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3 | Malnutrition and Mental Development in Rural Guatemala

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Though the problem of malnutrition is a very old one, an accurate understanding of its effects has only recently begun. Stimulated by international attention to the losing race between population growth and world food production, the last decade has witnessed a proliferation of studies of the effects of malnutrition on human development. Many such studies have focussed on the relationship between malnutrition and mental development. In agreement with folk wisdom, an association between malnutrition and deficient mental development has not been difficult to establish. Yet, unequivocal evidence as to a causal relationship has eluded investigators. At least some of the reasons why are not difficult to understand. Problems of definition and measurement of nutritional status are considerable. Such problems are equally great for mental development, and these are complicated by the fact that the effects of malnutrition are generally studied in developing countries, by social scientists employing instruments and concepts foreign to the research setting. Thus, the problem of cross-cultural understanding and measurement is usually present in research on the effects of malnutrition and mental development. Finally, the usual research strategies are difficult to apply to the study of the effects of malnutrition: one can neither cause malnutrition in order to observe its effects, nor erase the poverty, illness and social deprivation which almost invariably exist simultaneously with malnutrition, and which constitute plausible alternative explanations of deficient mental development.

This paper will briefly describe previous research on the effects of malnutrition on mental development (for more extensive reviews, see those of Birch, 1972; Klein *et al.*, 1971, Latham, 1974; Read, 1975; Warren, 1973) and then describe in some detail the design and findings to date of one such research project, the Institute of Nutrition of Central America and Panama's (INCAP) on-going longitudinal prospective study of the effects of malnutrition on mental development in rural Guatemala.

I. A SELECTIVE REVIEW OF THE LITERATURE

In this brief review of the published literature, we will focus on several areas of research conception and design which have been troublesome in previous studies. These include adequate definition of nutritional status, consideration of the effects of the timing of malnutrition, appropriate operationalization of mental development, effects of the age of measurement of mental development, and attribution of causality.

A. Definitions of Malnutrition

Malnutrition is a difficult concept to operationalize because, while it refers in part to input, or the food a person eats, the only measures usually available are output measures (i.e. growth or health status). Thus the criteria for classification (summarized in Jelliffe, 1966) are all inferential, with past malnutrition inferred from present physical state. In particular, protein–calorie malnutrition (PCM) has been variously defined using indicators of physical growth, various clinical signs, and biochemical indicators. It is generally agreed that PCM is a continuum, with clinically identified kwashiorkor (caused primarily by protein deficiency) and marasmus (primarily a calorie deficit) at one end, and "good" nutritional status (maximal growth, appropriate weight for height) at the other. The primary indicator is low weight for age or low weight for height and the extreme category is defined as having less than 70% of expected weight for age. In this range kwashiorkor is indicated by the presence of oedema, skin rash, changes of colour of hair, and apathy, while marasmus is indicated by wasting, little subcutaneous fat, and irritability. The moderately malnourished child is usually thought to be identified only by growth retardation, say, of less than 90% of the normal weight for age. It may be accompanied by biochemical indications and/or evidence of reduced food intake, but almost never by clinical signs. Finally, designation of malnutrition is complicated by the fact that children with deficient diets may also exhibit signs of various vitamin and mineral deficiencies in addition to the signs of protein–caloric malnutrition described here.

The majority of studies of human malnutrition and mental development have dealt exclusively with the effects of severe malnutrition (Birch *et al.*, 1971; Botha-Antoun *et al.*, 1968; Brockman and Ricciuti, 1971; Cabak and Najdanvic, 1965; Champakam *et al.*, 1968; Chase and Martin, 1970; Cravioto *et al.*, 1966; Cravioto and DeLicardie, 1970; Cravioto and Robles, 1965; DeLicardie and Cravioto, 1974; Edwards and Craddock, 1973; Evans *et al.*, 1971; Hertzig *et al.*, 1972; Liang *et al.*, 1967; Mönckeberg, 1968; Montelli *et al.*, 1974; Pollit and Granoff, 1967; Stein *et al.*, 1972a, b; Stoch and Smythe, 1963, 1967). Typically, subjects have been children hospitalized for one of two forms of acute malnutrition, marasmus or kwashiorkor (Birch *et al.*, 1971; Brockman and Ricciuti, 1971; Cabak and Najdanvic, 1965; Champakam *et al.*, 1968; Chase and Martin, 1970; Cravioto and Robles, 1965; DeLicardie and Cravioto, 1974; Evans *et al.*, 1971; Hertzig *et al.*, 1972; Mönckeberg, 1968; Montelli *et al.*, 1974; Pollit and Granoff, 1967). These studies of severe malnutrition typically find an association between early PCM and poor cognitive performance. However, one could easily suspect that the trauma associated with having a serious illness and being hospitalized has in itself negative effects on mental development. Also, there is a problem of selection: though usually unlikely, the possibility does exist that some children become malnourished because they are in some ways more difficult children, perhaps with more feeding problems. These problems, as well as a variety of others to be discussed shortly, have made it difficult to make unambiguous causal statements about the effects of malnutrition on mental development.

Fewer investigations have focussed on less severe forms of malnutrition, although the number of children affected is far greater. Though severe malnutrition is a relatively rare condition except during times of natural disaster, it has been estimated that 75% of all children growing up in developing countries are malnourished to some degree (Béhar, 1968). The effects of mild-to-moderate PCM have been studied by Boutourline-Young *et al.* (1973), Chávez *et al.* (1974), McKay *et al.* (1969), Montelli *et al.* (1974), Mora *et al.* (1974), and Patel (1974). Like the studies of severe PCM cited, these studied have typically reported an association between malnutrition and poor cognitive performance. However, these investigators have not been able to make strong causal statements because possible alternative explanations for their findings exist.

B. Timing of Malnutrition

In all but a few studies (e.g., Cravioto *et al.*, 1966; Cravioto and DeLicardie, 1970; Edwards and Craddock, 1973; McKay *et al.*, 1969; Mönckeberg *et al.*, 1972), diagnosis of malnutrition has been made during the first few years of life. Since most studies have consisted of follow-ups of previously hospitalized children, nutritional-status data are reported for only one or at most two points in time. While these are important data, we would be in a stronger position to specify effects of malnutrition if we had nutritional-status measures collected during the child's entire early life, including the prenatal period. This kind of data has various advantages: it allows precise estimation of the effects of malnutrition on mental development at the time of the malnutrition and its long-term effects on later mental development. Such information also permits inferences to be more readily made concerning the mechanisms involved in these effects: a consistent association of prenatal malnutrition with retarded mental development, for example, would suggest the possibility of a neuroanatomic mechanism, because of the rapid growth and vulnerability of the nervous system during gestation, while greater effects of later appearing malnutrition might suggest that the mechanism involved was insufficient energy levels available for environmental exploration and stimulation. Data collected over a long period of time also allow the investigator to define nutritional status directly, in terms of nutrient ingestion, rather than indirectly, as physical growth. Only long-term longitudinal investigations allow the collection of such data. Longitudinal investigations other than the INCAP study are those of Stoch and Smythe (1963 and 1967) in South Africa; Botha-Antoun *et al.* (1968) in Lebanon: McKay *et al.* (1969) and Mora *et al.* (1974) in Colombia; Boutourline-Young *et al.* (1973) in Tunisia; and those of Chávez *et al.* (1974) and DeLicardie and Cravioto (1974) in Mexico. To date none of these studies excepting those of Stoch and Smythe and Botha-Antoun *et al.* have published final results.

