Considerations on the Effect of Nutrition on the Body Composition and Physical Working Capacity of Young Guatemalan Adults*

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Introduction

Popular belief is that an individual must be well nourished to be a productive and efficient worker. Developing agricultural countries must depend on both the productivity and efficiency of peasants who employ rudimentary techniques for the exploitation of the earth. Dependency on the physical working capacity of peasants is particularly critical at the family level in areas where subsistence economy is the rule, and the land which provides the only family income is divided into small parcels.

In spite of the vital importance, both at family and national levels, of clarifying the role of nutrition in the physical working capacity of populations whose nutrition has been chronically suboptimal, very little research effort has been devoted to this area. It is still not known whether men who have lived for years in a condition of suboptimal nutrition are or can be efficient, productive agricultural workers, or whether improved nutrition in these adults would result in better working capacity.

The capacity to work and the productivity of social groups depend on a complexity of factors, socioeconomic, environmental, educational, nutritional and physiological. To discuss each one of these in its role as a determinant of work output and productivity is beyond the scope of this report. Only some nutritional and physiological aspects related to body composition and physical working capacity will be considered.

The relation between nutrition and working efficiency has been recently reviewed by Lowenstein in 1968[1] and by the Food and Agriculture Organization (FAO),[2] and Keller and Kraut in 1962[3]. These authors strongly suggest that well nourished workers are more efficient than those marginally nourished and that a poor dietary intake leads to reduced capacity to perform physical work. In 1949[4] it was stated that people who suffered from malnutrition in their childhood often did not seem able to attain a satisfactory physical working capacity, even if their dietary intake as adults had become adequate.

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The evidence upon which such conclusions are based vary from subjective, qualitative impressions,[5] some of which are widely cited in spite of the lack of scientific rigor,[6] to very seriously conducted scientific studies.[7-9] The scientific data available, however, must be characterized as to the populations studied and conditions of the experiments. The studies of Keys et al.[7] were conducted in previously well nourished adults who underwent a relatively acute period of semistarvation. Kraut's investigations[8] were also done on previously well nourished subjects who suffered from a restricted intake during the Second World War. Work output was measured in terms of industrial production, and the impact of nutrition and physical effort on health was evaluated by the weight changes that took place concomitant to variations in caloric intake.

Wyndham et al.[9] reported that African miners responded with both an increase in weight and maximal oxygen consumption to an improved dietary intake and to a stable, regular job which demanded physical effort. From the work of Kraut and Müller,[10] which stressed the importance of adequate intakes of protein and calories required to achieve increased muscularity brought about by physical training, it can be inferred that improved nutrition was a major factor in the betterment of the physical capacity of the African miners.

Very few reports have come to our attention on the working efficiency of adults suboptimally nourished over a long period of time. The work of Cullumbine[11] and that of Phillips[12] indicate that there is very little difference between the working efficiency of Ceylonese and Nigerian subjects and that of European subjects. In contrast Ramanamurthy and Dakshayani[13] show that the basal metabolic rate and the energy cost of heavy work is lower in Hindus than in Europeans. Unfortunately, detailed body composition determinations were not performed in any of these studies to clarify the reasons for the differences or the similarities observed among the various populations.

In a recent study, Areskog, Selinus, and Vahlquist et al.[14] found that the work output required to reach a constant heart rate of 170 per minute was lower among Ethiopian workers than in Swedish controls when expressed in absolute terms; but the difference between these two populations was very small when work output was expressed on a per kilo basis. The same phenomenon occurred when Ethiopian workers and military cadets were compared in Ethiopia.

Detailed body composition studies in otherwise healthy adults suffering chronic malnutrition have not been found, although there is abundant literature on the physical and anthropometric characteristics of these populations.[15-18]

Objectives The primary aim of these investigations, which are being pursued at the Physiology Laboratory of the Biomedical Division of the Institute of Nutrition of Central America and Panama (INCAP), is to determine the relation between nutrition and working capacity in adults poorly nourished for a long time, who are representative of a great number of men in developing areas. Through these studies scientific evidence will emerge on the protein-calorie nutrition of these populations, on their capacity to perform physical work, and on the effect of past and present nutrition on body composition and working efficiency.

Experimental Design

Four groups of young adult male volunteers were chosen for this study. The reference group consisted of cadets from the military academy who belonged to middle- or high-socioeconomic levels and who had always consumed an excellent diet and were physically fit. A group of peasants with a history of very poor nutrition who were still inadequately nourished, and two groups of peasants with poor nutritional backgrounds but adequate current dietary intake, constituted the other population groups studied. One of the latter groups had received a dietary supplement for 3 years prior to being studied. Comparisons among groups with different nutritional backgrounds and current intakes provide information on the relative importance of past and present nutritional status and working performance.

The body composition of population groups was chosen as the primary indicator for quantifying protein and calorie nutriture. Dietary studies of the populations provided another parameter by which to estimate the state of nutrition. Both techniques suffer from limitations in defining a dynamic, functional state of nutrition, unless protein and calorie balances and a series of physiological measurements, leading to an estimation of functional capacity, are obtained in the same population groups. Therefore as an addition to these studies and of importance in itself, physical working capacity was also investigated in the field, under natural conditions, and in the laboratory, under standard conditions. In the field, energy cost of work and calorie balances were obtained through careful time-motion studies, collection of excreta, nutrient intake measurements at individual levels, and accurate measurements of weight changes during the period of study.

In the laboratory, accurate measurements of a series of physiological functions were obtained under standardized conditions to estimate the working capacity, exercise tolerance and physical fitness of the subjects. Ideally, subjects participating in a study of this sort should have the same degree of training or physical activity, should work and live under similar environments with regard to altitude and climate, and should be enthusiastic about taking part in the study. To the best of our abilities the populations chosen for this study fulfilled these three basic conditions. All the subjects were volunteers who were highly motivated by the investigators, carefully explaining to them the importance of the work being performed in the field and in the laboratory, and by making them compete with each other when maximal work tests were performed. The groups of subjects to be studied met with the investigators several times before the study to acquire rapport and to establish friendship.

