Short- and long-term effects of low or restricted energy intakes on the activity of infants and children

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INCAP Publication I-1558

In: "Activity, Energy Expenditure and Energy Requirements of Infants and Children". B. Schürch & N.S. Scrimshaw, eds. Lausanne: IDECG (c/o Nestlé Foundation), 1990

Abstract

Low or restricted energy intakes reduce the amount or intensity of physical activity of infants, preschool and school children. This can occur within a few days as a compensatory response to maintain energy balance while preserving growth. If energy intake becomes adequate again after a short time, it may have no important morphologic, functional or behavioral consequences. Conversely, a prolonged dietary deficit may result in a sustained decrease in physical activity that can limit or reduce the child's physical fitness, social interactions and exploration of the immediate environment. This is more evident in younger children who are less influenced by social constraints and peer pressure, and among children who are encouraged to participate in physically demanding games and sports, or who must work or perform chores that result in relatively high energy expenditures. A reduced physical activity can also contribute to a decrease in longitudinal and lean body mass growth which, together with a decrease in maximal oxygen consumption, may limit maximal work output. All this may hinder the child's potential for biological, behavioral and social development. Therefore, the reduction in physical activity due to low dietary intakes may be an adequate compensatory response in the short term, but it cannot be considered a desirable adaptation because of its actual or potential consequences in the long term.

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1. Introduction

Apart from the energy needs for growth, energy expenditure determines the dietary energy requirements of children. Within limits that allow physiological accommodation or metabolic adaptation, there tends to be a balance, such that expenditure influences intake and vice versa. In order to maintain that balance, a decrease in energy intake would have to reduce some or all the components of energy expenditure and/or reduce growth.

The effect of low energy intake on the growth of children is widely recognized. However, it only becomes evident after a period of several weeks or months, depending on the child's age. Furthermore, this reduction in growth is one of the deleterious end-results of low intake and, as such, cannot be considered a desirable adaptive response.

A reduction in energy expenditure might be an adequate metabolic response, as long as it does not limit the child's function or behavior. This could be manifested by a decrease in basal metabolic rate (BMR) while the child is growing adequately, or by a greater efficiency in the performance of energy-demanding activities. The latter has not been adequately studied and the former is not known to occur, as a decrease in BMR has been demonstrated only after growth is already impaired.

Physical activity becomes a major component of energy expenditure after early infancy. From that age onward, a decrease in energy intake could be expected to induce a compensatory reduction in activity. This paper will review the evidence that such reduction occurs, and it will analyze whether this is a suitable response or an undesirable effect with negative consequences for the child.

2. Infants and children under two years of age

CHAVEZ and collaborators (1979) conducted a longitudinal study in a rural Mexican community of about 300 families to assess the influence of nutritional conditions on various physical and behavioral functions. Forty-one women received a daily supplement of milk, vitamins and minerals, beginning on the second month of pregnancy and continuing through lactation until they became pregnant again. Their babies were also supplemented with milk and strained foods.

These children grew better than their non-supplemented counterparts and they were significantly heavier by 11 and taller by 17 months of age. The differences continued increasing gradually with age.

Physical activity was assessed for one year at 2- or 3-month intervals in 19 supplemented and 17 non-supplemented children, whose ages ranged between 4 and 12 months at the beginning of the study (CHAVEZ *et al.*, 1972). They were observed on one day for 10 minutes every 2 hours, between 8 a.m. and 8 p.m. The observer recorded the number of steps taken by the child during that period and, in babies who did not walk or were lying down, the number of kicks or other foot contacts with the floor, mattress, sides of the crib, and walls. Physical activity was quantified in terms of 'foot contacts' in 60 minutes. Figure 1 shows the results of 47 sixty-minute observations in each group. Between 13 and 24 months of age, the supplemented children were 3 to 6 times more active that the controls ($p < 0.01$).

Other observations in the children's homes at 2- to 6-month intervals also suggested that the better-nourished were more active (CHAVEZ and MARTINEZ, 1979):

- After 40 weeks of age, the supplemented group tended to sleep less during the day. By 1 year of age, they slept approximately 25% less and were out of their cribs more often that the non-supplemented controls.
- At around 8 months of age, the supplemented children already tended to spend more time outdoors. According to Chavez and Martinez, this did not depend only on the mothers' atti-

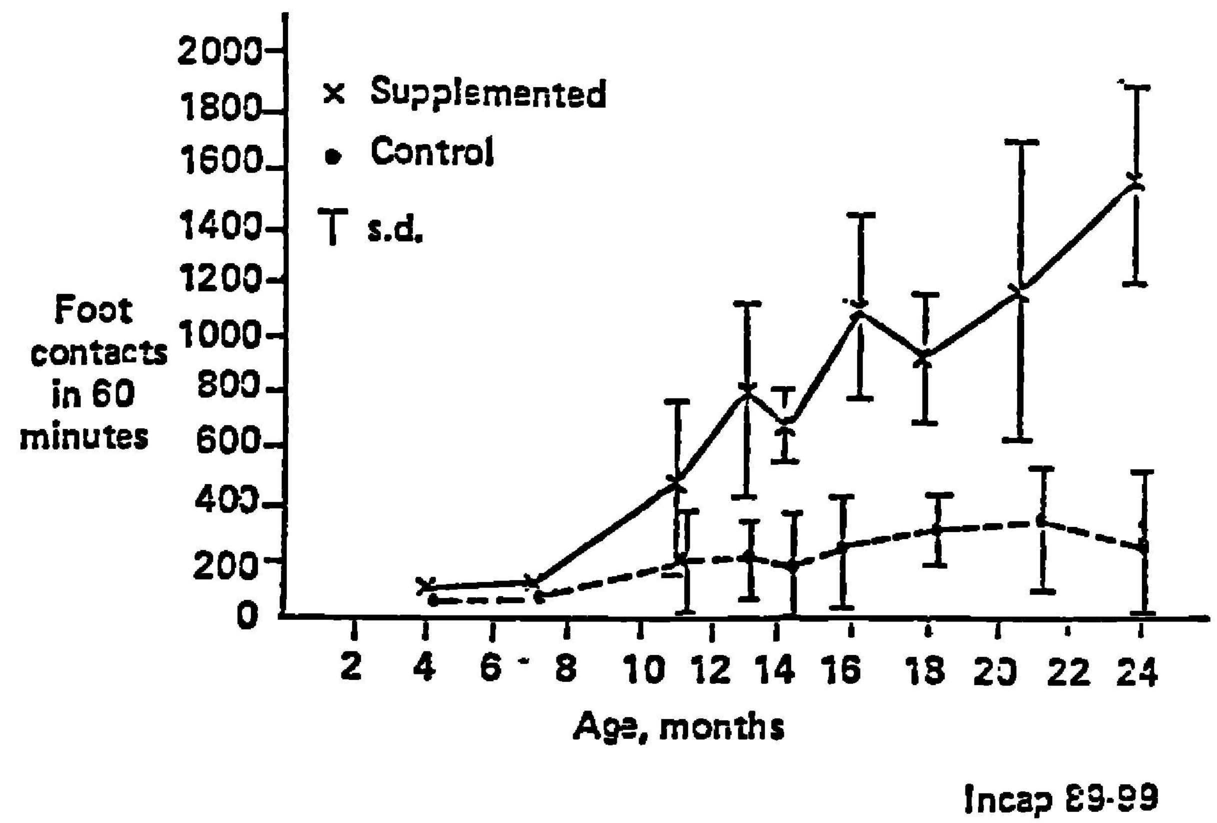

Figure 1. Physical activity of supplemented (×) and non-supplemented (•) children, assessed from contacts of feet with supporting surface or surrounding objects. From CHAVEZ *et al.*, 1972.

