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The relationship in poorer, developing nations of the world between small body size of the adult population and nutritional deprivation during the period of growth has been discussed at length in previous chapters. Some of the functional consequences have also been discussed. It is my task to address the results of chronic undernutrition and associated small body size on physical work capacity (PWC) and productivity in work that can be classified as heavy. I attempt to demonstrate that, within limits, larger individuals have an advantage in this kind of work over their smaller counterparts in the same population. It has been suggested that in mild or moderate states of malnutrition, where individuals may be "small but healthy," there is little or no functional deprivation, and that when assessing the incidence of malnutrition, different standards than those used for more advantaged groups ought to be applied to populations where smallness is common (1). Gopalan (2) has rejected this double standard for rich and poor. Furthermore, Margen (3) has stated that although it is obvious that a larger individual can perform heavier work than a small one, this may not be the proper interpretation since, if expressed per unit of lean body mass (LBM), the work that can be performed by a small person is as great as that of a large one. This chapter attempts to show that mild to moderate malnutrition is accompanied by functional decrements in work capacity that have particular importance when it occurs during the period of growth and that it is the total work capacity that matters, not the PWC normalized for weight or LBM.

The concern with PWC and its relationship to hard physical work is valid only if both hard physical work and malnutrition are associated. In the less developed areas of the world, where the incidence of protein–calorie undernutrition is high and mechanization is at a minimum, human labor provides much of the power for economic productivity (4). For example, using data published by the United Nations (5), it is possible to estimate for six South American countries that about
54% of the actively employed male population is engaged in work that can be classified as moderate to heavy (agriculture, forestry, mining, construction, etc.). Arteaga (6), using the same source of data for 1972, concluded that in all of Latin America, about 54% of employed men were engaged in heavy work, 20% in medium-intensity work, and 26% in sedentary occupations. Consequently, hard physical work is a reality for the majority of adult males in the work force of poor countries, and factors that affect it will have bearing on economic development (7).

DEFINITIONS

Malnutrition is used here as a convenient synonym for undernutrition and, in the present context, refers to chronic undernutrition in which the subjects' daily struggle to obtain sufficient nutrient intake may be a losing one, lasting over many years or a lifetime where the food supply is precarious.

The definitions of physical fitness and physical work capacity (PWC) are difficult to formulate (8). An expert committee of the World Health Organization was able only to relate one to the other: "Physical fitness is the ability to perform muscular work satisfactorily" (9). Physical fitness is frequently confused with physical performance as measured by tests representing basic performance demands (skill, flexibility, strength, etc.). These tests are related to special gymnastic or athletic performance and consequently are not suitable for evaluation of basic physiological functions (10). Where gymnasia are few or unknown, subject populations are handicapped, and even in more developed areas, previous motor learning is an important factor (8). Consequently, in this discussion physical performance is limited to measures of productivity (where these exist) in actual work situations and to a few measures of performance in relation to load carrying. Productivity is also an elusive concept, but in some types of industrial and agricultural work, payment is based on piecework, and so productivity in terms of the manufactured or harvested goods or pay received can be measured. Work is a complex entity and involves, in addition to the biologic component, psychological (motivational), type-of-work, and work-setting components (11). The effects of malnutrition on work and productivity deal only with the biological component.

The overall physical fitness of an individual is best determined by the maximal work capacity (physical work capacity) as measured by the maximal oxygen consumption (\(V_{O_2}\) max). The PWC of a person is the result of a number of contributing factors: natural endowment (genes), physical condition (training), sex, age, and, as will be discussed, nutritional status, to mention the most important. Measurement of the \(V_{O_2}\) max provides information on the maximal output of aerobic energy-liberating processes in the skeletal muscles involved in the work as well as the functional capacity of the circulation, since there is a high correlation between \(V_{O_2}\) and cardiac output in both submaximal and maximal work (10). Consequently, the \(V_{O_2}\) max as an assessment of physical work capacity is a measure of functional (physiological) capacity and has particular importance when related to nutritional
status with its implications for the developing world (12–14). The $\dot{V}O_2$ max, then, can be defined as the highest oxygen uptake an individual attains during physical work while breathing air at sea level (10). $\dot{V}O_2$ max, aerobic capacity, and maximal aerobic power are terms that are frequently employed interchangeably, but because of the emphasis in this chapter on the absolute oxygen cost (liters/min) of submaximal work tasks in comparison to the maximum $\dot{V}O_2$ (liters/min), a distinction will be made. Thus, the term $\dot{V}O_2$ max is limited to this measurement in units of liters per minute, whereas the term maximal aerobic power or capacity is retained for the maximal oxygen consumption as a function of body weight (milliliters/min/kg) or one of the compartments of body weight such as the lean body mass (LBM), muscle cell mass (MCM), etc. Endurance, in the present context, means the maximum time an individual can continuously sustain a given submaximal work load.

Mechanical efficiency is the ratio of work accomplished to the energy required to do the work. In terms of the intact organism, it has been measured using the oxygen cost of performing work on the bicycle ergometer or treadmill and expressed as a percentage with or without the subtraction of various base lines (15–17). It appears that $\Delta$ efficiency [(change in work accomplished/change in energy expended) × 100] represents the most accurate estimate of muscular efficiency (16). However, even this has been questioned, since values obtained by the subtraction of various base lines yield unreasonably high efficiencies when compared to those found for isolated muscle preparations. Furthermore, considerations of elastic energy storage and eccentric contractions further complicate the picture (18). Stainsby et al. have suggested that although exercise efficiencies using base line subtractions may be useful, they do not indicate muscle efficiency, and that studies of exercise (work) metabolism might be more profitably directed at quantifying the determinants of energy expenditure (18). Thus, the energy expenditure (oxygen uptake) at various tasks might better be termed the economy of submaximal work (exercise) expressed per unit of body weight (19).

STUDIES IN ADULTS

Because short adult stature is largely the result of chronic undernutrition during growth, the results of studies of acute starvation and semistarvation under laboratory conditions, which have been reviewed (13,14), are not treated here. Attention is directed to the few studies available in the literature on the relationships among nutritional status, PWC as measured by the $\dot{V}O_2$ max, and productivity in some work situations with comments on endurance as a component of productivity in chronically undernourished subjects. Since the malnourished individual is usually not working (a reason for his malnourished state), particularly in moderate or heavy work tasks, it has not been possible to relate malnourished states directly to productivity. Rather, the attempt has been made to relate both nutritional status and productivity (measured in nutritionally normal, employed subjects) to a common measurement ($\dot{V}O_2$ max) and from these relationships to infer the association
between nutritional status and productivity in moderate to heavy work. Most reports in the literature are the result of measurements in male subjects.

**Malnutrition and $\dot{V}O_2$ max**

Viteri (20,21) compared the PWC of several groups of young Guatemalan adults, one of which, their subjects from San Antonio La Paz (SAP), can probably be considered at least marginally malnourished on the basis of the adiposity, LBM, and muscle cell mass (MCM, calculated from daily creatinine excretion). The SAP group, another group of recent inductees into the army who were from a similar rural socioeconomic background, and 10 nutritionally supplemented agricultural workers all had significantly lower $\dot{V}O_2$ max and maximal aerobic power (expressed per kilogram of body weight and of LBM) than army cadets from middle or upper socioeconomic levels who had never been exposed to nutritional deprivation. When compared on the basis of "cell residue" (body weight less fat, water, and bone mineral), all differences in maximal aerobic power between groups disappeared. Viteri (20) observed that the differences in maximal aerobic power were associated with differences in body composition and not with differences in cell function.