Two groups of peasants were the subjects in time-motion studies. These were performed in their own environment, during the early part of the rainy season, when daily temperatures ranged from 14° to 32°C. with mean temperatures of 21° to 26°C. Only 1½ months after the completion of the field studies were the subjects brought to INCAP's Physiology Laboratory for detailed body composition determinations and standard exercise tests. Their weight was the same as when the time-motion experiments started.

At INCAP all the subjects were housed in the sleeping quarters of the Laboratory for one week; during this time they received an intake equal to their habitual diets.

Unfortunately, some of the subjects failed to meet the demands required by some of the tests performed. For example, some could not relax while basal oxygen consumption was being measured. Others were not able to follow simple instructions while under water for the body density determinations, and others did not do their best on maximal excercise tests. Whenever doubt arose as to the optimal conditions of any test, it was discounted.

Description of the Subjects The subjects were healthy according to a thorough clinical examination. Their hemoglobin concentrations were above 13 g/100 ml and their serum proteins were within normal levels. Some of the characteristics of the groups studied are summarized in Table 1.

Twenty-three cadets took part in detailed body-composition and work-physiology studies. They had been in the military academy for at

Table 1 Characteristics of the groups of subjects studied

Group	Socioeconomic status	Nutritional background	Present intake	Physical work
Military cadets	Middle–High	Good	Very Good	Active (sports, drill)
Supplemented peons	Low	Poor	Good	Active (agricultural)
Soldiers	Low	Poor	Adequate	Moderate (army)
Recruits	Low	Poor	Adequate	Active (agricultural)
San Antonio La Paz (S.A.P.)	Very Low	Very Poor	Poor	Active (agricultural)

least 2 years. Another group of twelve cadets participated in a longitudinal body composition investigation. They were studied on admission to the military school and again 8 to 16 months after admission.

The other four groups of young peasants belonged to the rural population of Guatemala whose socioeconomic status is low or very low. (1) The peons who received supplementation, 19 in all, were employed on a farm where, for the 3 years prior to the study higher than average wages were paid, cow's milk was easily available, and a supplement of Incaparina, which supplied 5.5 g of high quality protein and 250 calories, was administered to them daily. (2) The recruits are representative of typical healthy peasants; they were studied within 2 weeks of being drafted. Twenty-seven recruits took part in the detailed body composition and work physiology investigations and only 17 in the body composition studies. (3) This last group of recruits was restudied after they had been in the army for 16 months and constitute the sample of soldiers. Only body composition studies were performed in this group. (4) The peasants from San Antonio La Paz (S.A.P.), totalling 20, belonged to a particularly poor community located in an arid region of Guatemala.

With few exceptions, none of the recruits were subjected to a change in altitude when being brought to Guatemala City for the work physiology studies. The few recruits who came from other altitudes had been in the city for at least one week before the study began.

The recruits, the peasants receiving dietary supplements, and the S.A.P. groups had all been engaged in physically hard agricultural practices using rudimentary nonmechanized techniques. According to the soldiers, their physical activity while in the army was substantially less than their agricultural work at home. Three of the subjects in these four groups gave a history of severe protein-calorie malnutrition in childhood.

Methods

Dietary Evaluation: Dietary intakes were assessed as follows: cadets and soldiers by inventory method and composite analysis of representative diets; supplemented peons and S.A.P. subjects, by individual daily intake records, with weighing of the food actually consumed and composite analysis of representative diets. The recruits' intakes were obtained by recall. Their protein and calorie intake before joining the army was assumed to be as follows, based on the Guatemalan dietary survey carried out in 1965[19]: 3100 calories: 88 g protein, of which 18 percent was of high biological value.

Estimation of Caloric Expenditure The caloric expenditure of soldiers and cadets was estimated by daily time records of activities, which were verified during the study by direct supervision on random days. In the groups of supplemented peons and S.A.P. subjects, a careful time-motion study was carried out for 3 to 6 days while they were performing their usual occupations in their own environment. Since in the S.A.P. group this practice resulted in an obvious effort to appear very active and also in clearly negative caloric balances and loss of body weight, their usual caloric expenditure has been assumed to equal their intake. The same assumption (caloric expenditure = caloric intake) has been used to express the caloric expenditure of the recruits. This is justified because on careful questioning, all of the recruits reported stable weights for several months before joining the army.

The energy cost of work during every type of activity in which the subjects were engaged was measured by means of indirect calorimetry using the Müller-Franz respirometer[20] and by determination of oxygen consumption and CO_2 production in a collected sample of expired air, as well as in ambient air. By multiplying the time spent in each activity by the caloric expenditure for that activity, in each subject, a total estimate of caloric expenditure was obtained.

Each subject's weight was obtained at intervals during the time-motion studies, always including early morning weights under the following conditions: nude, fasting; and with empty urinary bladder. These weights were also obtained immediately before and at the end of the time-motion study. A careful record of weights of both total intake and excreta were obtained while the subjects were being followed.

The following techniques have been used for the study of body composition:

Anthropometry, with emphasis on bony diameters to estimate skeletal weight, and estimation of bone minerals by applying Matiegka's formula[21] on skeletal weight, modified by Allen and Krzywicki[22] to assess bone mineral content.

Body density was measured by underwater weighing, following the general principles outlined by several investigators.[23]

Total body water and extracellular water were estimated by the distribution spaces of antipyrine and thiocyanate.[24,25] The thiocyanate space was corrected by a factor of 0.93 to equate it to the inulin space.[26]

Urinary creatinine was determined in at least three 24-hour collections by the method of Clark and Thompson.[27]

Lean body mass and adiposity were calculated by the formula of Brozek et al.,[28] based on body density; cell mass by the formula of Grande, Anderson, and Keys,[29] based on intracellular water; muscle mass by assuming that 1 g of urinary creatinine equals 17.9 kg of muscle;[30] and fat and cell residue by the method of Allen et al.[31]

Basal oxygen consumption was measured in an open system, collecting duplicate samples of expired air for 10 minutes in Douglas bags on two consecutive days. Simultaneous samples of ambient air were also obtained to arrive at the true oxygen consumption and CO_2 production.[32]

Maximal exercise was accomplished by having subjects walk on a treadmill at a speed of 5.4 km per hour, for the first 4 minutes at a 4 percent grade, then increasing the grade 1 percent per minute until a 19 percent grade was achieved, maintaining this grade until the subject was exhausted. The subjects were highly motivated, all reaching heart rates above 180 per minute. Expired air was collected serially and continuously for 5-minute periods and for the last minute of exercise in a chain of Douglas bags, except in the group of recruits where only air expired in the last minute of exercise was collected. Ambient air was collected periodically during exercise.