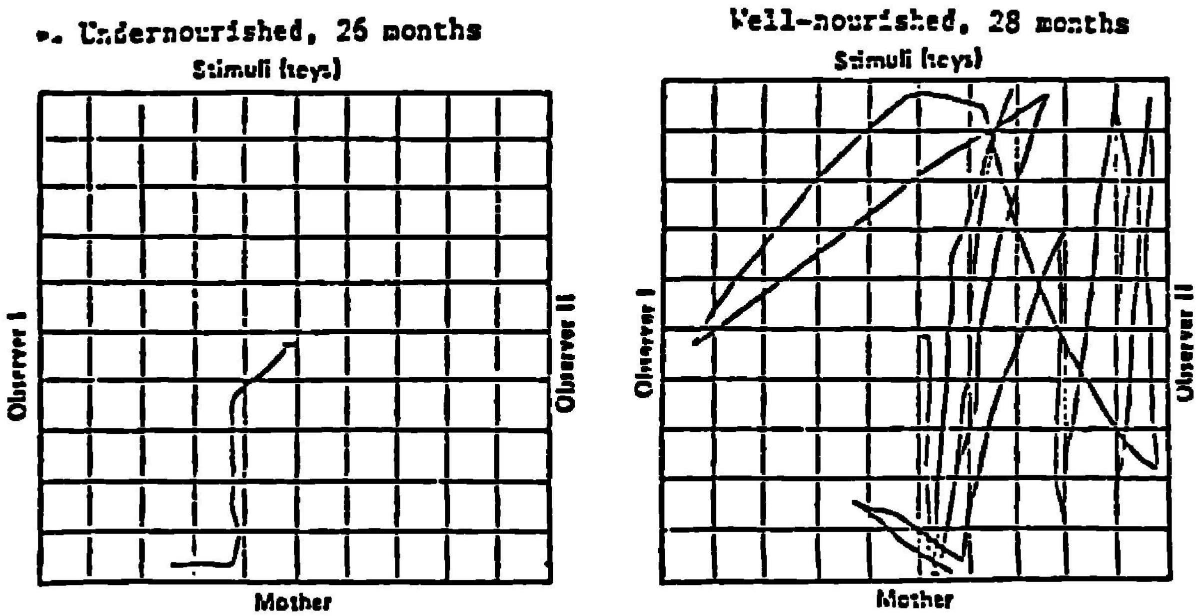

Figure 2. Spontaneous displacement within a fenced quadrangle during 10 minutes, of two 2-year-old children with different nutritional conditions. From CHAVEZ and MARTINEZ, 1979.

tudes but also on the children's independent movements and demands.

- During the second semester of life, the supplemented infants were carried, wrapped in a shawl on their mother's backs, 30% less time than the controls. This seemed partly due to increased restlessness of the children, and partly to the greater burden imposed on the mothers by their heavier body weights.
- 'Play' activities were recorded in several supplemented babies beginning at 6 months of age, whereas they began 12 weeks later in most of the control group.

CHAVEZ and MARTINEZ (1979) also showed exploratory and behavioral differences between the supplemented and non-supplemented children. A child was placed in the center of a square of 3 × 3 m, surrounded by a 90 cm fence and with perpendicular lines drawn as a grid on the floor at 30 cm intervals. The child's mother stood outside the fence in the middle of one side, toys were placed inside the fenced area on the opposite side, and two observers stood outside the fence in the middle of the other two sides of the square. The child's movements within the square and its behavior were recorded during 10 minutes by both observers. Figure 2 shows that a supplemented 2-year-old child moved around more, played with the toys, approached the unknown observers and did not cry, in contrast with a non-supplemented counterpart.

The increased activity seen in these studies among the supplemented children could be due to many factors, including the child's greater and more advanced motor development with better nutrition, the mother's attitude towards a healthier-looking

baby and other behavioral modifications among the family members induced by the supplementation program. Nevertheless, a causal effect of the higher food (i.e., energy) intake cannot be ruled out.

3. Preschool children

3.1. Short-term study in a clinical setting

A direct effect of food intake on activity was clearly demonstrated in short-term studies of well-nourished Guatemalan children who had fully recovered from protein-energy malnutrition, before and after taking them off the high-energy, high-protein therapeutic diet (VITERI and TORUN, 1981). A minute-by-minute time-motion technique was used under controlled clinical conditions to record the activities of 5 boys, 1.5-4.5 years old, on 4 days prior to, and in the last 4 days of a week during which dietary intake was reduced from 120-150 kcal and 3-4 g protein/kg/d to the 70-90 kcal and 1.8-2.0 g protein/kg/d provided by the home diets of most children from poor Guatemalan families. Supplementation with vitamins and minerals did not change.

Table 1 and Figure 3 show that the time spent in the more energy-demanding activities was reduced, on the average, by 17 to 56%. In contrast, the time spent lying down in the games' room, either resting or in sedentary play, increased twofold.

Basal metabolic rate remained constant at 55±5 and 53±4 kcal/kg/d (mean ± SD), before and one week after the dietary change, respectively. Using indirect calorimetric measurements for some activities and estimates of the energy cost of others, it was calculated that, on the average, the children were in energy balance during the two weeks with standard deviations of 19 and 27 kcal/kg/d, respectively. Mean weekly weight changes decreased from 2.5±1.2 to −0.5±0.6 g/kg/d. The mean weight gain expected in healthy children of the same ages and heights, eating home diets with about 100 kcal/kg/d, is approximately 0.6 g/kg/d (US-NCHS, 1976; FAO/WHO/UNU, 1985).

This study showed that changes in activity pattern occur within a few days of the reduction in dietary energy intake. It is unlikely that this was due to the concurrent decrease in protein intake, as even the lower diet contained more than the recommended safe levels of protein (FAO/WHO/UNU, 1985).

3.2. Longer-term study in a clinical setting

Five boys, 25 to 40 months old, participated in a longer-term study, also under strict supervision at INCAP's Clinical Center (TORUN and VITERI, 1981a). Dietary modifications only involved decreases in energy density, without changes in protein, vitamin

Table 1. Changes in time allocated to different physical activities by 6 preschool children after dietary intake was reduced from 120-150 to 70-90 kcal/kg/d (mean of 4 days)

Change relative to initial time allocation	Sleeping or resting in bed	Lying down in games' room	Eating or sitting	Standing activities	Walking or running	Riding tricycle*	Other games and activities
Minutes/day	+68	+48	+4	−81	−17	−15	−4
% change	+8	+112	+1	−56	−23	−52	−17

* n=4

Source: VITERI and TORUN, 1981.

