NOTE ON THE INFLUENCE OF DIET ON THE ENERGY EXPENDITURE IN WORK.

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INTRODUCTION.

In 1918, Cathcart and Orr (1919) (1) conducted an investigation to determine the energy expenditure of the infantry recruit in training. Some observations which were made in the course of the investigation seemed to indicate that the amount of energy expended per unit of work is influenced by the nature of the preceding meal. It was impossible during the course of the inquiry, owing to its urgency, to devote more time to this question, but the few results obtained seemed to warrant further investigation, and the experiments recorded here were therefore carried out.

NATURE AND METHODS OF INVESTIGATION.

Following the taking of food there is a stimulation of metabolism which is shown by an increased heat production in the body. Thus in a subject at rest after a very high protein meal the heat output may be almost fifty per cent higher than in the preceding post-absorptive state, i.e., when food is not being absorbed from the intestine. The increase is somewhat less after a high carbohydrate meal and least after a high fat meal. When work is done there is of course an extra heat production due to the work.
82 Influence of Diet on the Energy Expenditure in Work

In work after a meal therefore there is in addition to the basal metabolism, i.e., the rate of metabolism at rest in the post-absorptive state, an increased metabolism due to food and a further increase due to work.

The object of the investigation was to determine (1) whether there is a simple summation of extra metabolism due to food and extra metabolism due to work, or (2) whether the energy evoked due to food is available for work production, or (3) whether the increased rate of metabolism due to food involves also an increased rate in the additional metabolism due to work.

As the energy yielding constituents of food affect the rate of metabolism to different degrees and possibly by different means, it was necessary to determine the energy expenditure on a constant amount of work in different experiments in which either protein, fat or carbohydrate predominated in the preceding meal. To obtain a common basis of comparison the resting metabolism and the energy expenditure on the given amount of work were determined in the post-absorptive state immediately before the meal in each case. The procedure was as follows: In the morning about fifteen hours after the last meal, the subject being in the post-absorptive state, the resting metabolism—ten-minute periods—and immediately thereafter the energy expenditure—four-minute periods—on the fixed rate of work were determined. The meal was then taken, and after an interval of ninety minutes the resting metabolism and the energy expenditure on the work were again determined.

The work consisted of marching along a corridor at the rate of 100 yards per minute. In covering the measured distance a uniform rate of stepping of 120 per minute was maintained. The subject was allowed to march for a preliminary period of ten minutes to ensure that a uniform rate of progression had been reached before the sample of expired air was drawn.

The energy expenditure was estimated by the indirect method of calorimetry. The expired air was collected in a Douglas bag, and the analysis done with Haldane's apparatus. The oxygen figures and the Zuntz values were employed in calculating the results. The complete apparatus and method of calculation were as described by Cathcart (1918).

The test meals had each 50 grammes of oatmeal, to which was added for the high protein meal 100 grammes "plasmon" (about eighty per cent casein), for the high carbohydrate 80 grammes of cane sugar, and for the high fat 35 grammes margarine. The protein and carbohydrate meals had each about 540 calories, the fat about 480. Preliminary trials had shown that the subject would not eat more than thirty-five grammes of margarine at once without complaining of nausea.

Experimental Data.

The only figures discussed are those showing the energy expenditure on the work. To reduce the size of the table, only the number of calories
and the respiratory quotients are given. From these the O₂ and CO₂ figures can be calculated. Each result for lying is the average taken with an interval of a few minutes.

