INCAP Publication I-921

Acta Pædiatr Scand 66: 579–584, 1977

GENETIC-ENVIRONMENTAL INTERACTIONS IN PHYSICAL GROWTH

REYNALDO MARTORELL, CHARLES YARBROUGH, AARON LECHTIG, HERNAN DELGADO and ROBERT E. KLEIN

From the Division of Human Development, Institute of Nutrition of Central America and Panama (INCAP), Guatemala, Guatemala, C.A.

ABSTRACT. Martorell, R., Yarbrough, C., Lechtig, A., Delgado, H. and Klein, R. E. (Division of Human Development, Institute of Nutrition of Central America and Panama (INCAP), Guatemala, C.A.). Genetic environmental interactions in physical growth. Acta Paediatr Scand 66: 579, 1977.—Variability in stature among young children is often ascribed to health and nutrition differences in malnourished populations and to genetic differences in well-nourished populations. Hence, it was hypothesized that parent–child correlations in malnourished Guatemalan populations would be markedly lower than those reported for European samples. Instead, it was found that parent-child and sibling correlations were similar in both kinds of populations. The simplest interpretation of these results is that variability in stature among malnourished children is as much a reflection of genetic differences as in developed nations. However, explanations can also be advanced which would attribute the higher than expected correlations to the environment. For instance, it could be that socioeconomic and nutritional status is correlated across generations. In other words, parents who had relatively better conditions as children are more likely to provide a better environment for their children. Consequently, the relative contribution of genetics and environment to variability in height is still unsettled. Nonetheless, it appears that variability in body size in malnourished populations, regardless of the relative importance of its causes, is a useful indicator of health and nutrition.

KEY WORDS: Growth, genetics, height, preschool children

Public health officials working with malnourished children of developing nations generally assume that variability in height principally reflects differential nutrition and health histories (7). This belief is derived from numerous studies indicating that chronic malnutrition (4) and high morbidity rates (13) cause physical growth retardation.

On the other hand, the corresponding assumption in industrialized nations is that variability in height is to a large extent a reflection of differences in growth potentials (19). This assumption results from large bodies of data yielding genetically predictable relationships between parental and child stature (10).

The variables one would like to correlate in growth genetic studies are the growth potentials of parents and children. In the developed nations, environmental conditions may permit full expression of the genetic potential for stature. On the other hand, in chronically malnourished populations, height of both parents and children are not full expressions of the growth potential (5). Hence, stature should be a poor proxy of genetic potential in malnourished populations, and parent–child stature correlations would be expected to be much lower in chronically malnourished populations than in well-to-do nations.

This paper describes parent–child and sibling correlations in height in data collected in four Guatemalan villages. Correlations at ages from 0.5 to 7 years are presented. Since chronic protein-calorie malnutrition is endemic in

Table 1. *Means and standard deviations for parental height (cm) in a rural Guatemalan sample*

Mothers			Fathers			Mid-parent[a]		
n	X̄	S.D.	*n*	X̄	S.D.	*n*	X̄	S.D.
374	148.8	5.4	331	160.4	5.9	260	154.9	4.1

[a] Average of height of father and mother.

Table 2. *Correlations between heights of parents and their children in rural Guatemalan data*

Age (y.)	Sons				Daughters			
	Fathers		Mothers		Fathers		Mothers	
	n	*r*	*n*	*r*	*n*	*r*	*n*	*r*
0.5	186	0.30	251	0.35	155	0.19	202	0.27
1	212	0.37	262	0.33	178	0.22	227	0.22
2	251	0.35	301	0.34	207	0.18	253	0.33
3	253	0.35	299	0.32	235	0.16	275	0.31
4	244	0.33	269	0.30	224	0.24	243	0.40
5	219	0.30	231	0.30	224	0.23	240	0.40
6	199	0.31	201	0.41	206	0.19	211	0.37
7	178	0.24	178	0.42	192	0.17	186	0.38

these populations, the hypothesis to be tested is that the correlations obtained in this study will be substantially smaller than those obtained in well-nourished populations of European descent.

