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THE INFLUENCE OF DIETARY FACTORS ON PERFORMANCE OF MUSCULAR WORK

A short review of the present knowledge of the influence of dietary factors on muscular performance is presented. The paper is divided into four separate parts: approach to experimental work in man, the fuel of muscular work, individual dietary factors and general and miscellaneous factors. A selected bibliography of 58 references is given.

APPROACH TO EXPERIMENTAL WORK IN MAN

The human race undertakes muscular work for two reasons; because they have to, and, because they want to. Work undertaken under obligation is perhaps best referred to as labour, while work for pleasure is typified as sport. It is labour and sport that provide the principal applications of physiological study of the conditioning factors of muscular work.

For the present purpose it is convenient to classify work according to its characteristics rather than its object. There seems to be a distinction between muscular work, in which a maximum effort of short duration is required and work of a type, where the maximum performance over a considerable period of time is important. Almost without exception it is in the field of sport, that a maximum effort of short duration is required without the necessity for maintenance. The momentary maximum effort is of primary importance to the high jumper, the weight-lifter, the discus-thrower and also the sprint-runner. Though the sprinter's effort lasts over say 12 seconds in a 100 metres race, A. V. Hill has shown that in a race of about this length the speed maximum has not to be maintained for more than a fraction of a second (Eggleton, 1936).

On the other hand, in industrial labour and in athletic events such as long-distance running we find examples of effort, which must be maintained for a number of hours.

It is therefore of some importance in the study of the relation of any one set of conditioning factors to muscular work, that the nature of the work be considered in the above terms.

The Assessment of Performance at Work

Performance at work requiring short duration maximum effort is simply measured; the condition of the subject immediately following the effort is irrelevant. Thus in experimental work on the relation of diet to this kind of work, there are relatively few variables. If reasonable precautions are taken to ensure that the experiments are conducted under constant physical and psychological conditions, it is simply necessary to vary the diet and measure the appropriata maximum effort. The ways in which the diet may be varied include qualitative and quantitative change in components and change in the times of administration and the conditions under which the ingestion occurs.

In the assessment of performance at work of a prolonged nature the condition of the subject must be considered, in addition to the work he puts out. An industrial labourer, who does an enormous amount of work one day and then takes a week off to recuperate, is as uselesss as a marathon runner, who trains so exhaustively, that he is unable to run on the day of the event. It is therefore necessary to make sure, that the physical condition of the subject remains unchanged over several consecutive days of experimental work. An extensive discussion of the short and long term physiological changes which may be expected to occur in response to exercise will be found in the volume by Herxheimer (1932).

If the above factors are adequately controlled, the total output of work in kilogram-metres over a given period provides a measure of performance. Though this gives a gross rate of working in kilogram /metres/ hour, the results are not freely transferable in this form. It cannot be assumed that a man who can do 80,000 kilogram-metres in four hours can do 160,000 kilogram-metres in eight hours. More information can be obtained by recording the performance at intervals over the period of work. The maximum amount of muscular work the subject can do on a given diet can be recorded in this way, and information obtained on the time for which he is able to maintain a high level of performance, and the extent to which this declines, when fatigue occurs.

The time for which a given diet has been administered must be considered. It is often desirable that the subject should have been on the diet under test for several days before the experimental observations are made in order that there is no sudden change of diet coincident with the start of the experiments. Comparison of results obtained on consecutive days will then show, whether the performance improves with practice or not, that is, if there is an element of skill in the task. If a »learning curve«, or improving performance from day to day is found, then only observations made after the upward trend has ceased and the subject has obtained his maximum skill at the task, are representative of his performance at muscular work. Conversely, if the performance falls off from day to day, this suggests, that physical or psychological deterioration is occurring in the subject.

The information lacking in data expressed in the above way is the relation between the energy content of the diet and the amount of energy the subject converts to external work. The remainder is used in the maintenance of body functions and dissipated as heat. It is important economically, that as large a proportion as possible of the calorie intake should be used in external work.

In the case of the explorer or soldier in hot climates, where the weight of food to be carried must be the minimum consistent with adequate performance, similar conditions apply. In cold climates, energy converted to heat is of greater importance.

For these reasons, measurements of the mechanical efficiency of muscular work are often made. The Gross Efficiency of the body in performing a set task may be calculated from the oxygen consumption, which provides a direct measure of the total energy consumption (1 litre of oxygen is equivalent to 5 Calories), and the energy appearing as external work (measured by the performance at the task), by the use of the formula:

$$\text{Efficiency} = \frac{\text{Energy as external work}}{\text{Energy consumption}} \times 100$$

Efficiency is thus expressed as a percentage.

As the total energy consumption is the sum of energy appearing as external work and of energy appearing as heat, we have:

$$\text{Efficiency } (\%) = \frac{e_1}{e_1 + e_2 + e_3} \times 100$$

where e_1 = Energy as external work (at the task)

e_2 = Energy used in waste movements, maintenance of posture, respiratory movements, etc.

e_3 = Energy produced as heat.

Thus a fall in efficiency at constant work output denotes an absolute increase in wasted energy production, while the energy utilised by the muscles in performing the work remains constant. Such a fall may be due to changes in resting metabolic rate, which is dependent upon environmental temperature, or to changes in the quality of the work such as an increase in waste movements. If efficiency measurements are required to indicate changes in performance related to changes in diet, the atmospheric conditions must be stable and the quality of the work must be checked. The latter factor may be partly eliminated by using a simple machine such as the bicycle ergometer or the hand ergometer and by using a highly trained subject.

In the hope of eliminating changes in resting metabolism and in the energy used in maintaining posture, Garry and Wishart (1931) developed the use of a measure of Net Efficiency of muscular work. This is calculated from the formula:

$$\text{Net Efficiency} = \frac{(\text{Energy consumption at work}) - (\text{Energy consumption at rest})}{(\text{Energy as external work})} \times 100$$

The energy consumptions are calculated from oxygen consumption. Garry and Wishart found that this measure of efficiency gave questionable results and that its theoretical significance was doubtful. In Wishart's later experiments (1934) he resumed the use of the Gross Efficiency measurement.

Psychological Factors

In the interpretation of results of experiments of this type, the possible influence of psychological factors must be considered. Factors concerned with the ingestion of food are just as much dietary factors as are protein: carbohydrate: fat proportions in the diet. The psychological factors concerned in the performance of work are also relevant. It is widely recognised, that these factors derived from the environment can influence, favourably or unfavourably, performance at muscular work. In order that they may be eliminated, the environment should, as far as possible, be constant.

The Choice of a Subject in Experimental Work

The subjects chosen should be considered in relation to the object of the experiments. If it is of interest to determine the response to dietary change of patients with disturbed metabolism such as diabetics or victims of chronic starvation, the subjects will clearly be selected from patients with the appropriate disorder. If, on the other hand, the approach is essentially physiological, and the results are to be representative of the normal human, then there is little objection to the use of any healthy individual. If results of doubtful significance are obtained, they may often be confirmed with the aid of statistical procedures, using a group of subjects.