We have studied three groups of chronically malnourished adult males who were selected for their existing degree of undernutrition (22). The most severely malnourished of these subjects were also studied during a 45-day basal period in the hospital and during 79 days of a dietary repletion regimen (23). Subjects were classified into those with mild (M), intermediate (I), and severe (S) malnutrition based on their weight/height (W/H) ratio, serum albumin concentrations, and daily creatinine excretions per meter of height (Cr/H) as detailed in Table 1. Each group was significantly different ($p<0.001$) from the other two in regard to each variable used in the classification. Detailed body composition and biochemical measurements on the three groups were made shortly after admission to the metabolic ward (24) and during the dietary repletion regimen of group S (25). On entry into the

<table>
<thead>
<tr>
<th>Subject groups</th>
<th>Weight/height (kg/m)</th>
<th>Serum albumin (g/dl)</th>
<th>Daily creatinine/height (mg/day per m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M ($n = 11$)</td>
<td>A &gt; 32</td>
<td>&gt; 3.5</td>
<td>&gt; 600</td>
</tr>
<tr>
<td></td>
<td>B 33.3 ± 2.1</td>
<td>3.8 ± 0.5</td>
<td>660 ± 67</td>
</tr>
<tr>
<td>I ($n = 18$)</td>
<td>A 29–32</td>
<td>2.5–3.5</td>
<td>450–600</td>
</tr>
<tr>
<td></td>
<td>B 30.8 ± 2.0</td>
<td>3.0 ± 0.7</td>
<td>559 ± 75</td>
</tr>
<tr>
<td>S ($n = 18$)</td>
<td>A &lt; 29</td>
<td>&lt; 2.5</td>
<td>&lt; 450</td>
</tr>
<tr>
<td></td>
<td>B 27.4 ± 2.1</td>
<td>2.1 ± 0.5</td>
<td>391 ± 76</td>
</tr>
</tbody>
</table>

*From Spurr (13).*
hospital, the subjects were placed on an energy intake (2,240 kcal/day, 9.4 MJ/day) adequate for the sedentary conditions of the metabolic ward but were maintained on the same protein intake (27 g/day) they were ingesting prior to entry.

Studies of work capacity and endurance in the severely malnourished men were made at the beginning and end of the 45-day basal period on this diet. The protein intake was then increased to 100 g/day for the 79-day repletion regimen; the increased caloric intake from protein was balanced by reducing carbohydrate intake to maintain the diets isocaloric. Measurements of \( \dot{V}O_2 \) max and endurance were repeated after 90 and 124 hospital days. The results for the three groups and the changes in the severely malnourished men during dietary repletion are presented in Figs. 1 and 2 and compared with data on 107 nutritionally normal control subjects who were sugar cane cutters (26), loaders (27), or general farm laborers (28). There were progressive differences in body weight, W/H ratio, serum albumin, and total proteins in the control (C), M, I, and S groups (Fig. 1). Groups C and M were not significantly different in regard to hematocrit and blood hemoglobin, but I and S were significantly and progressively depressed in these measurements. There was a slight gain in body weight of group S during the basal period, but otherwise the variables did not change. Weight, W/H ratio, and the serum proteins showed progressive improvement during the repletion regimen, but the hematological values did not show improvement until the final round of measurements (Fig. 1).

Figure 2 presents the results for maximal heart rate (\( f_H \max \)), maximal aerobic power (\( \dot{V}O_2 \), ml/min/kg body weight), and \( \dot{V}O_2 \) max (liters/min) for the control and malnourished subjects. Average \( f_H \max \) values were not different in the various groups, nor did they change during dietary repletion. However, \( \dot{V}O_2 \) max and max-

![FIG. 1. Average values of some anthropometric and blood variables in nutritionally normal (C) subjects and men with mild (M), intermediate (I), and severe (S) malnutrition. The severely undernourished were studied during a basal period on adequate calories and low protein followed by a dietary repletion period on an isocaloric but high-protein diet. Solid lines connect points that are significantly different from each other. (From Spurr, ref. 13.)](image-url)
imal aerobic power were progressively less in C, M, I, and S subjects, did not change in the latter during the basal period, and then progressively improved during dietary repletion, although they did not return to even the level of group M during the period of study. Figure 2 also expresses a theoretical submaximal work load of 0.75 liters/min $V_O_2$ in terms of percent $V_O_2$ max for each of the groups. From Fig. 2, it is clear that $V_O_2$ max and maximal aerobic power are markedly depressed in chronic malnutrition and that the degree of reduction is related to the severity of depression in nutritional status. Among the three groups of malnourished subjects, a stepwise multiple regression analysis (22) revealed that the $W/H$ ratio, log of the sum of triceps and subscapular skinfolds in millimeters (SK), total body Hb (TotHb) obtained as the product of blood Hb and blood volume (grams per kilogram body weight), and daily creatinine (Cr) excretion (grams per day per kilogram) contributed significantly to the variation in $V_O_2$ max (liters/min):

$$\hat{V}_O_2 \text{ max} = 0.095 \frac{W}{H} - 0.152 \text{SK} + 0.087 \text{TotHb} + 0.031 \text{Cr} - 2.550$$

$$r = 0.931; \text{ SEE} = 0.21$$

All of the variables in the equation are related to nutritional status.

Figure 3 expresses the data for the three malnourished groups and for group S during recovery in terms of various body compartments. It was not possible to do detailed body composition studies on the control subjects. The salient feature of Fig. 3 is that over 80% of the difference in $\hat{V}_O_2$ max between M and S subjects is accounted for by difference in MCM. The remaining difference might be ascribed to reduced capacity for oxygen transport either because of low blood Hb (Fig. 1) or reduced maximum cardiac output. There do not seem to be any reports of studies on maximum cardiac output in malnourished subjects. Another possibility is
that the skeletal muscle cells have reduced maximal aerobic power because of reduced oxidative enzyme content. Tasker and Tulpule (29) found a marked decrease in the activities of oxidative enzymes in skeletal muscle of protein-deficient rats, and Raju (30) reported that after recovery from 13 weeks of reduced protein intake, rat skeletal muscle had an increase in glycolytic and a decrease in oxidative enzymes and activity. However, there appear to be no studies that have measured similar biochemical changes in humans, although Lopes et al. (31) have recently shown that malnourished patients exhibited marked impairment in muscle function. There were both an increased muscle fatigability in static muscular contraction and a changed pattern of muscle contraction and relaxation, which were reversed in patients undergoing nutritional supplementation. Their data indicate the possibility of a decreased content of ATP and phosphocreatine in the skeletal muscle tissue of malnourished subjects.