C. Definitions and Measurement of Mental Development

No consensus exists among scientists concerning an appropriate definition of mental development. The term subsumes an almost infinite number of human characteristics that could be evaluated, and in fact, there exist hundreds of tests designed to measure mental ability, which is simply level of mental development at a given point in time. However, in spite of this profusion of tests, the majority of investigators have chosen to employ IQ (or in the case of infants, DQ) scores as their operationalization of the construct (Birch *et al.*, 1971; Botha-Antoun *et al.*, 1968; Boutourline-Young *et al.*, 1973; Cabak and Najdanvic, 1965; Chase and Martin, 1970; Chávez *et al.*, 1974; Cravioto and Robles, 1965; DeLicardie and Cravioto, 1974;

Edwards and Craddock, 1973; Evans *et al.*, 1971; Hertzig *et al.*, 1972; Liang *et al.*, 1967; Mönckeberg, 1968; Mönckeberg *et al.*, 1972; Montelli *et al.*, 1974; Mora *et al.*, 1974; Patel, 1974; Pollit and Granoff, 1967; Stoch and Smythe, 1963, 1967).

While the use of IQ scores can be defended on some pragmatic grounds (i.e. the tests are well known, well standardized in some settings, and predict school success), their use does not focus attention on possible mechanisms which might link malnutrition to mental development, or on possible differential effects of malnutrition on various mental capacities. A few attempts to study such specific effects have been made; some studies have reported several subscale scores for infant psychomotor scales (Chase and Martin, 1970; Chávez *et al.*, 1974; Cravioto and Robles, 1965; Mönckeberg, 1968; Mönckeberg *et al.*, 1972; Montelli *et al.*, 1974), describing deficits in malnourished infants on each subscale. Others have addressed themselves to specific types of cognitive performance such as intersensory integration (Champakam *et al.*, 1968; Cravioto *et al.*, 1966; Cravioto and DeLicardie, 1970; Klein *et al.*, 1969; McKay *et al.*, 1969; Witkop *et al.*, 1970). Such studies have been informed by the hypothesis that malnutrition causes neurointegrative deficits Results of these studies have to date been equivocal, with Cravioto *et al.* (1966), Cravioto and DeLicardie (1968), Champakam *et al.* (1968), and Witkop *et al.* (1970), reporting an association of deficient intersensory integration and malnutrition, but Klein *et al.* (1969) and McKay *et al.* (1969), reporting none. Champakam *et al.* (1968) assessed performance in four general areas: memory, perceptual ability, abstract thinking and verbal ability. They found deficits associated with malnutrition in all four areas. These deficits were greatest in abstract thinking and perceptual ability. As we shall show in the latter part of this paper, the INCAP study has attempted to go considerably beyond previous investigations in the range of its infant and preschool mental test batteries. Such inclusiveness should permit testing of hypotheses concerning specific and differential effects of malnutrition. Furthermore, with this information it may be possible to choose among hypothetical mechanisms linking malnutrition and mental development.

A further problem related to the definition of mental development concerns the cultural validity of the operational definition of mental development employed. Intellectually competent behaviour and the mental development which makes such behaviour possible takes place in, and is inextricably tied to, a particular environmental context. Thus, as Berry (1969), Irwin *et al.* (1974), and Scribner and Cole (1973) have argued, measurement instruments employed in any cultural setting must be appropriate to that setting. They must also be interpretable to scientists. In general, investigators in the area of malnutrition and mental development have concerned themselves with the latter requirement and paid little attention to the question of local, or emic validity (Berry, 1969).

This problem would appear to be insignificant in testing children during the first one or two years of life. However, for preschool and older children, the question of emic validity in cognitive test performance is a serious one. In a few cases the problem has been ignored, with unadapted Western tests employed (Edwards and Craddock. 1973; Hertzig *et al.*, 1972). Even where cultural adaptation of Western tests has been attempted (e.g. Cabak and Najdanvic, 1965; Champakam *et al.*, 1968; Evans *et al.*, 1971; Liang *et al.*, 1967; Stoch and Smythe, 1963, 1967) such attempts do not assure emic validity of measurement. This would require that the tests actually measure traits (in this case, facets of intellectual competence) which have meaning in the context of the local culture, and that their operationalizations, the test items and tests employed, measure these traits accurately. Even where Western psychometric instruments have been successfully adapted to employ indigenous materials and concepts (and it is generally very difficult to determine on the basis of published research reports to what extent this has been achieved), nothing can be known about the relationship of test performance to local definitions of competence and the ability to function as an effective member of the community, without the collection of independent measures of such competence and ability. Where IQ tests are adapted to measure a population fairly, they may, as Biesheuvel (1949) has suggested, simply measure Western educability. Such information is of value as one index of the effect of nutritional status. It is, however, at best a culture-bound and limited index of the effects of malnutrition on mental development and intellectual competence, and one which may be unlikely to reveal how early malnutrition will affect the adult lives of its victims. For a more extensive discussion of the methodological problems of establishing both emic and non-emic validity of measurements in cross-cultural field studies, the reader is referred to Irwin *et al.* (1975). To address the problems of both emic, or local, validity, and non-emic, or Western, validity, the INCAP project has employed a variety of non-psychometric measures which are described in the second half of this paper.

D. Age of Measurement of Mental Development

Mental development is, of course, a process which unfolds over time. Measurements of cognitive performance are snapshots of the status of development at particular points in time. As such, these measurements have meaning first in relation to the age or developmental period in which they are made, and much less to other periods, such as adulthood. However, mental test performances measured in later childhood (from age seven onwards) are more similar to and predictive of adult performances than are performances measured in earlier childhood (c.f. Bayley, 1968). Since malnutrition and mental development researchers are ultimately most interested in the effects of malnutrition on adult functioning and competence, studies which report the mental test performance of older children are of more intrinsic interest than those which report the performances only of very young children, such as those of Cravioto and Robles (1965), Pollit and Granoff (1967), Brockman and Ricciuti (1971), and Montelli *et al.* (1974). The optimal design to measure mental development at various ages is, again, the long-term longitudinal prospective study, which enables description of the relationship of malnutrition to cognitive ability and to the ability to cope with the various tasks of childhood as development proceeds.