It is in fact helpful to have as a subject a man, who is highly trained in the particular form of work to be used experimentally. In this way some of the factors endangering the value of the experimental results are eliminated. The trained man is unlikely to show physical deterioration as a result of exerting his maximum effort over a reasonable period of time. His performance in short duration events is more regular and thus reflects dietary changes in a more regular and more significant fashion.

His effort in long-duration work is better applied to the task, he makes the minimum of »waste movements«, and his endurance is greater. His performance is less likely to be affected by psychological and environmental factors. Finally, the trained man is generally found to be extremely interested and co-operative in any experimental work on the relation of diet to his performance, especially if the work is athletic in nature.

THE FUEL OF MUSCULAR WORK

A considerable amount of experimental work has been performed with a view to discovering what is the primary fuel used by the muscles during work. The available evidence as to the nature of this fuel will now be considered.

The Fuel of Muscular Cantraction

The majority of dietary constituents – protein, fat, carbohydrates, and their derivatives, are capable of being oxidised and thus of furnishing energy. It is necessary to consider which of these groups of substances is actually subject to combustion in the muscles and is thus the direct source of the energy of muscular contraction. At one time, because the muscles contain so much protein, it was believed that the destruction of muscle protein was the source. Liebig expressed the view, that such protein breakdown occurred. Some support was given to this view by contemporary workers who found rises of urinary nitrogen occurring in association with increased muscular activity. Their results were controversial, other workers finding no change in urinary nitrogen. Such changes as were found were small and irregular. (CATHCART, 1925).

On August 30th, 1865, Fick and Wislicenus performed their classical ascent of the Faulhorn, taking urine samples throughout. Their experiments were, in the light of modern methods, crude and uncontrolled and many of their findings have been widely criticised, but their demonstration, that their increase in nitrogen excretion could not possibly account for the energy they used in the climb, has never been effectively challenged. It has never been seriously suggested since that time, that protein provides the primary fuel of muscular contraction, though evidence that certain changes in protein metabolism are associated with muscular activity has accumulated.

It is therefore apparent, that the primary fuel of muscular contraction is derived from the non-nitrogenous constituents of the diet, carbodydrate and fat. Recent work has demonstrated that the energy for the contraction of muscle is initially provided by a complex cycle of changes involving the breakdown of high-energy phosphate bonds. The process of resynthesis of these bonds is rapidly set in motion, and it is necessary to consider the nature of the substances whose oxidation provides energy for the resynthesis.

Meyerhof in 1919 demonstrated that the Respiratory Quotient (R. Q.) of an excised muscle contracting in an atmosphere of oxygen is very nearly 1.0, which indicates that the source of the energy is carbohydrate, the R. Q. of whose combustion is 1.0, while that of fat is 0.7. Work on the fat and carbohydrate content of excised muscles before and after extensive stimulation supports this view, the carbohydrate content falling, while the fat-content remains unchanged. Experiments on the R. Q. in man led to a different conclusion. It is possible from the non-protein R. Q. of the body as a whole to determine the proportions of fat and carbohydrate that are undergoing combustion, provided that the observations are made when work at a steady rate is in progress. Benedict & Cathcart (1913), and many other workers since have made studies along these lines and results agree fairly well. In general, it has been found, that during heavy work the R. Q. rises almost at once to between 0.95 and 1.0 and then slowly decreases to a value of about 0.75 as the exercise continues. During the recovery period after work the R. Q. remains low for a while, then slowly rises to the resting value, which is roughly 0.85, but is determined by the individual's dietary habits. If after a rest the exercise is continued, the same sequence of events occurs, but the fall in R. Q. sets in and occurs more swiftly. Cathcart & Barnett (1926) showed with a subject who had been existing on a diet of olive oil for three days, that, although the resting R. Q. was 0.75, it still rose to 0.85 over a period of work and recovery. Courtice and Douglas (1936) showed, that the fall in R. Q. after a ten mile walk at 4.5 miles per hour was associated with a ketosis, which occurred in the period immediately following the cessation of work. They also found, that a high carbohydrate diet gave a higher R. Q. throughout and abolished the ketosis.

It is clear, that these R. Q. figures are influenced to a considerable degree by the CO_2 loss which occurs immediately after the start of exercise as an effect of hyperpnoea, and by CO_2 retention to make up the loss during recovery. These factors, which are not metabolic in origin, have been shown to produce R. Q.s as high as 2.0 and as low as 0.4 respectively (see Herxheimer, 1932). Some caution is therefore necessary in attributing metabolic origins to R. Q. variations with exercise. More reliance can probably be placed on calculations of the »Extra R. Q.« due to exercise. This value for the R. Q., due to work alone, is computed from the values for gaseous exchange during work, after subtraction of the resting values. Gases are collected during the period after the cessation of work until the gross R. Q. has returned to the basal level, and the Extra R. Q. is thereby freed from the influence of non metabolic CO_2

loss and retention. Calculations of the Extra R. Q. due to exercise give results generally comparable with those obtained from the gross non-protein R. Q. The evidence from experiments in man therefore suggest, that at the start of exercise the muscles burn preferentially carbohydrate, thereafter utilising a steadily increasing proportion of fat as the exercise proceeds.

Thus work on isolated muscles indicates, that carbohydrate is the sole fuel of muscular work, while experiments in man appear to show that fat plays a significant role. It might be thought, that a decision could be reached by analyses of fat and carbohydrate concentrations in the blood during work – but as Gemmill (1942) has pointed out, many factors other than the rate at which these substances are added to and removed from the blood, are concerned in their blood concentrations. Such changes as variation in renal excretion, concentration or dilution of the blood, and change in rate of blood flow and the distribution of blood confuse the issue.

The work on excised muscles is open to the obvious criticism that it may not represent the situation in the body when the circulation is intact and can transport metabolites to and from the liver and other organs of high metabolic activity. The R. Q. work may be criticised on the grounds that it may not represent the activity of the muscles alone. The observations of Himwich & Rose (1929) provide a solution to the problem. Using arterial and venous puncture to obtain samples of blood entering and leaving the muscles, they calculated the R. Q. of muscular activity in the body from the arterio-venous differences of CO_2 and O_2. Their results were in agreement with those obtained from R. Q. work on the whole body.

