). For those at the lower end of grade attainment, there were no differences between Atole and Fresco subjects.

Results of the hierarchical analyses for other outcome variables were similar (**Table 2**). After controlling for potentially confounding variables, there were significant effects of Atole on performance on tests of numeracy, knowledge, vocabulary and reading achievement. The percent of variance accounted for by inclusion of the treatment variable was generally small, yet statistically significant, ranging between 1 and 5%. Examination of significant interactive terms permits the identification of subgroups in whom effects were greatest. In almost all instances, effects of Atole were evident in children from families at the lowest levels of SES. In several cases (e.g., reading, vocabulary and reading achievement), effects were observed in children with the highest levels of education.

Information processing

Results of the regression analyses on reaction time of the memory task are presented in **Table 3**. In contrast to the results on the psychoeducational tests, none of the predictor variables were associated with performance, with the exception of grade attainment. After controlling for all potential confounders, treatment was associated significantly with performance, with Atole subjects having significantly faster reaction times ($b = -0.321$, $P < 0.01$) than Fresco subjects. Neither of the interactive terms was significant.

Results of hierarchical analyses for other information processing outcome variables were similar (**Table 4**). In general, the percent of variance accounted for by the models was small (between 3 and 10%), with males, higher SES, earlier school entry and higher grade attainment associated with enhanced performance. In seven analyses, there were three significant main effects of treatment. Atole subjects responded faster and more efficiently than Fresco subjects on the memory task and reached criterion faster on the paired associates task. None of the interactive terms was significant.

DISCUSSION

The results of the INCAP follow-up study show that, after controlling for socioeconomic factors and

TABLE 2

***Summary of results of hierarchical regression analyses for psychoeducational tests*[1]**

	R^2	*F* values		
Dependent variable	Full model	Treatment†	SES by treatment	Treatment by grade
Literacy	56	0.44	0.14	0.54
Numberacy	48	7.75**	10.06***	0.01
Knowledge	27	8.57**	6.74**	0.79
Raven	15	0.22	8.39**	2.18
Reading	30	0.03	2.49	5.36*
Vocabulary	30	22.35***	11.28***	6.13**
Reading Achievement	30	20.05***	14.91***	13.14***

[1] Adapted from Pollitt et al. (1993).

† After controlling for age at testing, gender, attendance, SES, age at school entry and maximum grade attained. SES = socioeconomic status.

* $P < 0.05$.

** $P < 0.01$.

*** $P < 0.001$.

formal educational experience, subjects exposed to Atole during the pre- and early postnatal period obtained significantly higher scores on measures of general intellectual abilities than subjects exposed to Fresco. Furthermore, better information processing abilities were observed in subjects exposed to Atole. There was great consistency to the results when examined by specific test; Atole subjects performed significantly better than Fresco subjects on tests of numeracy, general knowledge, reading and vocabulary achievement (Pollitt et al. 1993). Furthermore, significant interactions with SES were found for tests of numeracy, knowledge, reading achievement, vocabulary and the Raven's Progressive Matrices. Finally, significant interactions with grade attainment were reported on the three reading-related tests.

Elsewhere (Pollitt et al. 1993) we reported that mother's education, father's occupation and house quality, the three indicators of SES, correlated positively with scores from all the psychoeducational tests (including vocabulary) administered. As expected, subjects at the lowest end of the SES distribution were at the highest risk of poor cognitive test performance. Because of it, the finding that the interaction between treatment and SES accounted for significant portions of the vocabulary test scores and of other tests of the battery administered is particularly important for developmental theory and public health. The direction of the interaction shows that the strongest beneficial effects of the Atole on cognition were observed among those at the lowest end of the SES distribution. This selective effect was sufficient to cancel the expected test score differences between those at the lowest and highest end of the SES distribution in the group that received Atole. Conversely, the distribution of cognition test scores in the Fresco group follows what is generally a truism in developmental psychology: cognitive competence varies as a positive function of SES status. Accordingly, in this study, we view the effect of the Atole as a social equalizer.

TABLE 4

***Summary of results of hierarchical regression analyses for information processing tests*[1]**

	R^2	*F* value
Dependent variable	Full model	Treatment†
Simple RT	03	0.03
Choice RT	02	1.01
Trials to criterion	06	3.65*
Memory RT	04	9.25**
Memory efficiency	10	8.40**
Memory impulsivity	04	2.06
Memory percent correct	07	1.02

[1] Adapted from Pollitt et al. (1993).

