

An Experimental Study of Rationing

MEDICAL RESEARCH COUNCIL

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**AN EXPERIMENTAL STUDY
OF RATIONING**

by

R. A. McCANCE and E. M. WIDDOWSON

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PREFACE

The experiment described in this report, on the effect on health of drastic food rationing, was begun at the outbreak of war in September, 1939, and was completed early in 1940. Because of the war-time implications of the research, a brief account of it was circulated as an official paper in March, 1940, to various Government Departments concerned with the subject. In January, 1941, the Medical Research Council proposed to publish a full report, and this was accordingly set up in type and proof copies were again circulated to Government Departments. Certain of the latter, however, raised objections to its publication at that time; and these objections were maintained when the question was once more raised by the Council at a later stage in the war. This unusual imposition of censorship on the results of medical research work ended with the termination of hostilities, and the report can now be published for its scientific interest. It is important to realise that the work here recorded has been in print for five years, *and that statements made at the beginning of that period are reproduced without alteration.*

When Dr. McCance informed the Council in September, 1939, that he proposed to make this investigation, he indicated that, with Miss Widdowson, he intended to study on human beings the effect of a diet (a) which might be available under conditions of war, and (b) at which we ought to aim as a minimum even if the country were in dire straits as a result of the enemy blockade. It will be seen, therefore, that the planning of the work involved some prophecy as to what might happen with regard to feeding arrangements in the war. We can now look back and see how closely the prophecy tallied with reality.

It is interesting to note, in the first place, that the experimental diets were planned to meet much more serious blockade conditions than were actually experienced in the war. Allowing for this, the similarity of the experimental diet to the war dietary is close. Thus, in both the experimental and the war diets, bread, potatoes and other vegetables were unrationed. Under the conditions envisaged by McCance and Widdowson, however, smaller quantities of wheat would have been imported for the production of the same amount of bread, since the test subjects ate a browner bread, made of 92 per cent. extraction flour, as compared with the war-time national flour of 85 per cent. extraction. The experimental subjects ate large quantities of potatoes, and, indeed, during periods of strenuous exercise their consumption of these was enormous—up to 3 lbs. a day in one case. There seems little doubt that, if the country had suffered blockade to the extent foreshadowed by the McCance and Widdowson experiment, a high degree of health and vigour could have been maintained only by growing far larger quantities of potatoes, and probably of other vegetables, than were in fact produced. As regards rationed foods, the McCance and Widdowson diets were more restricted. Thus, the subjects were allowed 4 oz. of fat and 5 oz. of sugar weekly; the war-time rations were 8 oz. of fat, 8 oz. of sugar, and some jam. Again, the milk allowance was only 35 oz. per week, i.e. less than 2 pts., as compared with the 2 pts. up to unrestricted amounts allowed during the war period; and the experimental diets did not contain any dried separated milk, as did the war dietary. Cheese allowance was 4 oz. weekly, as compared with 4 and later 3 oz. in the war dietary. The total amount of meat, fish, poultry and rabbit in the McCance and Widdowson diet was 16 oz. per week—an amount which was clearly smaller than that obtained on the 1s. 2d. ration, together with 3 to 6 oz. of bacon plus unrationed fish, poultry and rabbit. It will be agreed, therefore, that the experimental diet was

generally the more severe, and would have required the importation of much smaller quantities of food than were actually achieved during the war period. In spite, however, of all these conditions, the experimental subjects, at the end of the feeding period of three months, were very fit and could carry out satisfactorily, and without undue fatigue, most severe exercise tests, requiring a very high expenditure of energy.

The results of this interesting work thus indicate that young adults, at least, could have maintained a high standard of health under dietetic conditions much more austere than those actually experienced in the war. What would have happened to children and old people under these dietary conditions is not known, but it is probable that those who could eat the food allotted would have maintained good health. Although the diet, on the basis of ordinary peace-time food standards, might be regarded as unattractive, the fact is that the food was enjoyed by the subjects. So much was made of aestheticism in food questions before the war that this lesson, reiterated by the present investigation, is timely—namely, that, if normal people are living under conditions of stress and qualitative restriction of food, a diet which is biologically good need not be attractive, nor need it be varied, in order to be compatible with the best health. A lesson of this kind is clearly still of the greatest importance, when it is necessary to feed a large portion of the population of the world, in order to maintain life, on food mixtures which are restricted in variety and amount. It is well that we should be reminded again how greatly food can be simplified and yet remain compatible with excellent health, so long as it conforms to certain well defined nutritional principles.

The Medical Research Council recognise that research work of this kind can be carried out only under conditions of much personal inconvenience, which require the highest individual discipline. They wish, therefore, to express thanks to Professor McCance and Miss Widdowson, and all those who submitted themselves to these studies; and to congratulate them on their important and successful contribution to basic knowledge of nutrition. The unequivocal results obtained must have provided solid scientific support to those responsible for feeding the country during the war.

MEDICAL RESEARCH COUNCIL,

38, Old Queen Street,

Westminster, S.W.1

2nd January, 1946.

AN EXPERIMENTAL STUDY OF RATIONING

BY

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(FROM THE DEPARTMENT OF MEDICINE, UNIVERSITY OF CAMBRIDGE)

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ORIGIN AND OBJECTS

As soon as war broke out and it became clear that within the next few years all Europe was likely to be faced with severe nutritional exigencies, it occurred to us that in this fight for food, as in so many other fields of human endeavour, scientific experimentation might help to win the day. We felt that it might be useful to create artificially, and within a small and manageable compass, the state of affairs likely to arise later upon the grand scale. The data could then be examined before the artificial situation had become a reality, and while there was still time to profit by a study of the experimental findings. We therefore decided, since we had the necessary facilities at our disposal, to carry out such an experiment; and its description forms the basis of the present report. The experiment was finished at the end of January 1940, just as rationing was being introduced into this country, and the report was written soon afterwards. Since that time many of the changes envisaged by us have come to pass, but we have found no reason to modify our conclusions and only very minor alterations have been made in preparing the report for publication.

In designing our investigation we were guided by three general principles. We felt, firstly, that the study should be arranged with special reference to these islands; secondly, that in order to get results within a reasonable length of time the conditions should be severe: thirdly, that normal men and women—but not in the first instance children—should be employed as the subjects, and that their health should not be endangered by the proposed régime. With these considerations in mind, we decided to pretend that the importation of foodstuffs into this country was gravely curtailed, and to adopt the principles of rationing which were in force between 1917 and 1919, but to make the actual restrictions more severe. The result of this was to produce a diet which was in many particulars very restricted indeed, but which was not limited in calories and which was thought to be biochemically satisfactory. We planned, by arranging the experiment like this, to find out how normal persons reacted to such a diet, and hence to be able to forecast to some extent its effects upon the general population. We hoped in this way to be able to devise or suggest means of improving the diet should it turn out to be unsatisfactory, and possibly even to be able to advise those responsible for the nation's food supplies on how best to make use of the available acreage and tonnage. Finally, we wished, if it were possible, to be able to reassure the general population that rationing, if carried out along these lines, should not be prejudicial to health.

DESCRIPTION OF THE EXPERIMENT

Preliminary Outline

After a preliminary week of ordinary food, eight people were subjected to the experimental (restricted) diets for periods varying from 2 weeks to 3½ months. During the preliminary, the experimental, and in certain cases the post-experimental weeks, the subjects weighed all the food which they ate, noted how they enjoyed it, what effects it had upon them, and whether they felt fit. In the preliminary and certain subsequent weeks six of the subjects collected their excreta for investigation and for chemical analysis. Laboratory tests of their nutritional fitness were carried out from time to time on the long-term subjects, and towards the end of the experiment field tests were applied. These consisted of mountaineering and of long distance cycling.

The Subjects

Anyone who has attempted to perform an experiment such as this will appreciate at once that it was not merely a matter of biochemistry. It was rather an attempt to record people's mental and physical responses to a diet which promised to be very much less appetising and possibly less nutritious than that to which they had been accustomed. It was, in short, a study in human behaviour under stress; and in consequence it is impossible for outsiders to appraise the results without some inkling of the character and previous history of the subjects.

Miss B. was a graduate of Cambridge University. Her age was 24 and she was healthy. Where physical endurance and bodily discomfort were concerned she had plenty of that indefinable quality known as "guts," but she was rather apprehensive about this experiment and a little unwilling to undertake it. She prepared us for trouble later by announcing that we "needed a grumbler to balance the party."

H., aged 21, was a medical student and graduate of Cambridge University who had had an excellent academic record and was then just commencing his clinical work. He was physically fit and mentally stable. He was unknown to us till the experiment began, and was invited to participate on the suggestion of a friend. He volunteered to do so without cavil and was with us to the end. He did not take part in the balance experiments.

R., aged 25, was a graduate of Cambridge University with a first-class academic record, three years' research and a Ph.D. to his credit. He had been brought up as a semi-invalid—see p. 44—but he was studying medicine when the war began, volunteered to co-operate in the experiment, and took part meticulously in both the dietary and balance work.

C., aged 22, was a graduate of London University, engaged in research at Cambridge when war broke out. He was athletic, rowed regularly in his College boat, practised jujitsu and led a very strenuous life. Hearing about the experiment, he volunteered to try whether he found the food as satisfactory as his normal

diet. We had the benefit of his co-operation for one preliminary and four experimental weeks.

Miss T., aged 23, was a recently qualified doctor who had not had any previous experience of this kind of experimental work, but who offered to try the diet for a short time and to carry out the balance experiments.