**SUBJECT:** T. B., aged 26; **Weight,** fifty-seven kilograms; **Height,** 5 feet 4½ inches.

<table>
<thead>
<tr>
<th>Date</th>
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<th>Marching</th>
<th>Increase due to work</th>
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</thead>
<tbody>
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<td>Calories per minute</td>
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</table>

The following table gives the averages of the results obtained in the post-absorptive state and after the meals:

**AVERAGES IN CALORIES PER MINUTE.**

<table>
<thead>
<tr>
<th></th>
<th>Lying</th>
<th>Marching</th>
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</thead>
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<td>Net</td>
<td>Gross</td>
<td>Net</td>
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<tr>
<td>Carbohydrate</td>
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<td>4.82</td>
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<tr>
<td>Protein</td>
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<td>4.99</td>
</tr>
<tr>
<td>Fat</td>
<td>1.06</td>
<td>4.65</td>
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<table>
<thead>
<tr>
<th></th>
<th>Lying</th>
<th>After meal</th>
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<tbody>
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<td>Net</td>
<td>Gross</td>
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</tr>
<tr>
<td>Carbohydrate</td>
<td>1.29</td>
<td>4.94</td>
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<td>Protein</td>
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<td>5.27</td>
</tr>
<tr>
<td>Fat</td>
<td>1.69</td>
<td>4.96</td>
</tr>
</tbody>
</table>
Influence of Diet on the Energy Expenditure in Work

Discussion of Results.

The individual results show considerable variation under what are as nearly as possible identical conditions. It is impossible to march in an absolutely straight line or to lift the foot the same height at every step. Even in lying differences in the degree of tension of the muscles and involuntary movements give rise to variations in the energy expenditure. In view of these variations the average results of such a comparatively small number of experiments must be regarded with caution. Certain points are however brought out sufficiently clearly to warrant discussion.

The average gross heat production in marching in the post-absorptive state is 4·89 calories per minute. After meals the average is 5·06 calories. After the protein meal the gross energy expenditure is 5·27 calories per minute as against 4·94 and 4·96 for carbohydrate and fat respectively. An increase in the gross heat production following the ingestion of protein is noted by Cathcart and Orr (1919) (3). The net energy expenditure due to work following the different meals is shown by the following table:

<table>
<thead>
<tr>
<th>Meal</th>
<th>Increase due to work in post-absorptive state</th>
<th>After meal</th>
<th>Differences</th>
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<tr>
<td>Protein</td>
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<tr>
<td>Carbohydrate</td>
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<td>3·65</td>
<td>− 0·06</td>
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<tr>
<td>Fat</td>
<td>3·77</td>
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<td>− 0·00</td>
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</table>

Protein.—After the high protein meal the increase due to the work is 3·96 calories, as compared with 3·86 in the preceding post-absorptive state. There is thus more than a summation of extra metabolism due to food and that due to work. There has been an increased rate in the additional metabolism due to work causing a greater heat production per unit of work.

Carbohydrate.—The increase due to work is here 3·65 calories per minute, as compared with 3·71 in the preceding post-absorptive state. The heat output per unit of work is thus 0·06 calories per minute less after the meal. Either the muscles work more economically with carbohydrate as fuel or part of the increased metabolism due to food is available for work production.

Fat.—After the high fat meal there seems to be a simple summation of extra metabolism due to food and that due to work.

Rubner (1910) investigated the influence of diet on work. On a diet of 600 grammes cane sugar the increase due to work (100,000 kilogrammetres) was 845 calories. On a high protein diet the increase was 855 calories. This is a smaller difference than that obtained by us. The small difference obtained by Rubner is probably due to the fact that he dealt with the twenty-four-hour periods. After the ingestion of carbohydrate the increase in metabolism is of comparatively short duration from three to seven hours, varying with the amount given and the previous diet: Magnus-Levy (1894), Gephart and Du Bois (1915) and others. The increase following protein ingestion on the other hand is much more prolonged. Cathcart and Orr (1919) (3) found that the
stimulus due to ingestion of protein was continued into the post-absorptive state, i.e., over fifteen hours after food. The post-absorptive heat output after a high protein diet was 44.8 calories per square metre as against 35.6 after carbohydrate and 40.9 after a mixed diet. This observation has been confirmed by Krogh and Lindhard (1920). In a twenty-four-hour period therefore the work is superimposed not upon the highest point of the rise due to carbohydrate, but on an average rise of twenty-four hours, which would include a period of low metabolism; whereas in the case of the protein the rise due to food being more prolonged, the work would be superimposed upon an average that would approximate more nearly to the maximum-rise. That this explanation seems valid is shown by the fact that the increase in resting metabolism found by Rubner due to the ingestion of 600 grammes cane sugar is only 2.4 per cent, whereas the average increase found in these experiments, in which the determination was made for a short period on the second hour after eating, is 20.6 per cent. As the net expenditure of energy, i.e., the amount expended on the work alone, is the gross expenditure minus the resting expenditure, the low output at rest found by Rubner after the ingestion of the carbohydrate gives a high figure for the increase due to work on carbohydrate diet, and makes it approximate to that found on the protein diet.