Thus it seems, that active muscles use preferentially carbohydrate as their primary fuel. When stimulated to strenuous activity they use almost entirely carbohydrate at first then gradually change over to fat derivatives. The excess metabolism associated with recovery uses largely fat. If exercise is recommenced, the muscles employ carbohydrate again in preference, soon returning to fat. These changes are readily interpreted biochemically. The energy for muscular activity is released by the tricarboxylic acid cycle in the muscles, which is supplied with carbohydrate, primarily from the muscle glycogen stores, and secondarily from the liver glycogen via the bloodstream. As the glycogen stores, which are not overgreat, are depleted, more and more keto-bodies from mobilised fat are utilised in the tricarboxylic acid cycle. On the cessation of work, in order to restore the glycogen reserves, mobilisation of fat for conversion to carbohydrate continues at a high rate. As the fat derivatives are no longer being directly bunt, ketosis results during the process. The partially replenished glycogen stores will provide carbohydrate for the initial stages of a further bout of exercise. Further, on a high carbohydrate diet, the glycogen stores will be better filled initially, and hence more carbohydrate will be available.

Some workers are of the opinion, that fat is first converted to carbohydrate in the liver before use in the muscles. More recent studies have shown that, although the glycerol part of the molecule may be utilised in this way, the tricarboxylic acid cycle is capable of directly oxidising two-carbon-atom fragments from the fatty acid chains.

The above observations on the primary fuel of muscular activity provide a basis for consideration of the dietary needs of muscular work.

INDIVIDUAL DIETARY FACTORS

Calorie Intake

It is clear, that calorie intake places a primary limitation on man's performance at a daily task. The calorie requirement of a man performing physical work has three components, that for his basal metabolism, that concomitant with maintenance of the extra bodily functions associated with the conditions of the work such as increased cardiac activity, postural requirements, maintenance of body temperature etc., and that actually appearing as external work. The first two of these components are highly individual in nature both as regards the man and the work, and a detailed analysis of them would be relatively unprofitable for the present purpose. Gross calorie requirements are more easily estimated from gross considerations than from the summation of isolated factors. It is, however, interesting to note the unexpectedly low number of calories which are actually devoted to external work in some cases. The simplest example is that of the sprint athlete. Abrahams (1948) states, that in his actual training the sprinter seldom performs more daily running than would warrant the use of 400 Calories; his total intake would be of the order of 5,000 Calories. On the other hand, competitors in duration events, who consume on the whole considerably less food, may use anything up to 2,000 Calories in the actual event, though they seldom approach this figure in their daily training. It appears, that in the field of sport the total calorie requirement bears little relation to the energy required for the physical effort. In the case of the heavy labourer on the other hand, calorie output at work may well account for an important fraction of the daily calorie turnover. Really vigorous physical labour such as that of lumberjacks may take as much as 500 Calories per hour giving a daily requirement of approximately 4,000 Calories for work alone, but this is an extreme. The average man giving his maximum performance over a long period produces work of the order of 250 Calories per hour.

The most reliable information with regard to total calorie requirement is provided by regular and accurate measurement of body weight, and it is by this procedure that the adequacy of the daily intake may be assessed. Obviously an intake in excess of requirement will lead to an increase in body weight and the reverse is true. This method is applicable to all forms of work, its advantage being that it eliminates individual variation as regards the subject and the work, providing the latter is constant from day to day. Once a steady state of body build has been achieved by regular work of any type, this being indicated, by constant body weight, the natural compensatory mechanisms will be found to have produced the optimum bodily condition for the man on whom they operate. With a trained man performing a constant daily work routine, inadequate calorie intake will affect performance deleteriously due to consumption of body tissues, while if calorie intake is too large, deposition of fat will worsen performance by increasing the load to be carried. In both cases the deterioration in performance is directly attributable to deviation from the optimum bodily condition.

It must be noted, however, that with a man changing from a sedentary occupation to physical labour or an athlete entering upon training, changes in body weight must be expected, which do not necessarily denote calorie inadequacy or excess. In such a man an initial fall in weight due to the removal of unnecessary fat stores followed by a rise associated with muscular hypertrophy are to be expected. Morehouse & Miller (1948) have discussed this point further.

It is instructive to consider the conclusions reached by Cherry-Gerrard (1948) in connection with Scott's last expedition. At the time he first wrote, he considered that the death of Scott and his companions in the Polar Party was due to inadequate calorie intake, though he has since expressed the view, that vitamin deficiency also played a part. He points out that Seaman Evans, the first to die, was by far the biggest and strongest member of the party, but he was subsisting on the same rations as the others. This emphasises the importance of individual variation. The ration at the time consisted of approximately 5,000 Calories and was found to be fairly adequate for strenuous work at an atmospheric temperature of O°F., but Scott and his party met temperatures of —20° to —30° F. over a period of weeks; in addition, they met conditions necessitating a much greater amount of physical work than was anticipated. Cherry-Gerrard (1948) considers that food deficiency from these causes led to the weakening, which was the precipitating cause of their death. Such occurences emphasise the importance of a knowledge of the individual's calorie requirement for a given performance of work under given conditions.

The Carbohydrate Component of the Diet

Carbohydrate is the preferential fuel of the muscles during the performance of muscular work. There is a considerable body of evidence that the onset of exhaustion is related to a fall in blood sugar, and that this fall in blood sugar may be obviated by small amounts of sugar-containing foods administered during the work. Dill, Edwards & Talbott (1932) found, that in a dog doing fairly heavy work on a treadmill, exhaustion occurred after $6^1/_2$ hours, associated with a fall in blood sugar to 65 mgm. %. When the dog was fed at intervals with glucose candy, it was not exhausted after 13 hours, its blood sugar remaining normal. In a man doing heavy work, they found that as exhaustion approached, the blood sugar fell to 50 mgm.% and the heart rate from 240 per minute to 220 per minute. On administration of glucose both blood sugar and heart rate recovered their former values, the man being enabled to continue work. Studies have been made on the runners in the American Marathon Race, which is run over a course of 20 miles. It was found that the winner, who was in excellent physical condition, had a normal blood sugar; four runners, who were prostrated at the finish, each had blood sugars approximately one-half of normal. In the following year's race, the runners were advised to eat moderately large amounts of carbohydrate before the race and were supplied with candy and sweetened tea during its course. At the end of the race their blood sugars were nearly normal and their physical condition far better than after the previous year's race (Schneider, 1939).

Certain aspects of the carbohydrate factor warrant further discussion. The merits of a diet containing a high proportion of carbohydrate must be considered. Anderson & Lusk (1917) showed that the specific dynamic action of carbohydrate is available for muscular work; hence carbohydrate ingestion produces no waste calories. Wilson, Bowers and Cherry-Gerrard (Cherry-Gerrard, 1948), testing diets under antarctic coditions, found, that carbohydrate and protein alone were inadequate. The latter found, that he could eat up to 24 ozs. of biscuits and was still not satisfied – wanting fat. He suffered from »heart-burn« and was also more frost-bitten than the others whose diets were mixed. These workers concluded, that a daily diet of 16 ozs. of biscuits together with 12 ozs. of pemmican and 3 ozs. of fat was adequate and satisfying.