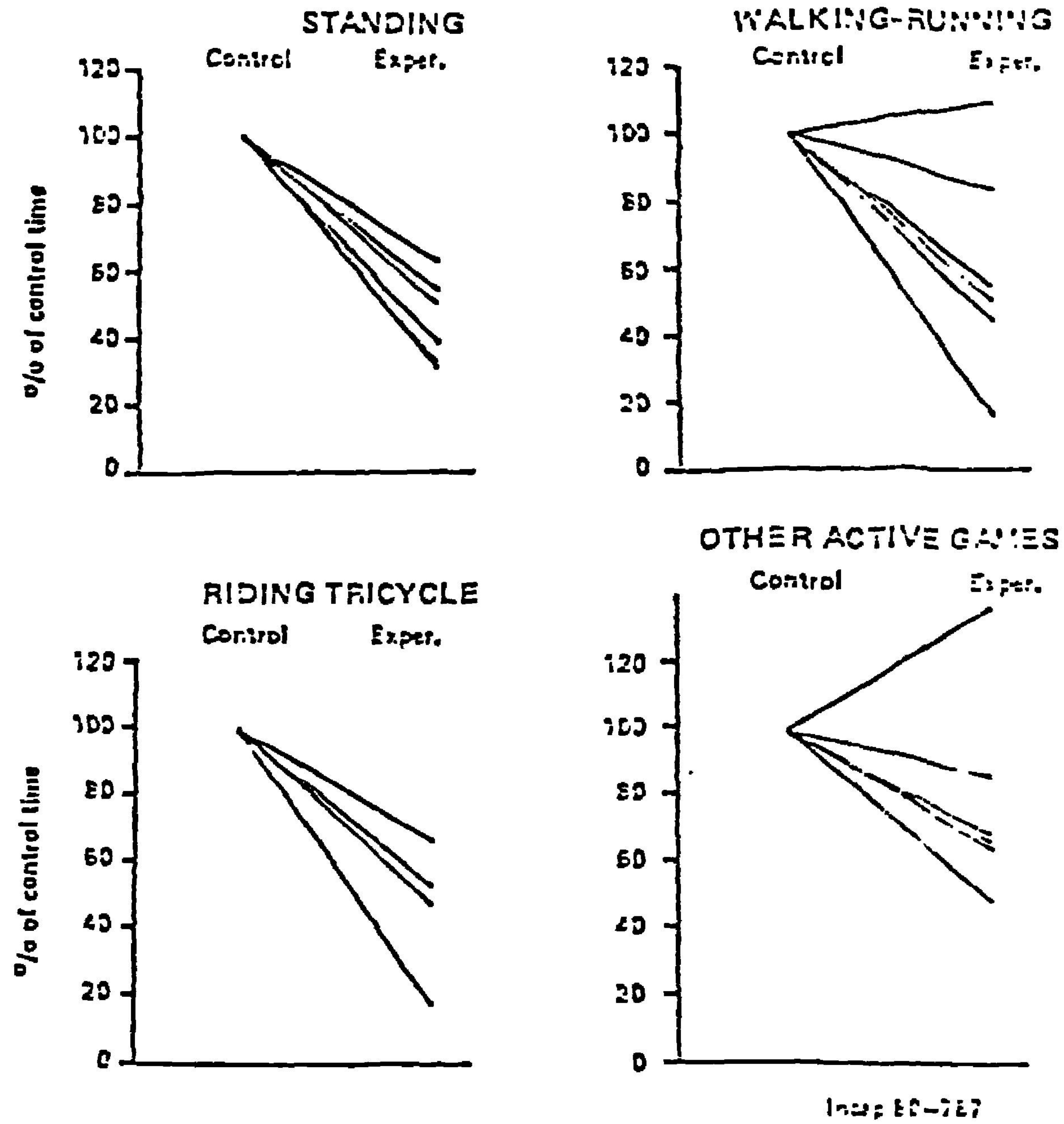

Figure 3. Reduction in time spent by preschool children in energy-demanding activities after decreasing dietary energy from 120-150 (Control) to 70-90 (Experimental) kcal/kg/d. From VITERI and TORUN, 1981.

and mineral contents, and the energy reductions were of a smaller magnitude than in the preceding study.

The children first ate a diet that provided net or metabolizable energy (i.e., food energy minus fecal energy, measured by bomb calorimetry) equivalent to 90±3 kcal/kg/d, which had been shown to be the requirement of similar children living at INCAP's Clinical Center (VITERI *et al.*, 1981; TORUN and VITERI, 1981c). The energy content of the diet was then reduced twice at 40-day intervals. During these experimental periods the children ate the equivalent of 82±4 and 71±4 metabolizable kcal/kg/d. The lower of those levels of intake is often found in dietary surveys among low-income preschool children in Guatemala.

The children were encouraged, but not forced, to participate in active play several times each day. Their energy expenditure was calculated every 20 days from individual calibrations of heart rate to oxygen consumption relationship and heart rate monitoring during the day, and from their basal metabolic rates at night.

Table 2 shows that the reduction in energy intake from 90 to 82 kcal/kg/d was accompanied by a decrease in total daily energy expenditure ($p<0.025$) without affecting weight gain. An additional reduction of intake to 71 kcal/kg/d did not significantly affect expenditure, but weight gain was markedly reduced ($p<0.01$). Growth in height was not affected.

Energy balance was calculated from gross dietary energy (bomb calorimetry), *minus* fecal energy (bomb calorimetry), *minus* urinary energy (estimated at 5 kcal/g urinary nitrogen), *minus* sweat losses (estimated at 0.1 kcal/kg/d, based on 8 kcal/g sweat nitrogen), *minus* total energy expenditure. Table 2 shows that, on the average, the children were near equilibrium and there were no differences in the mean energy balances with the different levels of dietary energy intake. Since BMR did not change throughout the study, energy balance was maintained through a reduction of energy expenditure in activity after the first dietary modification, and mostly through weight loss or a decrease in weight gain after the second dietary energy reduction.

3.3. Community-based studies

3.3.1. Uganda

RUTISHAUSER and WHITEHEAD (1972) used a modified time-motion method to evaluate the physical activity of 20 black, undernourished children and 5 well-nourished children of European parents, 1.5 to 3 years old. The black children weighed less and were shorter than the Europeans. Their dietary energy intake was 67 ± 14 kcal/kg/d, or 33% lower than current recommendations (FAO/WHO/UNU, 1985). Dietary intakes measured in two of the expatriate children averaged 109 kcal/kg/d.

During two consecutive 5-hour daytime periods, an observer recorded the activities performed by a child and classified them into six categories. Table 3 shows that the African children spent significantly more time sitting and standing, and less time walking and running than the European children.

Applying the energy cost of activities of older children and adults (PASSMORE and DURNIN, 1955; DURNIN and PASSMORE, 1967) to the time allocations shown in Table 3, Rutishauser and Whitehead estimated that the Ugandan children had a daily expenditure of 78 kcal/kg/d, while the European children spent 98 kcal/kg/d. Using the energy cost of activities measured in preschool children to avoid the errors of applying data from adults (TORUN 1983; TORUN *et al.*, 1983), the daily energy expenditure of the Ugandan and European children can be calculated as 74 and 79 kcal/kg/d, respectively. This left the latter with more dietary

Table 2. Total energy expenditure, energy balance and weight gain of 5 children with successive reduction in energy intake (mean ± standard deviation)[a]

	Net dietary energy (kcal/kg/d)[b]		
	90	82	71
Energy expenditure (kcal/kg/d)	89 ± 9*	76 ± 8	72 ± 6
Weight gain (g/kg/d)	0.9 ± 0.4	0.9 ± 0.3	0.05 ± 0.3**
Energy balance	−3 ± 6	6 ± 10	−2 ± 6

[a] Energy expenditure calculated from heart rate and the corresponding heart rate to energy expenditure relationship during the day, and from BMR at night. Energy balance calculated from gross energy intake (bomb calorimetry) – fecal energy (bomb calorimetry) – estimated urine and sweat energy – energy expenditure.

[b] Net dietary energy = dietary – fecal energy, measured by bomb calorimetry.

Differs from the two other levels of intake: * $p<0.025$; ** $p<0.01$.

Source: TORUN and VITERI, 1981a.

Table 3. Estimated time allocation of native Ugandan and European children, 1.5-3 years old (mean ± standard deviation)

Activity	Time allocated (minutes)	
	African	European
In bed[a]	600 to 720	660 to [illegible]
Lying down	81 ± 67	[illegible] ± 56
Being carried	7 ± 17	[illegible] ± 46
Sitting	300 ± 64**	[illegible] ± 43
Standing	265 ± 93*	143 ± 54
Walking	108 ± 46**	234 ± 54
Running	17 ± 17**	54 ± 32

[a] Ranges estimated from mothers' information.

Means differ: * $p<0.05$; ** $p<0.01$.

Source: Calculated from RUTISHAUSER and WHITEHEAD, 1972.

energy available for growth and for physical activity during the unsupervised hours of the study.

3.3.2 Guatemala

TORUN and CHEW (unpublished) studied 69 boys and girls, 2-6 years old, who lived in a poor neighborhood in the outskirts of Guatemala city. The activities that they performed between 8 a.m. and 5 p.m. were recorded and timed on two separate weekdays using a modified time-motion technique (TORUN, 1984). The

55 activities recorded were classified in six categories of physical effort, from sedentary to very heavy (Table 4).

Twenty-one children were considered mildly malnourished, based on weights-for-height between 81 and 90% of the NCHS/WHO median values, whereas 43 had between 91 and 110%, and 5 between 112 and 119% of the standard weights-for-height.