In all the gas samples, volume corrected for temperature and barometric pressure was obtained and O_2 and CO_2 content were determined by the Scholander microtechnique,[33] or by O_2 and CO_2 electrodes (amperometric for O_2 and potentiometric for CO_2) with periodic checks in the Scholander apparatus.

Maximal aerobic capacity was determined by plotting oxygen consumption during exercise to determine the maximum oxygen consumption.[34] The oxygen consumption during the last minute of exercise was on the average 5.6 percent less than the maximal oxygen consumption obtained by serial sampling of expired air. Consequently, the last minute expired air values of the recruits were corrected by this factor to obtain the maximal aerobic capacity.

Results

Dietary Studies Table 2 shows the daily nutrient intake and caloric expenditure of the groups studied. The highest caloric intake is that of the supplemented peons and the lowest that of the S.A.P. group. Measured caloric expenditures correspond to caloric intake in cadets and supplemented peons. In the group of soldiers, however, caloric expenditure is lower than intake and also lower than the calculated expenditure of recruits (representative of the general adult, healthy agricultural peon of Guatemala).

Total protein intake appears adequate; however, the percent of high biological value protein consumed by the S.A.P. group is only 8 percent.

Table 2 Average daily nutrient intake and caloric expenditure of the groups of subjects studied

Group	Caloric		Protein (g/24 h)		Mineral and vitamin deficiencies
	Intake	Expenditure	Total	% High biological value	
Cadets	3279	3200	112	44	None
Supplemented peons	3446	3450	106	26	None
Soldiers	3171	2700	95	21	Vitamin A riboflavin
Recruits	3100	3100	88	18	Vitamin A riboflavin
San Antonio La Paz (S.A.P.)	2693	2700	82	8	Vitamin A riboflavin

Table 3 Anthropometric characteristics and body composition of the groups of subjects studied

				Weight	Percent of Weight			Grams/cm height		
Group	Age (yr)	Weight (kg)	Height (cm)	Height (g/cm)	Lean body mass	Muscle mass	Adiposity	Lean Body mass	Muscle mass	Adiposity
Cadets	18.8*	60.82	165.8	366	87.6	47.2	12.4	320	167	46
(N = 22)†	(1.9)	(5.20)	(4.9)	(26)	(3.7)	(4.3)	(3.0)	(26)	(22)	(4)
						N = (23)			N = (23)	
Supplemented peons	25.8	57.78	161.2	358	87.4	40.2	12.6	313	145	45
(N = 9)	(9.0)	(4.48)	(4.1)	(25)	(3.2)	(5.6)	(3.2)	(19)	(27)	(3)
						N = (12)			N = (12)	
Recruits	20.1	52.54	160.8	326	87.1	41.1	12.9	284	135	42
(N = 22)	(3.2)	(5.28)	(5.7)	(25)	(3.0)	(4.0)	(3.0)	(22)	(16)	(3)
San Antonio La Paz	18.6	50.77	158.5	320	91.9	36.2	8.1	294	119	26
(N = 16)	(2.6)	(4.10)	(5.1)	(22)	(3.3)	(6.8)	(3.8)	(24)	(23)	(2)

* Mean (Standard deviation).
† N = Number of subjects.

With the exception of the cadets and the supplemented peons, all the groups had intakes of vitamin A and riboflavin lower than the recommended allowances for these vitamins, but none presented clinical signs of deficiency.

Body Composition Some anthropometric and body composition characteristics of the groups studied are presented in Tables 3 and 4.

The ages of the subjects varied between 17 and 27 years. Only one supplemented peon, who was lean and physically fit, was 38 years old. No detectable influence of age on body composition or physical performance was found in the subjects within each group.

The weight-height ratio clearly differentiates the cadets and supplemented peons from the recruits and S.A.P. subjects. The difference persists in the amount of lean body mass per cm height of the various groups but it disappears when lean body mass or adiposity are expressed as percent of body weight. These last expressions of the two major body compartments as well as adiposity/cm height characterize the S.A.P. group as being extremely lean.

Further breakdown of body constituents into bone mineral, water, fat and cell residue (Table 4) expands the results shown in Table 3.

Bone mineral contributes more of the lean body mass in recruits and S.A.P. subjects than in cadets and supplemented peons. Overhydration

Table 4 Body composition of the groups of subjects studied

	Percent of weight				Grams/cm height	
Group	Bone mineral	Water	Fat	Cell residue	Fat	Cell residue
Cadets (N = 22)†	5.60* (0.44)	64.15 (2.38)	12.86 (3.59)	17.17 (1.86)	48.26 (11.21)	63.12 (9.51)
Supplemented peons (N = 9)	5.70 (0.32)	68.18 (5.47)	10.40 (5.02)	15.71 (1.78)	37.45 (18.70)	56.21 (2.02)
Recruits (N = 22)	6.02 (0.40)	66.04 (2.44)	12.51 (2.77)	15.44 (1.58)	40.54 (10.46)	50.32 (6.93)
San Antonio La Paz (N = 16)	6.11 (0.59)	73.66 (1.54)	4.16 (2.20)	16.07 (2.38)	13.15 (6.92)	51.60 (9.29)

* Mean (Standard deviation).
† N = Number of subjects

and very little fat are evident in the S.A.P. group. Cell residue and fat/cm height are higher in the cadets than in the other groups.

The longitudinal changes in body composition that took place in recruits and newly admitted cadets during their stay in the military institution are depicted in Figure 1. The average cadet became leaner, increasing his lean body mass and cell mass during his stay in the military school. In contrast, adiposity in the recruits increased substantially while lean body mass, muscle mass, and cell mass showed a small declining trend.