E. Attribution of Causality

The classical scientific paradigm for generating inferences of a causal effect of one variable on another is experimental manipulation of the first variable accompanied by control or randomization of other variables representing alternative causal explanations. The experimental manipulation possible in malnutrition research is limited by ethical considerations; investigators do not malnourish children in order to observe the effect of malnutrition on mental development. One form of experimental manipulation is possible, however. Where malnutrition exists, nutrition can be improved through supplementation of inadequate diets, and the effect of this intervention can be observed. The effects of deprivation are measured indirectly by observing the extent of *improvement* with adequate nutrition. The present investigation has employed such a design. So have the longitudinal investigations of McKay *et al.* (1969), Boutourline-Young *et al.* (1973), Chávez *et al.* (1974), and Mora *et al.* (1974).

Other studies have employed observational, rather than experimental designs; naturally occurring severe or moderate malnutrition has been identified, and correlated mental development has been measured. With the single exception of Stein *et al.*'s (1972a, b) follow-up study of children of the Second World War pregnant famine victims (who were malnourished for a relatively brief period, with average birth-weight never dropping to levels common in the third world today), every one of these observational studies has found associations between early severe or moderate malnutrition and deficient mental development. The near unanimity of these findings is impressive. However, alternative causal explanations do exist. One is that poverty and accompanying social deprivation almost invariably co-exist with malnutrition. In those studies where social variables have been measured (Chase and Martin, 1970; Chávez *et al.*, 1974; Cravioto and Robles, 1965; Evans *et al.*, 1971; Mönckeberg *et al.*, 1972; Mora *et al.*, 1974; Patel, 1974; Schlenker *et al.*, 1968; Stein *et al.*, 1972a, b; Stoch and Smythe, 1963, 1967), this association has been confirmed. Since social deprivation may well play a causal role in deficient mental development (e.g. Hess *et al.*, 1968, 1969; Whiteman and Deutsch, 1968), the effects of nutritional and social variables on mental development are confounded. Klein *et al.* (1972) have attempted to estimate both the independent and the combined contributions of social deprivation and malnutrition to mental development. Their conclusion is that both malnutrition and social factors contribute importantly to psychological test performance. Analyses of the kind performed by these investigators require either the collection within a longitudinal prospective study of quantitative social status and social deprivation data of the kind that will permit statistical control of social factors, or a design that separates nutritional status and conditions of social deprivation, or preferably both.

II. THE INCAP STUDY

The preceding literature review indicated a number of characteristics of the design and choice of variables in major studies linking malnutrition and mental development that have prevented firm conclusions about the effects of mild-to-moderate PCM on intellectual functioning. The following section describes the design of the INCAP study; the final section summarizes the major results to date of that study.

A. Design

The INCAP investigation is a longitudinal quasi-experimental intervention study. Four villages from an Eastern, Spanish-speaking section of Guatemala, where malnutrition is endemic, were matched on a number of demographic, social, and economic characteristics. The experimental intervention was differential supplemental feeding of two matched groups; two villages were selected at random as "experimental" villages, in which a high protein–caloric drink similar to a popular corn-base gruel (*atole*) was made available twice daily at a central dispensary for *all* residents; and two were selected as "control" villages in which a drink was also made available to all who wished to partake. This drink (*fresco*), similar to Kool-Aid, contained about one-third of the calories contained in the *atole*. Both drinks contain enough iron, vitamins and minerals so that none of these substances should be limiting. In both experimental and control villages, free outpatient medical care has also been provided since the inception of the study.

The design is longitudinal; all children in the villages from birth to 7 years of age have been measured on both independent and dependent variables since 1969. Our primary concern here is with the children for whom we have information on supplemental food ingested by mother or child since the child's conception. The design is prospective in that data about a child's health and feeding are collected in advance of mental testing.

This design also permits us to examine change over time, from one testing to another, and thus to ask whether supplemental feeding during a certain period is related to increases in test performance during that same period, or at what stage of mental development the largest effects of the supplemental feeding are likely to appear, and whether there are critical periods in development during which malnutrition has an effect on mental development. Finally, the longitudinal design allows one to ask whether effects seen at one age persist to later ages, or are erased by intervening circumstances. However, these analyses require that the measures of mental development be highly reliable over short periods of time. A large amount of effort has therefore been directed at accurately assessing test-retest reliability at all ages.

B. Definition of the Independent Variable

The desired measure of nutritional status in this study is total nutrient ingestion by the mother during pregnancy and lactation and by the child up to the point of mental testing. This measure would be a sum of supplemental feeding and level of home diet of the mother and child during these periods. Home diet information that is individually reliable is extremely difficult to obtain because of vagaries of individual reporting, variability in what a child eats from day to day, and real changes in the biochemical and nutrient composition of various foods from year to year. In fact, estimates of the total home diet, based on dietary surveys, are less precise than supplemental food ingested, which can be measured very accurately. Thus, home diet serves as a family background variable that permits us to be sure that our villages do not differ in this respect.

C. Definition of the Dependent Variable

The dependent variable, mental development, has been measured with a series of tests that represent various theories and constructs about the processes of mental development. The approach has been purposely eclectic. In the light of the paucity of evidence on specific cognitive effects of malnutrition (e.g. evidence that there are effects on one type of processing and not on another) it was felt that this approach would provide the greatest chance of identifying which specific kinds of functioning are affected by malnutrition.

As previously noted, testing has been longitudinal; testing is begun with the newborn and repeated at 6, 15, and 24 months, then annually from 36 months to 84 months. At each age emerging abilities are measured, and the Test Battery becomes increasingly larger and more varied.

Neonates are tested within 10 days of birth with the Brazelton Neonatal Scale, and then at 6, 15, and 24 months with an infant scale composed of items compiled from the Bayley, Cattell, Gesell, and Merrill-Palmer Infant Scales. From 36 months to 7 years, children are tested annually on a battery of 24 tests chosen to tap memory, language, perceptual reasoning, learning, and abstract reasoning ability.

The Brazelton Scale was designed by T. Berry Brazelton and his colleagues, and is currently being employed by a number of investigators (e.g. Freedman and Freedman, 1969; Horowitz, 1973; Scarr-Salapatek and Williams, 1973). The scale assesses behavioural state (varying from deep sleep to crying), reaction to distal stimulation, and incipient social responses, in addition to neonatal reflexes. Inter-observer reliability among INCAP's testers has ranged from $r = 0{\cdot}93$ to $r = 0{\cdot}97$. Test-retest reliabilities for the summary variable employed in our analyses is $r = 0{\cdot}67$ for a sample of 20 infants.

At 6, 15, and 24 months of age, infants in our study are tested with an infant battery called the Composite Infant Scale (CIS). Items are scored as mental or motor, according to traditional infant batteries. Test-retest and inter-observer reliabilities for the CIS are presented in Table 1. With the exception of the 24-month motor sub-scale ($r = 0{\cdot}44$), these reliabilities are high, ranging from 0·82 to 0·99. The 24-month motor sub-scale appears to be approaching a ceiling at this age.