Compared with the well-nourished children, the malnourished spent 11.2% more time in sedentary activities, and 4.8, 1.7 and

Table 4. Activities performed by preschool children in a marginal area of Guatemala, and classified according to effort. The energy costs of the grouped activities were estimated as multiples of basal metabolic rate

Sedentary 1.2 × BMR	Light 2.0 × BMR	Moderate 2.25 × BMR	Moderately heavy 2.5 × BMR	Heavy 3.0 × BMR	Very heavy 4.0 × BMR
Carried by someone	Bathe, wash	Climb up and down	Bounce on bed	Carry garbage or water pail	Run, hop and jump
Eat	Dress, undress	Hang clothes	Climb tree	Cut firewood	Run with a load
Hurl stones with sling	Hammer while sitting	Miscella-neous play	Dance, hoola-hoop	Housechores squatting	Run uphill
Lie and play	Lift light objects	Run and stop (with a ball)	Jump from a chair	Running ball-games	Walk fast uphill
Lie or sit quietly	Open doors or drawers	Slide	Ride scooter	Swing sus-pended from arms	
Nap	Push a hammock	Spin around	Ride tricycle or bicycle	Walk fast, level ground	
Play guitar	Push or pull a cart	Stand and carry some-thing	Somersaults		
Sit and play	Push or pull a light toy	Sweep floor	Walk with a load		
Sit and carry something	Squat or crawl	Walk slowly level ground	Walk slowly uphill		
Sit on swing	Stand and play	Walk with stick and hoop	Wrestle		
Sleep late	Throw a ball	Wash clothes			
Stand quietly	Walk with pauses				
Stand and sit					

Source: TORUN and CHEW, unpublished observations.

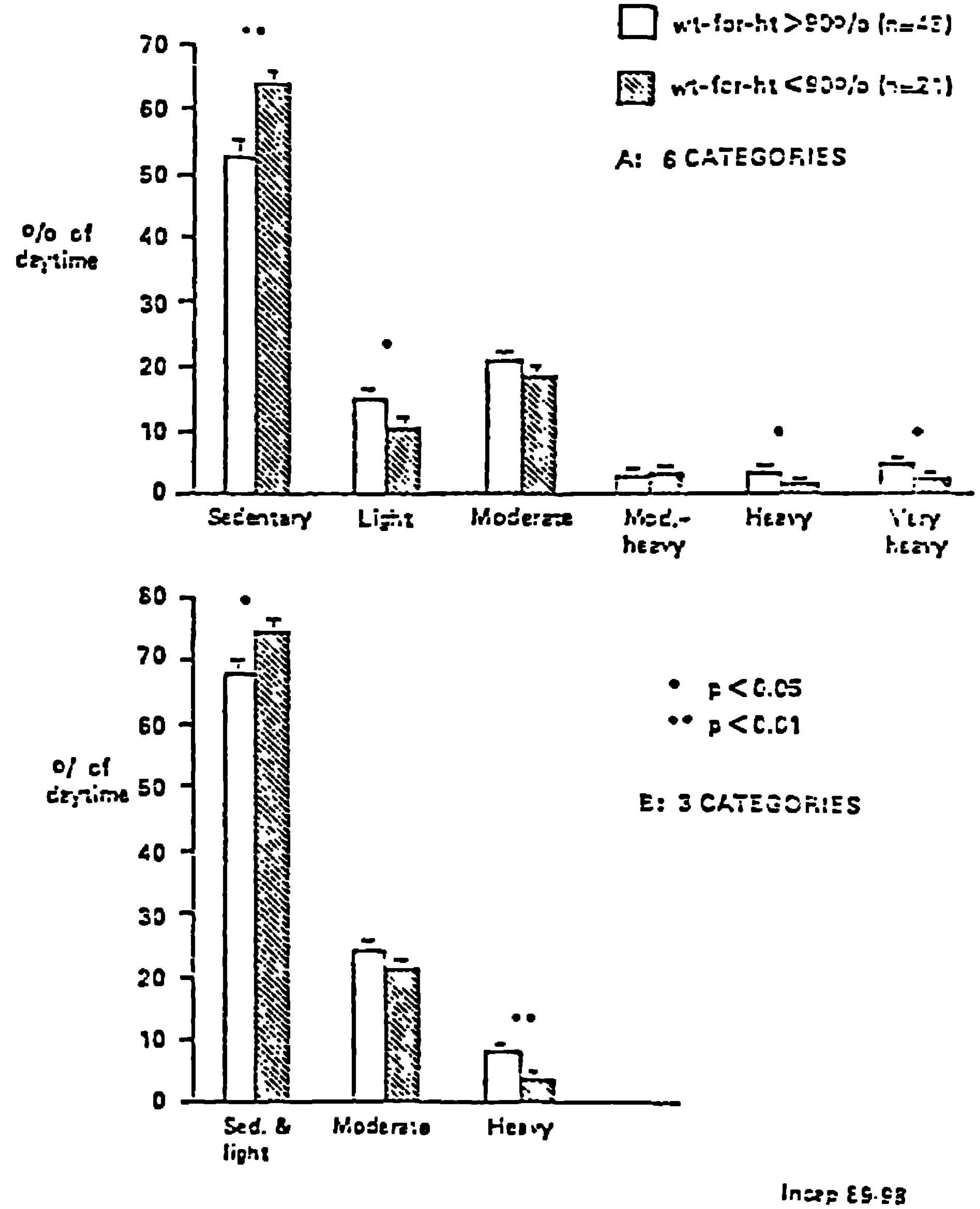

Figure 4. Proportions of observed time devoted by well-nourished and mildly malnourished preschool children to activities that require different amounts of effort. From TORUN and CHEW, unpublished.

2.5% less time in light, heavy and very heavy activities, respectively (Figure 4A). The longer time spent in light physical activities at the expense of those that demanded more energy became even clearer, when the activities were classified in only three categories of physical effort (Figure 4B).

Energy expenditure was estimated applying energy-cost factors of 1.2, 2, 2.25, 2.5, 3 and 4 times basal metabolic rate

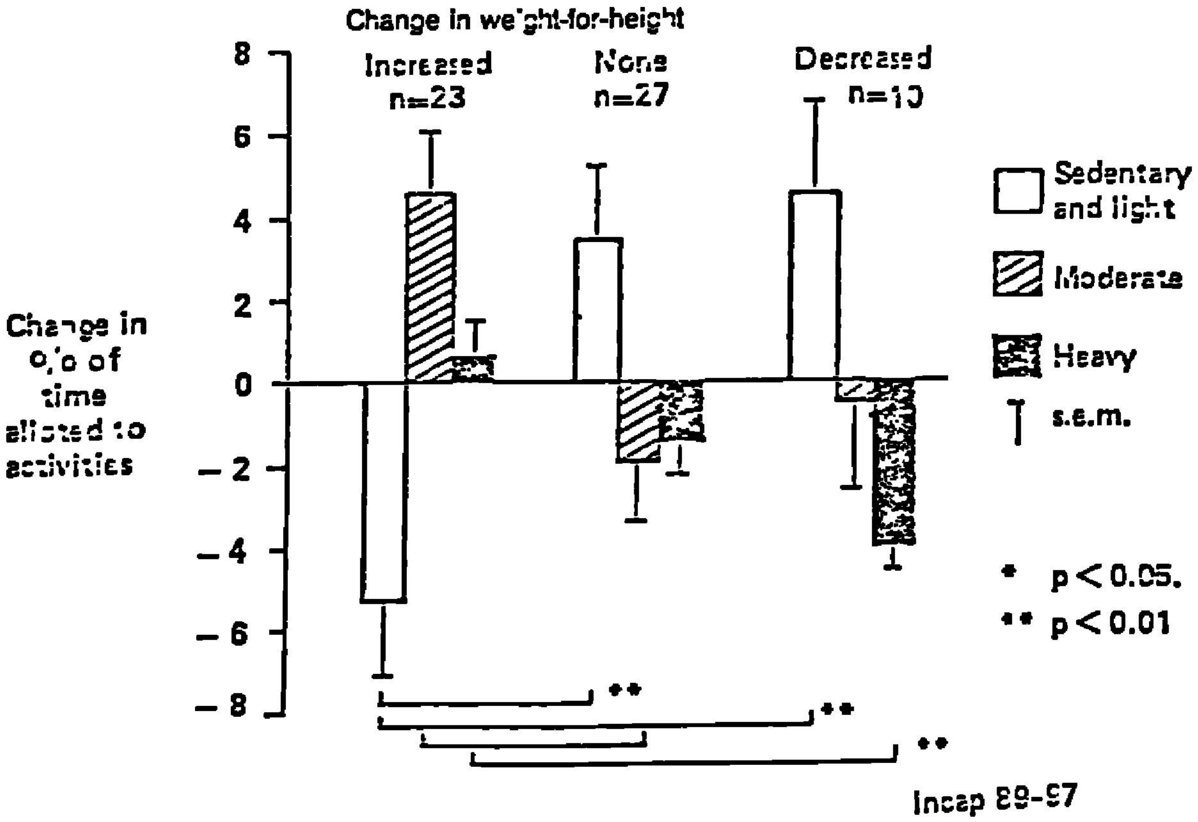

Figure 5. Changes in proportions of time allocated by preschool children to activities of different physical effort as their nutritional status changes. From TORUN and CHEW, unpublished.