Mrs. G. was a lady, aged 70, who was known from previous observation to eat very sparingly and who was asked to take part in the experiment for a short time to let us see what difference the restrictions made to her dietary habits. She was active and healthy, but some years before she had had trouble with a gall stone, for which she was still being dieted. She weighed her food for a preliminary and for two experimental weeks.

Miss W. and M., the instigators of the experiment, were aged 32 and 40 respectively, and each was physically fit and in the habit of leading an active life. They both had considerable experience of human experiments, and were accustomed to using themselves as subjects. They considered the diet likely to be biochemically satisfactory, and embarked upon the régime without apprehension or enthusiasm.

The Rations

It was inevitable that the forecasting of dietary exigencies, and therefore the design of an experiment such as this, should have been largely a matter of guess work. We did our best, however, to make it a matter of intelligent guess work, and with the assistance of Prof. Engledow, we based our rations firstly upon the experiences of the first World war, secondly on the 1938-39 agricultural position, and thirdly upon the scientific knowledge of nutrition available in 1939. Table I summarises the experimental rations adopted; they are discussed in detail below.

TABLE I
A Summary of the Experimental Rations

	<i>Quantities in ounces per week.</i>
Bread	Unrationed
Meat (edible portion, including offal and sausage meat) ..	
Fish	} 16
Poultry and rabbit	
Cheese	
Butter	4
Margarine	0
Cooking fat	4
Total fats	4
Sugar (including jam, marmalade, etc.)	5
Oatmeal	2
Rice	4
Dried pulse	10
	(could have been omitted).
Eggs (No.)	1
Whole milk	35
Potatoes and other vegetables	Unrationed
Fruit	6
	(home grown, e.g. apple).
Sweets and pastries	0

(a) *Meat, Bacon, Fish, etc.*—We decided that our consumption of meat, offal, poultry, bacon and fish together should not exceed 1 lb. of edible raw material per person per week; and further, that not more than 2 oz. of this should be bacon and not more than 4 oz. fish. This figure for bacon was chosen to make it accord with the amounts produced in this country in 1938. In 1934 about 11 oz. of fish per person per week were available, so that our figure allowed for a considerable reduction in landings, due to enemy action in the North Sea and to trawlers being commandeered for patrol work. Fresh pig meat was prohibited altogether, since it was considered that all the carcasses would be required for bacon. For the same reason, pork sausages were not allowed. If beef sausages were eaten, two-thirds of their weight was to be reckoned as meat and to be included in the weekly ration. In 1918 the meat ration was about 1½ lbs. of purchased weight per person per week. Poultry, game, rabbits, fish, sausages, etc., were not rationed at that time.

(b) *Eggs.*—According to the League of Nations (1937) and the Market Supply Committee, the egg consumption in this country before the war was of the order of three per person per week. Of these, two were home produced. We assumed that difficulties in importing enough feeding stuffs would limit the poultry population and that foreign eggs would be unobtainable. Our ration therefore was fixed at one egg per person per week.

(c) *Milk.*—The pre-war consumption of milk in this country was of the order of half a pint per person per day. This was all home produced, but the cows were fed very largely upon imported feeding stuffs. If the country were really *in extremis*, there is little doubt that many of the cattle would have to be killed off and the supplies of milk would be reduced. We therefore fixed our ration at a quarter of a pint per person per day (35 oz. per week). We originally planned to make this up from dried milk only, thus stressing the value we placed upon dried milk as an import, and at the same time leaving, in imagination, all the fresh milk for the children. We decided not to do so, however, because the supplies of dried milk, whether from home or abroad, were too small to be seriously considered as a national supply.

(d) *Butter, Margarine and Cooking Fats.*—We assumed that no butter could be obtained from abroad and that no home-produced milk could be spared for butter manufacture. We therefore excluded butter from our rations altogether. We expected that some whale oil and red palm oil would be available for margarine, but to make the experiment severe, and more interesting scientifically, we decided to limit ourselves to half the butter-cum-margarine ration imposed during the last war. Furthermore, to make conditions still more stringent we assumed that no cooking fats would be available. We there-

fore limited ourselves to 4 oz. of margarine per person per week, no butter, and no fat for cooking other than the small amounts rendered out of our meat. We used throughout a margarine to which no vitamins had been added, since we wished to find out whether the natural supplies were sufficient.

(e) *Cheese*.—The consumption of this commodity per head in the United Kingdom before the war was of the order of 3 oz. per week, of which about 1 oz. was home produced. We argued that if home-produced milk was not available for butter, it would not be available for cheese manufacture, and that therefore the British production of cheese would fall. We considered, however, that cheese was one of the most valuable foods which could possibly be imported, and that a plentiful supply could probably be obtained from the Dominions. We therefore decided to encourage its importation by fixing our allowance at 4 oz. per head per week.

(f) *Sugar*.—We assumed that no sugar was being imported and we calculated from the figures published by the League of Nations (1937) and the Market Supply Committee that this country could produce about 8 oz. of sugar per person per week. We allowed for a considerable falling off in home production capacity in war time and fixed the weekly ration of this commodity at 5 oz. per person per week. This could be taken as sugar in tea or coffee or as the equivalent amount of jam, marmalade, syrup or honey, as each subject desired.

(g) *Fruit*.—If tonnage was very short, it would be uneconomical to import fresh fruit. We therefore limited ourselves to 6 oz. of home-grown fruit—weighed without waste—per person per week. The *per caput* production of home-grown apples would allow a raw weight ration of about 6 oz. per week, so that with the other fresh fruit available our ration was probably well within the country's capacity. Tomatoes are largely imported, and we decided not to ration them by weight but to limit ourselves to a serving very occasionally while English tomatoes were in season. Almost all dried fruits are imported, but we sometimes allowed ourselves small portions of dates, sultanas and raisins.

(h) *Vegetables, dried and fresh*.—It was thought that lentils, dried haricot and butter beans would be scarce, since they mostly come from places such as Greece and Iraq. They cannot be grown satisfactorily in this country as field crops, but they are a valuable food. We limited ourselves to 3 oz. per person per week. Since peas can be grown and dried or canned in this country, supplies were likely to be more plentiful. We gave ourselves somewhat arbitrarily an allowance of 7 oz. (dry weight) per person per week. Onions were allowed in moderate amounts, and for flavouring only, because home supplies of this vegetable are small owing to its high cost of production. Home-grown root vegetables were allowed *ad lib.* in season, but preference was always given to those which can be grown easily

upon a large scale. Cabbage, Brussels sprouts and greens were unrestricted, but lettuces were eaten only twice in the experiment and that during the English season. We allowed ourselves unlimited quantities of potatoes.

(i) *Nuts* were served on Christmas Day and on one or two other occasions.

(j) *Beverages*.—Trifling though their nutritive properties may be, tea and coffee have an immense psychological appeal, and we decided not to restrict them in our experimental diet. We made the same ruling about alcoholic drinks, but our consumption of these was negligible.

(k) *Cereals*.—Rice was allowed, but only one serving a week. Each person ate about 4 oz. (raw weight) weekly. Oatmeal can be produced in Britain, but it is not a very popular article of diet in England. Under conditions such as we were visualising we considered that most of the home-grown oats might be required for livestock, but we allowed the experimental party to eat oatmeal in moderation. Some never touched it, others ate it four or five times a week while carrying out their field tests; one subject took it regularly twice a week and another almost every day throughout the experiment. The average consumption was 2 oz. per person per week.

In addition to the rations described and the unlimited potatoes and green vegetables, we assumed that there would be enough wheat available to cover the needs and demands of the population. We considered, however, that we should use a flour for all baking and culinary purposes which included 92 per cent. of the original wheat. This we did for two reasons. We thought, firstly, that in a crisis the wheat should be made to feed as many people as possible, and, secondly, that the parts of the wheat usually removed in milling contained substances of great value to persons living on restricted diets. The figure of 92 per cent. was adopted because it was the one to which wheat was extracted at the worst period of the last war. The meal was specially prepared for us by Foster Mills Ltd., and was unbleached.

NOTE.—To have been consistent we should perhaps have arranged to eat all the skins of our potatoes. This we did not do, but baked potatoes were served once a week at least and of these the skins were always eaten.

(l) *Extras*.—An autolysed yeast preparation, made and supplied free of charge by English Grains Ltd., was allowed *ad. lib.* for flavouring. "Oxo" cubes and "Bisto" were sometimes used for gravies.

General Organisation and Sequence of Events

The experiment began on the 20th September, 1939, when Miss W. and M. started to weigh their ordinary food for one week and to collect urine and faeces over the same period of time. This served as their control period. The other subjects began to weigh their

food a few days later and R. to collect his excreta. By the 1st October M.'s and Miss W.'s preliminary collections and tests of vitamin saturation were completed, and on this date they started the experimental diet. Miss B. and R. began the experimental diet on the 5th October and H. one day later. By the 18th October Miss T. had weighed her food and collected her excreta for a preliminary week. She then began to eat the experimental food, and continued to do so till the 2nd November; she collected urine and fæces during the second week of this period. By the 11th November Mrs. G. and C. had each weighed their normal food for one week and commenced their experimental diets. Between the 24th November and 4th December R., M. and Miss W. each collected urine and fæces for one week. The 8th December saw the conclusion of the University term, and R., H. and M. were all much less tied and began to go for walks and cycle rides in preparation for the cycling and walking tests to be carried out later. A third series of vitamin saturation tests was carried out in mid-December. Miss B. gave up the experiment on the 21st December. On the 27th R. and M. commenced their cycle ride to Langdale, Westmorland, and on the next day H. and Miss W. set out by car. From the 29th December till the 12th January the party were in Langdale. R. and H. returned to ordinary food on the 10th January, but continued to weigh all they ate for another week. M. and Miss W. made their change on the 14th January. After taking vitamin D (see p. 41) M., R., Miss W. and Miss T. returned to the experimental diet on the 22nd January, and on the 25th January these four subjects began their third week of metabolism studies with collection of urines and fæces.