Courtice & Douglas (1936), found, that a high carbohydrate diet gave a consistently higher work R. Q., presumably indicating, that the glycogen stores are better filled on a high carbohydrate diet. Christensen & Hansen (1939) found that a subject doing work at a rate of 2,800 ft. lbs./minute could continue three times as long on a carbohydrate diet as on fat.

Eggleton (1926) points out, that insulin resistance is encountered on any carbohydrate-poor diet. Mills (1938), working on the depression of glucose tolerance with exercise, noted, that this depression occurred on a low carbohydrate diet and it appears to be associated with depleted carbohydrate stores.

Morehouse and Miller (1948) point out, that the symptoms of physical exhaustion are referable not to the muscles but to the central nervous system; the brain having no carbohydrate stores and being entirely dependent for its metabolism on glucose and lactic acid supplied by the blood. When the blood glucose falls, brain function is depressed and unconsciousness usually occurs when the blood sugar falls below 40 mgm.%. Dill, Edwards & Talbott (1932) noted a depression in cardiac function corresponding to the onset of exhaustion. This might be attributed to glucose depletion.

There is therefore good evidence, that a high carbohydrate diet is a primary factor conditioning performance at muscular work. In addition, significant proportions of protein and fat must be included in the diet, particularly under the somewhat abnormal conditions often associated with hard physical work. A high carbohydrate diet has been found to be relatively indigestible. Hence, it is only justifiable to increase carbohydrate in the diet to such a point, that the glycogen reserves are full – and it must be remembered that these stores are situated only in the liver, where the maximum concentration of glycogen is 10% and in the muscles, where the maximum is about 2%. If carbohydrate can be supplied as sugar during the exercise in amounts sufficient to maintain the glycogen stores, so much the better.

It is therefore suggested, that in the case of long duration workers, daily carbohydrate intake should be slightly greater than the quantity actually used at muscular work, part being administered during the work as sugar. In the case of workers such as short-duration performers, whose energy output as external work is not large compared with the basal and subsidiary metabolic output, the carbohydrate intake might well be greater than the actual work energy output to allow for the relative increase in body maintenance function. It is probable, that there is an optimal carbohydrate intake, and that this can be related to muscular activity; an intake markedly above this level is not justified.

On this basis, the carbohydrate intake of a sprint runner would represent approximately 20% of his total calorie intake, i. e. would be of the order of 800 to 1,500 Calories, or 200 to 250 gms. of carbohydrate; while that of a really heavy worker would represent approximately 50% of his diet, being of the order of 3,000 Calories or 750 gms. These suggested figures are compatible with the selection of an attractive and palatable diet.

Fat

As has been noted, the information derived from R. Q. measurements clearly indicates, that the combustion of fat is not a negligible factor in muscular work of some duration. On the other hand, fat stores in the body are valueless except in work performed under certain specialised conditions such as low temperature, where it will be apparent, that a high fat reserve can assist the maintenance of body temperature; similar considerations apply in the case of swimmers. Where it is anticipated, that periods without food of such duration that the body glycogen stores must inevitably be exhausted will occur, a high fat reserve is also indicated. Recent biochemical work suggests, that there seems no reason why such stores should not be deposited on an excess calorie intake of any nature.

Gemmill (1942) considers, that the indirect utilisation of fat must be an efficient process since the exclusive feeding of protein and fat does not have a marked effect on muscular efficiency during short periods of exercise. Again, fasting dogs were found by Anderson and Lusk (1917) to show no signs of exhaustion after a 9-mile run on a treadmill in 3 hours, even though their R. Q.'s indicated that the fuel of their muscular activity was almost entirely fat. These authors quote that in deer-hunting it is the custom to fast dogs for five days beforehand, no impairment of muscular function occurring. The Harvard Fatigue Laboratory has found, that a fasting dog could do 27 hours non-stop in a treadmill, when the work done was equivalent to ten times the body glycogen reserves. In a similar experiment on an athlete, the R. Q. fell from 0.83 to 0.75, indicating use of fat (Schneider, 1939). Such experiments cannot be taken as evidence that only fat as such is being burnt, for there is biochemical evidence, that conversion of fat to carbohydrate can occur, and this is supported by the fact that Anderson & Lusk (1917) observed a rise of R. Q. in the initial stages of work under these conditions, though admittedly it was small and of short duration. Cathcart and Burnett (1926) showed in man that an effect of three days on an exclusive fat diet was to exaggerate the rise in urinary nitrogen normally associated with work. This suggests that some protein was utilised.

The experiments of Courtice & Douglas (1936) showed, that the ketosis observed during recovery was abolished by a high carbohydrate intake; but the R. Q. followed the same pattern of initial rise followed by slow fall as it did on the low carbohydrate intake although the fall was slower and less in extent. Their experiments suggest, that the ketosis was associated with restoration of the glycogen reserves, but even on a high carbohydrate diet supplemented by glucose adequate to provide calories used for work their R. Q. measurements indicate some oxidation of fat. This has also been shown in the Harvard Fatigue Laboratory, results indicating, that even with a plethora of carbohydrate some fat is utilised.

As the carbohydrate reserves diminish, the proportion of energy derived from fat increases from 8% to 77% (SCHNEIDER, 1939).

Eggleton (1936) suggests, that a high fat diet provides a suitable basis for heavy manual labour, basing this conclusion on the facts firstly that weight for weight fat provides energy in a more highly concentrated form and secondly, that it can be stored in a concentration of 80%, deriving this from the relation that body fat stores have sixteen times the potential energy of body carbohydrate stores. She says, on the other hand, that a fat diet is ill-suited to athletes as it does not provide adequate maintenance for strenuous exercise, exhaustion occurring more quickly in these circumstances than on a high carbohydrate diet; in addition, a fat diet causes a 10% decrease in efficiency. It is difficult to see the reason for her distinction, since if, as Schneider (1939) suggests, the reason why a high fat diet increases liability to fatigue is due to acidosis from the presence of keto-bodies in the blood, there is no apparent reason why manual workers should be less affected in this respect than athletes.

On the other hand, a high fat diet is certainly indicated in cold climates. Decrease in mechanical efficiency and consequent increase in heat production associated with fat intake is then useful in the maintenance of body temperature. This is no doubt correlated with the craving for fat felt in arctic climates. Such craving was noted by Cherry-Gerrard (1948) subsisting on an experimental fat-free diet in the antarctic. This author notes two important reservations – that a considerable proportion of the fat ingested was not absorbed and that his colleague Wilson, on a diet containing 8 ozs. of butter daily, found he could not eat it all.

The foregoing observations suggest that a moderate intake of fat, so long as carbohydrate supplies are really adequate, is consistent with a high performance at muscular work, the muscles appearing to use it as a fuel; excess fat should be avoided. Constant body weight may prove an adequate criterion of this. In cold climates a fairly high fat intake is indicated so long as it is not inconsistent with appetite and fairly complete absorption.