(X BMR) to the six categories of activities observed. Based on information provided by the mothers, sleeping time was added at 1.0 X BMR, and an energy expenditure of 1.52 or 1.43 X BMR was assumed for the balance of 25 hours. The children with weight-for-height >90% of the NCHS median had an estimated expenditure of 81 kcal/kg/d, compared with 77 kcal/kg/d among the mildly malnourished.

Sixty of the 69 children were studied again, 2 and 4 months after the beginning of a nutritional education and supplementation program, on 2 separate weekdays each time (TORUN and CHEW, unpublished). At the end of the 4-month period, weight-for-height had increased by 3% or more in 23 children, remained stable within ±3% in 27, and decreased more than 3% in 10 children. An analysis was done of the time that those three groups of children dedicated before and after the intervention to activities that demanded different levels of physical effort.

Figure 5 shows that the children whose nutritional status improved, reduced the time dedicated to sedentary and light activities and significantly increased the time in moderate activities. On the other hand, the children whose nutritional status deteriorated, increased the time devoted to sedentary activities by reducing heavy activities.

The comparison between groups (Figure 5), showed that the children whose weight-for-height improved: (a) reduced the time spent in sedentary and light activities, in contrast with the other two groups, (b) increased the performance of moderate physical activities, and (c) continued with the same proportion of heavy activities, in contrast with the children who lost weight-for-height.

4. School-age children

Spurr and collaborators (SPURR *et al.*, 1986; SPURR and REINA, 1987, 1988a, b, c, 1989a) did a series of studies in a total of 300 boys and 146 girls between 6 and 16 years old, who lived in economically deprived urban areas of Cali, Colombia. They were classified as nutritionally normal (controls) when weight-for-height and weight-for-age were between 95 and 110% of Colombian standards, and as marginally undernourished when both indicators were <95% of the standards. Total daily energy expenditure was calculated from individual heart rate to oxygen consumption calibrations when heart rate was above a critical value, from resting metabolic rate when heart rate was below that value, and from BMR at night.

In many of these children, energy expenditure was also calculated at specific times during the day from minute-by-minute heart rate measurements. This allowed the evaluation of patterns of activity of different intensity (SPURR and REINA, 1988b, c) and the time spent in activities with energy costs equivalent to various multiples of BMR (SPURR and REINA, 1989a).

During the school year, there were no consistent differences related to nutritional status in the patterns of activity levels (SPURR and REINA, 1988b). However, when a group of boys 10-12 years old were studied during an ordinary schoolday, and again about 6 months later in a summer camp, where they were encouraged to participate in supervised sports (soccer, basketball, calisthenics, foot races, etc.) and play (walks, swimming, games), important differences were observed between the marginally undernourished and the controls (SPURR and REINA, 1988c). As shown in Figure 6, the controls increased their activity level in the summer camp, compared with the schoolday. In contrast, the undernourished boys did not show marked changes between summer camp and school, except for a transient increase in activity level in the early afternoon. Consequently, the difference between the two nutritional groups became more accentuated at summer camp. Table 5 shows that the estimated total daily energy expenditure did not differ between groups on schooldays, but it did during the summer camp ($p<0.01$) due to the increased expenditure shown by the control group in relation to the energy they expended on schooldays ($p<0.05$).

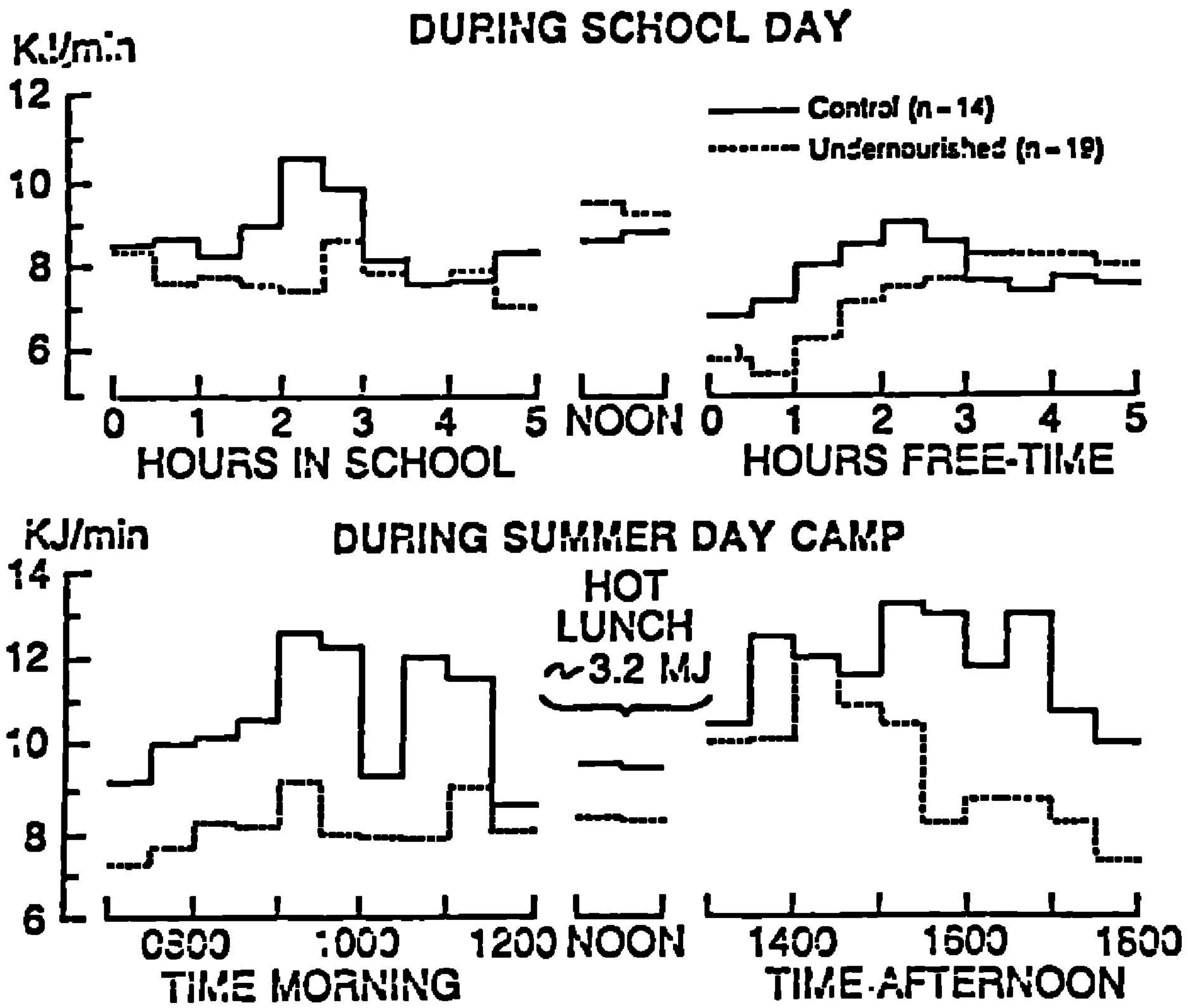

Figure 6. Average energy expenditure of well-nourished and marginally undernourished 10- to 12-year-old boys, measured in 30-minute periods during a schoolday and 6 months later in a summer camp where more physical activity was encouraged. From SPURR and REINA, 1988c.

Table 5. Total daily energy expenditure of 10- to 12-year-old boys, measured during the school year and about 6 months later in a summer camp (mean ± standard deviation)

Energy expenditure (EE) (kcal/d)	Wt-for-ht <95% (n=19)	Wt-for-ht 95-110% (n=14)
Total daily EE		
School day	1,826±378	2,008±421
Summer camp	1,979±311	2,452±490
	p<0.01	p<0.05

Source: SPURR and REINA, 1988c.