For the first two months of the experiment the day's meals were arranged as follows:—Breakfast was taken by the subjects in their own homes. Lunch and tea were eaten at the laboratory. Dinner was the main meal, and for this the subjects were divided into two parties until the 9th December. Miss W. cooked the evening meal for herself and M., and sometimes also for Miss B. The other members, except Mrs. G., went each evening to a private house in Cambridge where Mrs. N., a member of the Women's Voluntary Services, prepared and served a meal for them. Mrs. N. and Miss W. selected their own menus, but all the actual purchasing of food was done by Miss W. After the 9th December Miss W. catered and cooked for the whole party. Mrs. G. had her meals where she lived, and while she was taking part in the experiment M. joined her for a number of his meals.

Methods

(a) *Dietary.*—M. and Miss W. weighed their food on spring balances reading to the nearest gram, the others on 2 lb. spring butter balances reading to the nearest $\frac{1}{4}$ oz. R. and M. took a small spring letter balance with them on their bicycle ride to Langdale. The food was weighed after being cooked, just before it was eaten, and so far as possible each kind of food was treated

separately. Thus meat was fractionated into "fat" and "lean." Dishes containing several ingredients in known amounts were often prepared for each person. These did not have to be weighed at the table. Oatmeal was generally weighed out raw and the whole of the resulting porridge eaten. Soups were weighed, but not thin gravies. A seven-day supply of margarine, and of sugar, jam or marmalade, was apportioned to each person at the beginning of every week. Most subjects dealt with their daily ration of milk in a similar way. In the case of bread they frequently weighed a loaf for themselves and cut from it till it was finished.

The bread was baked for us six days a week by Mr. and Mrs. Wilkin of Barrington, Cambs. They used for this purpose their own yeast, the 92 per cent. flour and a CaCO_3 — NaCl salt mixture, supplied by us and made up to contain 10 per cent. of precipitated chalk. The newly baked bread was kept for at least 24 hours before it was eaten. The chemical composition of this bread was determined by direct analysis. For this purpose aliquots of the daily bakings were dried while the balance experiments were being carried out, and at the end of the week the aliquots were pooled. In Langdale, bread was baked for us from our own flour by Miss Earl. The special salt mixture was not used.

The chemical composition of the diets was calculated from the tables of McCance and Widdowson (1940).

(b) *Analytical*.—The urines were collected under toluene in glass-stoppered Winchester quart bottles, and 1/10th of the total volumes retained for analysis. Carmine was used to mark the fæces, which were collected in counterpoised glass bowls. Each subject used the same bowl for the weekly period, and at the conclusion of this the fæces were weighed and about 1/50th of their weight of "Analar" HCl added. Distilled water was then poured in if and as required, and with a stout glass rod flattened at the end the fæces, water and hydrochloric acid were reduced to a uniform paste, and left overnight. Next day, after further stirring, the contents of the bowl were weighed, and two 150 g. aliquots were taken out into counterpoised glass petrie dishes and dried for 48 hours at 70°C . The material was then weighed and rapidly ground up. Aliquots were dried to constant weight at 100°C ., and other aliquots were taken for nitrogen, fat and inorganic analyses.

Total N and all mineral determinations were made as described by McCance and Shipp (1933) or McCance, Widdowson and Shackleton (1936). Fat in fæces was determined by the method of Holt, Courtney and Fales (Harrison, 1937). Cole's (1937) method was used for the estimation of urea in urine. Creatine, creatinine, uric acid and ammonia were determined by methods taken from Peters and Van Slyke (1932). All chemical determinations were carried out in duplicate.

Dr. J. Yudkin kindly undertook to determine the amounts of aneurin, ascorbic and nicotinic acids excreted per day by the long-term subjects. For the vitamin C determinations, urines were

collected over consecutive periods of 12 hours in bottles containing 25 c.c. of glacial acetic acid. The estimations were made at the conclusion of each 12-hourly period. Urines in which nicotinic acid was to be determined were collected under a specially purified toluene. Ascorbic acid was determined by indophenol titration, aneurin by the thiochrome method (Wang and Harris, 1939), and nicotinic acid by Harris and Raymond's (1939) method.

Dr. Yudkin also tested the long term subjects' powers of dark adaptation. He did this twice before the experiment began and four times at intervals during the experiment. The method used was a modification of the method of Jeans and Zentmire (1934) using the Birch-Hirschfeld photometer.

(c) *Tests of physical fitness.*—The subjects kept records of their body weights throughout the experiment. In Cambridge they used a beam and platform balance on which results accurate to an ounce could be obtained. The readings were always taken before lunch (or, in the case of two persons, before tea) and directly after emptying the bladder. R. and M. weighed themselves naked, the others in standard garments. All the figures given later refer to unclothed persons. At Langdale R., H., M. and Miss W. used a portable spring balance, kindly lent for the purpose by Dr. D. C. Wilson, on which it was only possible to read to half a pound.

The technical difficulties of assessing physical fitness in adults are so great that, after considering a large number of semi-scientific instruments such as dynamometers and bicycle ergometers, we came to the conclusion that the best way to assess a person's physical fitness was to get some idea of his desire and ability to undertake severe physical exertion of a type to which he was accustomed and which he normally enjoyed. R. was fond of cycling, H. and Miss W. of mountain walking, and we decided to make these interests the basis of their tests. M. was willing to cycle and fond of mountaineering, so that he was able to accompany both parties. Distances cycled or walked were measured on maps of appropriate scale by an instrument bought for the purpose. Cycling distances were checked by a cyclometer. An ordnance map (1 in. = 1 mile, with 50 ft. contours) was used for all the expeditions from Langdale. Heights were read off these maps to the nearest contour and checked in a good many instances by a portable aneroid.

RESULTS

Rations, Food and Meals

It is one thing to prescribe rations; it is quite another thing to convert them into meals, and the first problem which confronted us in this experiment was to find whether it was possible with the rations allowed to provide meals which were satisfying and palatable to persons accustomed to a generous English diet. It may be stated at once that our cooks were able to solve this problem to our complete satisfaction, although the shortage of fat and sugar greatly restricted the culinary possibilities open to them. Miss W. prepared far more of the food than Mrs. N. and on the whole her efforts

were more successful. Mrs. N. was an excellent cook—much better than Miss W.—and she prepared very dainty meals, but she was not eating them herself as Miss W. was, and this made all the difference. She found it difficult to realise how essential gravy was to help down the large helpings of rather dry vegetables, and failed to provide the enormous quantities of potatoes which the subjects would have eaten if she had placed them on the table. It took some little time to find out which foods and recipes made the three meals most interesting. At first, breakfast tended to be a dull meal of toast or bread with nothing on it, or with the merest scrape of margarine, jam or autolysed yeast. Miss W. and M., however, soon found out that reheated potato, cabbage, or a potato-cabbage mixture made breakfast much more appetising, and they ate something of this sort nearly every day. Vegetable soup soon came in as a lunch-time dish, and we enjoyed large quantities at least three days a week. R. consumed $2\frac{1}{4}$ pints of soup on one occasion! On the alternate days we had baked potatoes or some vegetable concoction devised by Miss W. We always had coffee for lunch and M. frequently took only toast and autolysed yeast with it. The evening meal consisted usually of a single course. Mrs. N. sometimes provided soup, but, except on Christmas Day, the only “sweets” served were occasional baked apples. Supper always contained the meat, fish or cheese portion for the day, and potatoes and other vegetables were always provided even if the made dish already contained them. We quickly discovered that we had been wise in allowing ourselves a generous portion of cheese. The 4 oz. a week provided us with two tasty evening meals and were very much more appreciated than another few ounces of meat would have been. This was because a little cheese was enough to make a large dish of potatoes, rice or vegetables not only palatable but delicious. For the same reason, curry, herbs, vinegar and spices proved themselves to be very valuable adjuncts to a dietary such as ours, and we allowed all of them in moderation. We also allowed home-made chutney in reasonable quantities and fish paste once a week. Some subjects appreciated these very much, others got on perfectly well without them. Mrs. G. ate her ration of cheese on bread and Miss B. sometimes took some of hers in this way. The soups, which were always popular, were merely vegetables cooked in water and flavoured in various ways. Milk was never added, and stock was seldom available. Large quantities of bread were eaten with the soup by some of the party, and it will readily be appreciated that with so little jam and margarine this was a good way of making dry bread palatable. The soups were sometimes used as gravies and eaten with potatoes and vegetables.

We never got tired of the three staples, bread, potatoes and green vegetables, although some ate more freely of one than another. In Langdale and while cycling, when M. and H. were eating up to 3 lbs. of bread a day, they ate large quantities of bread dry. They took whole loaves with them when they went out, and munched steadily through them. The extraordinary thing is that they

enjoyed this food thoroughly—and in fact H. frequently stated that he could not understand why in his previous existence he had ever bothered with sandwiches. Most subjects seemed to prefer green vegetables to root vegetables, although the latter were much enjoyed. Dried peas were popular in soups—not so popular as a vegetable.