Protein

Since Liebig expressed the opinion, that protein intake and output were fundamental factors in the activity of the body, almost excessive attention has been focussed on its dietary significance with respect to work. At the present time there is no evidence that protein is utilised as a primary fuel of muscular activity and many physiologists have committed themselves to the view that a high protein intake is of negligible importance to man's performance at work.

It is not proposed to review at length the extensive and conflicting evidence derived from the influence of exercise on the urinary nitrogen output. Cathcart (1925) has reviewed the literature and concluded, that there is a small but definite rise in nitrogen excretion as a result of muscular activity. His own carefully controlled experiments (CATHCART & BURNETT, 1926) confirmed this view. He found, that on a varied series of diets which were consumed in a preliminary period until nitrogen balance had been reached, a consistent but slight rise in nitrogen output with an associated rise in urinary sulphur during and after 25,000 kgm./metres of work performed in a hour, daily for six days. The S/N rations of the excess outputs could not be directly correlated with combustion of muscle protein, except on a diet containing a high proportion of lean beef. There was no association of the rise in nitrogen turnover with any specific urinary constituent. Wilson (1932) performed experiments on similar lines consisting of three days rest followed by eighteen days work and a six–day recovery period. He found, that in general the excess nitrogen output over the basal level rose to a maximum about the 11th day of work, and then fell, reaching a level below basal by the eighteenth day of work. Cuthbertson, McGirr & Munro (1937) discovered that if work is performed shortly before a meal containing carbohydrate in quantity sufficient to cover the work utilisation of energy, the rise in urinary nitrogen noted if the work was performed shortly after meals was inhibited.

The above experimental approaches provide the basis for various theories. There are no grounds for the assumption that a rise in urinary nitrogen is due to the usage of protein as a primary fuel by the muscle – Fick & Wislicenus (1866) demonstrated, that the rise bore no possible relation to the energy used. In addition it has been clearly shown, that the energy released by the specific dynamic action of protein is superimposed upon and not utilised by the metabolism of contracting muscles (ANDERSON & LUSK, 1917).

For a long time it was thought that the increased protein catabolism was due to a hypothetical process best described as mechanical wear and tear on the muscles. If this was the case, the rise would be expected to be not only unaffected by conditioning factors such as meals, but also independent of the nitrogen content of the basal diet and simply proportional to the amount of work performed. On the other hand, Cathcart & Burnett (1926) were able to demonstrate, that the rise of nitrogen excretion is roughly proportional to the protein content of the diet, and many investigators have shown, that other factors have various effects, there being no simple relation between the increase and the amount of work done. Wilson (1932) points out, that there is often a considerable latent period between the initiation of work and the rise. This is very inconstant and such indefinite time relations alone preclude the possibility of »wear and tear« as a cause. If we are to accept modern conceptions of the dynamic nature of cellular structure, this mechanical hypothesis may be discarded.

Wilson's finding of the appearance of a phase of nitrogen retention, presumably indicating protein anabolism, after the phase of catabolism, provides a possible explanation. He suggests, that work is a primary stimulus to carbohydrate metabolism and further, that a complex linkage and interrelation of protein, fat and carbohydrate metabolisms exists. This view is supported by more recent biochemical work. The catabolic phase may be due to a generalised stimulation of catabolism metabolically linked with the specific rise of carbohydrate metabolism. The succeeding phase of nitrogen retention is probably associated with muscular hypertrophy.

Cuthbertson *et al.* (1937) have provided an alternative explanation on the basis of their experiments. They suggest, that amino-acid deamination is concerned in glyconeogenesis in the liver for the purpose of restoration of glycogen stores, and this process causes increased nitrogen excretion. This is compatible with the inhibition of the rise by a carbohydrate plethora. It seems likely, that both processes, that suggested by Wilson and that suggested by Cuthbertson *et al.* may play some part in the increased nitrogen excretion associated with muscular work.

Having established that a protein usage is associated with muscular activity our attention will be turned to some other aspects of the effect of dietary protein on performance of muscular work.

The prevalent idea of the layman and indeed of many experts, that high protein intake is necessary for the training of athletes has some foundation in that its high specific dynamic action may assist the combustion of excess body-fat in the initial stages of training. Further, Wishart's (1934) experiments on a professional cyclist provide a purely empirical basis for the idea, that a high protein intake increases performance. There was, however, a decrease in efficiency with a high protein diet. The great difficulty of controlled assessment of the value of protein in such experiments lies in its psychological effect.

For this reason the scientific basis for a high protein diet is relatively weak. Mirsky *et al.* (1938) have suggested an interesting hypothesis. They were able to show in rats that the carbohydrate reserves of the liver, if laid down on a protein rich diet, behave differently from those deposited on a diet of carbohydrate. They found, that the liver glycogen, muscle glycogen, and blood sugar of the rats on a high protein diet were much higher than those of the rats on a high carbohydrate diet, after fasts of duration 15, 24 and 48 hours respectively. The difference was also very marked after such stimuli to carbohydrate usage and general metabolism as phlorizin injections, exposure to cold, the action of dinitrophenol or the injection of paratyphus B toxin. If on the other hand the animals were fed with an excess of fat and the usual moderate dietary protein, maintenance of the glycogen reserves was not observed; the reactions must therefore be connected with the usage of protein. Further experiments showed that the recovery of the rat's glycogen reserves and blood sugar, after one or two hours swimming in a bath at 30° C. had depleted them, was much more rapid and more complete on a high protein diet than on a high carbohydrate diet. The results suggest that the availability of dietary protein assists the maintenance and restoration of glycogen reserves after depletion by muscular work, presumably by glyconeogenesis. There are as yet no grounds for assuming that the results are applicable to man, but in conjunction with Wishart's (1934) experiments they are suggestive.

It is thus concluded that an excess of protein in the diet, above that required for resting metabolism of the body, is advantageous to man's performance at muscular work for three reasons. Firstly, because an admittedly small yet definite increase in protein metabolism is associated with muscular activity; secondly, because there is suggestive evidence, that protein intake is associated with the maintenance of glycogen reserves; and thirdly, because of the psychological effect of protein in the diet, a factor of far from negligible importance.

GENERAL AND MISCELLANEOUS FACTORS

Subjective and Psychological Factors and their Significance

Austin Flint, Professor of Physiology at Bellevue Hospital Medical College, New York, pointed out in 1877, that the training diet for athletes, recognised everywhere on empirical and scientific grounds, consisted of the most nutritious constituents, in such a form as to be easily digested, and that quantity should not be limited except within the limits of good digestion. Professor J. R. Marrack, Chairman of the Nutrition Society's conference on »The Nutrition of Athletes«, July 1948, said in summary of the day's proceedings, that with regard to diet the two chief points seemed to be the provision of enough food and the choice of food which could be easily digested. It is clear, that opinions on this subject have changed little in 70 years.