The data of Heymsfield et al. (32) indicate changes in the biochemical composition of skeletal muscle in both acute and chronic semistarvation, particularly in glycogen and total energy contents. In any event, it should be emphasized that the $\dot{V}O_2$ max not accounted for by differences in MCM is small (Fig 3). After 2.5 months of recovery, the $\dot{V}O_2$ max increased significantly in liters per minute when expressed in terms of body weight and LBM, but, although mean values were elevated in terms of body cell mass (BCM) and MCM, the increases were not statistically significant. However, at the termination of the experiment, PWC had not returned to values comparable to those seen in mild malnutrition (Figs. 2 and 3), which indicates that the recovery process is a long one, particularly under
the sedentary conditions of the hospital metabolic ward. It is interesting to note that the $V_{O_2}$ max was increased 45 days after beginning the repletion diet (90 hospital days), when blood Hb concentration had not yet increased (Fig. 1) but MCM was significantly increased over basal values (25). This also points to a primary dependence of $V_{O_2}$ max on MCM (Fig. 3). Furthermore, it appears that supplying adequate calories alone was not sufficient to bring about an increase in $V_{O_2}$ max or MCM and that only after increasing the protein intake to 100 g/day was there improvement in these two variables (23,25).

**Endurance**

An endurance test is carried out on a treadmill or bicycle ergometer at a work load ($V_{O_2}$) of 70 to 80% of the subject's maximum until exhaustion supervenes, usually with the $f_H$ within about 5 beats of $f_{H\text{ max}}$. Because of the difficulty in performing this test, only a few laboratories have attempted measurement of endurance times in normal individuals and, to our knowledge, none except our own in malnourished subjects.

From a number of sources, it is known that the maximum relative work load that can be sustained for an 8-hr work day usually does not exceed about 35 to 40% $V_{O_2}$ max. Thus, Michael et al. (33) found in laboratory treadmill work that 8 hr could be tolerated without undue fatigue when the relative load did not exceed 35% $V_{O_2}$ max. In the building industry, Astrand (34) reported that about 40% $V_{O_2}$ max was the upper limit that could be tolerated for an 8-hr work day, and we have estimated that sugar cane cutters worked at about 35% of their $V_{O_2}$ max during an 8-hr day (26). These studies were performed in physically fit subjects. Sedentary individuals can be expected to have lower upper limits for 8 hr of work (10, p. 292).

We have measured maximum endurance times at 80% $V_{O_2}$ max ($T_{80}$) in the groups of malnourished subjects described above (22,23). We did not find any significant differences among the groups (M, I, and S) of malnourished men; $T_{80}$ averaged 97 + 12 min (mean ± SE) in all subjects (22). However, it might be assumed that the $V_{O_2}$ max of group S subjects would be about 2.4 liters/min had they not been malnourished, and that about 35% (0.84 liter/min) could be sustained for an 8-hr work day. The value of 0.84 liter/min is 80% of the $V_{O_2}$ max (1.05 liters/min) for these subjects, who had maximum endurance times at this relative work load of a little over 1.5 hr, a loss of about 6.5 hr of daily working time or about an 80% reduction in productive potential (22). Using a similar method of estimation, Barac-Nieto (35) has calculated a 16% reduction in work output of the M subjects, a 35% decrease in I, and a 78% reduction in S men.

In the case of group S during dietary repletion, an interesting change in $T_{80}$ was observed. Endurance times were significantly reduced from 113 min at the first measurement of the basal period to 42 min at the final determination at the end of the dietary repletion (23). The explanation for this surprising reduction is still not clear. Hanson-Smith et al. (36) reported decreased work endurance times in rats...
on high-protein diets compared to animals ingesting an isocaloric carbohydrate diet, and Bergstrom et al. (37) and Gollnick et al. (38) have shown that diets in which the energy value of carbohydrate has been replaced with fat and/or protein lead to reduced stores of muscle glycogen. Furthermore, Bergstrom et al. (37) demonstrated that the maximum endurance time in humans is directly related to the initial glycogen content of skeletal muscle. During the dietary repletion period of the group S subjects, carbohydrate intake was reduced from 64% to 50% of calories. In a normal individual this amount of carbohydrate should be sufficient to maintain muscle glycogen stores, but definitive studies seem not to have been done (39). The rebuilt muscle tissue of group S subjects may not store glycogen normally and, together with the lack of regular exercise in the protracted sedentary existence in the metabolic ward, may lead to reduced muscle glycogen and shorter endurance times. Heymsfield et al. (32) found reduced muscle glycogen in subjects who had undergone acute or chronic semistarvation prior to death. Muscle nutritive supply and the metabolic and endocrine responses that regulate it during both short-term and prolonged exercise have not been investigated in malnourished individuals. Even though there is little reason at the moment to suspect abnormal muscle function in acute exercise testing to maximum levels, the responses to prolonged exercise may be worth investigating.

**Productivity and Physical Work Capacity**

With a direct relationship established between nutritional status and physical work capacity in undernourished men, attention can now be directed towards the association between $\mathrm{VO}_2\max$ and productivity. The amount of work done in terms of output of a product is usually difficult to measure, particularly in the lighter work tasks in which the intellectual component may have as much or more to do with "productivity" as the physical use of one's body. In moderate and heavy work, it has sometimes been possible to estimate productivity by measuring the quantity of product or income where piecework is the basis for payment of the worker. Sugar cane cutting and loading are heavy work tasks, and the weight of cane cut or loaded is measured carefully since workers are usually paid by the tonnage cut. Because the pay scale in many sugar-harvesting operations is very low, one might expect that the motivation factor would be fairly similar in different groups of workers and that they would work close to the limit of their physical capacities. Also, logging is heavy physical work (40) and has been used to relate productivity to worker characteristics. The time to accomplish standard work tasks is another method that has been utilized to estimate productivity (21).

Hansson (41) measured submaximal work and estimated $\mathrm{VO}_2\max$ in a group of "top" producing lumberjacks and a group of average producers and found that the former had a higher estimated $\mathrm{VO}_2\max$ than the latter. Davies (42) studied sugar cane cutters in East Africa, dividing them into high, medium, and low producers based on the daily tonnage cut. He found no difference in the three groups in height, weight, summed skinfolds, LBM, leg volume, or the circumferences of
biceps and calf but did encounter a significant correlation between daily productivity and \( \dot{V}O_2 \) max \( (r=0.46; p<0.001) \). Davies et al. (43) also measured productivity in Sudanese cane cutters during a 3-hr period of continuous cutting and reported a significant correlation between \( \dot{V}O_2 \) max and rate (kilograms per minute) of cane cutting \( (r=0.26; p<0.01) \).