A feature of diets such as these is the length of time it takes to eat the meals. The food is bulky and often tastes dry, although it may actually contain a high percentage of moisture, so that with the best will in the world it is impossible to eat it quickly. M. frequently took over an hour to eat his evening meal and H. and R. took almost as long over their lunch. When Miss T. was taxed with having eaten much less during her experimental weeks than she had done in her preliminary one, she replied at once that she simply had not had the time to get through the food. R. noted how long it took him to eat a small number of his meals, and it will be evident from Table II that his experimental meals tended to take longer than his normal ones. This was not due to the length of time taken to weigh the former, for the latter were also weighed or else a time allowance was made for this process. It is not possible to get any further information out of R.'s data, for even during the experiment R. did not know his bread consumption at individual meals, his practice being to cut his bread from weighed loaves and to record only the amount eaten in 24 hours. After the experiment he merely timed and weighed his total meals, and no record was kept of the weight of the separate items. Miss W. also timed some of her meals during and after the experiment, and M. timed a considerable number. It is possible to analyse their data much more completely, and it will be seen from the averaged results in Table II that not only was more time taken over the experimental meals, but less food was eaten per minute at them. The differences in the time and speed of M.'s meals were statistically significant. Several things have contributed to these results. Firstly, given that a person's calorie intake during two contrasted periods is to be the same, and that in each he is to eat the same weight of food per minute, then the more concentrated the food the shorter the time he will require in which to eat it. The normal diet was much more concentrated than the experimental one, for it contained more fat and sugar, and this tended to make the normal meals shorter than the others. Secondly, weight for weight, some foods take longer to eat than others. Porridge slips down very rapidly: bread makes a slow meal, toast even slower. The experimental meals often contained much bread and sometimes toast. Thirdly, a combination of foods is often eaten more quickly than one of the foods alone. Butter and jam not only lubricate toast and enable it to be chewed and swallowed more rapidly, but by their very addition they increase the weight of food eaten in a given time. These adjuncts, therefore, (which were very much curtailed during the experiment) have two actions, both of which shorten meal times and increase the rate of food consumption. A further analysis of M.'s and Miss W.'s experi-

TABLE II

The Rate of Food Consumption During and After the Experiment

<i>Subject R.</i>	<i>Breakfast.</i>		<i>Lunch.</i>		<i>Tea.</i>		<i>Supper.</i>	
	<i>Experi- mental.</i>	<i>Normal.</i>	<i>Experi- mental.</i>	<i>Normal.</i>	<i>Experi- mental.</i>	<i>Normal.</i>	<i>Experi- mental.</i>	<i>Normal.</i>
No. of observations	8	5	10	5	7	3	7	5
Average time (minutes) ..	18·8	12·0	47·7	24·0	16·2	11·7	36·7	25·6
Range.. .. .	15-20	10-15	40-65	20-30	13-20	10-15	35-40	23-30

<i>Subject M.</i>	<i>Breakfast</i>				<i>Supper.</i>			
	<i>Experimental (23 observations).</i>		<i>Normal (14 observations).</i>		<i>Experimental (39 observations).</i>		<i>Normal (18 observations)</i>	
	<i>Time mins.</i>	<i>Rate g./min.</i>	<i>Time mins.</i>	<i>Rate g./min.</i>	<i>Time mins.</i>	<i>Rate g./min.</i>	<i>Time mins.</i>	<i>Rate g./min.</i>
Average	17·8	24·5	10·6	40·7	57·8	36·8	42·1	50·0
Standard deviation	3·2	3·1	2·0	7·6	7·5	5·1	5·4	5·3

<i>Subject Miss W.</i>	<i>(12 observations.)</i>		<i>(6 observations.)</i>		<i>(20 observations.)</i>		<i>(6 observations.)</i>	
Average	16·5	9·3	9·8	28·5	28·7	37·9	22·7	45·2
Range	12-21	4-18	7-16	22-42	20-46	25-55	20-26	41-58

mental and normal meals shows that the main factor which reduced their rate of food consumption during the experimental period was the amount of bread they were eating at that time. Thus, among Miss W.'s experimental breakfasts there were six at which she had no vegetable dish and ate only bread or toast with some very small quantity of catalyst. Her average rate was 5.5 g. of food per minute. Her other six experimental breakfasts included vegetable dishes and she ate, on an average, 13 g. per minute. All her normal breakfasts after the conclusion of the experiment consisted of a generous helping of vegetables and very little bread, and they were eaten at an average rate of 28.5 g. per minute. Among his experimental breakfasts M. had four which consisted essentially of toast and bread. He averaged 21.8 minutes for these meals and ate at them 10.8 g. of food per minute. He had six breakfasts with porridge as well as toast and bread, averaged 19.3 minutes over them and ate 34.5 g. per minute. His normal breakfasts mostly consisted of porridge and milk, a vegetable dish, or fruit and were eaten correspondingly rapidly, as Table II shows. M.'s experimental suppers differed from his normal ones chiefly in that the former always contained 250 to 500 g. of bread, the latter none. A minor difference was that some of his normal suppers included a pudding or a fruit tart. Both of these are rapidly-eaten foods. These differences account for the figures shown in Table II. Miss W.'s normal suppers were very like her experimental ones, except that there was rather more meat in the former and sometimes a pudding. Neither contained bread, and the times and rates were not very different (Table II). The element of time helped to make Mrs. N.'s meals less popular than Miss W.'s. The subjects had three-quarters of an hour for their meal at the former's house. This was just enough for those who arrived punctually. It was not enough for anyone who was late. When this happened the unfortunate one had to satisfy his hunger with bread later in the evening.

It has several times been suggested to us that this diet must have been monotonous or nauseating. Nothing could have been further from the truth. To begin with, the diet did not seem to us monotonous and further, monotonous diets are the lot of the great majority of mankind—particularly perhaps of the more primitive races—and the testimony of all is that, given good health and food which is supplying all the needs of the body, one approaches the same dishes every day with an appetite unimpaired. Nauseating is the last epithet to apply to this diet. On it we have felt hungry, satisfied, full of food, almost in fact the whole gamut of gastrointestinal symptoms—but not nauseated. We are inclined to attribute this to the absence of fat but recognise that there may be some much more subtle reason.

Two points will be mentioned here but their discussion postponed till later. The first is that the same rations present each person with a different problem. One person may have to reorganise the pattern of every meal, another may have to make only quite small changes in his normal dietary régime. The second is that theoretically

the small eater has far fewer difficulties to surmount than the large eater. Nevertheless, in this experiment the large eaters, who were, incidentally, the men, adapted rather better than the smaller eaters of the other sex.

Adaptation and Habit

Man is a creature of habit, and perhaps more so over food than over anything else. This characteristic is undoubtedly one of the things which tend to stabilise the food which nations eat and make it difficult to effect alterations for better or worse without public outcry.

The sudden change from normal to experimental food forced us all to break a great many well established habits. We accepted the changes because we were prepared for them, and within a few days had developed a new *modus vivendi*. What we had not anticipated was the length of time it would take us to become fully adapted to the new régime, and the difficulties some of us would experience in the process. Thus, quite early in the experiment, as already described, M. and Miss W. took to eating vegetables for breakfast and found them exceedingly palatable. H. and R. had not done so and had depended upon bread with a scrape of margarine or jam. When, later in the experiment, R. and H. were offered potatoes and green vegetables for breakfast, at first they both declined. By the end, however, vegetables were their first choice, preferred every time to porridge. Thus, quite late in the experiment example and chance enabled H. and R. to make a very valuable adaptation. All her life Miss W. had eaten white, as opposed to wholemeal, bread, and at first she found the experimental wholemeal bread a great hardship and could hardly face it at all when toasted. During the three months on the diet, however, she gradually acquired the taste for it. This she did so imperceptibly that she herself scarcely realised that any change had taken place till, two days before the experiment finished, she once again tried toasted wholemeal bread and found she liked it very much.

By the end of the three months we had become so well accustomed to the new régime that we had no desire to go back to our pre-experimental dietary habits. This is not to say that the "flesh-pots of Egypt" had no attractions for us at all. There were items of everyday food which we all desired. M. wanted more milk and fruit. He also wanted more boiled eggs and Miss W. more cheese, and these two latter desires are particularly interesting since before the experiment M. had not eaten a boiled egg for years and Miss W. had rarely touched cheese. In each case, therefore, the taste for the food had been acquired during the experiment. Nevertheless, we were at the end quite contented with our lot and asked for little better. This may sound almost an affectation, but perhaps the personal touch may carry conviction where the general statement fails. Miss W.'s taste in bread was so changed by the experiment that she did not go back to white bread. As a matter of fact, all the long term subjects continued to eat wholemeal breads. A fortnight after the experiment finished, the party met

for lunch. To the surprise of the others in each case, R. was observed still to be putting saccharine into his coffee and H. to be covering his bread with an almost invisible film of margarine. M. and Miss W. did not lose their taste for large quantities of vegetables and continued to eat them. These little points of detail show better than any general statement could do, how well we became adapted to the experimental régime, although it took us some time to do so. The significance is obvious. If people can once be induced to accept a change of diet they are likely to become so used to it and contented on it that they may never wish to revert.

