THE EFFECTS OF HARD PHYSICAL WORK UPON NUTRITIONAL REQUIREMENTS

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BEFORE considering the nutrition of men doing hard physical work, it is essential to understand what constitutes hard work as the expression is used in this discussion. When a man walks up a 4 per cent grade at three miles per hour he produces about four times as much heat as he does in the basal state. The flow of oxygen and food to his tissues and CO_2 from his tissues must proceed at four times their usual rate to keep him in equilibrium. This increased flow of materials through him and his blood stream is easily maintained at this grade of work without disturbing the chemical equilibria of the blood to any extent. It is described as moderate work. If the grade is increased to 8 per cent, which doubles the work, these equilibria, particularly the acid-base balance, are measurably displaced as can be seen from an inspection of Henderson's nomographic descriptions of blood in rest (1), and in work of approximately this intensity (2). Even in this heavy work the changes in the blood though definite are small in comparison to those produced by disease (3, 4). However, if the work is again increased by raising the grade to 12 per cent, (an increase of 50 per cent in the work), it becomes exhausting; the ordinary man will be pushed near his limit and the equilibria of the blood will be shifted very considerably. If the work is further increased by raising the grade to 16 per cent, (only a 33 per cent change in the amount of work), it may be impossible for a man who is not an athlete to attain a steady state. The equilibria will be greatly and increasingly displaced and the work cannot be continued. In an athlete all these changes will occur at roughly 50 per cent higher levels of work, e.g. walking on the same grades at four and a half miles per hour instead of three. Thus the displacement of the equilibria of the blood,

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though related to the work done, is by no means proportional to it. At levels of work up to five times the basal value, the displacement is negligible; at seven or eight times it is small; at ten times, large; and at twelve times so great as to become intolerable to many. On the other hand the calories dissipated and the food required are directly proportional to the work done if allowance is made for the basal metabolism and if some minor variations in efficiency are neglected.

The primary need of a man who changes from a low level of work to a high one is for more calories. This has been known from antiquity and our knowledge has been put on an exact basis by the work of Atwater and Benedict (5) and many others (6, 7, 8). But even with all this work there has as yet been no comprehensive study of how fast the ability to perform hard work will disappear with different degrees of caloric deficiency. Christensen (9) has shown that a man who is fasting and working hard will deteriorate considerably in two days. Benedict and his co-workers (6) found surprisingly little change in men who were doing light work on a moderately low diet even after they had been on the diet four months. It seems not unlikely that in a given period of time as the caloric deficit is increased, either by reducing the food or by increasing the work, the disability may increase (like the disequilibria described above), at first less but finally more than in proportion to the deficit. A consequence and corollary of this is that a fasting man working hard, like Christensen's subjects, has a large caloric deficit per unit of time and may receive great benefit from being given a single meal containing even a small fraction of his daily requirements. A sedentary man on two-thirds of his requirements may not show a measurable improvement from receiving his whole requirements for the day.

Next in importance to the well-recognized and easily ascertainable caloric needs come the needs for special substances. Of these only the vitamins (especially the B group) and protein will be dis-

cussed here. It is convenient for discussion to consider three of the ways in which the requirements for such substances may behave as the work is increased. The requirements may be either (a) practically unaltered, or (b) increased in proportion to the work, or (c) increased in proportion to the displacement of the equilibria of the body, that is show little change until the work becomes really hard and then show a great increase.

The studies upon man give only clues as to which pattern is characteristic for which vitamin. There is a great need for work which is systematic enough to offer definite proof. There are two classes of observations which have a bearing on the vitamin requirements in heavy muscular work. One is upon the final effects of the deficiency, whether it appears to diminish the ability to work or not; and the other upon the influence of hard work on the rate at which the deficiency develops. The former class is primarily useful as a negative argument. If, as is the case with Vitamin A, the effects do not appear to have much connection with the muscles and even prolonged deficiencies do not impair physical efficiency (10) it seems probable, though not certain, that hard work does not increase the needs for this vitamin. It probably belongs to class (a) of the preceding paragraph.

With vitamin C on the other hand the effects of pronounced deficiency are to diminish greatly the ability to do work (11, 12, 13), but there is little in the records of explorers to show whether hard work brings on scurvy rapidly, though it is true that the necessity of doing hard work calls attention quickly to the disabilities of the condition. Experiments last summer in which both sedentary and working men were kept on scorbutic diets for eight weeks failed to show any difference between the groups (14). What little evidence there is does not suggest that for man muscular work per se increases the need for Vitamin C to any great extent. It is probably in class (a), possibly in class (b).