We have studied nutritionally normal sugar cane workers in Colombia, where the tasks of cutting and loading the cane are performed by separate gangs of men. The former is a self-paced and continuous task, whereas the loading of cane is discontinuous, depending on the availability of wagons. The cutters were divided into good (group I), average (group II), and poor (group III) producers, depending on the daily tonnage cut. The cutters worked at about 35% of their \( \dot{V}O_2 \) max during the 8-hr day (26), which is close to the maximum that can be sustained for this period of time (33,34). In relating various anthropometric measurements and age to productivity, there were statistically significant positive correlations of height, weight, and LBM with productivity (44). The correlations with age and body fat were not significant. Figure 4 summarizes the relationship of \( \dot{V}O_2 \) max and maximal aerobic power with productivity, both of which were significantly correlated. A stepwise multiple regression analysis revealed that \( \dot{V}O_2 \) max, percentage body fat (F), and height contributed significantly to the variation in productivity (tons/day) such that

\[
\text{Productivity} = 0.81 \dot{V}O_2 \text{ max} - 0.14 F + 0.03 H - 1.962
\]

\[ r = 0.685; p < 0.001 \]

The \( \dot{V}O_2 \) max and body fat are influenced by present nutritional status (20,22),

![Figure 4](image-url)
and adult height by past nutritional status during the period of growth (45). Equation 2 states simply that those who are presently in poor physical condition or malnourished (low \( \dot{V}O_2 \) max) or whose height is stunted because of past undernutrition are at a disadvantage in terms of ability to produce in cutting sugar cane. The negative coefficient for percentage body fat indicates that there is some advantage to low body fat content. The relatively low correlation coefficients between productivity and \( \dot{V}O_2 \) max obtained in our studies (Fig. 4) and those of others (43,44) preclude the use of regression equations in the prediction of productivity and bring into question the homogeneity of motivation alluded to above. The results shown in Fig. 4 indicate that the more physically fit subjects were better producers. Also, since malnutrition reduces \( \dot{V}O_2 \) max, one can predict that it will have proportional effects on productivity in hard work.

Even in the case of the sugar cane loaders, who do not work continuously, productivity was positively correlated with maximal aerobic power and negatively with resting and working \( f_H \), demonstrating again the relationship of productivity to the physical condition of the worker (27).

In the case of sugar cane cutting, which at an average expenditure of 5 kcal/min per 65 kg of body weight during the 8-hr day (26) can be classified as moderate industrial work (40), the worker productivity is related to his body size, height, weight, and LBM (44). This has also been demonstrated by Satyanarayana et al. (46,47) for industrial factory work of presumably less intensity than sugar cane cutting. Their subjects were nutritionally normal workers engaged in the production of detonator fuses, which could be measured in terms of the number of fuses produced per day. They found that body weight, height, and LBM were significantly correlated with productivity and that after partialing out the effect of height, weight and LBM were still significantly correlated with productivity. That is, the total daily work output was significantly higher in those with higher body weight and LBM.

STUDIES IN CHILDREN

With the recognition that the reduced work capacity found in malnourished adults was largely the result of reduced muscle mass, the next question to be addressed was the effect of chronic marginal malnutrition, which is so prevalent in the poorer segments of developing countries, on the growth of work capacity in school-aged children. There are few studies of exercise and work capacity in malnourished children, and most of these have been carried out using submaximal exercise testing. Areskog et al. (48) determined the physical work capacity at a heart rate of 170 (PWC\(_{170}\)) in 10- and 13-year-old Ethiopian boys from public and private schools with the aim of including both poorly nourished (public schools) and well-nourished (private schools) subjects. The older public school boys were shorter, weighed less, and had smaller skinfolds and midarm circumferences than their private school counterparts. The performance of the public school boys was somewhat better than the private school children in the tests of PWC\(_{170}\). Davies
(49) predicted $\dot{V}O_2$ max from submaximal bicycle ergometry, demonstrating that malnourished (underweight) children had low values for $\dot{V}O_2$ max but that maximal aerobic power in terms of body weight, LBM, or leg volume was well within the normal range. Satyanarayana et al. (50) have also reported the results of measurements of $PWC_{170}$ in boys 14–17 years of age categorized according to their nutritional status at age 5 years. They found that about 64% of the variation in $PWC_{170}$ could be explained by the subjects' body weight at the time of the testing, and another 10% by their habitual physical activity levels. But even severe malnutrition at age 5 had no effect on work performance when $PWC_{170}$ was expressed in terms of body weight. However, the undernourished subjects had higher values for $fHu$ at the same submaximal work load, i.e., were working at a higher percentage of $\dot{V}O_2$ max than normal children.

In the work to be described from our laboratory, all subjects were boys and had to present their official birth certificates as a first condition for inclusion in the study. They were grouped into five age groups at 2-year intervals from 6 to 16 years of age. According to the Colombian standards established by Rueda-Williamson et al. (51), children were selected who had weight for age and weight for height >95% (but <110%) of predicted as being nutritionally normal (N) and without a history of undernutrition. Those with both weight for age and weight for height <95% of the standard were considered to be undernourished at the time of study. The choice of 95% as the cut-off point was entirely arbitrary, and the expectation was that the group averages would be considerably below this point (52). The details of the selection process and the methodology employed in the anthropometric and maturation (52), $\dot{V}O_2$ max (53), body composition (54), and work efficiency measurements (55) have been described previously.

**Anthropometry, Sexual Maturation, and Body Composition in Boys**

The average heights and weights of the five age groups of nutritionally normal and undernourished boys are plotted on the NCHS percentile grids in Fig. 5. The number of subjects in each group varied from 24 to 60. The nutritionally normal boys followed the 50th percentile in the younger age groups and deviated towards the 25th percentile in the older groups (Fig. 5) for both height and weight. The tendency towards shorter stature in these boys is probably the result of the high percentage of mestizos (74%), who have shorter stature than other children (56,57). Both height for age and weight for age of the undernourished boys were on or below the fifth percentile during this period of growth. The weight for height of the normal subjects fell slightly above the 50th percentile throughout this period, whereas the undernourished boys followed approximately the 10th percentile (52). In addition to the depressed growth pattern seen in Fig. 5, the undernourished subjects had significantly lower values for skinfolds, significantly delayed growth spurt and sexual maturation (52), and, in a subgroup, increased fasting levels of circulating growth hormone (*unpublished*). Consequently, the selection process resulted in the separation of undernourished boys, who were smaller and
thinner than normal boys, who were following essentially normal growth development compared to either national or international (NCHS) norms. However, the physiologic data (slowed growth velocity, delayed sexual maturation, and high circulating growth hormone concentrations) make it clear that the reason for their smallness and thinness is that they were undergoing a process of chronic malnutrition, which is no doubt "marginal" in nature but nevertheless real. Furthermore, the fact, that there is a progressive deviation from predicted values of height and weight for age from younger to older boys (Fig. 5) (52) indicates that the process is cumulative with age.

We have demonstrated (54) that the empirical equations developed by Pařízková (58) for estimating body fat from skinfolds in children also apply to our subjects. The results of average estimates of LBM derived from these equations are plotted in Fig. 6 (panel C) together with values for height and weight for the 6 to 8, 10 to 12, and 14 to 16-year-old boys (panels A and B) to compare with similar values for the four groups of adult Colombian men discussed previously (C, M, I, and S) and a group of 10 nutritionally normal North American men. The LBM of the C group was calculated from the skinfold equations of Pascale et al. (59), and that of the American men from those of Durnin and Womersley (60). The LBM of the three groups of malnourished Colombian men (M, I, and S) were obtained from measurements of total body water (24).
FIG. 6. Body composition and maximum work capacity of normal and undernourished Colombian school-aged boys and adult agricultural workers classified as nutritionally normal control subjects (C) or as mild (M), intermediate (I), and severe (S) in the degree of their nutritional deprivation. Also shown are the values for a group of North American men and the NCHS 50th-percentile values of weight and height for adult men.
It can be seen (Fig. 6C) that the development of LBM of the undernourished boys is significantly attenuated during growth (54). When expressed as percentage of body weight, the undernourished boys had significantly higher values of LBM than well-nourished subjects because of lower fat values in the former (54).