Mental Effects of the Rationed Dietary

M., R., H. and Miss W. were not worried by the experiment. They slowly perfected their adaptation until in the end, as already described, they were fully satisfied with the diet and asked for nothing better. Miss B. reacted quite differently. She was just as hungry for her meals as the others—and she liked the food—but she was apprehensive of the régime from the first and refused to allow herself to settle down under it. At the beginning she refrained from eating till she became perturbed about her loss of weight. Later she ate well. If she was hungry, and sometimes even if she was not, she found it very difficult to restrict herself to the food she was allowed. On one occasion she ate the whole of her 2 oz. ration of golden syrup as soon as she received it. One evening she incited R., H. and Miss T. to overstep their meat rations and did so herself, announcing that this had been her first decent meal since the beginning of the experiment. She was a little afraid that she might get 'flu in the spring if she did not eat fat; that she might get some sort of obscure anæmia if she ate so little meat, and that we should all feel the cold weather excessively, owing to the lack of fat in our diets. Health phobias are common enough in young persons living on the borderland of medicine, but in Miss B. the experiment was the exciting cause. She was apt to attribute perfectly normal symptoms to the régime, and if they occurred in fellow subjects, tried to make use of them to undermine her colleagues' experimental morale. Thus, when Miss W. appeared one morning in early December and exclaimed "Oh! it is cold to-day," Miss B. replied "It's the diet makes you feel cold." On another day she stated "Everyone says M. is looking very ill." It may be mentioned here as an interesting aside, which experienced investigators will no doubt confirm, that this is the sort of remark outsiders are very apt to make as soon as they hear that any kind of auto-experiments are in progress. M. had some such remark as this made to him six or seven times during this experiment, although he was looking and feeling extremely fit throughout. Many people assured him that he was losing weight. Fig. 3 shows how little truth there was in this remark.

It will be clear from what has been said that, while Miss B. would have been an unsatisfactory subject for most dietary experiments, she was a splendid one for our work, for in her we could see just how a certain section of the community might react in similar

circumstances. If an educated person with a scientific training behaves in this way when faced with restrictions which her teaching and rational senses should be able to convince her are harmless, one can sympathise with the reactions of the less well informed who feel that any interference with their usual diet is likely to be a menace to their health.

C., Miss T. and Mrs. G. were subjected to the restrictions only for periods which we later found to be too short to bring out many of the points of interest. C. found the food palatable and throve on it. He was a very hearty eater, of the type that would have made the most of any diet once he had got into the swing of it. He found he could do his work well and even went so far as to say that he thought it a most satisfactory diet on which to row. Mrs. G. very much missed her sugar. Apart from that she seemed to have no troubles, and obviously felt that her 14 days of sugar privation was a small sacrifice to make if by it, even at her age, she was able to help.

*Effects of the Rationed Dietary upon the Natural Functions
of the Body*

All the long-term subjects have noticed that on the experimental diet, contrary to their usual custom, they have frequently had to get up once and occasionally twice during the night to empty their bladders. We have no single explanation to offer for this phenomenon, and we are inclined to think that there were several factors at work. The diets themselves were bulky and contained a great deal of water, but so did some of the preliminary diets (Table III). The food, however, "tasted dry" and there was

TABLE III
Water in the Food and Urinary Volumes

Subject.	Preliminary diet (September, October).		Experimental diet (November, December).		Experimental diet (January).	
	Food water c.c./day.	Urine Vol. c.c./day.	Food water. c.c./day.	Urine Vol. c.c./day.	Food water c.c./day.	Urine Vol. c.c./day.
M. ..	2,173	2,690	2,078	3,406	2,076	3,740
Miss W. ..	1,356	2,286	1,471	2,860	1,785	3,240
R. ..	1,164	1,536	1,670	2,490	2,043	2,500

Note.—Milk and soup have been reckoned as "food", but not water and beverages.

more sodium chloride in it than there had been in the control period. In consequence, the subjects drank more and there was a very real increase in their urine volumes (Table III). It is possible also that the nocturnal diuresis was connected with the fact that the diet contained more potassium than ordinary diets, and that the main meal was taken in the evening. (The figures for the excretion of sodium chloride and potassium are given in Table XIII.) The suggestion has also been made that the time of the evening meal relative to bed-time caused an unusually rapid filling of the bladder during sleep, and hence a desire to empty it prematurely. It is

even possible that irritability of the bladder due to flatus in the large bowel (see later) helped to produce this effect.

The majority of the subjects found the diet laxative. This was the personal testimony of all except Mrs. G., whose dietary habits were very little altered by the régime, and of Miss B., who must be reckoned rather an unreliable witness, but who always maintained that for her the diet was constipating. The increased bulk of the fæces brought about by the diet in four subjects is shown in Table IV. Personal observations of M. and Miss W. suggest that the active agent which increased the bulk of the fæces was the bread, not the potatoes or other vegetables.

TABLE IV
Average Daily Weight of Fresh Fæces

Subject	Preliminary diet (September, October). g./day.	Experimental diet (November, December). g./day.	Experimental diet (January). g./day.
M.	183	425	493
Miss W.	57	125	178
R.	111	347	262
Miss T.	45	119	85

One of the most striking results of the experimental diets was the amount of intestinal flatus to which they gave rise. All the subjects noticed this except Miss B. and possibly Mrs. G., and to some the effects have sometimes been remarkable. Volumes of flatus were frequently passed *per rectum*, generally without any previous discomfort or distension, and since this was the usual daily experience, it was often, to say the least of it, somewhat embarrassing. It is, of course, no new discovery that bread and starchy foods generally cause wind. It was made at least as long ago as 1743 by three Russian sailors who had lived on meat alone for six years and who, on returning to civilisation, "were strong and healthy but having lived so long without bread, they could not reconcile themselves to the use of it and complained that it filled them with wind" (Mangles, 1852). The evening meal was apt to produce an immediate feeling of distension in some subjects, which generally passed off in half to three-quarters of an hour. This was not indigestion in the ordinary sense. It may have been due to a surfeit of vegetables, or in some instances to eating too fast.

Effects of the Restrictions on the Quantities of the Different Foods Consumed

Rationed foods.—Most of the subjects ate the whole of their rations, but in spite of this the restrictions reduced their normal consumption of these foods very considerably. The extent and nature of the limitations can best be appreciated by comparing the amounts of these rationed foods which were eaten before and after the experiment began. Data for seven subjects are recorded in Table V, and in the same table may be found the chemical

TABLE V.
Intakes of Rationed Foods
Quantities in ounces per week

Food.	H.		R.		C.		Miss W.		Miss B.		Miss T.		Mrs. G.	
	Preliminary diet.	Experimental diet.	Preliminary diet.	Experimental diet.	Preliminary diet.	Experimental diet.	Preliminary diet.	Experimental diet.	Preliminary diet.	Experimental diet.	Preliminary diet.	Experimental diet.	Preliminary diet.	Experimental diet.
Milk	73·0	35·0	140·0	35·0	177·0	35·0	128·0	35·0	66·0	35·0	150·0	35·0	37·0	35·0
Butter or margarine on bread	12·0	4·0	8·0	4·0	9·0	4·0	6·5	3·5	7·0	4·0	7·5	4·0	1·5	3·0
Cooking fat	10·0	0	7·0	0	14·0	0	2·0	0	8·0	0	16·0	0	3·4	0
Cheese	17·0	4·0	7·0	4·0	0	4·0	0	4·0	6·0	4·0	0	4·0	1·2	3·0
Eggs (No.)	6·0	1·0	1·0	1·0	0	1·0	6·0	1·0	2·0	1·0	8·0	1·0	1·0	1·0
Sugar.. .. .	14·0	5·0	25·0	5·0	37·0	5·0	16·0	4·4	14·0	4·6	38·0	5·0	17·0	5·0
Meat	41·0	10·7	39·0	10·0	43·0	9·5	35·0	11·2	46·0	10·1	45·0	11·4	9·0	7·8
Fish	21·0	5·2	13·0	5·5	6·7	4·3	0	4·4	5·0	5·3	5·7	4·7	1·7	0
Fruit	78·0	5·1	51·0	6·1	11·0	3·0	64·0	4·6	58·0	6·5	33·0	6·0	3·1	5·5
Dried peas	0	7·0	0	7·0	0	7·0	0	7·0	0	7·0	0	7·0	0	0
Dried beans or lentils	0	3·0	0	3·0	0	3·0	0	3·0	0	3·0	0	3·0	0	0
Protein g. per day from rationed foods ..	77	30	66	29	59	28	48	30	50	29	66	30	16	14
Animal protein g. per day from rationed foods	74	21	65	21	59	19	46	21	49	21	66	21	16	14
Fat g. per day from rationed foods ..	150	35	104	35	139	34	84	33	107	35	138	35	29	26
Carbohydrate g. per day from rationed foods	104	49	148	50	192	48	114	47	98	48	199	50	79	53
Calories per day from rationed foods ..	2,137	649	1,844	649	2,320	629	1,445	622	1,602	641	2,370	654	659	516

TABLE VI
M's Intake of Rationed Foods
(Quantities in ounces per week)

<i>Food.</i>	<i>Prelimi- nary week.</i>	<i>Week 1.</i>	<i>Week 2.</i>	<i>Week 3.</i>	<i>Week 4.</i>	<i>Week 5.</i>	<i>Week 6.</i>	<i>Week 7.</i>	<i>Mean of last 8 weeks.</i>
Milk	178·0	35·0	35·0	35·0	35·0	35·0	35·0	35·0	35·0
Butter or margarine on bread ..	7·0	2·3	0·4	0·4	0	0	0	0	0
Cooking fat	5·5	0	0	0	0	0	0	0	0
Cheese	0	4·0	4·0	4·0	4·0	4·0	4·0	4·0	4·0
Eggs (No.)	0	1·0	1·0	1·0	1·0	1·0	1·0	1·0	1·0
Sugar	38·0	2·5	0·7	1·4	1·5	0·4	0·3	0	0
Meat	52·0	12·0	5·8	4·5	5·0	6·0	4·3	3·3	5·6
Fish	0	0·3	4·8	2·0	3·5	2·5	3·2	3·5	2·9
Fruit	200·0	5·0	8·0	8·0	6·0	6·0	0	3·0	2·5
Dried peas	0	3·0	3·0	4·3	2·0	0	2·0	0	3·3
Dried beans or lentils	0	3·0	3·0	0	5·0	3·0	2·5	3·0	2·7
Protein g. per day from rationed foods	63	24	23	18	22	19	19	17	21
Animal protein g. per day from rationed foods	60	19	18	15	16	16	15	15	16
Fat g. per day from rationed foods	117	28	19	17	17	17	16	16	17
Carbohydrate g. per day from rationed foods	268	32	26	25	30	17	17	14	20
Calories per day from rationed foods	2,443	490	377	335	371	296	297	276	326