Vitamins D and K seem, like A, to be concerned with special

processes not closely related to physical work, and I believe there is no evidence as yet whether muscular work increases the requirements. The very absence of evidence in the face of the various peculiar and limited diets which are found in many parts of the world suggests that for adults deficiencies in these substances do not in practice limit the amount of physical work which can be done.

The relationship of the various muscular dystrophies found in ducks and rodents on E deficient diets to muscular weakness in man is unknown. The condition appears to be rare, but if it occurred work might well aggravate it, judging from experiments on animals.

The situation with vitamin B is different. Most observers have found that on diets deficient in the whole complex men first lose their willingness and then their ability to work. Weakness is among the symptoms of deficiency and there is evidence that hard work greatly hastens the onset of the symptoms (15, 16, 17, 18). The cases of acute beri-beri seen in China frequently follow a bout of hard work and a large carbohydrate meal (19). On the other hand Keys (20) in the most careful study so far reported has found no effects from a B deficient diet continued for a matter of weeks, even when the men worked hard. The discrepancy between his results and those mentioned above is not easy to explain, but in my opinion an explanation is possible by assuming that the requirements for this complex follow the general pattern of class (c) described above. Though the evidence is not unequivocal, it seems from the descriptions of the experiments that Dr. Key's subjects, though doing a great deal of work, were well trained for it, and that this work did not constitute as great a strain for them as the work given to the subjects both trained and untrained used by the other workers. If, as in the description given above of different grades of work, it is not the absolute amount a man does but how near he gets to his own individual limit which determines the disturbance in his homeostasis; and if further the requirements of the B complex are related

to this disturbance, then many of the conflicting observations can be harmonized. Really exhausting work which may be accompanied by muscle soreness and the breakdown of a little muscular tissue and from which a man scarcely recovers before the next day may require large amounts of certain members of the B complex, while work which is hard but not exhausting may not. Work which is so exhausting as to be "unphysiological" offers a tempting analogy to various pathological conditions (including hyperthyroidism) which are reported to result in increased requirements for the B group.

Very little is known about the needs for the various members of the B complex. Johnson's work, (16) though it was a preliminary study and incomplete, indicated that thiamin is by no means the only members of the complex which men working hard must have to stave off deterioration. Riboflavin, however, did not prevent deterioration (16) nor will deficiency in this factor interfere with physical performance (21).

Recent papers (22, 23) seem to confirm again the earlier experiments of Chittenden (24) and others in showing that the need for protein is not increased by muscular activity in spite of the popular idea that athletes, loggers, etc. must have meat in quantity. The period in these recent studies was only eight weeks, the protein not very low, and the work only moderately hard, but there were no indications at all of greater needs in the working group. The question of storage complicates the picture here as it does with all short-term experiments upon diet, but it seems fair to say that the trend of recent work has been to support the view that work does not increase demonstrably the protein requirements, but the possibility remains that long continued very heavy work may do so.

Water and salt should be mentioned because under ordinary conditions the requirements of the former particularly are increased by work. It is not the work per se but the extra heat that accompanies it which calls for extra water. Under most modern conditions

our clothes and buildings are adjusted to be comfortable for the man who is sedentary or doing very light work. A man at four or more times his basal rate of metabolism will be hot and sweating. Recent work (25) indicates that water, even in excess of quenching thirst, is beneficial and that the importance of salt has been over emphasized. Salt is necessary when sweating is heavy, but part of its benefit is due to the extra water which is taken with it.

The question now arises what proportion of the population does hard work as it is defined here. The answer is that the proportion is small. For 10 to 20 cents one can purchase electrical current which will provide as many horsepower hours as a strong man can deliver in a week, consequently in industry heavy work is done by motors. Farmers do moderate work, loggers and a few other trades hard work (26), soldiers on occasion hard or even exhausting work, though this is avoided by intelligent commanders, except during training. Nothing is known of the extra requirements, if any, for the kind of work that the average industrial worker performs, namely, work which is physically easy but nervously or emotionally tiring.

This survey may be summarized by saying that though definite proof on most points is lacking the indications are that light or moderate or even hard physical work adds primarily to the caloric requirements and increases the needs for protein and vitamins A, D, C, and K little if at all. The need for the B complex may be increased somewhat but probably less than in proportion to the extra calories until the work becomes hard or exhausting, when it almost certainly rises considerably. Nothing is known about E deficiency in man, but judging from animals the requirements may well rise in work. In view of the foregoing it seems possible that a man on a diet limited in quality but not in quantity, if on the borderline of deficiency, might make his nutritional status better rather than worse by doing moderate work because of the larger quantity of food he will consume.

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