METHODS

The data presented are drawn from an ongoing longitudinal study investigating the effects of chronic malnutrition on mental development and physical growth (9). Four rural ladino communities of Guatemala are being studied. These villages are very poor, their annual income per family being around $200 (USA); protein-calorie malnutrition is endemic and morbidity rates are high.

In the study described herein two variables were utilized: total body length in children (which will be referred to as height) and standing height in parents. Both were measured following standard techniques (22), and adequate measures of quality control (14). Children were examined within ±7 days of the required age. Information

Table 3. *Correlations between mid-parent heights, and heights of their children in the study sample and in USA and Europe*

Age (y.)	Sons										Daughters	
	Guatemala		USA[a] (Fels)		USA[b] (Berkeley)		Pool of European cities[c]		Finland[d]		Guatemala	
	n	*r*	*n*	*r*	*n*	*r*	*n*	*r*	*n*	*r*	*n*	*r*
0.5	182	0.38	170	0.38	32	0.35	141	0.44	–	–	152	0.31
1	202	0.44	175	0.42	29	0.39	139	0.52	55	0.45	172	0.28
2	234	0.42	166	0.45	27	0.36	131	0.49	54	0.46	197	0.34
3	236	0.44	166	0.45	26	0.44	128	0.61	52	0.51	222	0.30
4	219	0.45	162	0.48	25	0.52	134	0.57	54	0.47	200	0.40
5	187	0.45	162	0.48	23	0.50	133	0.58	53	0.43	198	0.38
6	165	0.55	160	0.49	26	0.56	129	0.49	46	0.38	171	0.32
7	145	0.53	153	0.47	24	0.54	129	0.55	42	0.36	150	0.34

[a] Garn (2).
[b] Bayley (1).
[c] Tanner, Goldstein & Whitehouse (19).
[d] Tiisala & Kantero (20).

as to parenthood was obtained from the civil records, which are believed to be highly reliable. All information was collected between January 1969 and July 1975.

The sample included 1 115 children for whom anthropometric data were available for one or more points in time and for one or both of the parents. This represents 78% of the total population at risk. Means and standard deviations of height from birth to 7 years of age for this sector, which have been reported elsewhere (23), show rural Guatemalan children of both sexes to be substantially shorter than a well-nourished reference sample from Denver, Colorado (6). At birth, differences are minor, but later on increase until two years of age. During the period comprised from 2 to 5 years these differences are rather stable, but then increase up to the age of 7 years, when Guatemalan children are 13 cm shorter than those from Denver.

The number of fathers, mothers and parent pairs (i.e. both of them measured) as well as their mean height are given in Table 1. The percentage of fathers and mothers measured were 58% and 66%, respectively. In comparison to 21-year-old males from Denver (6) the fathers in our study are 19 cm shorter, while the corresponding statistic for mothers is 17 cm. Assortative mating for height is negligible for this population as the father–mother height correlation is 0.09 (n=260, N.S.). This value is lower than that of 0.3 usually reported for European populations (18, 19).

For comparative purposes, this paper utilizes data from samples of European descent. The basic assumption is that these are healthy, well-nourished populations. Two samples from the United States of America are included, one from the longitudinal study of the Fels Research Institute in Ohio (2, 3) and one from the Berkeley longitudinal study (1). The European samples include a combined sample of the London, Brussels, Stockholm and Zurich longitudinal studies (19), and a sample from the Finnish longitudinal study (20). While these studies on populations of European descent do not constitute the total carried out up to date, all of them are of a longitudinal character, where children were carefully measured at specific ages, and which included measured rather than reported parental heights.

RESULTS

Table 2 shows parent–child correlations for height for ages 0.5 through 7 years. Father–daughter correlations appear to be the lowest, with no apparent differences between father–son, mother–son and mother–daughter correlations. Livson et al. (10) have emphasized the fact that mother–child correlations are generally higher than father–child correlations. The present findings are therefore only partially in agreement with the above observation. As Tiisala & Kantero (20) point out, highly conflicting observations have been reported in the literature on the relative effect of paternal and maternal height on the height of sons and daughters.