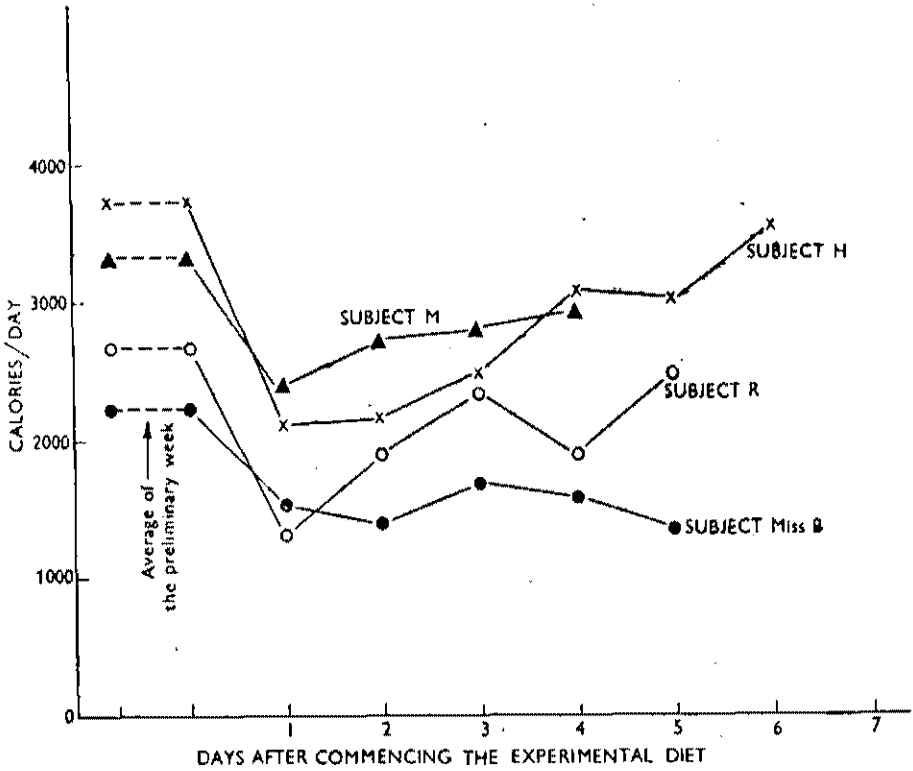
composition (proximate principles and calories) of the rationed fraction of the diets. It will be seen that for all except Mrs. G. the rationing meant much less milk, butter, cooking fat, sugar, meat and fish, and fruit. For most it meant fewer eggs, but C., who by chance had no eggs in his preliminary week, naturally ate the one he was allowed during each of his experimental weeks, and so appears to have increased his egg consumption. For the same reason, rationing led others to eat more cheese, and all except Mrs. G. to begin eating dried pulses which they had not touched before. It was not our intention when we designed the rations to produce this general increase in the consumption of the pulses, and we have felt subsequently that it was a mistake to have included them in the diets. We would have fared perfectly well without them, and they are largely imported from considerable distances. It will be noted that in spite of these minor increases in the consumption of certain foods, rationing deprived all except Mrs. G. of most of their normal supplies of animal protein and fat, and deprived them also to some extent of carbohydrate. Mrs. G.'s record is quite different. She has been for many years a curiously small eater and her average daily calorie intake during her preliminary week was only 1,254. Only her sugar consumption exceeded her rationed allowances to any great extent. She ate less cheese, meat and fruit than her rations would have permitted. Consequently, rationing for her meant relatively minor readjustment and had she eaten all the rationed foods to which she was entitled she would have suffered no loss of calories. In point of fact, however, she did not eat up to her allowances, and reduced her calorie intake from rationed sources by about 150 per day.

Soon after the experiment started, Miss W. and M. decided that the conditions were not severe enough, and Miss W. slightly reduced her sugar, margarine and fruit ration for many weeks of the experiment (Table V). M. at once reduced his meat and later his fruit ration, and within a few weeks eliminated all margarine and sugar from his diet. The course of these reductions and their effect upon the chemical composition of the rationed moiety of M.'s diet is shown in Table VI. It will be seen that these restrictions greatly curtailed his animal protein and fat, and reduced his calorie intake from rationed sources by over 2,000 per day.

It is clear that with the start of the experiment the rationing of meat, fat and sugar deprived all the subjects except Mrs. G. of a source of calories to which they were accustomed. They could not make good their animal protein and fat, but as regards calories there were three possibilities open to them. Firstly, they might accept the restrictions without any attempt to increase their consumption of unrationed foods. Secondly, they might fully compensate for the loss of calories from rationed foods by eating more unrationed foods. Thirdly, they might compromise between the first and second possibilities. A great part of the interest and value of this experiment has turned upon the way in which each subject individually and all the subjects taken together have adapted themselves to this new situation.

FIG. 1

Intake of calories before and for the first few days after commencing the experimental diet.



Calories and unrationed foods.—Fig. 1 shows the total calorie intakes of M., H., R. and Miss B. before, and for the first five or six days of, the experimental régime. All showed a fall on the first day, due to the sudden deprivation of the calories previously obtained from the rationed foods. Within the next few days H.'s, R.'s and M.'s calories rose again till they were near their original levels. This was due to a steady increase in the consumption of unrationed foods, and was entirely a matter of unconscious adaptation on the part of these three subjects, for none of them at that time had any idea what his calorie intake had been or was likely to be. Miss B.'s calorie intake did not increase in this way. Fig. 2 shows M.'s and H.'s intake of total calories and calories from rationed and unrationed foods before and for the first seven or eight weeks of the experiment. Within the first week they had almost compensated for the fall in calories from rationed foods. Fig. 2 shows also that after the second week, by which time the calorie intake from rationed foods had become almost constant, all the fluctuations in "total" calories were due directly to fluctuations in "unrationed" calories. This is true of all the variations in total calorie intakes to be shown in subsequent figures, and is the inevitable consequence of a system of rationing so comprehensive and severe that people always eat up to the whole of their allowances.

FIG. 2

Intake of calories from rationed and unrationed foods during the preliminary and early experimental weeks.

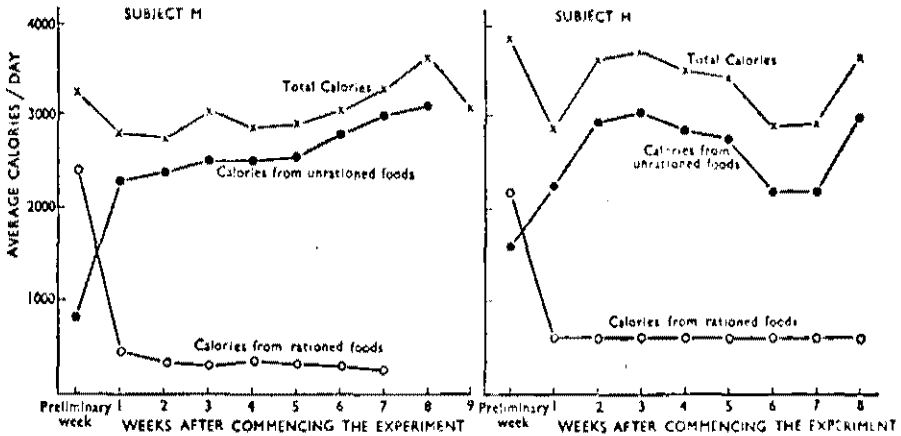
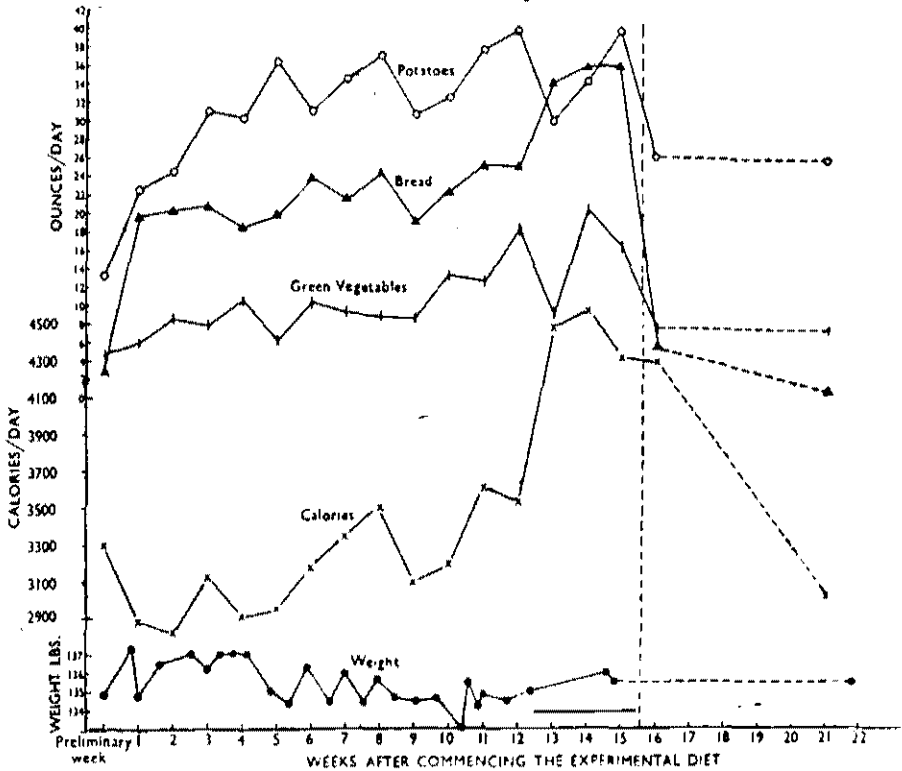