Benedict and Murschhauser (1915) found that "the heat production per unit of work is practically independent of the taking of food." They note, however, an increase in the heat production per unit of work with the protein diet as compared with the carbohydrate diet, amounting to approximately nine per cent on the low speed (about 70 metres per minute) and to three per cent on the high speed (110 to 140 metres per minute). The percentage increase obtained in our experiments is approximately 8.5 per cent at 100 yards per minute.

A very marked reduction in the heat output per unit of work after carbohydrate as compared with the preceding post-absorptive state has been shown by Anderson and Lusk (1917). In a dog after taking 70 to 100 grammes of glucose the increase due to work was 0.550 kilogram-metres per kilo body weight per metre travelled as against 0.530 in the previous post-absorptive state and 0.587 following the ingestion of meal.

Since these experiments were completed, Krogh and Lindhard (loc. cit.) have shown by a series of excellently conducted experiments that in the post-absorptive state the output of heat per unit of work is markedly less following a heavy carbohydrate diet than following a fat diet. They conclude that work is more economically performed on carbohydrate than on fat, and suggest as a reason that fat may be changed by an exothermic process to some body allied to carbohydrate before being catabolized. Whether the reason given for the difference be correct these results certainly show that for work production fats and carbohydrates are not isodynamic.

In the present experiments where the work was superimposed about the highest point of metabolism following food ingestion, the reason for
Influence of Diet on the Energy Expenditure in Work,

the different result following the different meals may partly be due to the different nature of the stimulus produced by the food.

The specific dynamic action of protein has been shown by Lusk (1913) to be due to a direct chemical stimulus produced by certain amino-acids. This stimulus seems to persist during work, causing an increased rate on the additional metabolism due to work. In the case of carbohydrate and fat the stimulus following ingestion of food appears to be due to a plethora of metabolizable material, Lusk (1917). The increased consumption of material during work would reduce the relative excess and as the muscles tend to metabolize the carbohydrates first (Lusk, loc. cit.), the increase due to this constituent would tend to disappear earlier than that due to fat, so that the gross output on work following a high carbohydrate meal and consequently the net output would tend to be less than following a fat meal.

It should be noted that these conclusions are drawn from data obtained from work in the second and third hour after food, and further that the work is of short duration, not more than half an hour including the preliminary period. They are therefore not comparable with results obtained at a different period relative to ingestion of food, or after a long period of work during which the plethora of metabolizable material causing the rise in metabolism after food would tend to have disappeared.

SUMMARY.

(1) The expenditure of energy per unit of work performed is influenced by the nature of the preceding meal.

(a) Following a high protein meal the increase due to work is greater than in the preceding post-absorptive state.

(b) Following a high carbohydrate meal the increase due to work is less than in the preceding post-absorptive state.

(c) Following a high fat meal there appears to be a summation of extra energy expenditure due to food and that due to work.

(2) It is suggested that the difference in the results obtained in these three cases is due to a difference in the mechanisms of stimulation involved in the increase of metabolism following the ingestion of protein and of carbohydrate and fat.

REFERENCES.


(2) Idem. Ibid., p. 51.

(3) Idem. Ibid., p. 11.


RUBNER (1910). Sitzungsberichte d e r  p r e u ß i s c h e n A c a d e m i e d e r Wissensc a f t e n, vol. xvi, p. 316. Cited by Lusk.