Correlations between mid-parent heights and heights of their children are presented in Table 3 for the study sample, for USA samples (1, 2) and for European samples (19, 20). In all of these studies mid-parent height was the average of the mother's and the father's height.

The differences seen between the correlations in the four studies on populations of European descent (see Table 3) exemplify the range of values reported in the literature for such populations, a point emphasized by Livson et al. (10) who demonstrated that even pooled estimates of such parent–child correlations have wide confidence intervals at all ages.

The correlations for the Guatemalan sample clearly do not differ from those of the European samples in the case of the mid-parent–son correlations.

There is some tendency for the Guatemalan mid-parent–daughter correlations to be lower than those of the European samples. In all cases correlations from the Fels (2) and the combined European sample (19) are higher than the mid-parent–daughter correlations from the Guatemalan study. Correlation from

USA[a] (Fels)		USA[b] (Berkeley)		Pool of European cities[c]		Finland[d]	
n	r	n	r	n	r	n	r
160	0.28	29	0.61	110	0.43	–	–
164	0.34	26	0.67	102	0.41	72	0.43
158	0.40	23	0.66	96	0.46	72	0.39
152	0.21	23	0.69	88	0.47	72	0.42
150	0.44	23	0.60	95	0.51	69	0.50
141	0.44	24	0.60	96	0.55	69	0.51
136	0.44	24	0.61	97	0.49	65	0.38
127	0.43	22	0.61	96	0.49	60	0.31

Table 4. *Correlations between siblings heights in USA and Guatemala populations*

Age (y.)	Sister–Sister				Brother–Brother				Sister–Brother			
	USA[a]		Guatemala		USA[a]		Guatemala		USA[a]		Guatemala	
	n	*r*	*n*	*r*	*n*	*r*	*n*	*r*	*n*	*r*	*n*	*r*
0.5	75	0.52	70	0.63	73	0.44	112	0.36	156	0.35	69	0.51
1	74	0.54	98	0.67	74	0.49	132	0.66	154	0.39	95	0.51
2	66	0.62	126	0.64	70	0.50	200	0.52	147	0.39	138	0.50
3	63	0.62	170	0.51	70	0.68	206	0.60	137	0.47	184	0.58
4	61	0.67	108	0.64	63	0.61	182	0.46	123	0.50	174	0.64
5	53	0.73	154	0.52	68	0.57	154	0.37	116	0.54	146	0.54
6	51	0.76	158	0.47	70	0.57	128	0.29	123	0.56	135	0.53
7	52	0.70	144	0.51	67	0.51	114	0.41	114	0.46	107	0.57

[a] Garn & Rohmann (3).

the Berkeley (1) and the Finnish study (20) are higher than the Guatemalan mid-parent–daughter correlations in all but two and one instances, respectively.

Sibling height correlation data are shown in Table 4 for the USA sample (3) and the Guatemalan population studied. There appear to be no differences between these two sets of correlations. The siblings' correlations are higher than the parent–child correlation in the Guatemalan and the USA sample (3). This is not a surprising finding, since siblings share a common home environment.

DISCUSSION

The results presented in this paper have two types of broad implications. The first has to do with current thinking on the nature–nurture debate, while the second is concerned with the public health implications of the data. We would like to comment on both of these concerns.

Nature–nurture debate

Mueller (15) has recently reviewed the literature on parent–child correlation among *school-age children* from a variety of genetic and environmental backgrounds. He divided the studies into samples of European and non-European descent and concluded that father–daughter and mother–daughter correlations for European samples were significantly greater but that this was not the case for father–son and mother–son. The absolute differences, however, do not appear to be very large. Moreover, because the non-European sample is over 50% Japanese and 8 to 9% American Black, it is difficult to evaluate the role of chronic malnutrition in this comparison. The same author (15) observed that in six samples roughly classified as malnourished, height at 7 years of age was positively correlated with father–son and mother–daughter correlations. However, if the same analyses are carried out for father–daughter and mother–son correlations, no relationship is observed.