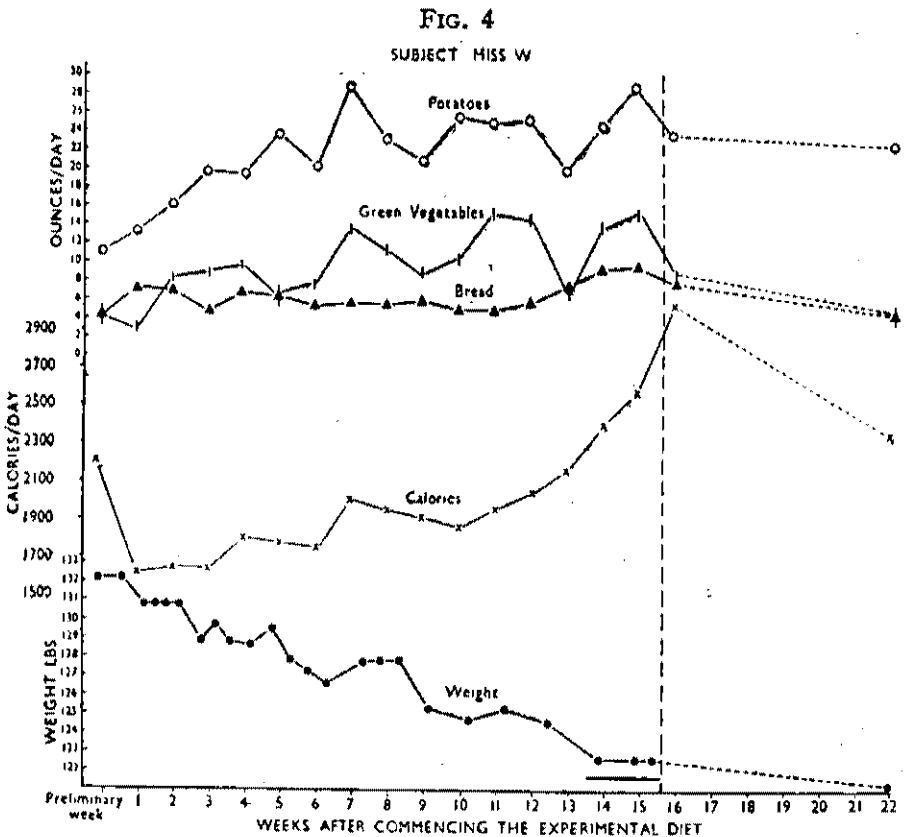
FIG. 3. SUBJECT M



The broken vertical line marks the conclusion of the period of rationing, the solid horizontal line the period of heavy exercise.

Fig. 3 shows M.'s weekly consumption of bread, potatoes and green vegetables throughout the whole period of observation. His calories are shown also, and his weight. It will be seen that within the first week his bread intake rose from 3 oz. to 20 oz. per day and then altered very little for five weeks. It then rose a little for a few weeks, fell again during the ninth week, and finally rose again till the end of the experimental period, which is indicated on the chart by a broken vertical line. For the last three weeks

of experimental diet M. was eating about 36 oz. of bread per day, i.e. about 2½ lbs. His potato intake rose gradually from 13.5 oz. per day before the experiment began to 36.8 oz. per day in the fifth week and thereafter fluctuated at about that level. His intake of green vegetables rose slowly but with fluctuations throughout the experiment. His calorie intake showed a fall for some weeks. This was due to the fact that, although his initial adaptation was good (Figs. 1 and 2), his increased consumption of vegetables and cereals did not quite compensate until about the sixth week for the removal of fats, sugar and meat. By this week, however, M.'s calorie intake was within 200 per day of its original level; it remained so till the 11th week, when it rose to 3,620, and in the 13th week it exceeded 4,400 per day. These later increases were the result of exercise and will be fully discussed on p. 48. Reference to the post-experimental period will also be deferred for the present (see p. 51). M.'s weight from first to last showed no significant change. Fig. 4 shows Miss W.'s weekly consumption of bread, potatoes and green vegetables, her calorie intake and her weight. Her record resembles M.'s in showing a rise of potato consumption for the first five to seven weeks and a gradual rise in the intake of green vegetables over the whole experimental period; it differs in that her daily intake of bread rose only from 4.3 to 7.3 oz. in the first week and thereafter slowly declined till the 11th



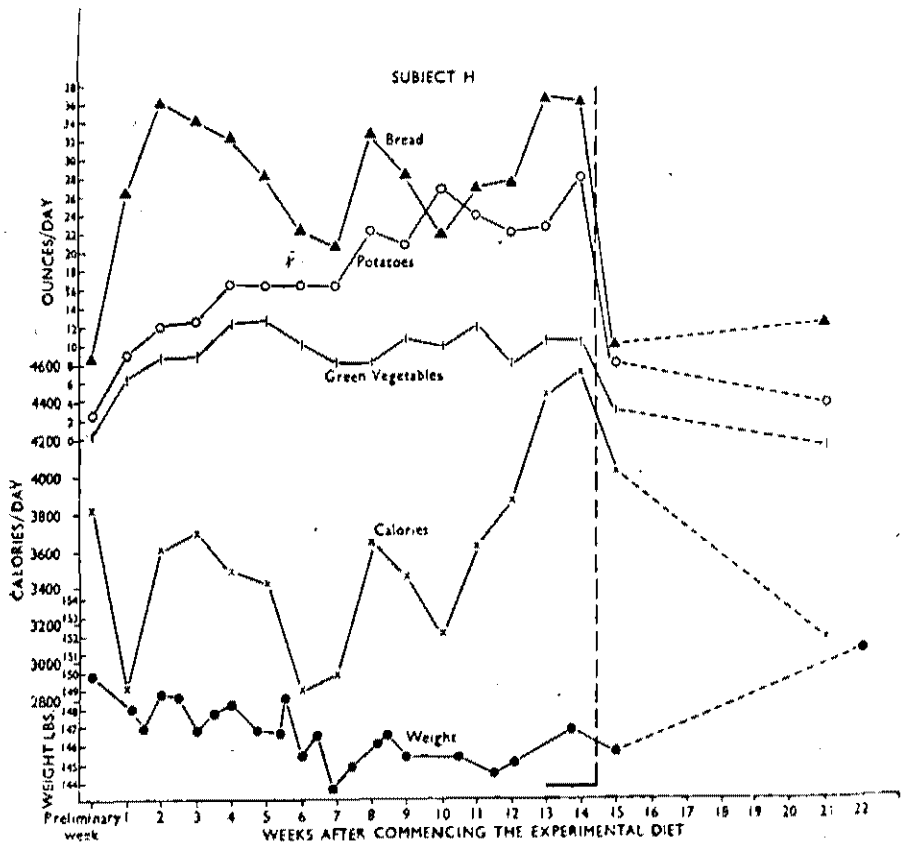
The broken vertical line marks the conclusion of the period of rationing, the solid horizontal line the period of heavy exercise.

week, when it was almost where it had been before the experiment started. In consequence, her calories fell from 2,200 per day to 1,600 during the first experimental week, and they did not again rise as high as 2,000 until the 13th week, which included Christmas. Thereafter there was a rise in bread consumption and in calories, associated with exercise in the Lake district. Miss W.'s weight fell throughout the whole period of observation. The increased calorie intake during the last two experimental weeks was evidently not enough to supply the increased demands due to the exercise.

This record therefore agrees in some but differs in other respects from M.'s. Both showed the initial fall in calories, both showed the increased consumption of potatoes, but Miss W. never increased her bread intake enough to compensate for her lack of meat, fats and sugar. In other words, she adapted much less completely than M. did to the changed conditions. Her loss of weight was not serious; indeed at the end of the experiment she was no lighter than she had been three years before—and she was extremely fit—but one cannot overlook the fact that in 15 weeks she had lost 9½ lbs.