From 3 to 7 years of age, all children in the study are tested on an extensive battery of tests, known as the Preschool Battery. The tests in the Preschool Battery derive from a number of psychological theories. Some have their origins in learning theory (Digit and Sentence Memory, Memory for Designs and for Objects, Incidental Learning, and Reversal Discrimination Learning). The Embedded Figures Test (EFT), Matching Familiar Figures

Table 1
Test-retest and inter-observer reliability of psychological test measures

VARIABLE	Test-retest	N	Inter-observer	N
Brazelton Neonatal Assessment				
BG 1	0·67	20	0·97	20
Composite Infant Scale				
6 months mental	0·88	20	0·82	15
6 months motor	0·92	20	0·82	15
15 months mental	0·88	20	0·87	15
15 months motor	0·87	20	0·87	15
24 months mental	0·86	20	0·85	15
24 months motor	0·44	20	0·85	15
Preschool Battery (36 months)				
Cognitive Composite	0·87	40	—[a]	—
Embedded Figures Test Sum	0·81	20	0·99	140
Embedded Figures Test Time	0·63	20	0·99	140
Embedded Figures Test Adaptability	0·63	20	—[a]	—
Digit Span	0·65	20	0·99	140
Sentence Span	0·60	20	0·99	140
Reversal Discrimination Learning Sum	0·60	40	—[a]	—
Reversal Discrimination Learning Time	0·40	20	N.A.	—
Naming	0·86	20	1·00	140
Recognition	0·91	20	0·99	140
Verbal Inferences	0·62	20	N.A.	—
Line Velocity	0·65	20	0·99	140
Persistence on an Impossible Puzzle	0·45	20	0·97	140

[a] Not appropriate; score is constructed, not observed.

Test (MFF) and Haptic Visual Matching Test (HVM) are tests of perceptual analysis. Another sub-set are problem-solving tasks similar to those found in well-known intelligence tests (Picture Vocabulary, Incomplete Figures, Verbal Analogies (inferences), Block Design, a concept matching task, a coding task, and the Knox Cubes test, itself an early IQ test). Three tests are Piagetian (conservation of area, of continuous quantity and of matter (Piaget and Inhelder, 1969)), and one other is designed to measure neurological changes occurring between 5 and 7 (perception of the midline). Finally, two tests measure the non-cognitive capacities of inhibition and control (Draw-a-Line-Slowly) and persistence (measured by persistence in attempting to solve an impossible puzzle). This complete battery is administered to 5- to 7-year-olds, with 3- and 4-year-olds receiving only ten of the tests. Of those ten, two were not initiated until the Spring of 1971, and the data for these tests are still too sparse for profitable analysis. The remaining eight come primarily from the learning area (Digit and Sentence Memory and Discrimination Learning) and the problem-solving tasks

(Picture Vocabulary and Verbal Inference). The EFT is also administered, as well as two non-cognitive tests (Line Velocity on the Draw-a-Line-Slowly task, and Persistence on an Impossible Puzzle).

For a few tests, response time is measured (EFT and Reversal Discrimination Learning) and an additional variable, "adaptability", has been generated for the EFT. This variable assesses how well the child adjusts his response time to the difficulty of each item. The Vocabulary test has two scores: number of pictures named and number recognized, which presumably measure somewhat different capabilities. In all, the Preschool Battery administered at 3 and 4 years yields 12 measures.

In addition to these variables, a composite variable, known as the Cognitive Composite, has also been constructed and is reported in the present paper. It consists of an equally weighted, standardized combination of five tests chosen to tap cognitive rather than motor or response time characteristics, and to give approximately equal representation to verbal and perceptual skills. Although the basis of selection was theoretical, the choice of variables and equality of weighting is congruent with a factor analysis of the test battery. The tests composing the Cognitive Composite at 3 and 4 years are Digit Memory, Vocabulary Recognition, Verbal Inferences, Embedded Figures, and Reversal Discrimination Learning.

Tests in the Preschool Battery were adapted to the research setting by a team consisting of American and Guatemalan psychologists, a Guatemalan cultural anthropologist, and Guatemalan testers and cultural informants (Klein *et al.*, 1969). Two years of pre-testing, during which some tests went through as many as ten revisions, were devoted to developing test materials and instructions which both the intuitions of testers, as well as the performances of local (pilot sample) children of various ages suggested were appropriate and meaningful.

Both emic or local validity as well as Western validity of these measures has been assessed (Irwin *et al.*, in press). Emic validity was assessed, first by employing adult's ratings of children's smartness (Klein *et al.*, 1973), which is translated as "listura", in Spanish, and is associated with the concepts of alertness, independence, verbal facility, and good memory. Also employed in emic validity studies have been parental judgments of children's intellectual ability, as revealed by their assignments of chores to their child at early ages, and by their decisions concerning sending their child to school (and thus losing an important labour source), or not sending him (Irwin *et al.*, in press). Non-local, or Western, validity has also been evaluated, through free behavioural observations of children's ability to engage in self-managed sequences (Nerlove *et al.*, 1974; and Irwin *et al.*, in press), and by school performance measures (Irwin *et al.*, 1976; and Irwin *et al.*, in press).

The result of these validity studies has been a considerable amount of converging evidence of both emic and Western validity; *listura* ratings, parental judgment measures, self-managed sequences and school performance have all been found to correlate significantly with various tests in the Preschool Battery. Each of these measures correlates with a different pattern of tests, suggesting that intellectual competence is a multidimensional concept in our rural Guatemalan research setting, and one which is somewhat different from the Western concept. Furthermore, the local concept of intellectual competence appears from our data to be defined quite differently for girls than for boys (Irwin *et al.*, in press).

D. Intervening Variables

The eventual aim of investigation in this area is a causal statement about nutritional effects on mental development. For instance, one would like to be able to assert convincingly that supplemental feeding has or has not contributed to or caused an improvement in mental functioning at a particular age. If we were manipulating only the independent variable, then the only considerations in making causal statements would be the statistical ones of significance and power. However, our treatment (the supplement) is voluntarily consumed, so it becomes important to be sure that observed relationships are not due to a third factor related to both. For instance, the association between family socio-economic level and mental test performance of these children is well documented (Klein *et al.*, 1972), and if the present study had found a positive association between amount of supplement ingested and socio-economic level (e.g. if richer families were more likely to make use of the supplemental feeding) then a positive association between mental test performance and supplement ingested could be attributed to the relationship each has with family SES rather than to a real relationship between nutritional status and mental development. However, our experimental design allows us to control for differences in SES; since the feeding is freely available to all those who wish it, lower SES children who attend frequently may be as well fed as children from higher SES levels who do not attend the supplementation centre, but have adequate home diets.