Data on parent–child correlations for pre-school children from chronically malnourished populations are scant. Some information has been provided for New Guinean populations (11, 12, 21), but the correlations reported in these studies are difficult to interpret because children of various ages are pooled in the analyses. For instance, groupings of children 1 to 4 years of age are utilized. The statistical noise produced by variability in age would tend therefore to lower the parent–child correlations. Pollit & Ricciuti (17) have shown that mothers and fathers of short children are shorter than the parents of relatively taller ones. The sample was drawn from children attending day care centers whose working mothers lived in the slums of Lima, Peru.

Unfortunately, parent–child correlations were not reported in this study.

As explained earlier in the introduction, on the bases of purely statistical considerations, it was expected that parent–child correlations obtained in our study would be substantially smaller in comparison to similar statistics found in studies of European samples. As we have seen, this is not the case. How can this be so? We would like to offer two possible explanations. It could be that the magnitude and severity of the environmental insults which the parents suffered as children are positively correlated with those which now plague their own children. In other words, parents with relatively better nutrition and health are likely to provide a relatively better environment for their children. This is suggested by the fact that an index of the family's socioeconomic status, a six-point scale which summarizes construction materials, size and cleanliness of the dwelling (8), is correlated with mid-parental height ($r=0.3$) in the same magnitude to which it is correlated with the heights of children ($r=0.3$). However, the partials of parental height on children's heights after controlling for socioeconomic status are not appreciably lower (i.e. 0.03 to 0.05 less) than the correlations already shown in Tables 3 and 4. Nonetheless, the findings are highly suggestive that this explanation partially accounts for the higher than expected correlations observed.

An alternative explanation can also be advanced. All families of the villages which formed part of the study would be considered poor by most standards. The within-village variabilities in income, health and nutrition are not as large as those to be found in urban settings in developing nations. Thus, it may be that the variability in environmental conditions is too narrow to noticeably lower the correlations. In other words, growth is less than maximal in these communities but the extent of growth retardation is more or less constant across individuals. In a correlation analysis this would be equivalent to subtracting a constant from both variables, the end result being that the original correlation would remain unchanged. We have no way of testing this hypothesis within the design of our longitudinal studies.

PUBLIC HEALTH IMPLICATIONS

Turning now to the public health use of physical growth as an indicator of nutritional and health status, the findings presented are such that one still cannot claim to know how much of the variability in height in malnourished populations is reflective of nutritional and health events. In well-nourished populations, relationships of the same magnitude as those found in our study have served as the basis for proposing parent-size specific standards (3, 19). Should the use of such standards be proposed for chronically malnourished populations as well? We think that they should not.

The use of parent-size specific standards would no doubt yield the conclusion that most children in communities similar to the ones studied by us are growing as expected, and hence, are normal. This could be dangerously misleading in that "normal" for such a setting may be well below optimum. Variability in body size among children is related to a series of risks such as morbidity and mortality (16), and to outcomes such as poor mental development. Therefore, it seems that variability in body size, regardless of the relative importance of its causes, is a useful public health measure until and unless body size can definitely be ruled out as an indicator of risk. Nevertheless, the question as to what standards should be used deserves careful consideration. More studies such as the one presented here, are needed before firm conclusions are reached.

ACKNOWLEDGEMENTS

This reasearch was supported by Contract No. NOI-HD-5-0640 from the National Institute of Child Health and Human Development, National Institutes of Health, Bethesda, Maryland, USA.