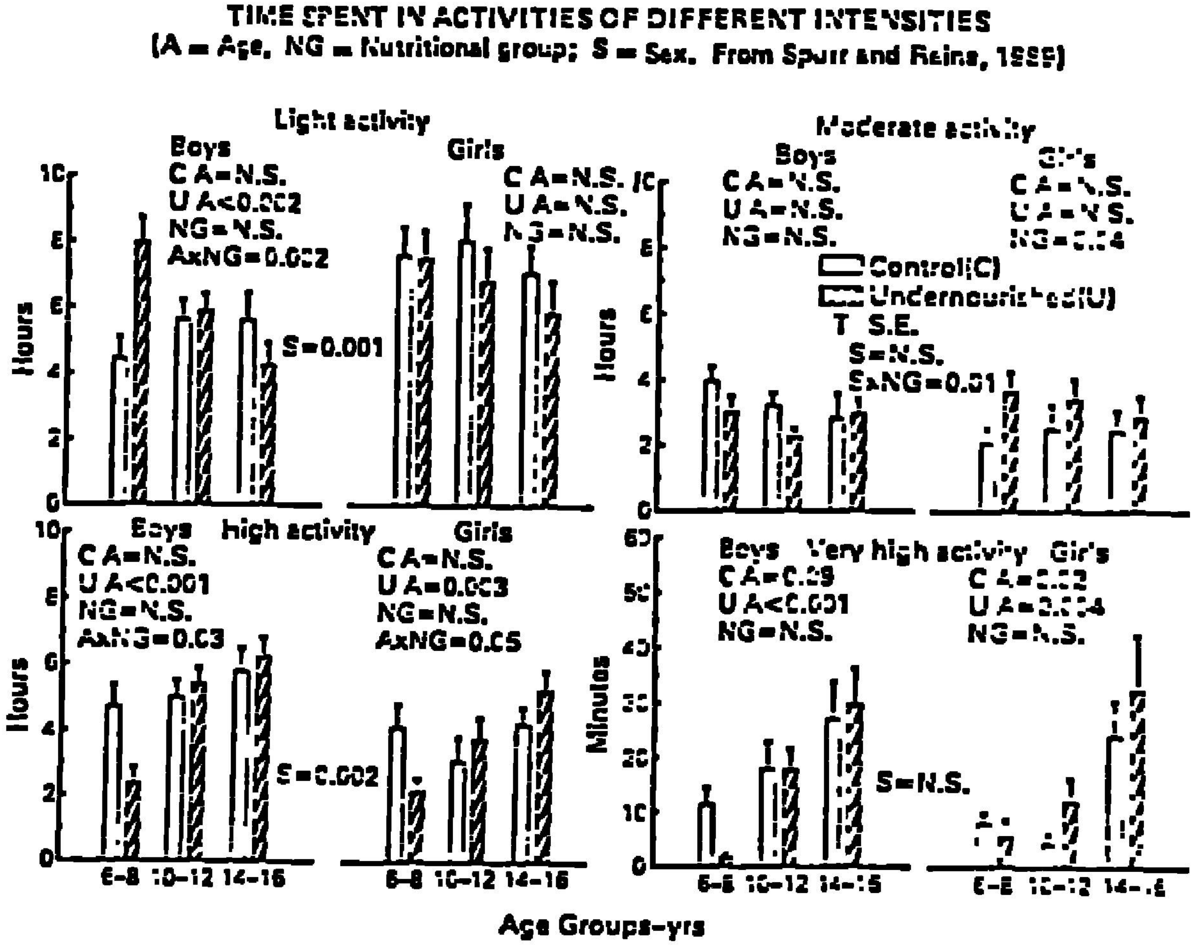

Figure 7. Time spent in activities of different intensity by control (C) and marginally undernourished (U) children. There was no effect of nutritional group (NG) when all ages (A) and sexes (S) were considered, but the 6- to 8-year-old boys and girls spent more time in light or moderate activities and less in heavy activities. From SPURR and REINA, 1989a.

Using the minute-by-minute heart rate technique, these investigators also calculated the time spent during daytime by boys and girls 6-8, 10-12 and 14-16 years old, in activities of light, moderate, high and very high intensity (SPURR and REINA, 1989a). Overall, they found no effects of nutritional status on the time allocated to the various levels of activity. However, if one looks at the time allocations separately for each age and sex group, there are differences between the undernourished and control children aged 6 to 8 (Figure 7): the undernourished boys spent more time in light activities and less in activities of high and very high intensity, compared with the control group. Similarly, the undernourished girls spent more time in moderate and less in heavy activities than their well-nourished counterparts.

This coincides with the separate (SPURR *et al.*, 1986; SPURR and REINA, 1988b) or aggregate (SPURR and REINA, 1989a) reports on the total daily energy expenditure of these and other Colombian children: on the average, undernourished boys 6-8 and 10-12 years old spent 18 and 10% less energy than their corresponding controls, respectively ($p<0.01$). Mean energy expenditures tended to be lower than in the controls, but the differences were not significant ($p>0.1$) among the 14-16-year-old boys (5%) and the girls aged 6-8 (7%), 10-12 (6%) and 14-16 (1%).

The sex-related differences in energy expenditure were explained by SPURR and REINA (1988b) as being due to cultural attitudes, whereby girls are less active than boys. We interpret the age-related differences as being due to social and peer pressures that increase as children grow older. The younger well-nourished boys are probably more prone to exert their physical activity without restraint during their daily routine, thereby increasing the difference from their undernourished peers, very much like what occured in summer camp (SPURR and REINA, 1988c). This is consistent with the nutrition-related differences in physical activity observed among preschool children in Uganda (RUTISHAUSER and WHITEHEAD, 1972) and Guatemala (TORUN and CHEW, unpublished).

5. Short- and long-term effects

The studies that have looked at the effects of low or restricted energy intakes on the activity of infants and children, although small in number, coincide in that reduced intake leads to shorter duration or lower intensity of physical activity. This occurs within a few days after dietary energy decreases (VITERI and TORUN, 1981). Initially, it seems to be a compensatory response to maintain energy balance without comprising growth. But if the dietary restriction is large enough, the decrease in activity and overall energy expenditure is not sufficient to preserve growth (TORUN and VITERI, 1981a).

5.1. Adaptation and accomodation

Children with a chronically low energy intake that is not so extreme as to produce the clinical signs and metabolic changes of severe malnutrition, maintain a state of energy balance. In discussing the implications of this balance, it is necessary to differentiate between what may be called adaptation and accomodation.

We speak of adaptation when metabolic and behavioral modifications allow a more efficient use of the energy available without producing undesirable effects (e.g., reducing BMR or performing mechanical work with less costly movements). This has a different connotation from metabolic and behavioral modifications that permit survival and function at the expense of actually or potentially undesirable effects (e.g., increased risk of diseases and severe malnutrition, or limitations to perform activities that are

healthy or economically and socially desirable). This can be referred to as accomodation (SCRIMSHAW and YOUNG, 1989; BENGOA *et al.*, 1989).

5.2. Reduction in energy expenditure

A decrease in BMR in the absence of reduced growth rate or an improvement in mechanical efficiency has not been demonstrated in undernourished children to explain the reduction in total energy expenditure shown in the studies discussed above. Even if these phenomena had occured without being detected, they could not be the sole explanation for the reduction in energy expenditure. Infants, preschool children and school-age children did become less active and engaged less or no longer in certain activities (CHAVEZ *et al.*, 1972; CHAVEZ and MARTINEZ, 1979; RUTISHAUSER and WHITEHEAD, 1972; VITERI and TORUN, 1981; TORUN and CHEW, unpublished; SPURR and REINA, 1989a).

This was more evident in younger children, probably because they were subject to less social constraints and peer pressure. In the case of children who go to school, it seems that the school routine, which occupies a large proportion of daytime and restricts free physical activity, tends to mask the potential differences in activity related to nutritional status. The differences may become evident when children are given the opportunity and are encouraged to be more physically active, as seen in the summer-camp studies of SPURR and REINA (1988c).

5.3. Behavior and social performance

CHAVEZ and MARTINEZ (1979) showed enhanced behavioral and exploratory activities associated with increased physical activity in the better nourished young preschool children. From the studies of preschoolers in Uganda and Guatemala it can be inferred that children who had adequate energy intakes and spent less time sitting or lying down and more time walking and moving around, had more frequent interactions with their peers, adults and their physical environment. This was, in fact, the subjective appraisal of the investigators and staff who participated in the clinical and community studies in Guatemala. Other investigators have also suggested that low energy intake and expenditure are likely to decrease the interactions between children and their immediate environment (GRAVES, 1976, 1978; RICCIUTI, 1981; BEATON, 1983).