Digestibility is a factor of no small importance; a man with indigestion, whether he be athlete or navvy, fails to do himself justice in the performance of muscular work. The causes of indigestion may be related to the type of food ingested or to the time of its ingestion. As to the quality of the diet, bulk and lack of balance are the operative factors. Wishart (1934) found the poorest performance of a professional cyclist associated with a large intake of a dry and bulky patent protein food-stuff, although the diet was of high energy value and comparable in actual protein content to others given; in fact, the subject was so discomforted from flatulence, that he collapsed before the completion of the experiment. It is well recognised, that ingestion of large quantities of bulky carbohydrate is often associated with flatulence and indigestion. Again, Cathcart & Burnett (1926) found they could tolerate a diet consisting solely of olive–oil for three days only, by which time it had caused practical incapacitation from digestive disturbance. Any small boy knows the effect of over–ingestion of fruit. It follows, that if any one dietary component is increased, this must be done in a way consistent with good digestibility.

The time of eating meals with respect to work is also of importance. Mild exercise facilitates digestion and increases peristaltic movements, but severe exercise just after a meal leads to indigestion. There is ample evidence that this is due to inhibition of intestinal and gastric function (e. g. ADAMS & PEMBERY, 1931; EGGLETON, 1936).

So far, these remarks on digestibility are applicable to any type of muscular activity; but while there is no evidence for the need for ingestion of food shortly before or during »no–duration« work (except in that the administration of small amounts of sugar or similar material can do no harm and may occasionally prove beneficial psychologically), there is a considerable body of evidence in favour of dietary intake during duration work. The average heavy worker would not be pleased at the suggestion that he should forego his mid–day meal; on the other hand it is seldom his main meal of the day, and he is often in the habit of taking half an hour's rest or gentle walk before embarking on the afternoon's labour, thus permitting the digestive processes to proceed. It is of interest to note, per day if provided with mid–morning and mid–afternoon snacks. Such that it has been found, that factory workers give a greater output or work examples, however, fail to provide the material for a controlled study of the necessity for dietary maintenance during prolonged work; manual labourers are never compelled to work for long periods without food. More adequate evidence for the value of dietary supplements during duration work is provided by the experiments on marathon runners already quoted. It will be noted, that the supplements were in the form of easily assimilable glucose.

Some results Wishart (1934) achieved with a professional cyclist are of interest in this connection. In one of these experiments the cyclist, who was a vegetarian, was allowed to choose his own diet and to consume it according to his custom in racing, – in small quantities at frequent intervals. He chose a diet containing easily digested foodstuffs such as milk, eggs and fruit. On this diet his work energy output was greater than any other diet tried, although it was comparable in biochemical constitution with at least one of the other diets; further, his work output was, during the final 2 hours out of 8 hours exercise, maintained at a steady level higher than that achieved in any of the other experiments. This was, however, associated with a greater drop in gross efficiency than shown in any of the other experiments. The data suggests that the main reason for this fall was a rise in the »body maintenance« metabolism. Wishart thinks, that this is correlated with the demonstration by Rubner (1910), Anderson & Lusk (1917) and Rapport (1929), that the Specific Dynamic Action of protein is superimposed on the resting and working metabolism of the body, the energy it liberates not being available for transformation into external work. On the diet administered at frequent intervals the fall in efficiency appears to occur at a greater rate than on a diet of almost the same protein content, administered at two-hourly intervals. It therefore seems possible that the waste energy is multiplied by frequent administration.

It appears to be a valid generalisation to conclude that for a man to put forward his best performance at work, his diet should not only be of a balanced and digestible nature, but also that it should be ingested in a fashion consistent with its digestion. The man, who is going to perform work of the »no-duration« type, needs no dietary maintenance near to the time of his performance. His last meal before the performance should be light and allow some time for the digestive processes to proceed unhampered, say about two hours. The man who is required to do heavy industrial work should be allowed mid-morning and mid-afternoon snacks and should not make luncheon his main meal of the day; a short gentle walk following it is beneficial. The endurance, efficiency, physical condition, and performance of a man who is required to produce a large effort extending over a long and uninterrupted period of time will be improved by a dietary supplement before he starts, and further maintenance supplements during his performance. These supplements should consist of carbohydrate in a readily assimilable form.

Digestability as a dietary factor has been considered as a subjective influence as it affects the performances in a fashion largely subjective in nature; the associated factor of absorbability is not of great significance in this respect, but this is a convenient point at which to give it brief consideration. Many of the remarks that have been made on the digestability of food stuffs are related, directly or indirectly to their absorbability. For example, the usefulness of sugar preparations as maintenance supplements is in part due to their ready absorption. Also, discomfort due to a bulky mass in the stomach is related indirectly to its non-absorption in that it cannot be absorbed until it has been digested.

The presence of certain quantities of unabsorbed constituents in the diet is necessary for the maintenance of normal bowel function. These are provided by the inclusion in the diet of vegetables and fruit.

There remains the subject of the psychological factor in diet. As the mechanisms involved are really of interest only to a psychologist, while the practical considerations are capable of general application, it is proposed to mention only the latter. As a primary consideration, the food of those required to perform muscular work of any type should be ingested in pleasant surroundings and should be well and attractively served.

It is a widespread idea that athletes as a class are notoriously susceptible to peculiar ideas about diet, but at the present time notions which cannot possibly be entertained seriously by the physiologist are the exception rather than the rule. In fact, there are cases, where the athlete knows intuitively what is most needed – the desire for sugar experienced by mountaineers and long distance runners and the desire for fat in cold climates are examples of psychological manifestations where the physiologist has been compelled to seek for, and has found, a scientific basis. The prevalent conception among athletes of the importance of high–protein foods such as beef must at least be seriously considered. Certain physiologists e. g. Bourne (1948) have expressed the opinion that the importance of a high protein diet is to be classed as an obsession and is fifty years out of date. There is, however, a considerable body of evidence to which reference has been made, that the protein factor is not of negligible importance.

Abrahams (1948) has pointed out, that long distance athletes are notoriously placid and long–suffering in temperament and that this can be correlated with a lack of interest in diet and a lower consumption of food; while sprinters and their like are generally highly strung and of a restless disposition, and finding training irksome, take larger quantities of food. In their case plenty of variety and appetising food including beer and occasionally champagne may help to ward off »staleness«, even though their actual calorie requirements for training are lower than those of the distance runner. Abrahams also stresses the fact, that many really great athletes do not seem to care what they eat. Such men, however, are not suitable material on which to base a generalisation.

Generally speaking, it would seem, that to obtain the best performance of physical effort from a man, it is necessary to superimpose such modifications as are required to keep him happy upon the diet we select as a result of physiological experiment.