E. Results to Date

This section must be introduced with a caveat characteristic of longitudinal studies in progress: the data which will be presented in this paper are necessarily incomplete. Though the project was conceived as a study, from birth to 7 years, of cognitive development and its antecedents, data have thus far been collected in sufficient quantity to examine effects only to 48 months of age. Furthermore, as previously noted, data have not yet been analysed for all tests employed in the study, as many are not given before age five. Finally, only a portion of the planned analyses of the data now available has been completed. Even though our analyses are preliminary, those results which are available are both interpretable and provocative.

Two types of analyses have been performed to examine the effects of nutritional status on mental development. The first consists of analyses of variance employing a categorical measure of supplementation history. For these analyses, each child is assigned to one of three categories on the basis of the number of quarters (3-month intervals) during which he (or his mother during pregnancy and lactation) was well supplemented. To be labelled well-supplemented, a child had to receive adequate supplementation in at least 75% of the time intervals (3-month intervals) he has passed through. The required quantity of supplement, measured in calories, varies by age of the child. During pregnancy (3 intervals), the mother must have consumed at least 20,000 calories. When the child was between 0 and 6 months, the mother had to ingest 10,000 calories per quarter; from 6 to 24 months, either mother or child had to consume 10,000 calories per quarter, depending on whether the child was being breast fed; and from 24 to 84 months of age, the child had to ingest 10,000 calories per quarter. Children who had received (either directly or through the mother) less than 5,000 calories per quarter in at least 75% of their time intervals (10,000 during pregnancy) were labelled "poorly supplemented"; all other children were considered intermediate.

The second type of analysis performed employs a continuous measure; the total amount of supplement ingested by the child or by his pregnant or lactating mother. As will be noted, similar results were obtained with each type of analysis.

1. The Effects of Nutritional Supplementation on Psychological Test Performance

Table 2 presents a comparison of mean psychological test performance by level of supplementation and results of analyses of variance. Neonatal psychomotor development is indexed in Table 2 by Brazelton variable BG1, which includes the positive signs of vigour, visual following, social interest in the examiner, and motor maturity. No significant effects of nutritional status were obtained for this variable. Other analyses have revealed a strong effect

Table 2
Means and standard deviations of psychological test scores by supplementation ingestion category, and analyses of variance

Test	Nutritional status category: 0 $\bar{X}$	1 $\bar{X}$	2 $\bar{X}$	F	S.D. (pooled)	Sig. level
Brazelton Neonatal Assessment						
BG I	38·83 (42)	36·00 (32)	39·05 (83)	0·66	13·12	NS
Composite Infant Scale						
6 months mental	74·17 (161)	76·45 (223)	77·81 (101)	2·54	13·44	<0·100
6 months motor	70·11 (161)	70·96 (223)	72·72 (101)	1·06	14·14	NS
15 months mental	61·77 (177)	66·30 (255)	72·31 (77)	16·40	14·14	<0·005
15 months motor	73·62 (177)	77·35 (255)	82·60 (77)	7·36	17·61	<0·005
24 months mental	59·44 (245)	65·39 (220)	67·85 (80)	17·46	13·76	<0·005
24 months motor	67·33 (237)	74·61 (218)	79·07 (80)	13·56	20·28	<0·005
Preschool Battery						
36 months						
EFT Sum	9·43 (270)	10·03 (232)	9·70 (50)	1·91	3·44	NS
EFT Time	3·15 (270)	3·01 (232)	2·89 (50)	1·58	11·45	NS
EFT Adaptability	0·009 (270)	0·013 (232)	0·072 (50)	1·48	0·240	NS
Digit Span	10·11 (224)	10·87 (197)	12·92 (44)	2·22	8·33	NS
Sentence Span	12·06 (228)	14·22 (210)	14·60 (48)	1·85	12·85	NS
RDL Sum	23·18 (232)	23·83 (220)	20·93 (45)	0·38	20·52	NS
RDL Time	2·34 (232)	2·07 (220)	1·83 (45)	5·13	11·49	<0·010
Vocabulary Naming	6·44 (262)	7·44 (227)	8·06 (50)	5·07	4·31	<0·010
Vocabulary Recognition	19·40 (262)	20·62 (227)	20·70 (50)	2·83	5·67	<0·050
Verbal Inferences	1·25 (120)	1·52 (106)	2·08 (12)	3·28	1·22	<0·050
Draw-A-Line Slowly (cm/sec)	10·59 (250)	9·34 (220)	9·44 (50)	4·84	4·55	<0·010

(contd.)

Table 2—(*contd.*)
Means and standard deviations of psychological test scores by supplementation ingestion category, and analyses of variance

Test	Nutritional status category: 0 $\bar{X}$	1 $\bar{X}$	2 $\bar{X}$	*F*	S.D. (pooled)	Sig. level
Persistence on an Impossible Puzzle	5·98 (203)	5·86 (223)	6·46 (50)	0·25	5·40	NS
Cognitive Composite	−5·28 (278)	48·97 (237)	54·20 (50)	2·75	280·39	<0·100
<u>48 months</u>						
EFT Sum	4·63 (205)	4·83 (236)	5·55 (31)	1·74	2·60	NS
EFT Time	2·90 (205)	2·69 (236)	2·85 (31)	1·54	1·24	NS
EFT Adaptability	0·022 (205)	0·054 (236)	0·024 (31)	2·02	0·175	NS
Digit Span	21·05 (200)	21·43 (233)	19·24 (29)	0·409	12·37	NS
Sentence Span	30·07 (204)	34·10 (231)	36·07 (28)	2·62	20·37	<0·100
RDL Sum	33·48 (209)	37·93 (240)	40·97 (31)	3·69	20·15	<0·050
RDL Time	1·69 (209)	1·55 (240)	1·58 (31)	2·66	0·64	<0·100
Vocabulary Naming	11·70 (212)	13·89 (238)	14·10 (30)	11·18	5·19	<0·005
Vocabulary Recognition	25·59 (212)	27·30 (238)	26·63 (30)	5·83	5·35	<0·005
Verbal Inferences	2·76 (155)	3·05 (191)	3·00 (23)	1·50	1·54	NS
Draw-A-Line Slowly (cm/sec)	7·30 (203)	5·97 (229)	4·44 (31)	9·65	4·18	NS
Persistence on an Impossible Puzzle	9·01 (184)	9·06 (236)	8·00 (31)	0·359	6·62	NS
Cognitive Composite	−17·53 (215)	56·52 (241)	67·87 (31)	4·08	291·50	<0·025

of gestational supplementation on birth-weight, and a relationship between birth-weight and various measures from the Brazelton scale (Lasky *et al.*, 1975; Lechtig *et al.*, 1975). However, the relation of maternal supplementation to the Brazelton variable is almost zero. Presently, both Brazelton himself and we at INCAP are experimenting with construction of new summary variables, and the possibility of an effect of nutritional status on neonatal behaviour cannot yet be ruled out.