POLLITT (1987) has pointed out the conceptual and methodological problems that do not allow making definitive statements about the influence of dietary energy deficiency on cognitive and socioemotional development. One of the major obstacles is the difficulty – if not impossibility – of isolating the nutritional components from other factors that affect the behavior and development of children. Nevertheless, the evidence that better nutrition allows more activity supports the suggestion of a sequential cause-effect linkage between adequate energy intake → enhanced physical activity → more interaction with people and the environment → better social performance and cognitive development.

5.4. Low physical activity and growth

Physical activity is markedly reduced in malnourished children. VITERI (1973) used an animal model to demonstrate that this reduced activity contributed, by itself, to growth impairment. Weanling rats were fed either 50 or 73% of the food normally eaten by rats of the same age. When they were inactive, living in small metabolic cages, growth in length and weight gain were significantly less ($p<0.01$) than in pair-fed animals who lived in larger cages and were forced to run in a revolving drum twice daily.

The negative effect of inactivity on the growth of malnourished animals and the positive effect of exercise can be reversed, as shown in another experiment with a cross-over design with rats fed 60% of the normal food intake (VITERI and TORUN, 1981). Whether the animals were inactive from the beginning of the study or became inactive after an initial period of forced activity, growth rate decreased. Conversely, an increment in activity produced better growth in length and weight.

The positive role of activity was further confirmed in the course of the nutritional rehabilitation of malnourished 2- to 4-year-old children (TORUN *et al.*, 1976, 1979). When a group of patients were encouraged to participate in games that involved running after a ball, walking up a slope, climbing stairs and rolling and tumbling, they grew more in length and lean body mass than a control group of patients who continued with the usual, limited activities customary in most nutritional rehabilitation centers. Based on individual weekly calibrations of heart rate to oxygen consumption and heart rate monitoring, mean energy expenditure during the daytime was calculated as 1.97 X BMR in the more active children, compared with 1.70 X BMR in the control group.

In a more recent study using a similar program of physical activity in a hospital for malnourished children in Guatemala, but with food intake *ad libitum*, preliminary results indicated that the more active patients reached normal weigth-for-height earlier than their less active counterparts (URIZAR and TORUN, unpublished).

It has not been shown whether physical activity has similar effects on the growth of children with mild and moderate dietary energy deficiency, but there are no reasons to believe that they would differ in this respect from the more severly malnourished children. As to the question of "How important is big?", we can answer that larger muscle (protein) and energy (fat) reserves

might give poor, underprivileged children better protection against a recurrence of protein-energy malnutrition. Furthermore, as discussed below, small body size can limit maximal work output.

5.5. Reduction in physical fitness

Physical fitness may influence the type of activities performed by children and the time allocated to those that demand most energy. Only a few studies have been done on the overall physical fitness of undernourished children or on its modification with changes in nutritional conditions. These have been based on aerobic capacity as a function of heart rate, on submaximal aerobic tests and on maximal oxygen consumption.

Physical fitness is reduced in children with severe protein-energy malnutrition. When adequate treatment is given, physical fitness increases with improvement of nutrition conditions, as shown by TORUN *et al.* (1976, 1979) in children between 2 and 4 years old. Figure 8 shows that, as nutritional rehabilitation progressed, there was a gradual weekly increment in the regression coefficients of oxygen consumption on heart rate, which indicates an increase in aerobic capacity.

Submaximal exercise tests have been done using a treadmill or bicycle ergometer in 6-year-old Colombian children (SPURR *et al.*, 1978) and in children of school-age in Ethiopia (ARESKOG *et al.*, 1969), Tanzania (DAVIES, 1973a, b), India (SATYANARAYANA *et al.*, 1979), and Brazil (DESAI *et al.*, 1983). Maximal oxygen consumption while walking on a treadmill, has been measured in Colombian boys and girls between 6 and 16 years old (SPURR and REINA, 1989b; other studies summarized by SPURR, 1983, 1987). The results obtained in most of those studies indicate that undernourished children had lower maximal oxygen consumption values, compared to children with better nutritional status or background from their own country, or from the United States and Europe. This is illustrated in Figure 9. However, the effect of nutritional status disappears when aerobic capacity is expressed per unit of body weight or lean body mass. Thus, it seems that the physiological potential to perform physical work is maintained in children with mild or moderate malnutrition, but their smaller size limits the maximal effort that they are capable of. This is consistent with the observations and conclusions of VITERI (1971) and SPURR (1983, 1987) in undernourished adults with reduced maximal oxygen consumption, largely due to their decreased muscle mass.

The decrease in maximal aerobic capacity may have a negative impact on the children's ability to do physical work that demands high energy expenditure. In rural areas of the developing world, culture and economics often demand that children of

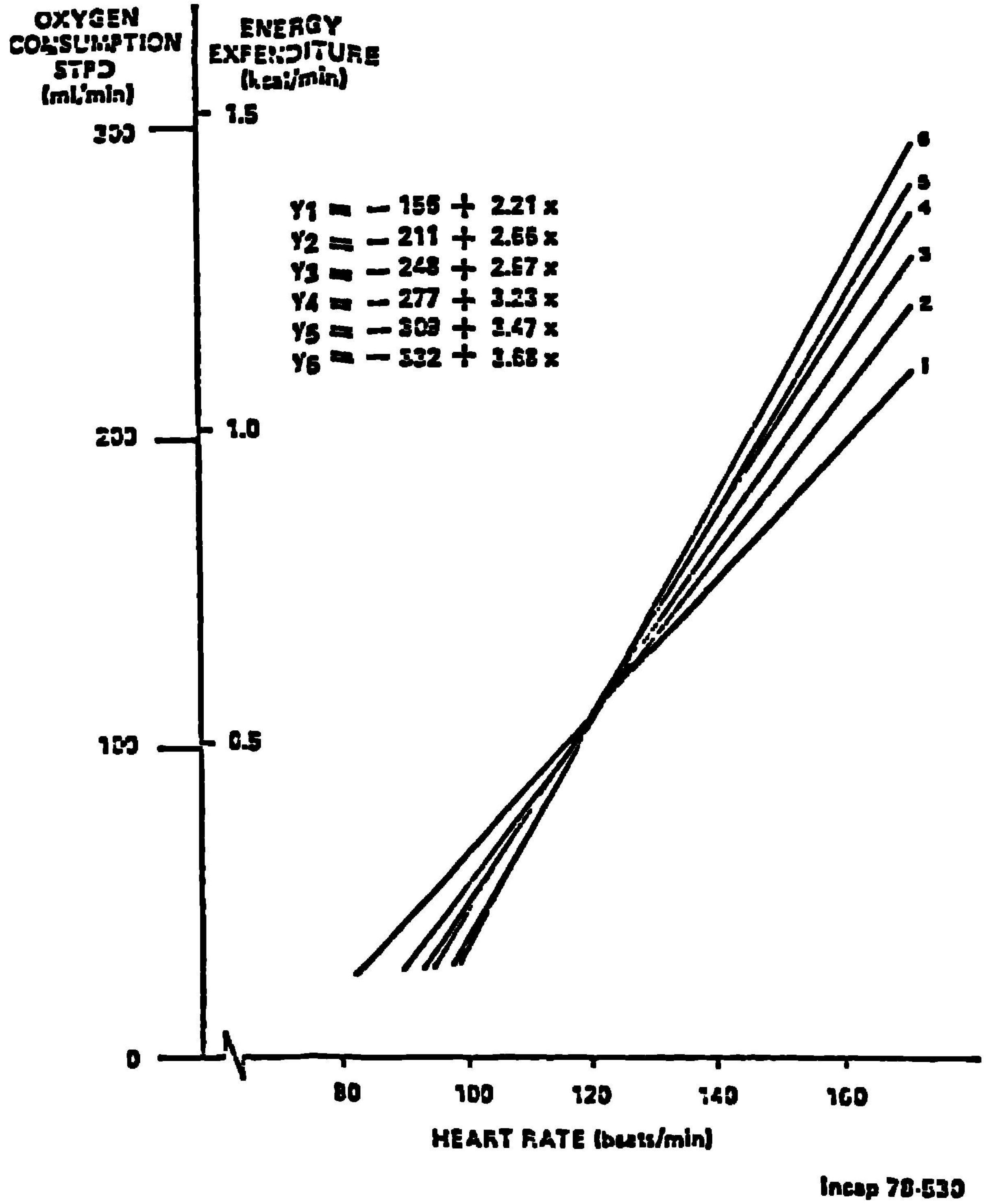

Figure 8. Mean weekly increments of oxygen consumption as a function of heart rate in 19 preschool children treated for protein-energy malnutrition. From TORUN *et al.*, 1979.

school age and adolescents engage in heavy physical work from an early age. Even in societies where child labor is not customary, the small size of undernourished children may have important consequences on physical activity in the long term. It is conceivable that these undernourished children will become small adults with depressed physical work capacity and reduced productivity in heavy work (DESAI *et al.*, 1984; IMMINK *et al.*, 1984; SATYANARAYANA *et al.*, 1979; SPURR, 1983; VITERI, 1971).