Accessory and Supplementary Components of the Diet

It is a popular conception that the ingestion of vitamins improves performance at muscular work; it has also been suggested recently that increase in vitamin B complex requirement might be associated with hard muscular work (Bourne, 1948). It has been shown that deficiency of the vitamin B complex in man has an adverse affect on working ability (Johnson *et al.*, 1942; Foltz, Barborka & Ivy, 1943; Barborka, Foltz & Ivy, 1943) as has vitamin E deficiency in rats (Knowlton & Hines, 1938; Tilford, Emerson & Evans; Kokas & Borka, 1943) but it is extremly unlikely, that deficiency of these vitamins can occur on a mixed diet of adequate calorie content in man. There is evidence that performance at work is unaffected by a low intake of vitamins A or C over long periods (WALD, BROUHA & JOHNSON, 1942; HENSCHEL *et al.*, 1944). Where, however, the conditions of work are such, that the diet is severely qualitatively restricted in nature, administration of supplementary vitamins might be necessary. Cherry–Gerrard (1948) considered vitamin deficiency might have played a part in the weakening of Scott's party on their return from the South Pole. A very approximate calculation based on Fixson and Roscoe's (1938, 1940) data on the vitamin content of foods suggests, that the diet of the exploring party contains vitamins A, B and C in quantities of the order of 1,000, 200 and 500 units per day respectively; while the corresponding international standards are 4,000–5,500, 125–300, and 700–1,000 units respectively. This lends some support to his opinion.

An incredible variety of supplementary factors have been at one time and another put forward as capable of increasing output of work. Morehouse & Miller (1948) list the claim of the following as having been discounted: lecithin in eggs and soya beans, vitamin B_1 in yeast, vitamin C, liver preparations, phosphates, calcium, alkalies, oxygen, ultra–violet radiation, Coramine, Cardiazol and adrenocortical hormone.

A few supplementary factors need further consideration. The patent »Energy Foods« provide a means of obtaining calories in an expensive and usually unpalatable and indigestible form. If additional calories are required, sugar and glucose take first place among the possibilities. Eggleton (1948) has stressed, that creatine administered as gelatine in the form of additional meat checks the excretion of phosphate, implying that additional creatine phosphate is thus available in the muscles. It has, however, been shown that glycine administered as gelatine on the basis that it increases the formation of creatine in the body, is entirely without effect on the composition of muscle (HORVATH, 1942). The evidence is far from clear on this subject (c. f. KEYS, 1943) but is sufficient to show that any effect occurring is not only minor but extremely inconstant.

Excessive loss of body water as sweat in muscular exertion entails concomittant loss of sodium and if »miner's cramps« are to be avoided the replacement of body water must be accompanied by replacement of body salt. This is achieved to some extent by the inclusion of fruit and vegetables in the diet and by culinary salt. If, however, large quantities of fluid are ingested they should contain a small proportion of salt.

It has been shown, that in exercise muscles lose potassium as fatigue develops and that the injection of potassium chloride delays muscular fatigue and restores the working capacity of fatigued muscle (HOFF, WINKLER & SMITH, 1941). The body has no potassium reserves wherewith to replace any loss and hence ample amounts should be provided in the diets. It is suggested, that the requirements with respect to sodium and potassium may be readily met by the inclusion of plenty of fruit and vegetables in the diet and the ingestion of some proportion of beer in the fluid intake. The effect of fruit is also useful in that it tends to increase the alkali reserve which is thus capable of neutralizing concentrations of lactic acid and keto-bodies produced during muscular activity without impairment of the respiratory function of the blood.

Ingestion of small amounts of caffeine in tea and coffee, and of theobromine and theophylline in cocoa can do little harm and possibly benefit performance at work by their action as psychic, motor and sensory stimulants. They should, however, be avoided in excess as there is some evidence that they may then effect the performance adversely and they may cause insomnia. Similar provisions apply to alcoholic beverages. In moderate amounts they may be useful psychologically or as a mild sedative, for example, for a nervous athlete before the race, but if they are taken in excess, performance will be decreased owing to the depressant action of alcohol on the brain. The importance of alcohol in moderate quantities as a source of calories is probably negligible.

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References

1. *Abrahams, A.:* Brit. med. J., *11* (1948) 219.
2. *Adams, T. W., Pembery, M. S.:* J. Physiol., *72* (1931) 1.
3. *Anderson, R. J., Lusk, G.:* J. Biol. Chem., *32* (1917) 421.
4. *Barborka, C. J., Foltz, E. E., Ivy, A. C.:* J. Amer. med. Ass., *122* (1943) 717.
5. *Benedict, F. G., Cathcart, E. P.:* Publ. Carneg. Instn., No. 187, 1913.
6. *Bourne, G. H.:* Brit. med. J., *11* (1948) 219.
7. *Cathcart, E. P.:* Physiol. Rev., *5* (1925) 225.
8. *Cathcart, E. P., Burnett, W. A.:* Proc. Roy. Soc. B., *99* (1926) 405.
9. *Cherry-Gerrard, A.:* The Worst Journey in the World, Harmondsworth, Penguin Ed.
10. *Christensen, E. H., Hansen, E.:* Skand. Arch. Physiol., *81* (1939) 160.
11. *Courtice, F. C., Douglas, C. G.:* Proc. Roy. Soc. B., *119* (1936) 381.
12. *Cuthbertson, D. P., McGirr, J. L., Munro, H. N.:* Biochem. J., *31* (1937) 2293.
13. *Dill, D. B., Edwards, H. I., Talbott, J. H.:* J. Physiol. *77* (1932) 49.
14. *Eggleton, M. G.:* Muscular Exercise, Paul, London, 1936.
15. *Eggleton, P.:* Brit. med. J., *11* (1938) 219.
16. *Fick, A., Wislicenus, J.:* Phil. Mag., *31* (1866) 485.
17. *Fixsen, M. A. B., Roscoe, M. H.:* Nutr. Abstr. Rev., *7* (1938) 823.
18. *Fixsen, M. A. B., Roscoe, M. H.:* Nutr. Abstr. Rev., *9* (1940) 795.
19. *Flint, A.:* J. Anat., *12* (1877) 91.
20. *Foltz, E. E., Barborka, C. J., Ivy, A. C.:* J. Amer. med. Ass., *121* (1943) 1411.
21. *Garry, R. C., Wishart, G. M.:* J. Physiol., *72* (1931) 425.