Growth of Work Capacity

The growth of $V_o_2$ max in the youngest, oldest, and intermediate age groups of boys presented in Fig. 5 is shown in Fig. 6D. The $V_o_2$ max of the nutritionally deprived boys was significantly lower (~85%) than the normal subjects throughout the age range studied (53). When expressed as per kilogram of body weight, with the exception of the youngest age group, the undernourished boys had higher aerobic capacities than the normal boys (Fig. 6E), which was thought to be because of differences in body composition (53). Subsequent studies (54) demonstrated that even when expressed in terms of LBM, the aerobic capacity of the undernourished subjects, at least in the older age groups, was significantly higher (Fig. 6F). That is, the undernourished boys show evidence of better physical condition (61). In a similar study on rural Colombian boys, although the difference in aerobic capacity between nutritionally normal and undernourished subjects expressed per kilogram of body weight was similar to that found for urban subjects (Fig. 6E) (53), the difference disappeared when aerobic capacity was calculated in terms of LBM (Fig. 6F); i.e., the rural boys did not exhibit a training effect (54). These results may be caused by a relative increase in the daily physical activity of the undernourished boys (in relation to their lower total $V_o_2$ max) (62, 63) or result from greater access of urban children to sports training facilities than rural boys (53, 54, 64).

These results make it clear that the lower values of $V_o_2$ max for the nutritionally deprived children are related to their lower body weights. This is essentially the same conclusion reached by Davies (49) and Satyanarayana et al. (50). As mentioned earlier for adults, there does not appear to be any basic deficit in muscle function in marginally malnourished children, only in the quantity of muscle available for maximal work. We have deliberately avoided analyzing these data on the basis of so-called "developmental" age because such an analysis would tend to obscure the differences seen in Fig. 6D; the responsibilities of adulthood occur with chronological, not developmental age.

BODY SIZE, COMPOSITION, AND $V_o_2$ max IN MEN AND BOYS

Persons of larger size in general appear to function better than those with smaller stature (65) in relation to reproduction (66), disease (67), cognition (68), and work performance (13, 14). Because physical work capacity is a function of body size (10), i.e., the mass of muscle tissue involved in the maximum effort, and muscle constitutes about 40% of the body weight and 50% of the LBM
BODY SIZE AND WORK CAPACITY

(69,70), it is interesting to note the correlations between the three components of body size and $\dot{V}O_2_{\text{max}}$ presented in Table 2. The correlations in boys are higher than those in men, probably because of a threefold greater range in values, but in either case it is clear that in nonobese subjects there are significant correlations between parameters of body size and PWC as measured by $\dot{V}O_2_{\text{max}}$. Taller individuals have more LBM and higher $\dot{V}O_2_{\text{max}}$ values (Fig. 6). Similar relationships exist for adult women, but the correlation coefficients are lower (71).

All of the data presented in Fig. 6 are from various studies in our laboratory (22–26,44,52–54,63) and permit a comparison between Colombian boys and men and between the latter and a small group of North American adult males. The differences in height between adults of developing and developed countries is well known (12). The average value of the C group of men in Fig. 6 is very close to that published for low-income Colombian men (12) and probably reflects some period(s) of undernutrition during the period of growth. The heights of the three groups of malnourished (M, I, S) men were not significantly different from each other but were lower than the C group. This is probably a result of more severe nutritional deprivation in groups M, I, and S during growth than occurred in group C. It is difficult to predict the adult height of the oldest boys, but it is likely that the nutritionally normal children will be taller (Fig. 6A) and perhaps have a higher $\dot{V}O_2_{\text{max}}$ than group C (Fig. 6D), whereas the undernourished group of boys in adulthood will most likely resemble more closely group M.

The lower values of aerobic capacity per kilogram of body weight and of LBM in adults than in boys are also well known and at least in part probably reflects the progressive decline in these measurements with age from the youngest ages (72). The differences also may reflect differences in the states of physical training in the boys and men.

ENERGY COST OF LOAD CARRYING

The smaller size of nutritionally at-risk populations has been considered an advantage when resources are limited, since energy expenditure for the maintenance

<p>| TABLE 2. Correlation coefficients of weight, height, lean body mass, and maximal oxygen consumption in nutritionally normal boys 6 to 16 years of age and adult males* |
|---|---|---|---|---|---|---|
| | Boys ($n = 406$) | | | | Men ($n = 35$) | |</p>
<table>
<thead>
<tr>
<th></th>
<th>Weight (kg)</th>
<th>Height (cm)</th>
<th>Lean body mass (kg)</th>
<th>Weight (kg)</th>
<th>Height (cm)</th>
<th>Lean body mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height</td>
<td>0.970</td>
<td>—</td>
<td>—</td>
<td>0.758</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>LBM</td>
<td>0.986</td>
<td>0.965</td>
<td>—</td>
<td>0.875</td>
<td>0.702</td>
<td>—</td>
</tr>
<tr>
<td>$\dot{V}O_2_{\text{max}}$</td>
<td>0.931</td>
<td>0.911</td>
<td>0.932</td>
<td>0.562</td>
<td>0.489</td>
<td>0.724</td>
</tr>
</tbody>
</table>

*Data on boys from Spurr et al. (53) and Barac-Nieto et al. (54); data on men from von Dobelin (71). All are statistically significant ($p < 0.01$).
Body Size and Work Capacity

of a small body would be less than that for a larger one, and the energy cost of movement would also be less.

The manual transportation of loads in developing countries persists as a major occupation of the adult work force (5,73), and although there have been a number of studies on the energy cost of load carrying (73,74), there seem to be none that compare this activity in nutritionally normal and malnourished subjects. Because the relationship between body size and energy expenditure in carrying out work tasks is incompletely understood, we have recently done some experiments on load carrying in nutritionally normal and malnourished boys and well-nourished men (63). The latter were included to give a wider range of body weights as well as a different environmental background. Three age groups of boys (6-8, 10-12, and 14-16 years of age) were studied while walking on a treadmill (3 miles per hour) at 0, 4, 8 and 12% grade without and with a 3-, 6-, or 9-kg backpack load in the youngest to oldest age groups, respectively. The adults also carried a 9-kg load. The results are summarized in Fig. 7, where the energy expended at each work load (grade) is expressed as a function of the body weight (without load) or body weight plus load.