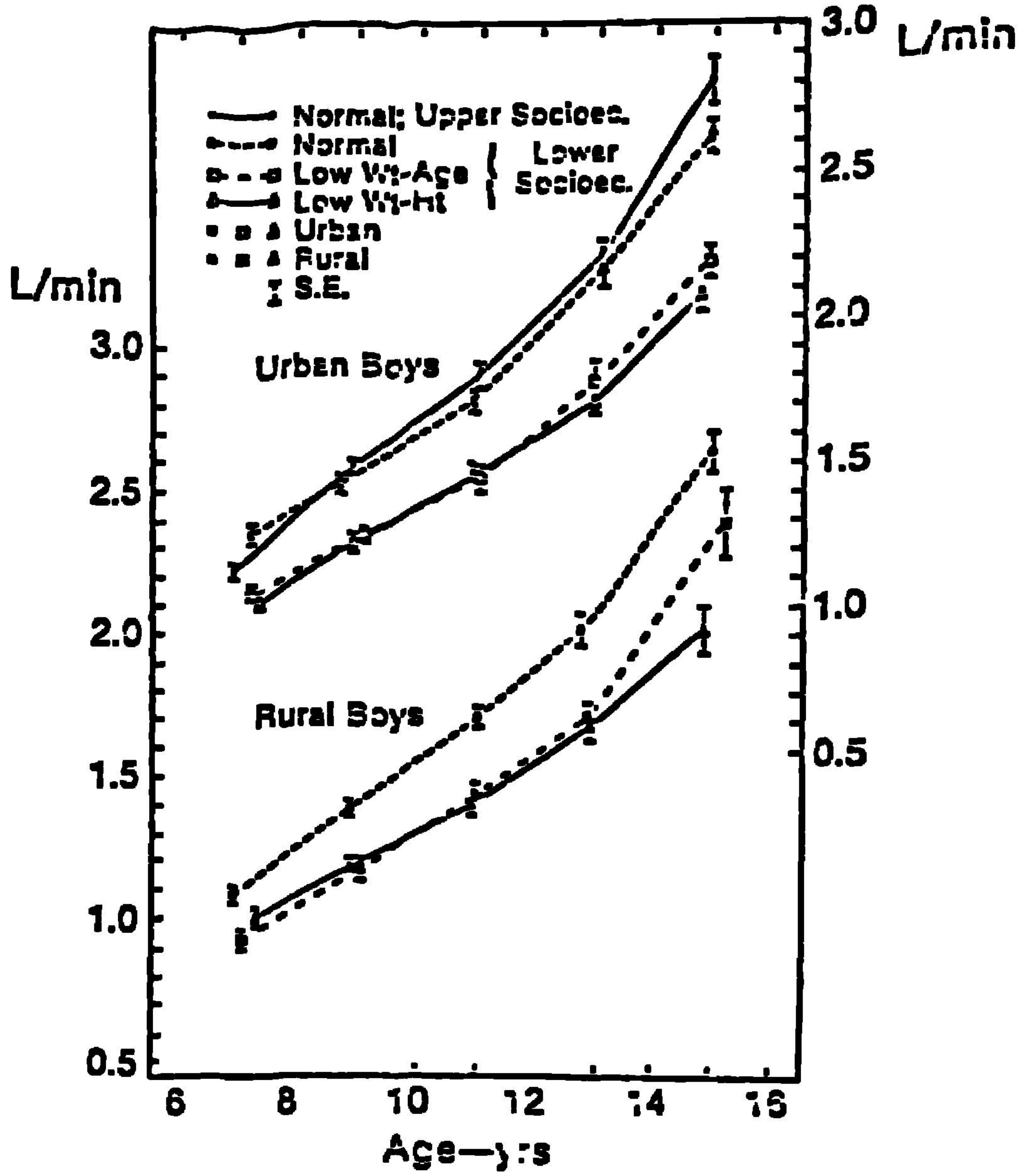

Figure 9. Maximal oxygen consumption of Colombian boys with different nutritional and socioeconomic conditions. From SPURR *et al.*, 1983.

6. Conclusions

Low or restricted energy intakes reduce the physical activity of infants and children, even at a very early age. When this is transient, it will be reversed rapidly with nutritional improvement, and it may have no important morphologic, functional, or behavioral consequences. However, a prolonged reduction in physical activity due to sustained low energy intake, may limit or reduce the child's social interactions and exploration of its environment. This is more evident under circumstances where children are encouraged or forced to participate in very energy-demanding activities. These include games, sport competitions and the need to work in rural areas.

Such limitations may contribute to a slower cognitive development, suboptimal social performance, smaller body size and reduced productivity in physical work. All this, in turn, will hinder the child's development to its full biological potential, reduce its quality of life in a broad sense, and limit its contributions to family welfare, either in childhood and adolescence, or in later adult life. Therefore, interventions to improve nutrition and function at an early age, and maintaining them through childhood, will have important biological, social and economic implications.

It is thus inappropriate to refer to the reduction of physical activity as an adaptation to low or restricted energy intake, as this term has the connotation of a desirable, positive adjustment. Under the best circumstances, it should only be considered as an adequate but short-term compensatory response.

Acknowledgements

Most of the work done by the author in this field was in collaboration with or through the inspiration and encouragement of Dr. Fernando E. Viteri. The guidance and support of Dr. Robert B. Bradfield and the late Dr. C. Frank Consolazio are gratefully acknowledged. Some of the INCAP studies quoted were partially supported by the World Health Organization and the United Nations University.

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Discussion (summarized by N. Solomons)

The first questions were asked to clarify some methodological aspects of the studies on which Torun had reported.

In Guatemala, during recovery from PEM, more active children showed greater linear growth than less active children on the same diet. In a new study, which is currently underway, weight-for-height is increasing more in the more active children. The individual calibration of heart rate against oxygen consumption is possible even in relatively small children. In Guatemala, a treadmill and a pediatric face-mask were used for this purpose.

There is some controversy about the usefulness of $\dot{V}O_2$ max measurements. For most work situations at a submaximal oxygen consumption level, the measured $\dot{V}O_2$ max does not allow prediction of work performance. The counterargument is that heavy physical work is quite frequent, and that individuals who can do such heavy work at 60% of their $\dot{V}O_2$ max can sustain this activity longer. Adjusting $\dot{V}O_2$ for body weight downplays the fact that a larger person can perform more work in absolute terms.

The study undertaken by Rutishauser and Whitehead in Uganda was criticized because of the small sample sizes and because the two groups of children came from different cultural backgrounds, which could explain, at least partially, their different behavior pattern. Others emphasize the pioneering nature of the study which was among the first to show that different activity patterns could be observed under such circumstances.

Durnin presents a graph on relationships between sample size, number of measurements required, and the power of a study to detect predetermined differences in energy intakes in longitudinal and cross-sectional studies. The required sample sizes appear very large; 200 subjects, for instance, are needed to detect a 200 kcal difference in intake as statistically significant ($p < .05$). By implication, this means that many of the studies involving nutritional supplementation could not be expected to yield statistically significant results, simply because of small sample sizes.