Also presented in Table 2 are the results of analyses of data for the Composite Infant Scale. Data for two summary variables are presented at each age at which the test is administered: mental score and motor score. Again, little effect is seen at 6 months of age. However, significant effects of supplementation ingestion emerge by 15 months, and these are particularly strong at 24 months. Individual items in the Composite Infant Scale at 15 and 24 months have also been examined separately. In general, these analyses indicate that the impact of supplement ingestion is more closely related to motoric and manipulative items within both the mental and motor scales than to more linguistic or cognitive items.

Table 2 presents, in addition, means and F ratios by nutritional status category for psychological test performance at 36 and 48 months of age. At 36 months, significant effects of supplementation category were found for response time on Reversal Discrimination Learning and on Vocabulary Naming, Vocabulary Recognition, Verbal Inferences and Draw-a-Line-Slowly. Cognitive Composite showed a marginally significant ($p<0{\cdot}10$) effect.

At 48 months as well, several tests showed significant effects associated with categories of supplementation ingestion: Vocabulary Naming, Vocabulary Recognition, Reversal Discrimination Learning Sum Correct, Draw-a-Line-Slowly, and Cognitive Composite score all showed significant effects at least at the 0·05 level, and Sentence Memory and Reversal Discrimination Learning response time were significantly different at the 0·10 level. Again, as at 36 months, well supplemented children responded faster on Reversal Discrimination Learning.

All analyses described thus far have combined data for boys and girls. We have also examined the possible existence of sex differences within our data by performing two-way ANOVAS of the supplementation ingestion categories by sex on the Composite Infant Scale at each age it is administered and on 36-month Preschool Battery scores. Small sample sizes prevented a similar analysis at 48 months. The only main effects for sex were on the Cognitive Composite ($F=4{\cdot}75$, $p<0{\cdot}05$) and Digit Memory tests ($F=2{\cdot}86$, $p<0{\cdot}10$) at 36 months, both favouring girls. A differential effect of supplement ingestion by sex was found for Draw-a-Line-Slowly. Well supplemented females succeeded in drawing a line significantly more slowly than poorly supplemented females ($F=4{\cdot}65$, $p<0{\cdot}05$) while the analogous comparison was not significant for males. In summary, neither strong mean sex differences nor differential responses to nutritional supplementation of the sexes are apparent in our data.

We have also examined the possibility that non-nutritional variables may be confounded with and responsible for the apparent effects of supplementation on mental development observed in our data. Among such variables

Table 3
The association of psychological test performance with supplement ingestion

Test	I With supplement ingested during pregnancy		II With total supplement ingested to time of testing		III With total supplement ingested to time of testing (II), controlling for supplement ingested during pregnancy (I)		IV With supplement ingested during pregnancy (I), controlling for post-natal supplement ingested to time of testing (II)	
	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls
Composite Infant Scale — 6 months mental scale	0·11	0·13[a]	0·04	0·01	—·07	—·18[b]	0·13[a]	0·15[a]
Composite Infant Scale — 15 months mental scale	0·09	0·24[b]	0·14[a]	0·12[a]	0·11	—·07	0·01	0·22[a]
Composite Infant Scale — 24 months mental scale	0·20[b]	0·15[a]	0·19[b]	0·13[a]	0·11	0·04	0·12[a]	0·09
36 months Cognitive Composite	0·09	0·11	0·04	0·10	0·00	0·04	0·12[a]	0·05
36 months Verbal Inferences	0·36[b]	0·25[b]	0·20[b]	0·12[a]	0·04	—·03	0·33[b]	0·23[b]

N = approx. 250 for all tests except Verbal Inferences.
N = approx. 120 for Verbal Inferences.
[a] $p < 0·05$.
[b] $p < 0·01$.

considered have been testing effects, morbidity of subjects, parental cooperation with the project, village differences and attendance to supplementation centres. Following statistical analyses, all of these variables have been ruled out as possible alternative explanations of our observed effects.

Effects of repeated testing, for example, are not in evidence up to 48 months of age. Correlations between morbidity and psychology scores are near zero, as are those between field staff ratings of family cooperation with the project and psychology scores. Village differences were not present at the time the project began, according to baseline evaluations done at that time. Furthermore, we have recently compared the least well-supplemented (and presumably least affected by our project) children from our two types of villages (*fresco* and *atole*) to determine whether these two groups of children differ significantly in psychological test performance on any test. They do not.

In addition to examining the possibility of confounding effects of testing, morbidity, family cooperation and village differences, we have also examined the effect of attendance to the supplementation centres on Preschool Battery test performance. Children who come to the centres could conceivably be intellectually stimulated by attending *per se*. However, within-child regression analyses have revealed that for every 100 days of attendance, an increment of 0·007 standard deviation units on cognitive composite score was produced. Thus, attendance *per se* does not appear to be a significant confounding variable.

2. *Timing of Nutritional Supplementation and Psychological Test Performance*

Having found evidence of an effect of nutritional supplementation on psychological test performance, we wished to learn whether this effect is a cumulative one or whether a crucial period exists when supplementation is particularly likely to exert an effect on test performance. On an *a priori* basis, logical arguments could be advanced for each of these alternatives; if cognitive development is conceived of as a process of active and continual interchange with the environment (as Piaget, for example, has frequently argued) one might expect the effects of good or bad nutrition, mediated by energy levels, to cumulate throughout childhood. On the other hand, since central nervous system development is extremely rapid during pre- and immediately post-natal life, one might expect the effects of poor nutrition to be strongest during gestation or very early in life.

Our results to date are consistent with the latter hypothesis. Table 3 presents correlations and partial correlations of CIS Mental Scores at 6, 15 and 24 months, and Cognitive Composite and Verbal Inferences scores at 36 months with supplement ingestion. Column I shows the correlation between supplement ingested during pregnancy by the mother and the child's later test performance; Column II shows the correlation between cumulative supplement ingested by the child and mother up to the time of psychological testing and the child's test performance; Column III shows the partial correlation of cumulative supplementation with test performance when maternal gestational supplementation is controlled by partialling; and Column IV shows the correlation of supplement ingested during pregnancy with child's test performance controlling for post-natal supplement ingestion. It will be noted that once gestational supplementation is partialled out of the correlations between total cumulative supplementation and test scores, virtually no relationship remains between later cumulative supplementation and test performance. On the other hand, the association of prenatal supplementation and subsequent test performance is unaffected by controlling for later supplementation. Thus, pregnancy appears to be the crucial period for supplementation as far as psychological test performance up to 36 months is concerned. The effect of supplementation during pregnancy on test performance after 36 months will be examined as more data become available for children followed since conception.