In summary, the results of the body composition studies indicate that the cadets had the highest lean body mass, muscle mass, cell residue, adiposity and fat/unit height, while the peasants from S.A.P. had the least amount of adiposity and muscle. In percent weight, this latter group had more bone mineral and water, less fat, and the same cell residue as all the other groups. The S.A.P. group, per unit height, had less fat, was not overhydrated, and the bone mineral and cell residue, although lower than the other groups, was similar to that of the recruits.

Interesting comparisons can be established between the supplemented peons and the recruits. The first group appears to have more lean body mass, muscle mass, water and cell residue than the second, while in terms of adiposity and fat both groups are very similar. These changes in the supplemented peon group contrast with those observed in the soldiers who, during their stay in the army, gained fat and tended to decrease their lean body mass, muscle mass and cell mass. These changes in the soldiers also contrast with those observed in the cadets who, after a short time at the military school, gained lean body mass, muscularity and cell mass, and lost fat.

Physical Performance Under Standard Laboratory Conditions The results presented in this section are only a small part of a series of physiological and biochemical parameters that have been measured in the groups of cadets, supplemented peons, recruits and S.A.P. peasants studied in the Physiology Laboratory of the Biomedical Division of INCAP, under standard maximal exercise conditions on a treadmill.

The amount of work performed by the various groups of subjects before exhaustion is depicted in Figure 2. The peasants from S.A.P. worked less than the other groups, while the supplemented peons produced more kilogrameters of work before exhaustion. The variation within each group was large, so that the differences are not statistically significant. The poorest performances, however, were observed in the

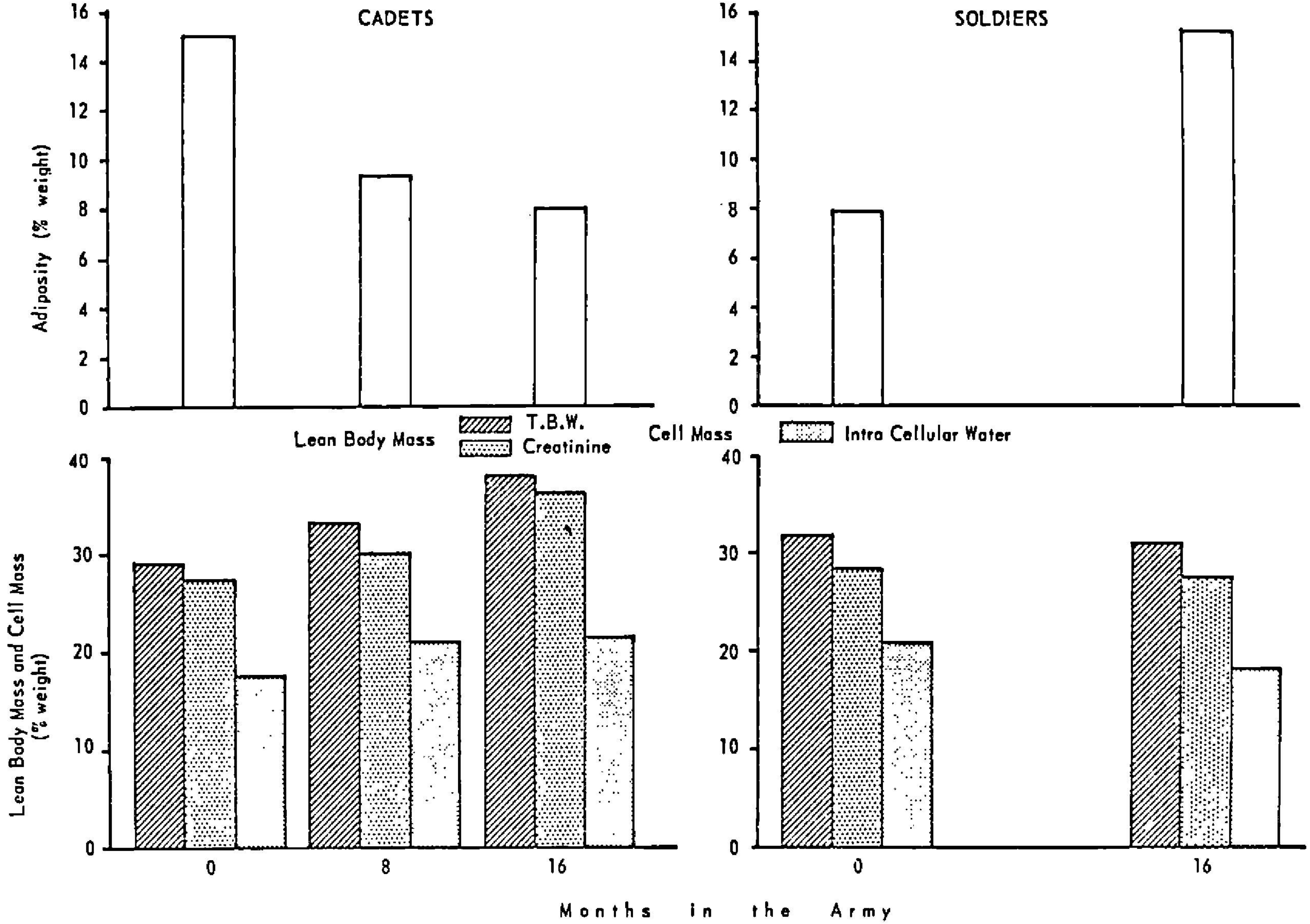

Figure 1. Changes in body composition in Guatemala Army personnel with time spent in the Army.