REFERENCES

1. Bayley, N.: Some increasing parent–child similarities during the growth of children. *J Educ Psychol, 45:* 1, 1954.
2. Garn, S. M.: Body size and its implications. *In* L. W. Hoffman & M. L. Hoffman (eds.): *Review of child development research.* Russell Sage Foundation, New York 1966, vol. 2, p. 529.
3. Garn, S. M. & Rohmann, C. G.: Interaction of nutrition and genetics in the timing of growth and development. *Pediatr Clin N Am, 13:* 353, 1966.
4. Gopalan, C., Swaminathan, M. C., Jumary, V. K. K., Rao, D. H. & Vijayaraghavan, K.: Effect of calorie supplementation on growth of undernourished children. *Am J. Clin Nutr, 26:* 563, 1973.
5. Habicht, J.-P., Martorell, R., Yarbrough, C., Malina, R. M. & Klein, R. E.: Height and weight standards for preschool children: Are there really ethnic differences in growth potential? *Lancet, I:* 611, 1974.
6. Hansman, C.: Anthropometry and related data. *In* R. W. McCammon (ed.): *Human growth and development.* C. C. Thomas, Springfield, Ill. 1970, p. 101.
7. Jelliffe, D. B.: *The assessment of the nutritional status of the community (With special reference to field surveys in developing nations of the world).* World Health Organization, Geneva, 1966, 271 p. (WHO Monograph Series No. 53).
8. Klein, R. E., Freeman, H. E., Kagan, J., Yarbrough, C. & Habicht, J.-P.: Is big smart? The relation of growth to cognition. *J Health Soc Behav, 13:* 219, 1972.
9. Klein, R. E., Habicht, J-P. & Yarbrough, C.: Some methodological problems in field studies of nutrition and intelligence, *In* D. J. Kallen (ed.): *Nutrition, development and social behavior.* U.S. Government Printing Office, Washington, D.C. 1973, p. 61 (DHEW Publication No. (NIH) 73–242).
10. Livson, N., McNeill, D. & Thomas, K.: Pooled estimates of parent–child correlations in stature from birth to maturity. *Science, 138:* 818, 1962.
11. Malcolm, L. A.: Growth and development of the Kaiapit children of the Markham Valley, New Guinea. *Am J Phys Anthropol, 31:* 39, 1969.
12. Malcolm, L. A.: *Growth and development in New Guinea.* A Study of the Bundi People of the Madang District. Institute of Human Biology, Papua, New Guinea 1970. (Monograph Series No. 1).
13. Martorell, R., Habicht, J.-P., Yarbrough, C., Lechtig, A., Klein, R. E. & Western, K. A.: Acute morbidity and physical growth in rural Guatemalan children. *Am J Dis Child, 129:* 1296, 1975.
14. Martorell, R., Habicht, J.-P., Yarbrough, C., Guzmán, G. & Klein, R. E.: The identification and evaluation of measurement variability in the anthropometry of preschool children. *Am J Phys Anthropol, 43:* 347, 1975.
15. Mueller, W. H.: Parent–child correlations for stature and weight among school aged children: a review of 24 studies. *Hum Biol, 48:* 379, 1976.
16. Puffer, R. R. & Serrano, C. V.: *Patterns of mortality in childhood.* Report of the Inter-American Investigation of Mortality in Childhood. Pan American Health Organization, Washington, D.C., 1973, 492 p. (PAHO Scientific Publication No. 262).
17. Pollit, E. & Ricciuti, R.: Biological and social correlates of stature among children in the slums of Lima, Peru. *Am J Orthopsychiatry, 39:* 735, 1969.
18. Spuhler, J. N.: Assortative mating with respect to physical characteristics. *Eugen Quart, 15:* 128, 1968.
19. Tanner, J. M., Goldstein, H. & Whitehouse, R. H.: Standards for children's height at ages 2–9 years allowing for height of parents. *Arch Dis Child, 45:* 755, 1970.
20. Tiisala, R. & Kantero, R. L.: Some parent–child correlations for height, weight and skeletal age up to ten years. *Acta Paediatr Scand,* Suppl. 220: 42, 1971.
21. Wark, L. & Malcolm, L. A.: Growth and development of the Lumi child in the Sepik District of New Guinea. *Med J Aust, 2:* 129, 1969.
22. Weiner, J. S. & Lourie, J. A.: *Human biology: A guide to field methods.* Blackwell Scientific Publications Oxford, London 1969.
23. Yarbrough, C., Habicht, J.-P., Malina, R., Lechtig, A. & Klein, R. E.: Length and weight in rural Guatemalan Ladino children birth to seven years of age. *Am J Phys Anthropol, 42:* 439, 1975.

Submitted Nov. 2, 1976
Accepted Febr. 8, 1977

(R. M.) Division of Human Development
Institute of Nutrition of Central America
and Panama (INCAP)
Carretera Roosevelt Zona 11
Guatemala, C.A.