† After controlling for age at testing, gender, attendance, socioeconomic status, age at school entry and maximum grade attained.

* $P < 0.05$.

** $P < 0.01$.

Particular characteristics of the subjects also modified the effects of the treatment, as suggested by the significant interaction of treatment and maximum grade attained. Whereas maximum grade attained was independent of test performance among those that received Fresco, this was not the case among those subjects that received Atole. In this last group, the scores in the vocabulary test varied as a positive function of maximum grade. In our view, this effect indicates that Atole provided an impetus to take advantage of the formal educational experiences to which they were exposed.

Are the results due to the supplementation program? Answering this question requires critical examination of the internal validity of the data (Cook and Campbell 1979). Among the potential threats to internal validity are differences between Atole and Fresco in several

TABLE 3

***Results of hierarchical regression analyses for memory reaction time*[1]**

Step	Variables	R^2	*F*(eq.)	*F*-to-enter	β	Direction of effect favors
1	Sex	0.002	0.24	0.03	−0.018	—
	Age			0.00	−0.051	—
	Attendance[a]			0.69	0.046	—
2	Socioeconomic status	0.004	0.43	1.01	−0.024	—
3	Age at entry	0.02	1.51	3.03	0.037	—
	Maximum grade			4.25*	−0.117	Higher grade
4	Treatment	0.04	2.64**	9.25**	−0.321	Atole

[1] Adapted from Pollitt et al. (1993).

* $P < 0.05$.

** $P < 0.01$.

*** $P < 0.001$.

areas: 1) pretreatment differences in social and economic characteristics; 2) differences in the provision of Atole and Fresco treatments; 3) differences in attrition and recruitment rates to the follow-up study; and 4) differential patterns of community development since the end of the longitudinal study in 1977 to the 1988 follow-up study. The possibility that differences in these areas provide an explanation for differences in test performance between Atole and Fresco subjects has been considered carefully elsewhere and rejected (Pollitt et al. 1993). Rather, the conclusion reached was that the nutritional differences between the Atole and Fresco supplements is the best explanation for the behavioral differences observed in the INCAP follow-up study.

A related issue regarding treatment effects and their programmatic implications is the nutritional status of the target population. The prevalence of growth retardation in the study population indicates high levels of malnutrition among infants and children. About 26% of the sample had severe stunting (≥3 SD below the reference median) and 43% had moderate stunting (2.9–2.0 SD below the median) at 3 y of age (Martorell et al. 1992).

Nutritional status is likely to interact with supplementary feeding to determine outcome. Thus, the external validity of the Guatemalan findings must be assessed in context and generalizations should be restricted to populations with nutritional status similar to that in the study population. However, it must be noted that there is no theoretical or empirical reason to suspect that the benefits of early supplementary feeding are observed exclusively below a certain level of nutritional risk.

On the basis of the results presented here and elsewhere (Pollitt et al. 1993), the internal validity of the effects of supplementation is high. However, although there is strong evidence for a nutritional effect, the specific nutrient or nutrients responsible for the changes observed cannot be identified from this study. Rather, the findings are informative of the potential of efforts to improve diets more generally. Thus, programs that are effective in improving diets in deficient areas, whether educational, food-based or other in nature, will achieve the same results.

The effects of public health programs, particularly as they refer to behavior, need to be evaluated in the context of a society's explicit and implicit social policy. In the context of rural Guatemala, the benefits and costs of nutrition programs to enhance development must be contrasted with those related to efforts to address other existing conditions that limit development. The school system, for example, is vastly inefficient and does not meet the basic educational needs of the population. Only about one half of the children enrolled in first grade ever finish primary school and a large percentage (>20%) remain functionally illiterate.

Programmatic actions that focus on unmet nutritional needs and have beneficial effects on human cognitive development are potentially a step forward in social policy. However, in our view, such actions are deceptive if framed in the context of a social policy that disregards other basic human needs and does not attend to the overall quality of life. Unmet nutritional needs generally coexist with, among others, unmet needs in education, housing, sanitation and health care. Only by meeting all these needs in conjunction with nutritional needs will we truly have moved forward toward a fair humane society that sustains the rights of children and fosters cognitive, social and emotional development.

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