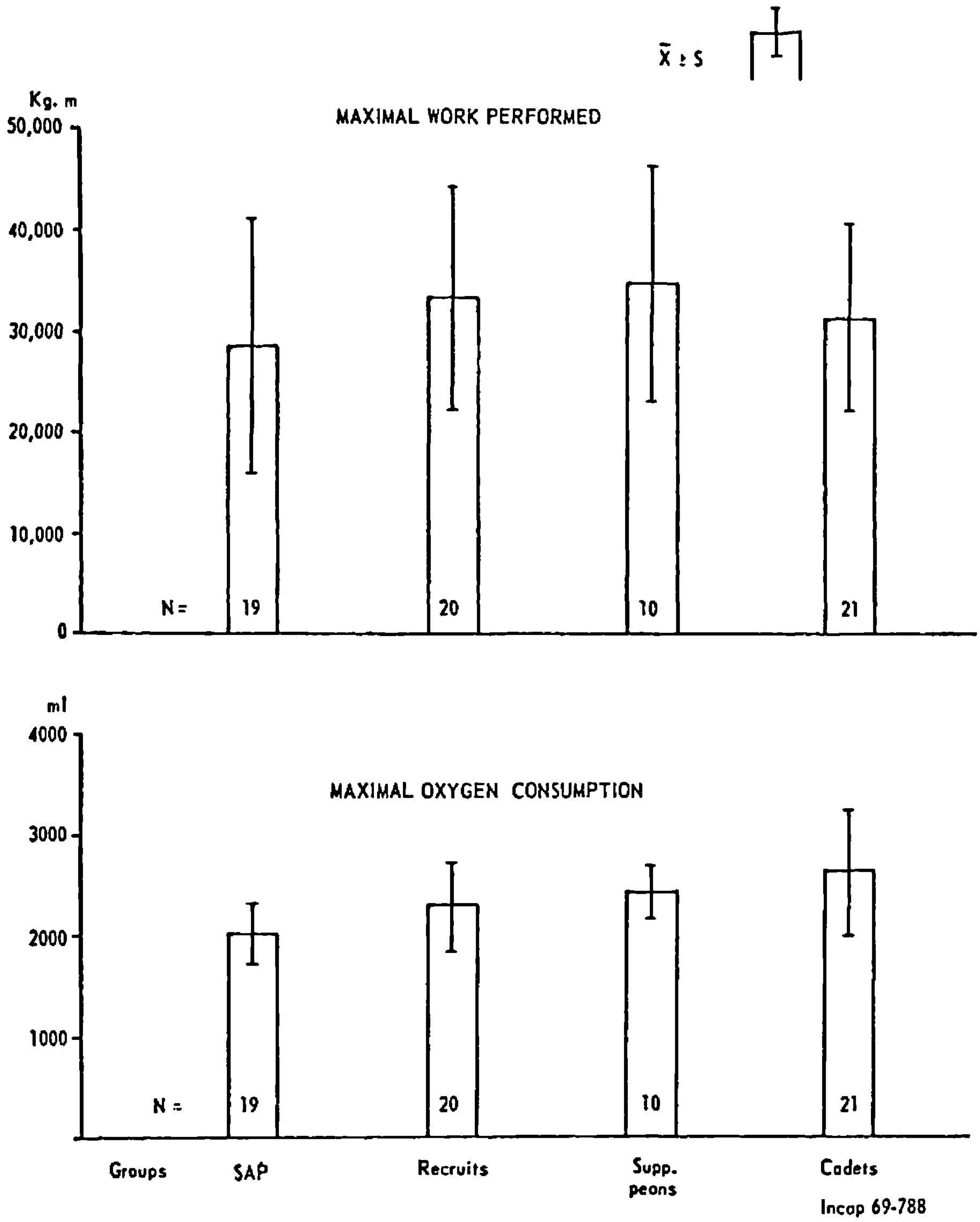

Figure 2. Maximal exercise (modified Balke Test).

S.A.P. group, where 37 percent of the subjects were exhausted very soon after they reached maximal aerobic capacity, compared to 12 and 16 percent of the subjects in the other groups.

In absolute terms, maximal oxygen consumption was greater in the cadets and least in the S.A.P. peasants (Figure 2); however, an analysis of both basal oxygen consumption and maximal aerobic capacity in terms of body weight, lean body mass and cell residue (Figure 3) results in a different picture. Based on nutritional background, nutrition during the study, body composition and physical training, the cadets are depicted as the reference group to which the others are compared.

The outstanding features of the data presented in this figure are (a) that basal oxygen consumption and maximal aerobic capacity followed the same trend for each group of peasants, when compared to the cadets, regardless of whether they are expressed per unit of body weight, lean body mass or cell residue; (b) that in terms of oxygen consumption, per kg body weight or per kg of lean body mass, the cadets consumed more oxygen, either under basal or maximal work situations; and (c) that all the differences among groups disappear when oxygen consumption, either basal or maximal, is expressed per kg of cell residue.

Studies in the Field A brief summary of the results of the time-motion studies carried out with the supplemented peons and the subjects from S.A.P. is presented here. The time-motion studies were carried out in the same season of the year in both groups. All the subjects performed almost identical tasks and the energy cost of work of 50 similar agricultural activities in both groups was the same. Differences in energy cost of work occurred in walking because of variations in weight of the subjects, weight of loads carried, and irregularity in the terrain where the peasants walked. However, the average caloric expenditures in different periods of the day at work, and at rest or asleep were very similar in both groups of subjects (Table 5).

Table 6 shows that, assuming a constant basal caloric expenditure for maintaining vital functions throughout the day, the supplemented peons still had 1852 calories available for physical work, not considering any losses due to specific dynamic action of food. The S.A.P. peasants had only 1167 calories available for physical work, which is only 63 percent of those available in the supplemented peasants.

The patterns of work in the supplemented peons group varied in that they either worked 8 hours performing several activities (day work) or they were assigned a certain amount of work which they had to per-