An additional analysis examining the importance of the timing of food supplementation on psychological test performance involves the comparison of siblings whose mothers ingested different amounts of the supplement across two successive pregnancies. These analyses have the advantage of controlling for potentially confounding variables which are constant within families. The slopes of gestational supplementation regressed on 6, 15 and 24 month total Composite Infant Scale performance are significant and much larger than those of cumulative supplement ingested at any later point up to the time of testing, replicating the results of our partial correlation analyses.

3. *Family Socio-economic Status and Psychological Test Performance*

Family socio-economic status has been measured regularly since the study began. We use a scale which combines ratings of each family's house (number of rooms and type of construction), parents' use of more modern clothing, and amount of direct teaching of children by parents and older siblings. This Composite SES score is standardized within village to control for inter-village differences in house style, etc., and then averaged across three surveys spanning five years.

The relationship of family SES to both home diet and supplement ingestion have been examined at 36 months. Home diet protein and calorie ingestion show modest correlations with family SES (for males: r prot. = 0·11, $p<0·05$; r cal. = 0·20, $p<0·01$; for females: r prot. = 0·09, n.s.; r cal. = 0·15, $p<0·01$). In contrast, a non-significant tendency was observed for children with lower family SES scores to ingest more food supplement.

We have also examined the relationship between family socio-economic status and psychological test performance. No relationship between SES and performance is evident for the Brazelton Neonatal Scale or for the Composite Infant Scale at 6, 15 or 24 months. We are in the midst of analyses of SES effects on 36- and 48-month variables but it appears that SES by 48 months becomes an important determinant of mental test performance.

We have also begun to examine the interactive effects of supplementation and family SES on cognitive test performance. The question motivating our examination of such an interaction is whether the effects of nutritional status or supplementation are greater among children from low as opposed to high SES families in our study villages. Two kinds of analyses have been performed to explore this question. The first has consisted of comparing test scores of least and best supplemented children (nutritional status categories 0 vs 2) in low and in high family SES groups. Such analyses have to date been performed for the Composite Infant Scale and for the preschool battery at 36 months. For the Composite Infant Scale, there is no evidence that effects of supplementation are greater among low SES children. However, at 36 months, several tests show a significant effect of supplementation only in the low SES group. These tests differ by sex, with an effect confined to low SES boys for Embedded Figures Sum Correct and Adaptability, Reversal Discrimination Learning Time and Vocabulary Recognition. Significant supplementation effects were confined to girls from low SES families for Embedded Figures Adaptability and Reversal Discrimination Learning Time.

Another type of analysis investigating the associations between nutritional status and psychological test performance within high and low SES groups has also been performed. This has consisted of constructing contingency tables examining a child's relative risk of being in the lowest (or highest) pentile (20%) of test performance as a function of being in each nutritional supplementation category.

These tables were first constructed for the entire population of children available, regardless of SES level. These, as well as tables broken down by SES, are shown in Table 4. Since before 15 months of age no association exists between supplementation category and relative risk of extreme test performance, tables for the Brazelton and 6-month Composite Infant Scale are omitted. For the Composite Infant Scale at 15 and 24 months and for the

Table 4
Relative risk of falling into extreme 20% according to supplementation ingestion and socio-economic status

Supplementation category	Sample size (N's)				Percentages				Chi-square		
	Psychological test performance group										
VARIABLE: COMPOSITE INFANT SCALE 15-MONTH MENTAL SCORE											
Total sample											
	Low[a]	Med.[b]	High[c]	Tot.	Low	Med.	High	Tot.	X[b]	d.f.	p
0	52	101	24	177	29	57	14	100	27·1	4	<0·01
1	44	157	54	255	17	62	21	100			
2	5	46	26	77	6	60	34	100			
T	101	304	104	509	20	60	20	100			
Low SES											
0	23	50	6	79	29	63	8	100	18·4	4	<0·01
1	22	79	29	130	17	61	22	100			
2	2	28	13	43	5	65	30	100			
T	47	157	48	252	19	62	19	100			
High SES											
0	27	45	18	90	30	50	20	100	11·7	4	<0·05
1	22	75	25	122	18	61	20	100			
2	3	18	13	34	9	53	38	100			
T	52	138	56	246	21	56	23	100			
VARIABLE: COMPOSITE INFANT SCALE 15-MONTH MOTOR SCORE											
Total sample											
	Low[a]	Med.[b]	High[c]	Tot.	Low	Med.	High	Tot.	X[b]	d.f.	p
0	43	114	20	177	24	64	11	100	16·2	4	<0·01
1	45	159	51	255	18	62	20	100			
2	5	54	18	77	6	70	23	100			
T	93	327	89	509	18	64	17	100			
Low SES											
0	17	55	7	79	22	70	9	100	9·1	4	NS
1	20	85	25	130	15	65	19	100			
2	3	29	11	43	7	67	26	100			
T	40	169	43	252	16	67	17	100			
High SES											
0	23	55	12	90	26	61	13	100	7·6	4	NS
1	24	72	26	122	20	59	21	100			
2	2	25	7	34	6	74	21	100			
T	49	152	45	246	20	62	18	100			

Table 4—(*contd.*)

Supplementation category:	Sample size (N's)				Percentages				Chi-square		
	Psychological test performance group										

VARIABLE: COMPOSITE INFANT SCALE 24-MONTH MENTAL SCORE

Total sample

Supplementation category:	Low[a]	Med.[b]	High[c]	Tot.	Low	Med.	High	Tot.	X[b]	d.f.	p
0	70	140	35	245	29	57	14	100	35·5	4	<0·01
1	30	137	53	220	14	62	24	100			
2	3	53	24	80	4	66	30	100			
T	103	330	112	545	19	61	21	100			

Low SES

	Low	Med.	High	Tot.	Low	Med.	High	Tot.	X[b]	d.f.	p
0	41	59	14	114	36	52	12	100	25·9	4	<0·01
1	18	69	27	114	16	61	24	100			
2	2	24	14	40	5	60	35	100			
T	61	152	55	268	23	57	21	100			

High SES

	Low	Med.	High	Tot.	Low	Med.	High	Tot.	X[b]	d.f.	p
0	28	78	21	127	22	61	17	100	11·7	4	<0·05
1	12	68	25	105	11	65	24	100			
2	1	29	10	40	3	73	25	100			
T	41	175	56		15	64	21	100			

VARIABLE: COMPOSITE INFANT SCALE 24-MONTH MOTOR SCORE

Total sample

Supplementation category:	Low[a]	Med.[b]	High[c]	Tot.	Low	Med.	High	Tot.	X[b]	d.f.	p
0	65	127	45	237	27	54	19	100	20·4	4	<0·01
1	34	131	53	218	16	60	24	100			
2	6	49	25	80	8	61	31	100			
T	105	307	123	535	20	57	23	100			

Low SES

	Low	Med.	High	Tot.	Low	Med.	High	Tot.	X[b]	d.f.	p
0	34	55	20	109	31	50	13	100	11·3	4	<0·05
1	18	63	32	113	16	56	28	100			
2	5	26	9	40	13	65	23	100			
T	57	144	61	262	22	55	23	100			