Two conclusions are immediately evident from these results. First, the energy expended in treadmill walking without and with loads is a function of the body weight and the weight carried and not of nutritional status, since the two nutritional groups fall on the same line. Furthermore, age per se does not seem to influence the relationship except as it influences body size (weight). Similar results were also obtained by Mahadeva et al. (75) for nutritionally normal subjects. They concluded that no significant increase in precision was obtained by also taking into account height or age. The linear regression values for walking at 0% grade in our experiments (Fig. 7) are very similar to those obtained by these authors (75). Sec-

* FIG. 7. Mean energy expenditure as a function of treadmill grade, body weight, and body weight plus weight of load carried in nutritionally undernourished boys walking at 3 miles per hour. Boys 6 to 8, 10 to 12, and 14 to 16 years old carried 3, 6, and 9 kg, respectively, and adults also carried 9 kg. (From Spurr and Reina, ref. 63.)*
ondly, the energy cost of carrying a given load (i.e., in excess of that required to move the body weight) is the same regardless of nutritional status or body size, since the slope and intercepts are constants and at a given body weight, only the change in weight carried will increase energy expenditure. A third conclusion can be deduced indirectly from the results in Fig. 7; since $\dot{V}O_2$ max (Fig. 6D) is less in the smaller (younger and malnourished) subjects, the O$_2$ cost of carrying a given load will be relatively higher (percentage $\dot{V}O_2$ max) in these subjects than in bigger ones. This is borne out by direct calculations (63). Finally, the divergence of subjects (normal and malnourished Colombian boys and North American adults) gives the expectation that the relationships seen in Fig. 7 may apply to other groups (racial, sexual, etc.) as well (63,75).

Hypothetical Work Task

A task is contrived in Fig. 8 to approximate a possible work situation to which we might apply the equation from the 0% grade in Fig. 7. The figures in Fig. 8 are unloading a truck carrying sacks a distance that, at 3 miles per hour, takes 1 min and returning at the same speed for the next load. The calculations of energy expenditure are also shown.

Using the average values of body weight and $\dot{V}O_2$ max for the five groups of adults presented in Fig. 6, it is possible to make estimates of the rate of energy expenditure, relative effort, and total energy expenditure during the 7.5-hr work day for men carrying loads of 20 or 50 kg, which are presented in Fig. 9. The rate (kcal/min) and total (kcal/7.5 hr of work) energy expenditure of the largest (North American) men (Fig. 6) were the highest, and there is a progressive decline proportional to the body weight in the other subjects (Fig. 6). The difference between 20 and 50 kg of weight carried is constant, so that the smallest men have

![FIG. 8. Hypothetical work task based on 0° grade load carrying (presented in Fig. 7) and calculated energy expenditure (presented in Fig. 9).](image)

**Energy Expenditure** (EE; kcal/min)

$$EE = [(0.047 \times \text{wt.} + 1.28) + (0.047 \times (\text{wt} + \text{Load}) + 1.28)]/2$$

$$\dot{V}O_2 = EE/4.9 = \text{l/min}$$

Relative Effort = $\%\dot{V}O_2\max = (\dot{V}O_2/\dot{V}O_2\max) \times 100$
to increase their energy output by the same amount as the largest when changing from the 20- to the 50-kg load (Figs. 7 and 9).

The most interesting estimates in Fig. 9 are those based on relative effort. Lines at 40% and 35% of $V_O_2$ max have been drawn for easy reference. For the moment, we assume that those who work below this level can sustain this work for 8 hr, whereas those who have to work above 40% $V_O_2$ max would become fatigued and unable to continue some time before the end of an 8-hr workday. With only this as a criterion, the U.S. and Colombian nutritionally normal subjects could sustain both work loads, whereas the mildly malnourished group M could carry out only the 20-kg task. The intermediate and severely malnourished groups could not sustain either work load; indeed, the percentage $V_O_2$ max of group S during carriage of the 50-kg load (Fig. 8) was calculated to be greater than 100%, and so no value for this situation is plotted in Fig. 9.

Rarely, particularly in physiology, is anything as absolute as the above discussion would imply. Michael et al.'s (33) estimate of the maximum percentage $V_O_2$ max sustaninable for 8 hr of treadmill work in the laboratory was 35%, as was our own in sugar cane cutters in the field (26). However, of the 54 cutters studied, 16 sustained estimated efforts greater than 40%, one as high as 56%, during 8 hr of work (76). Although Åstrand's (34) estimate was about 40% of $V_O_2$ max, Jørgensen (77) has recently suggested that individual tasks must be adjusted to metabolic levels not to exceed 30 to 35% $V_O_2$ max.

What this points to is that there has been an attempt to estimate upper limits of daily work and, consequently, of effects on productivity from too few data (13,14), particularly concerning undernourished subjects. There is little informa-
tion on sustained work efforts (percentage $\dot{V}_{O_2} \text{max}$) in undernourished subjects (21–23). Furthermore, the question arises about whether energy expenditure measurements are appropriate indicators for fatigue and productivity. There is some indication that strain and fatigue of back muscles (Fig. 8) can occur in long-term work even when metabolic rates are below so-called acceptable levels (77).

In any event, more detailed studies are needed of relative efforts sustainable for long periods in individuals of small stature as well as those with poor nutritional intakes. Anecdotal information abounds of small men, perhaps poorly nourished, who seem to perform superhuman work tasks. However, data are scarce.

**EFFICIENCY OF SUBMAXIMAL WORK IN MALNUTRITION**

It has been suggested that adults from developing countries are mechanically more efficient than their taller counterparts from the developed nations (78). The arguments on which this contention was made have been contested (13,55).

Edmundson (79,80) has presented data on basal metabolic rate (BMR) and mechanical work efficiency of men in East Java together with a review of related literature and attempted to make a case for metabolic adaptation to "undernutrition" as judged by the well-known reduction in BMR that occurs in undernourished subjects (81) and an increase in mechanical work efficiency in subjects on a chronic low energy intake. We consider only the mechanical work efficiency measurements made on two groups of his subjects who were selected from a group of 54 subjects studied. One group of five subjects was composed of high-energy-intake individuals (mean 2,754 kcal/day, 11.5 MJ/day) who were nearly identical in average height and weight to a group of six low-energy-intake subjects (mean 1,770 kcal/day, 7.4 MJ/day). It seems, therefore, that the subjects were selected for differences in their existing "metabolic efficiency." The BMR of the high-energy-intake group was almost twice that of the low-energy-intake subjects, and, perhaps not surprisingly, the gross calculated efficiency at 600 kpm/min on a bicycle ergometer was significantly higher in the latter group than in the former, although the difference at 300 kpm/min was not statistically significant. The A efficiencies calculated from Edmundson's (79,80) data were 16.1 ±6.48% (range 7.6–23.0%) in the high-intake subjects and 23.6±5.26% (range 16.8–31.0%) in the low-intake group and were not significantly different ($t = 2.07; \ p = 0.07$). It may be that a larger number of subjects would show a statistically significant difference in $A$ efficiency since the range of efficiencies is large. Also, the values are somewhat lower than those reported by others (16).

We have also reported on the efficiency of submaximal treadmill walking in the normal and marginally malnourished school-aged children described above (55). The submaximal $\dot{V}_{O_2}$ of treadmill walking at 3.5 miles per hour and 15% grade increased with age (body size) and was lower in malnourished boys than in their nutritionally normal counterparts. The gross economy (efficiency) followed the same pattern (55). However, when efficiency was expressed in terms of $O_2$ cost per kilogram of body weight, the opposite was true, i.e., higher $\dot{V}_{O_2}/kg$ body
weight in younger (smaller) than older (bigger) subjects and in undernourished (smaller) than control (larger) boys.