22. *Gemmill, C. L.:* Physiol. Rev., *22* (1942) 32.
23. *Henschel, A., Taylor, H. L., Brozek, J., Mickelsen, O., Keys, A.:* Amer. J. trop. Med.,*24* (1944) 259.
24. *Herxheimer, H.:* Grundriss der Sportmedizin, Leipzig, Thieme, 1932.
25. *Himwich, H. E., Rose, M. I.:* Amer. J. Physiol., *88* (1929) 663.
26. *Hoff, H. E., Winkler, A. W., Smith, P. K.:* Amer. J. Physiol., *131* (1941) 615.
27. *Horvath, S. M.:* Amer. J. Physiol., *138* (1942) 254.
28. *Johnson, R. E., Darling, R. C., Forbes, W. H., Brouha, L., Egana, E., Graybird, A.:* J. Nutrit., *24* (1942) 585.
29. *Keys, A.:* Fed. Proc., *2* (1943) 164.
30. *Knowlton, G. C., Hines, H. M.:* Proc. Soc. exp. Biol., *38* (1938) 665.
31. *Kokas, E., Borka, B.:* Pflüg. Arch. ges. Physiol., *246* (1943) 158.
32. *Marrack, J. R.:* Brit. med. J., *11* (1948) 219.
33. *Meyerhof, O.:* Pflüg. Arch. ges. Physiol., *175* (1919) 88.
34. *Mills, J. N.:* J. Physiol., *93* (1938) 144.
35. *Morehouse, L. E., Miller, A. T.:* Physiology of Exercise, St. Louis, Mosby, 1948.
36. *Mirsky, A., Rosenbaum, I., Stein, L., Wertheimer, E.:* J. Physiol., *92* (1938) 48.
37. *Rapport, D.:* Amer. J. Physiol., *91* (1929) 238.
38. *Rubner, M.:* S. B. preuss. Akad. Wiss., *16* (1910) 316.
39. *Schneider, E. C.:* Physiology of Muscular Activity, Philadelphia, Saunders, 1939, 2nd Ed.
40. *Tilford, I. R., Emerson, G. A., Evans, H. M.:* Proc. Soc. exp. Biol., (1939) 291.
41. *Wald, G., Brouha, L., Johnson, R. E.:* Amer. J. Physiol., *137* (1942) 551.
42. *Wilson, H. E. C.:* J. Physiol., *75* (1932) 67.
43. *Wishart, G. M.:* J. Physiol., *82* (1934) 189.

Sadržaj

UTJECAJ DIJETETSKIH FAKTORA NA MIŠIĆNI RAD

I. Eksperimentalni rad s ljudima

Kod nekih vrsta mišićnog rada nastoji se postići maksimalni efekt bez obzira na faktor izdržljivosti, dok je kod drugih vrsta mišićnog rada bitno, da se održi optimalni efekt kroz određeno vremensko razdoblje. Prvi tip rada često nalazimo u sportu, a s drugim se tipom susrećemo u svakodnevnom životu i shvaćamo ga radom u užem smislu riječi.

Kad ispitujemo utjecaj dijetetskih faktora na mišićni rad, radije biramo rad, kod kojeg se postižu maksimalni efekti, jer su eksperimentalni uvjeti pritom znatno bolji. Uz konstantne fizikalne i psihološke uvjete maksimumi će doista zavisiti samo od dijete, i to od njezinih kvalitativnih i kvantitativnih komponenata, kao i od njezine probavljivosti i vremena administracije.

Kao jedinica za izvršeni rad uzima se postignuti broj kgm u jedinici vremena. Mehanički radni efekt izražavamo procentima odnosa energije potrošene za taj rad prema ukupno utrošenoj energiji.

Dobro je, da se dijeta, koju želimo ispitati, primijeni već nekoliko dana prije početka pokusa, a vrlo je važno, da ispitanik bude unaprijed treniran za određenu vrstu rada.

II. Izvor energije za mišićnu kontrakciju

Iz rezultata pokusa s izoliranim mišićima izlazi, da su ugljikohidrati jedini izvor mišićne energije.

Iz eksperimentalnih radova s ljudima je međutim jasno, da i masti igraju znatnu ulogu. R. Q. raste za vrijeme teškog mišićnog rada do 1,0, a zatim, ako se rad dosta dugo nastavlja, pada na 0,75. Aktivni mišić troši ugljikohidrate kao primarni izvor energije. Ako se teški mišićni rad nastavlja, mišić postepeno prelazi na potrošnju masti. Izgaranje masti traje još i za vrijeme periode oporavljanja. Do mobilizacije masti dolazi, čim se isprazne glikogenske rezerve.

III. Individualni dijetetski faktori

Kaloričku upotrebu za vrijeme mišićnog rada možemo rastaviti na tri komponente:

— kalorije potrebne za bazalni metabolizam,

— kalorije potrebne za održavanje ostalih funkcija u vezi s radom,

— kalorije potrebne za vršenje samog rada.

Dok su prve dvije komponente vrlo individualne, na treću komponentu otpada razmjerno malen broj kalorija.

Konstantna tjelesna težina je možda najbolji indikator, da hrana zadovoljava što se tiče kalorija. Pri pristupanju novom radu mora proći određeno vrijeme, prije nego dođe do balansa tjelesne težine. Kad je ravnoteža jednom uspostavljena, svaki gubitak i povećanje tjelesne težine utječe negativno na radnu sposobnost.

Ugljikohidrati

Već dugo postoji mišljenje, da je visoka količina ugljikohidrata u dijeti primarni faktor za izvršavanje mišićnog rada.

Kod teškog mišićnog rada potrebna je dijeta sastavljena od 50% ugljikohidrata.

Masti

O ulozi masti u mišićnom radu postoje još oprečna mišljenja. Dok neki smatraju, da je rad, koji se vrši s isključivo masnom hranom, jednako vrijedan, drugi smatraju, da je pod tim uvjetima mehanički efekt 10% niži.

Visoka masna rezerva važna je pod uvjetima niske temperature, kod plivača i dugotrajnih napora, gdje brzo dolazi do iscrpljenja glikogenskih rezervi.

Kod niske temperature poželjan je manji mehanički efekt na račun povećane produkcije topline.

Općenito se može preporučiti umjereno uživanje masti uz adekvatnu količinu ugljikohidrata.

Proteini

Poznato je, da povećanu mišićnu aktivnost prati povećano trošenje bjelančevina. Naučna baza za visoku proteinsku dijetu je međutim još uvijek vrlo labava. Dodatni proteini u hrani mogli bi se dodati zbog toga:

što povećanu mišićnu aktivnost prati malo povećanje potrošnje bjelančevina;

što se čini, da održanje glikogenskih rezerva zavisi od količine proteina;

što proteinska hrana izaziva pozitivni psihološki efekt.

IV. Ostali faktori

Uz kvalitetnu i kvantitetnu kontrolu prehrane važno je odrediti probavljivost hrane kao i vrijeme administracije.

Radi li se o kratkotrajnom naporu, najbolje je, da se posljednji obrok, sastavljen iz lako probavljive hrane, uzme dva sata prije početka samog rada.

U industriji se preporučuje uzimanje hrane prije samog početka rada i u toku rada u razmjerno čestim intervalima.

Poželjno je, da se hrana uzeta u toku rada sastoji iz lako probavljivih ugljikohidrata.

Uloga je vitamina mnogo proučavana u dijetetici mišićnog rada, ali su efekti, ako su i nađeni, vrlo maleni i nepostojani.

Kofein, teobromin i teofilin djeluju u malim dozama stimulirajući. Isto vrijedi i za male količine alkohola.

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