High SES

	Low	Med.	High	Tot.	Low	Med.	High	Tot.	X[b]	d.f.	p
0	30	71	24	125	24	57	19	100	15·7	4	<0·01
1	16	68	20	104	15	65	19	100			
2	1	23	16	40	3	58	40	100			
T	47	162	60	269	17	60	22	100			

Table 4—(*contd.*)

Supplementation category	Sample size (N's)				Percentages				Chi-square		
	Psychological test performance group										
VARIABLE: COGNITIVE COMPOSITE SCORE AT 36 MONTHS											
Total sample											
	Low[a]	Med.[b]	High[c]	Tot.	Low	Med.	High	Tot.	X[b]	d.f.	p
0	67	162	49	278	24	58	18	100	5·9	4	NS
1	39	145	53	237	16	61	22	100			
2	8	31	11	50	16	62	22	100			
T	114	338	113	565	22	60	20	100			
Low SES											
0	39	71	13	123	32	58	11	100	10·1	4	<0·05
1	22	72	26	120	18	60	22	100			
2	4	16	5	25	16	64	20	100			
T	65	159	44	268	24	59	16	100			
High SES											
0	26	88	36	150	17	59	24	100	0·5	4	NS
1	17	73	26	116	15	63	22	100			
2	4	15	6	25	16	60	24	100			
T	67	176	68	291	16	60	23	100			

[a] Lowest pentile.
[b] Middle 60% of scores.
[c] Highest pentile.

Cognitive Composite Score at 36 months, poorly supplemented children were much more likely to be in the lowest than the highest pentile of test scores. Well supplemented children were much more likely to be in the highest than the lowest pentile of test scores. Chi-square tests performed on the entire contingency tables (including the middle 60%) are significant at 15 and 24 months.

To examine the effect of SES on the relationship between nutritional status category and risk of falling in the lowest or highest pentile, contingency tables were constructed within low and high SES groups. As was the case for contingency tables constructed with the entire sample, no significant associations in either high or low SES groups were seen before 15 months.

At 15 and 24 months, the relative risk of falling into the lowest pentile of test performance as a function of nutritional status category was accentuated in the low SES group. For 15-month mental scores, for example, poorly supplemented (category 0) children in the low SES group were nearly four times as likely to be in the lowest pentile as in the highest pentile (29% vs 8%), whereas in the high SES group, the poorly supplemented child's probabilities of falling into lowest and highest pentiles were more similar (30% vs 20%). Similar accentuation of nutritional status category effects in the low SES group were observed for 15-month motor scores, 24-month mental scores, and also 24-month motor scores, though the accentuating effect of SES was less for this last score. The greater similarity between percentages of poorly supplemented children falling into highest and lowest pentiles observed among high SES children suggests that these children can be high scorers even without nutritional supplement, but that the low SES children's chances of being high scorers are more related to their nutrition. In both high and low SES groups, well supplemented children were more likely to be high than low scorers.

These patterns were repeated at 36 months; in the high SES group, a poorly supplemented child was about equally likely to fall into low or high pentile (17% vs 24%) but in the low SES group, a poorly supplemented child was about three times as likely to be in the lowest rather than the highest pentile (32% vs 11%). Also, in both high and low SES groups, well supplemented children were more likely to be high than low performers. In the low treatment group, SES and mental test performance were associated ($p<0{\cdot}01$), but not in high (or middle) treatment groups.

Chi-square analyses performed on tables which include a performance category containing the middle 60% of children were more often significant for the low SES group than the high SES group. This was the case for the Composite Infant Scale mental and motor scores at 15 months, the mental score at 24 months, and the Cognitive Composite score at 36 months.

III. DISCUSSION

In this paper, we have presented some preliminary results from an on-going longitudinal study of the effects of nutritional and other environmental factors on mental development. Employing voluntarily consumed dietary supplementation, we have to date accumulated considerable evidence of an effect of nutritional status on mental development up to 48 months of age. These effects do not become apparent before 15 months, but are evident in performances on mental and motor infant scales at 15 and 24 months, and on a variety of cognitive tasks administered at 36 and 48 months of age. Our data suggest that the locus of these effects is in maternal nutrition during pregnancy.

While the INCAP study is not the first to find evidence of a relationship between malnutrition and mental development, these findings are especially important for several reasons. Unlike most previous studies, the present investigation has employed a prospective and precisely monitored intake measure of nutritional status, rather than approximate measures such as growth or retrospective reports and clinical records of episodes of malnutrition. Furthermore, by supplementing a population suffering from endemic mild-to-moderate malnutrition as opposed to studying severely malnourished clinic cases, we have been able to focus on the effects of levels of malnutrition which afflict enormous numbers of children growing up today.

In addition to differing in its definition of nutritional status and in level of malnutrition studied, the present study has employed a wide variety of culturally appropriate measures of mental development, as compared with the single global IQ-type measures frequently used in previous studies. At present it is difficult to discern patterns of effects on specific cognitive skills, since data for only a subset of tests and ages are yet available in sufficient quantity for analysis. However, the beginnings of such a description can be made. Our data indicate that general verbal reasoning processes are most consistently affected at 36 and 48 months. Variables showing an effect at these ages include Verbal Inferences, Vocabulary Naming, Vocabulary Recognition, and Response Tempo measures. Other tests showing an effect, and, of potentially equal importance, tests showing no effect, are heterogeneous and difficult to characterize, though relatively little effect was seen for Perceptual Analysis, Verbal Memory, and Persistence measures. Further specification of the nature of nutritional effects on mental development, and a subsequent attempt to identify mechanisms involved in such effects, must await collection of more data. So, of course, must resolution of the crucial question of whether the effects of malnutrition on mental development persist into later childhood and beyond.

As we have noted, previous studies of the relationship between malnutrition and mental development have not been able to go beyond the description of an association between the two to a convincing statement that malnutrition plays a causal role in deficient mental development. We have in the present paper reported a variety of analyses investigating and ultimately eliminating non-nutritional explanations of our findings. Poverty and accompanying social deprivation consistently accompany malnutrition and constitute plausible alternative explanations for the poor cognitive performances of malnourished children. Thus, the within-family regression analyses we have described, which indicate effects of nutritional status on cognitive performance while controlling for family SES level, constitute the strongest evidence ever gathered for a direct and causal link between malnutrition and deficient mental development.

Out data permit us to dismiss the possibility that family socio-economic level alone can explain the lower test performances of less well nourished sample children. However, our findings also indicate an important role of socio-economic level in mental development. SES was seen to interact with nutrition such that children from poorer families were more strongly affected by nutritional supplementation than children from less poor families. Furthermore, the pervasive power of poverty to depress intellectual development was attested to by the presence, within a population among whom the range of wealth and opportunity is severely restricted, of significant cognitive test score differences between children from poorer as compared to less poor families.

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