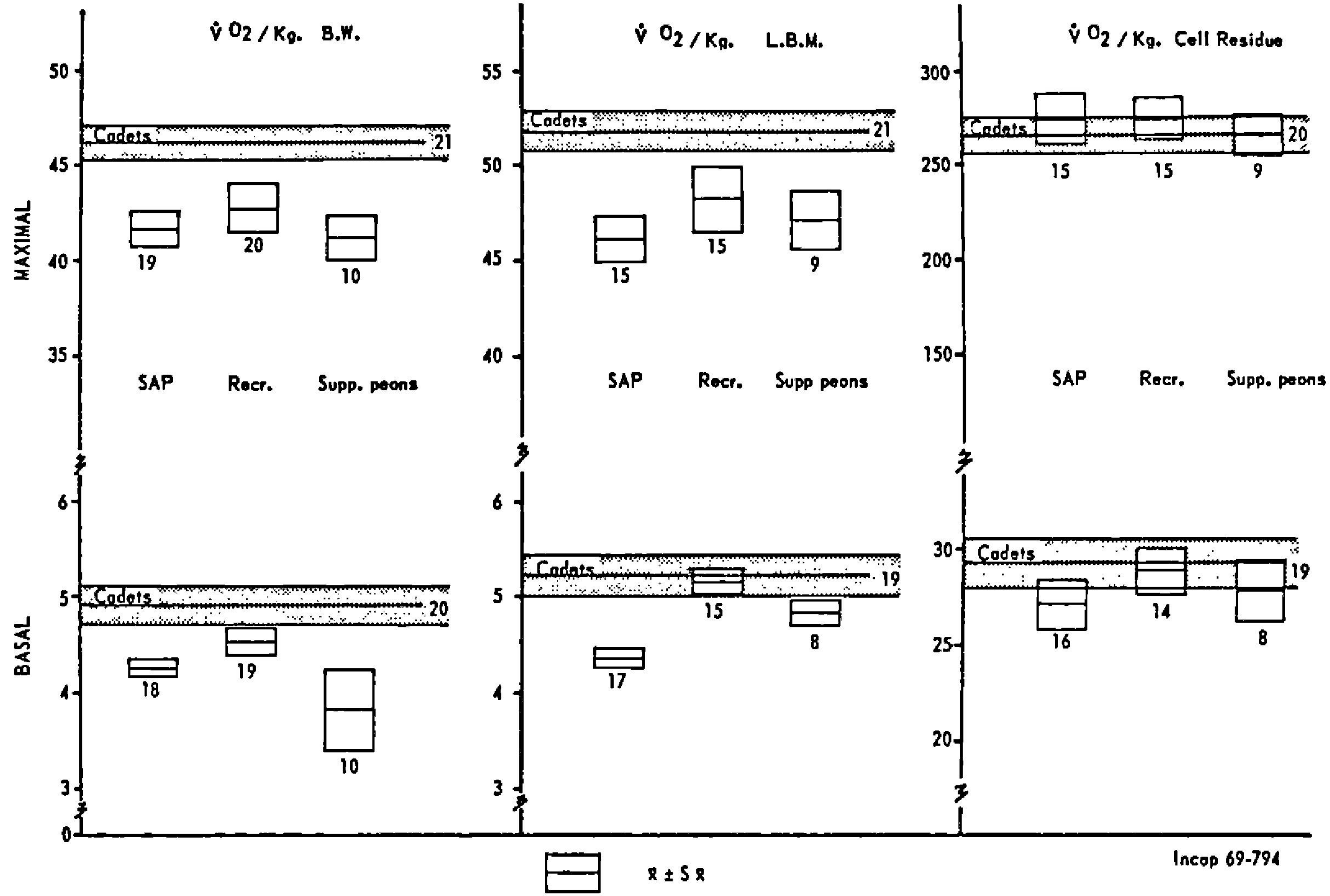

Figure 3. Basal and maximal oxygen consumption per unit of body weight, lean body mass, and cell residue of the four groups of subjects studied

Table 5 Caloric expenditure during different periods of one day (Average of 3 to 6 days) (cal/min)

Group	Type of work	Activity: Work	Activity: After work	At rest or asleep: After work	At rest or asleep: At night
Supplemented peons (N = 19)	Day	4.1	2.7	1.12–1.28	1.12
	Assignment	5.2	2.7	1.12–1.28	1.12
San Antonio La Paz (N = 20)	Assignment	4.6	2.5	1.06–1.26	1.06

Table 6 Summary of time-motion studies and energy cost of work in the field (24-hour values, average of 3 to 6 days)

Group	Total caloric intake	Basal caloric expenditure	Calories available for work	Total caloric expenditure	Caloric balance	Weight change (g)
Supplemented peons (N = 19)	3446	1594	1852	D* 3697	−251	−35
				A* 3568	−122	−19
San Antonio La Paz (N = 20)	2693	1526	1167	A* 3396	−703	−125

* Type of work: D = day; A = Assignment

form regardless of the time it took them (assignment work). The peasants in S.A.P. worked in a pattern very similar to assignment work.

The average total caloric expenditure of the two groups of peasants was similar but lower for the S.A.P. group. In spite of this, the S.A.P. peasants went into a clearly negative caloric balance, evidenced by their substantial loss of weight during the field study. There is no doubt that both groups of subjects tried to impress the investigators with their work output, even though they were warned that they should continue to work at their normal rhythm. This explains the very slight average weight loss that the supplemented peons also suffered.

The average data obtained from the same studies, emphasizing the time of day spent at different activities and at prolonged rests in both groups, are summarized in Table 7. Periods of physical activity include those displayed at work or going to and returning from work as well as the activities displayed after each work period was completed. Rest periods include the prolonged periods of rest after work, particularly

Table 7 Percent of time spent by subjects in various activities in their environment (24-hour values, average of 3 to 6 days)

		Percent of day			
		Active		At rest or asleep	
Group	Type of work	At work	After work	After work	At night
Supplemented peons (N = 19)	Day	37	30	0	33
	Assignment	14	53	0	33
San Antonio La Paz (N = 20)	Assignment	27	24	12	37

recumbent or sitting, and the time of night sleep. It can be seen that not only did the S.A.P. group sleep more at night but, under the conditions of the time-motion studies, they spent an average total of 2.9 hours resting after returning from work. The total prolonged resting periods in 24 hours for this group amounted to 49 percent of the time (11.76 hours); nevertheless their caloric balance was negative.

Several subjective facts confirm the suggestion that the S.A.P. peasants were extremely tired and almost exhausted during their work period, while the supplemented peasants were not. The second group often left us behind when climbing hills or moving on irregular terrain. The first group had the same intentions; they started with great stamina but soon we would catch up with them and even had to slow our pace to match theirs. Upon returning to the village this group of peasants tried not to look tired, but they appeared exhausted and disappeared into their houses for long periods of time. Later on they would come out and either sit quietly playing cards or stand and chat, while the supplemented peons would often work at home or walk around town or even play football.