The observation that the $O_2$ cost of treadmill walking or bicycle ergometry increases with age in children and decreases with age when expressed in terms of body weight is an old one (82,83) that has been repeatedly confirmed (84–86). The increase in $\dot{V}O_2$ with age is an expected result, since $\dot{V}O_2$ is related to body mass, and older and heavier boys are performing more work at the same treadmill speed and grade. This effect of body weight also seems to be a reasonable explanation for the fact that the smaller undernourished children follow a similar pattern with age but at lower $\dot{V}O_2$s than their nutritionally normal counterparts.

It has been implied that the fall in submaximal $\dot{V}O_2$, expressed in terms of body weight, with age represents an improved "efficiency" (86), perhaps as a result of the fact that younger, shorter individuals need to take more steps at the same speed than older, taller subjects (83,85). When Pate (85) analyzed his data on boys and men using stepping frequency as a covariate, the difference in submaximal $\dot{V}O_2$ between men and boys persisted. However, using only body weight as the covariate, the statistically significant difference disappeared, suggesting that the difference between men and boys may be accounted for by variation in body weight. This would also explain the results reported here, i.e., lower O$_2$ cost per kilogram of body weight in the heavier (older or nutritionally more adequate) boys. The possible reasons for this apparent "inefficiency" in smaller individuals have been discussed (62,63,87).

When $\Delta$ efficiencies were calculated for the normal and undernourished Colombian boys, there were no significant differences with age or between nutritional groups. The lack of age effects in $\Delta$ efficiency have been confirmed by Cooper et al. (88). Consequently, marginal malnutrition in school-aged Colombian boys does not appear to have any effect on the $\Delta$ efficiency of muscular work. Claims for increased work efficiency in populations of underdeveloped countries (78–80) are unconvincing.

WORK PERFORMANCE IN LARGE AND SMALL INDIVIDUALS

The data presented in Table 2 and Fig. 6 demonstrate that larger individuals have higher values for $\dot{V}O_2$ max. But when expressed per kilogram of body weight or LBM (Fig. 6E,F), larger individuals may have similar (North American versus Colombian groups C and M) or lower values (men versus boys) than smaller ones. The lower values for aerobic power of men compared to boys does not mean that the latter are capable of more work than the former. Rather, the higher values of $\dot{V}O_2$ max indicate greater work capacity, since they result from greater muscle mass performing maximally. The values of $\dot{V}O_2$ max per kilogram of mass (weight or LBM) are not indicators of quantity of work the individuals can perform, as has been suggested (3), but rather of O$_2$ consumption per kilogram of tissue at maximum effort, i.e., the physical condition. Furthermore, one can draw no conclusions from such data about work efficiency, as has also been suggested (3).
SUMMARY

Studies in nutritionally normal and malnourished men have shown that the physical work capacity, as measured by the $\dot{V}O_2\text{ max}$, is dependent on nutritional status such that, relative to the degree of malnutrition, undernourished subjects have depressed work capacities largely because of decreased muscle mass. Since productivity in hard physical work is also directly related to physical work capacity, by implication the productivity of undernourished individuals would also be depressed in heavy physical work.

During the growth of school children, even marginal malnutrition results in growth retardation, slowing of sexual maturation, delay of the growth spurt, and reduction in physical work capacity ($\dot{V}O_2\text{ max}$) because of the smaller body size. There are implications that in adulthood these smaller boys will be unable to produce as well in heavy physical work as their nutritionally normal counterparts. Studies of load carrying in men and boys indicate that only the body size (weight) and weight of the load carried influence the energy expended independently of nutritional status. Although bigger men have more lean body mass and higher values for maximum physical work capacity, they also expend more energy on body movement during work, but at lower relative effort (percentage $\dot{V}O_2\text{ max}$) than smaller nutritionally normal or undernourished men. The limits of effort that can be sustained for an 8-hr work day are about 35 to 40% $\dot{V}O_2\text{ max}$, but more studies are needed of small individuals working at heavy tasks in developing countries. There are no indications that smaller or undernourished people are more efficient in physical work.

Small children may have higher $\dot{V}O_2\text{ max}$ values per kilogram of body weight or LBM than adults, but their total $\dot{V}O_2\text{ max}$ is related to their body size and therefore is very much lower than that of adults. Consequently, the proper expression of the physical work capacity of individuals, children or adults, is in terms of total $\dot{V}O_2\text{ max}$.

ACKNOWLEDGMENTS

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DISCUSSION

**Dr. Waterlow:** You made a very convincing case, but I am not completely convinced. At the very end you almost let yourself off the hook by saying that you are dealing with heavy physical work. I would like to refine that a little and suggest that what we need to do for different activities and occupations or for different types of work is to separate out quantitatively, if possible, the component that depends on moving the body and the component that depends on doing some other kind of work such as cutting cane or carrying loads. Your conclusions are crucially dependent on this. If the main part of the work requires moving the body, then being small does not matter because the cost is proportional to the body weight. This comes out in the FAO/WHO report on energy requirements for walking on a treadmill without loads but with different body weights. Ann Ashworth (1), in Jamaica, gave people the task of carrying bricks from point A to point B. She made them carry either the number of bricks that was most convenient to them or fewer or more bricks and measured the energy cost. The energy cost of transferring these bricks was actually lower if they carried more at a time because the distance element was greater than the load element. I would therefore suggest that there is a continuum of situations from those in which a great deal of external work is done to those, as in farmers walking to distant fields, in which virtually all the work is moving the body. We then have to be very careful in generalizing, and we should try to pinpoint where we are on that continuum when referring to physical work.

**Dr. Spurr:** There is not enough information on this topic. I wasn’t aware of Ashworth’s work on the brick carrying, but it sounds as if it would fit in with some of our hypotheses. I contrived a work situation (Figs. 8 and 9) in order to separate the effect of body size, but we clearly need more measurements in real work situations. It is possible with the data obtained on the load-carrying experiments (Fig. 7) to estimate energy expenditure under varying percentage contributions of load carrying versus non-load-carrying work, i.e., the “load” versus “distance” components you mention. These estimates lead to the same conclusion. What I am trying to do with the information we have is to make people question some of the statements that occur in the literature, that if you are small, it really doesn’t make any difference because you are going to expend less energy but are still able to do the same amount of work. I simply don’t think that this is so, even with the information at our disposal.

**Dr. Keller:** I always thought that the daily energy expenditure for work in tropical countries was considerably less than 1,500 to 2,000 kcal. Is that really common? I think it was at Dr. Gopalan’s institute that they measured the energy expenditure of farmers in South India, and, if I remember correctly, they came out with about 500 work kilocalories per day. The reason is possibly that there are circulatory limitations to getting rid of the heat. What do you think is the daily workload that can be reasonably expected?

**Dr. Spurr:** Sugar cane cutting is extremely heavy physical work. We estimated (2) for the sugar cane cutters who were working in a hot environment that their total daily energy expenditure was about 3,600 kcal and that their maintenance estimate would be somewhere around 1,800, so you are getting pretty close to 2,000 kcal daily energy expenditure for work.

**Dr. Davies:** Have you looked at work capacity in normal small people as opposed to abnormal small people? Is it a function of muscle mass or of the composition of muscle mass?

**Dr. Spurr:** These Colombian agricultural workers, who included sugar cane cutters, load-
ers, and general farm laborers, are small, but they are nutritionally normal. From all the data that we have and that have been derived from Viteri and Torún's studies (3,4) at INCAP, it is not the quality of muscle but the quantity that is important. We do not have any data to indicate that chronic malnutrition affects the ability of the muscle that is there to do work; it is rather the quantity of muscle that is available.