Interpretation of Results and Discussion

Body Composition If the nutritional state of the four groups for which detailed body composition analysis is available were graded from best to worst, the order would be: cadets, supplemented peons, recruits and S.A.P. subjects. Body weight, height, and weight over height would also catalogue them in that order, although this ratio clearly separates also the two "better nourished" from the two "poorly nourished" groups.

When the body is divided into its two major compartments, lean body mass and adiposity, the S.A.P. group is separated from the others by being extremely lean; in spite of this characteristic of the S.A.P. group, the degree of muscularity, in absolute terms and as percent of body weight, was significantly lower than that of the other groups. This fact suggests that the S.A.P. group subsisted on a suboptimal protein-calorie nutrition which, besides reducing adiposity, had an even greater impact on this tissue. That this group was less muscular is further substantiated by its low creatinine output/cm height. The differences observed between this group and the others cannot be explained on the basis of meat intake according to the work of Addis et al.[35] Lean body mass and adiposity in the other groups, excluding the S.A.P., contributed in very similar proportion to body weight. Muscle mass, however, contributed more to the body weight in the cadets than in the other two groups.

When lean body mass, adiposity, and muscle mass are expressed on a per centimeter height basis, the cadet and supplemented peon groups become identical and significantly different from the other subjects studied except in muscularity, where recruits and supplemented peons are not statistically different in spite of the latter having, on the average, 10 g of muscle/cm height more than the former. The analysis of the protein intake also reveals that the cadet and supplemented peon groups consumed significantly greater amounts of protein than the others, a large proportion being of high biological value, although not consisting of meat in the case of the supplemented peons. Consequently, a higher dietary intake of proteins, without caloric limitations, could possibly improve lean body and muscle mass in populations where protein intake and particularly intake of high biological value protein is not optimal.

Further breakdown of the body into bone minerals, water, fat and cell residue continues to show that the supplemented peons were distinct from the ordinary peasant (recruit group) and the very poor peasant (S.A.P.), tending to approach the body composition of the cadets. This is true for the proportions of bone mineral and cell residue but not for either body water or fat. The important fact that lean body mass may, within certain limits, vary in its composition as the differences outlined point out may be significant from the standpoint of nutrition.

Cadets had more lean body mass and cell residue per cm height and less body water than the three peasant groups, regardless of the food intake of these groups during the study. This suggests that the state of nutrition during growth influences the capacity of adults to develop a normally constituted lean body mass. Animal experiments have indicated that early malnutrition produces an arrest in cell division which is irreversible.[36] Studies in humans indicate that alterations in body configuration and possibly composition occur as a consequence of malnutrition during childhood[37] and adolescence[38].

Besides diet, the level of activity may contribute to the improvement in body composition noted in the peasants who received the food supplement. The favorable effects of diet appeared to take place in the peasants if unrestricted activity was allowed, since in the soldiers, improved nutrition coupled with decreased activity during 16 months of army life resulted in a decrease in lean body mass and a clear gain in adiposity.

The changes in body composition with time observed in the cadets during their military academy training are exactly opposite to those noted in the soldiers. They appear to be due only to the increase in physical activity, because present studies and those of Flores, Garciá, and Sáenz[39] indicate that food intake in university students who belong to the same socioeconomic group is identical to that in the military school, and cadets stated that their diet in the military was similar to that habitually consumed by them at home.

In the light of these findings, improvement in the body composition of the supplemented peons compared to the recruits (average peasant) appeared to be due to two factors: (a) more and better food intake; and (b) an increment in activity. The evidence for this second factor is provided by the fact that even though their food intake for the 3 years prior to the study was at least 250 cal/day more than their intake prior to receiving the dietary supplement, the peons did not become obese as the soldiers did in a shorter period in the army. Furthermore, time-motion studies indicate that their total caloric expenditure was very similar to their intake, again in contrast with the soldiers. The activity increment was not the only factor responsible for these differences, since this study also provides evidence that increased activity alone with restricted intakes (S.A.P. group) resulted in clearly negative caloric balance and weight loss.

The similarities in body composition among the three peasant groups also deserve some comments. Lean body mass and cell residue, either in absolute terms or referred to body height, was the same in the S.A.P. and recruit groups. The composition of the lean body mass, in terms of water, cell residue and bone mineral, was similar among the three peasant groups.

These similarities suggest that availability of calories greatly influenced the activity displayed by the peasants, since obesity is very rare among them and normally they appear to work to the limit imposed by their caloric intake. A biological signal, which is translated into fatigue in chronic calorie limitation, must occur when caloric intake and reserves are nearly exhausted before utilization of lean tissues takes place. One possible mechanism responsible for this "signal" could be muscle glycogen depletion, as Swedish investigators propose.[40]

Physical Performance Under Standard Conditions The results presented in this report, under the above heading, indicate that in terms of maximal work output before exhaustion, all the groups studied performed well although the supplemented peons reached the highest values and the S.A.P. group the lowest. A discrepancy between the maximal work performed and the maximal oxygen consumption of the groups was noted in that cadets and S.A.P. peasants, who performed less work, had both the maximal and minimal values, respectively, for oxygen consumption.

The higher maximal VO_2 in cc/min in the cadets could be due to the differences in body composition already discussed or to a distinct metabolic state in this group of subjects with respect to the three peasant groups. The second explanation is unlikely, since the differences among groups decline as maximal VO_2 is expressed on a per kilo body weight or on a per kilo of lean body mass, and disappear completely when it is expressed per unit of cell residue.

Variations in body composition can explain the differences in maximal VO_2. The similarities in the relative differences in oxygen consumption, basal or maximal, among the groups give assurance to this interpretation of the data. This evidence also should disperse doubts regarding the normality of oxygen metabolism in suboptimally nourished populations who are apparently healthy and engaged in their habitual activities. The constancy of oxygen consumption per unit of cell residue agrees with similar evidence obtained in well-nourished populations[41] and reaffirms the concept of "cell mass" described by several investigators.[42] These results also point to the importance of detailed body composition studies in population groups in different nutritional states to give a proper interpretation of various metabolic functions.

According to other investigators, the working potential of individuals is directly proportional to their maximal aerobic capacity.[43]

Maximal aerobic capacity rises in absolute terms as body weight and absolute lean body mass increase. In maximal work, however, the capacity to withstand a mounting oxygen debt also determines total work output. The fact that a large number of S.A.P. subjects appear to tolerate less oxygen debt than the cadets and supplemented peons, establishes that the poorly nourished population is at a disadvantage to its better nourished counterparts in its work potential, since two unfavorable conditions are present: (a) smaller maximal aerobic capacity which implies that, given a work load, oxygen debt will appear sooner, and (b) decreased tolerance to oxygen debt.

Field Studies The results of the studies carried out in the natural environment of the S.A.P. and supplemented peasants serve to confirm several of the interpretations given to the laboratory data.

First, the energy cost of work in over 50 agricultural activities measured by us are very similar for each individual task in the very poor and in the supplemented peon groups. The results are also identical to those reported for either African or European workers.[12,44] This contributes further evidence that in terms of work efficiency for specific skilled tasks, different populations require essentially the same caloric expenditure, taking into consideration the body size of the individual. As a consequence, during periods of time in which similar activities are performed essentially at the same rythm, the energy expenditures in calories/min are very similar.

Second, the main limitation in the total amount of work that a peasant can perform appears to be his caloric intake, and indirectly his caloric reserves. Populations such as those in San Antonio La Paz, where the young men are very lean and caloric intakes are low, can not be as productive as those whose caloric intake is ample. If the subject falls into negative caloric balance, weight loss will take place. The tissue lost will include lean tissue;[45] this ought to give rise to a vicious circle consisting of less capacity to work, less output, lower economy, poorer nutrition, loss of more lean tissue, and so forth.

Third, the time-motion studies provide quantitative evidence that, when the subjects with low caloric intake tried very hard to work more, fatigue and physical deterioration overcame their desires and they were forced to rest a substantial part of the day.

It is clear that if more calories are provided to peasants they become more active and consequently increase their productivity. Apart from this eminently practical conclusion, this fact leads to a somewhat speculative consideration regarding body composition: Individuals whose survival depends in great part on their ability to perform heavy and prolonged physical work, as is the case for peasants in developing countries, spend essentially all the calories they ingest. A higher caloric intake makes possible an increase in physical activity appropriate to their socioeconomic status.

Summary
The influence of nutrition on body composition and working capacity has been investigated in five groups of young (17 to 27 years old) healthy males with the following characteristics: Thirty-five cadets constituted the reference group, since their past and present nutrition had always been excellent and they were very active in sports and military drill and, consequently, physically fit. Twelve were studied again after eight and 16 months in the school. The other subjects were peasants who came from rural areas in Guatemala, where children are poorly nourished. Three of a total of 83 subjects gave a history of kwashiorkor during the preschool period. The peasants form four distinct groups: (a) recruits and (b) soldiers, both representative of the average peasant. Forty-four recruits were studied within two weeks after they had joined the army. Seventeen were studied again after 16 months in the army. This group was comprised of soldiers. The soldiers stated that they were less active in the army than when they toiled on the land; (c) San Antonio La Paz (S.A.P.) peasants: 20 young men who came from an impoverished and arid region of Guatemala, where nutrition is very poor; (d) supplemented peon group, totalling 19 subjects, who had been working on a farm where higher than average wages were paid, milk was easily available and a high-quality dietary protein supplement was given to them daily for three years prior to the study.

All the subjects were volunteers, lived in regions within 4000 and 6000 feet above sea level, were enthusiastic about taking part in the study, and did their best to perform all the tests.

Subjects were studied in the Physiology Laboratory at the Institute of Nutrition of Central America and Panama and in the field. In the laboratory, detailed body composition studies were carried out, including body density, total and extracellular water, creatinine excretion, and anthropometry.

Maximal exercise on a treadmill was used to determine maximal aerobic capacity. Basal oxygen consumption was also measured. In the field, energy cost of work, time-motion studies and total caloric intake

and expenditure were measured. Individual dietary data were also collected for all groups.

Daily caloric intake ranged from 2700 to 3450 calories. Caloric expenditure was less than intake only in the soldier group. Daily protein intake ranged from 112 g, 44 percent of it being of high quality, to 82 g with only 8 percent of a quality in the range of most animal protein. The following are the main findings obtained from the body composition studies. Cadets lose fat and gain lean body mass after joining the army, while soldiers become fat and tend to lose lean mass. The changes in the cadets were primarily due to increased exercise, since their dietary intake while in the military school was the same as before they joined the army. In the case of the soldiers, even though calorie and protein intake was higher in the army than before, physical exercise was less. In contrast to these changes in the soldiers, the supplemented peon group was higher in lean body mass than the recruits and had essentially the same amount of fat. The most poorly nourished group (S.A.P.) had the same lean body mass as the recruits and the least amount of fat, while cadets had more of both.

The performance in the maximal exercise test was as follows: The supplemented peons produced more kilogrameters of work before exhaustion, while the S.A.P. group produced the least. In general, peasants outdid the cadets. Basal and maximal oxygen consumption progressively increased from the poorly nourished group (S.A.P.) to the best nourished group (cadets). Both basal and maximal oxygen consumption, when expressed per kilo of weight or lean body mass, were lower in the peasants than in the cadets, but these differences disappeared when expressed on a per cell protein residue basis. These findings suggest that the change in oxygen metabolism in the groups studied was due to differences in body composition and not to differences in cell function.

The results of the time-motion studies in the field clearly showed that the supplemented peons had a higher caloric expenditure than the poorly nourished group and maintained their weight, while the latter group went into a clearly negative caloric balance and consequently lost weight when they tried to work as hard as did the first group. The poorly nourished group spent up to 50% of the day resting.

Conclusions 1. Increased protein-calorie intake for a long period of time in chronically suboptimally nourished adults produces a beneficial effect in body composition and physical working capacity if energy expenditure is not limited. If a reduction in energy expenditure occurs, a higher calorie and protein intake results in obesity.

2. Poorly nourished populations have a lower working output and a lower working potential, mainly due to reduced lean body mass, earlier appearance of oxygen debt, and decreased tolerance to that debt.

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