Dr. Milner: Could I ask you to expand on the technology of measuring \( \dot{V}O_2 \) in children? The physiological maximum heart rate increases as age decreases; if you take a child to a heart rate of 190, he may not have achieved a plateau. I also noticed that you used 3-min time intervals when you were measuring \( \dot{V}O_2 \) max in the children. Did you use a Bruce protocol? We found that 3-min intervals are quite long for children to tolerate. The third problem that we found most difficult is tolerance to the mouthpiece. That led us to switch to having the children working to a heart rate maximum and voluntary cessation of the work whether they had achieved a \( \dot{V}O_2 \) max or whether they were on a heart rate plateau (5).

Dr. Spurr: Performance of the \( \dot{V}O_2 \) max test is difficult and has to be done with a great deal of care, particularly with children. The 3-min protocol that you saw was for a submaximal test. We routinely use 2-min intervals, and we start them after a 3-min warm-up at 5% grade. Then we increase by 2.5% grade increments until maximum is reached.

Dr. Millner: With constant speed?

Dr. Spurr: Yes, we choose a constant speed and maintain it there. We use either 3, 3.5, or 4.2 miles per hour, depending on the heart rate response during the warm-up. The average maximum heart rates of our children are somewhere around 207 or 208. We have had children going up to 230. That is unusual, but it happens. We do not accept a \( \dot{V}O_2 \) max measurement unless the heart rate is above 200 and unless the heart rate as well as the oxygen consumption are plateauing or at supramaximal values. We are very careful about accepting a measurement as a true \( \dot{V}O_2 \) max. In the studies that we have performed, we did \( \dot{V}O_2 \) max measurements on over 1,100 boys, and we got acceptable values in about 92% of the subjects (6).

Dr. Milner: How did you get them to accept the mouthpiece?

Dr. Spurr: The smaller children in particular cannot get the mouthpiece in, but we can make it smaller. We have mouthpieces of various sizes. We put the children through a preliminary test a day or so before the real test in which we explain what it is we want, what the mouthpiece is going to feel like; we teach them how to walk on the treadmill, etc.

Dr. Waterlow: I would find it a little easier to assess what you mean by "mild, moderate, and severe malnutrition" if you expressed the results as body mass index, at least for the adults. Nobody really knows what the lower limit of acceptable body mass index is; not many people in industrialized countries are lower than about 19 or 18. Shetty's laborers in India (7) were around 15 to 16 and apparently very fit. So for comparative purposes, it would be very helpful. I am not at all happy with Colombian standards because I have no idea what the standards are.

Dr. Spurr: We did not use body mass index. In adults, the classification "mild, intermediate, and severe malnutrition" was based on a point system derived from three parameters: weight-for-height ratio, serum albumin level, and 24-hr creatinine excretion (8). We set up a point system. Table 1 in the chapter gives the values that we used to make that decision. The Colombian norms that we used to classify the children were established in Bogotá in the upper socioeconomic group. The results that I presented here were all on children from lower socioeconomic classes. We did not include the studies that we made in the upper socioeconomic group (6,9). Within the lower socioeconomic group, it is possible to find
children with a relatively normal growth curve. I don't really think it makes any difference what norm is used, a local one or an international one, as long as some decision is made about cut-off points. We have artificially established our own cut-off points for marginal malnutrition at less than 95% of the Colombian standards, with the expectation that the average group values would be much lower than that. And they were (9).

Dr. Waterlow: It doesn't make any difference to you because you are comparing groups in the same population, but it makes a lot of difference to me if I want to compare your data with, say, Indian data. Regardless of the physiological validity of the international reference, as more and more people are performing similar studies to yours, it is important to use the same reference.

Dr. Spurr: One ought to be able to compare our children with Indian children or any other group. Ours grow on or below the fifth centile of the NCHS data (10), and our published work (Fig. 5) has been in reference to these standards (9).

Dr. Nnanyelugo: Was the food intake of the subjects standardized? Could the type of food consumed not affect work capacity?

Dr. Spurr: We were unable to control the dietary intake in these subjects; our children were recruited from the public schools in Cali. We have attempted time and time again to get some reasonable information on dietary intake without much success, because we could not send technicians into the homes for weighing. As far as the dietary recall method is concerned, it is absolutely unacceptable.

Dr. Kraisid: Do you analyze your \( \dot{V}O_2 \) max and heart rate data in relation to hematocrit or hemoglobin levels?

Dr. Spurr: In a sense, yes. We measure hemoglobin and hematocrit in all our subjects. In children, when we compute \( \dot{V}O_2 \) max as a function of body weight, to remove the effect of body size, and plot that against hemoglobin concentration, we get an absolutely flat curve: the correlation was 0.03 in children. Between 9 and 16 g/dl of hemoglobin, in children, there does not seem to be any relationship with oxygen-carrying capacity (6). That means that there have to be some other physiological adaptations in children that perhaps do not exist in adults, in which Viteri and Torun's work (11) has shown that there is a very close relationship between \( \dot{V}O_2 \) max and oxygen-carrying capacity of the blood. Earlier studies by Parsons and Wright (12) and Vellar and Hermansen (13) also indicated that in children there is some other adaptation, perhaps in blood flow or increased oxygen extraction across the capillary bed. These mechanisms have not yet been studied.

Dr. Golden: I am impressed by the psychological effects of malnutrition. Could you comment on the influence of nutritional status on the training effect and also on effort? You used the term "whining." Do malnourished children put less voluntary effort into the task that you have set them than well-nourished children?

Dr. Spurr: As far as I know, there is no information on the influence of nutritional status on the training effect and also on effort? You used the term "whining." Do malnourished children put less voluntary effort into the task that you have set them than well-nourished children?
is it because these subjects were sedentary during the whole period of repletion? Would it be different if they were undergoing exercise training? I don’t know, but here I am talking about the effect of nutritional status on effort in terms of percentage $\text{Vo}_2\text{max}$, whereas you are talking about a psychological effect. We have no measures of that. All I can say, subjectively, is that the marginally malnourished children do not behave differently as far as their willingness to perform work is concerned. 

Dr. Gopalan: I think you made a very important comment when you said that these laboratory studies must be supported by observations in real-life conditions. There is a need for more work of that kind, which unfortunately, up to now, seems to be largely done by observational social scientists and economists rather than by health and nutrition scientists. That would be great support to the type of work that you are doing in the laboratory.

Dr. Spurr: The measurement of energy expenditure in heavy physical work under field conditions is difficult. The use of the double-labeled water technique could be interesting. Even the minute-by-minute heart rate recording method might be used if done under appropriate conditions.

Dr. Waterlow: In relation to this last point, many years ago in Jamaica a study was done of the output of sugar cane cutters in relation to food intake. The men who ate the most food had the biggest output, but the relationship wasn’t as simple as it appeared because the men who ate the most food were those who were married and had good food provided. In Jamaica, you only marry if you are a steady, hard-working, productive person; otherwise you don’t marry. At least, that, I believe, used to be the case. This illustrates that sociologists do have something to contribute.

REFERENCES