Figs. 5, 6 and 7 show the food consumption and other records of H., R. and Miss B. respectively. They all resemble M.'s and Miss W.'s in showing a fall of calories during the first week and a

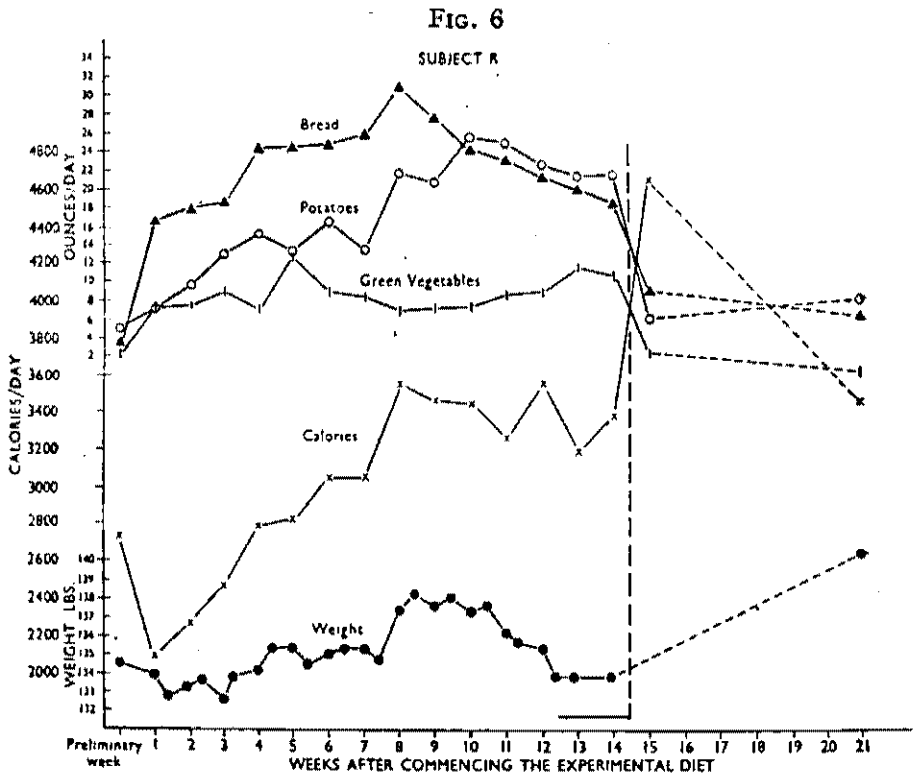
FIG. 5



The broken vertical line marks the conclusion of the period of rationing, the solid horizontal line the period of heavy exercise.

rise in the consumption of bread, potatoes and vegetables to compensate for the prohibited meat, fats and sugar. They differ among themselves, and from M.'s and Miss W.'s, in the rates at which the consumption of the unrationed foods rose and the extent to which it rose. The figures make these points clear. There are, however, certain others which require a little more explanation and discussion. H.'s bread and hence his calorie intake showed remarkable fluctuations from week to week. To some extent his weight followed these, and there is no doubt that they really took place, but we are unable to offer any explanation for them till the 13th and 14th weeks, when strenuous exercise was undoubtedly the cause. H. himself, who was the most perfect subject in that he was a trained observer but practically without food consciousness of any kind, could only say that at all times he ate till he was satisfied but that sometimes he felt inclined for more bread than others.

R.'s record differs from the others in that, for no apparent physical reason, he increased his bread and potato intakes till he had much more than made up for his initial fall in calories. By the fourth week his calorie intake was just above its initial level and during the eighth week it was 800 calories per day higher. Thereafter it remained about the same till the end of the experimental period. For the first 10 weeks his weight fluctuated with his calorie intake, but it fell between the 11th and 13th weeks without a corresponding fall in calories. This was probably due to increased exercise.

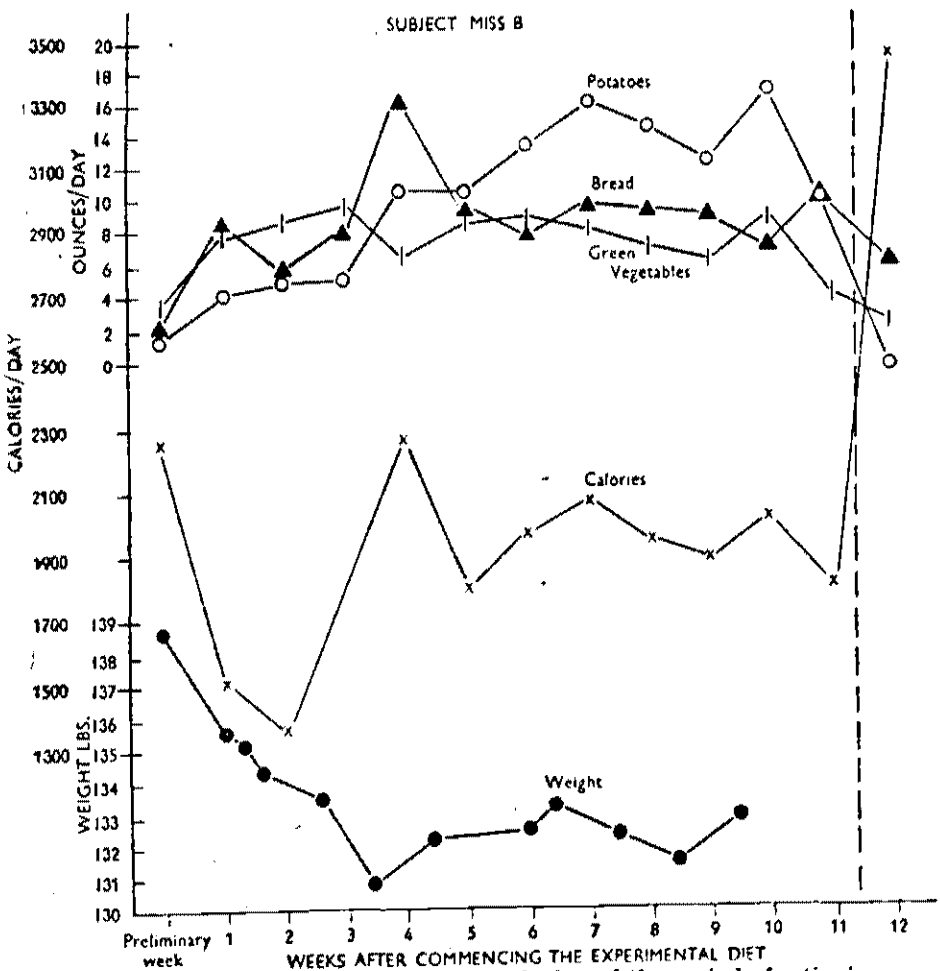


The broken vertical line marks the conclusion of the period of rationing, the solid horizontal line the period of heavy exercise.

Miss B.'s record is interesting for altogether different reasons. The initial increase in her bread, potato and vegetable consumption did not nearly compensate for her loss of calories from the food restrictions, and hence her total calories fell. Her weight also fell, but at the end of the third week she began to eat much more bread. The increased consumption of bread lasted only for a week, but by that time she had become more accustomed to bulky food, her potato intake was steadily rising and her calorie intake remained high enough to prevent further loss of weight.

C., Mrs. G. and Miss T. all showed a fall of calories in their first experimental week. C. then compensated well for the deprivation of meat, fats and sugar, and raised his calorie intake in the second week to near, and in the third week to more than, its original value. Very little adaptation would have enabled Mrs. G. to have kept up her calories to their original level (see Table V and p. 25), but she made little if any attempt to compensate for the restrictions imposed upon the foods to which she was accustomed. This is probably to be explained, partly at any rate, by her age. She might have eaten more and adapted better had we been able to devote more time to the study of her idiosyncrasies and individual requirements.

FIG. 7



Chemical Composition of the Diets

Table VII shows the chemical compositions of the diets before, during and after the period of rationing. Description and discussion of the last will be postponed until later (p. 51). The subjects are given separately, and the data as to the diets have been compressed by averaging periods during which the changes were small. It will be seen that there was an ample sufficiency of protein in the rationed diets. There was, in fact, often more protein in them than there had been in the normal food, and in the last three weeks of his experiment M. was taking nearly twice as much protein as before the experiment began. We wish to emphasise this, because there appears to be a popular misconception that diets such as these would be very low in protein. It has even been suggested to us that they should be enriched by the addition of some form of yeast. The rationed diets were admittedly very low in *animal* protein. M.'s was the lowest, and all except Mrs. G.'s were far below their normal levels. We have no evidence, however, that biologically they were any the worse for that.

The rationed diets were all very low in fat, particularly M.'s and Miss W.'s, and M.'s would have been much lower had it not been for the fat in the flour. The weekly ration of margarine provided 14 g. of fat a day, the milk 5 g. and the cheese 6 g. The fat from meat and fish was usually about 9 g. The carbohydrate intakes were proportionally high, and during the last two experimental weeks H.'s and M.'s intakes were of the order of 800 g. per day. M. was getting practically the whole of this from starch, since he was taking no sugar or jam of any kind. The other subjects who were taking the whole of their sugar ration, ate only 34 g. of their daily carbohydrate as sugar.

The calcium intakes were very little altered by the experiment. They would have been reduced 25 to 30 per cent. had the bread not been baked with chalk. Owing to the large amounts of phosphorus in the bread, the phosphorus intakes were always higher than they had been before the experiment began. In the case of the large bread eaters, M., H., R., and C., they were considerably higher. A proportion (probably about 40 per cent.) of the phosphorus in these diets was present as phytic acid, but the urinary excretion of phosphorus was raised rather than lowered during the experimental periods (see Table XIII), so that adequate amounts of phosphorus were certainly being absorbed. The iron intake of all the subjects was raised during the experiment, sometimes to a considerable extent. This again was attributable to the bread, and it is interesting to note that in some subjects the amount of iron introduced into the food by the bread was greater than the whole of the iron of which the subject had been deprived by the rationing of the meat.

TABLE VII
Chemical Composition of the Diets

Subject.	Period.	Protein g./day.	Animal protein g./day.	Fat g./day.	Carbo- hydrate g./day.	Calories per day.	Ca. g./day.	P. g./day.	Fe. mg./day.
M.	Preliminary week	81	63	134	409	3,252	1.11	1.44	16.5
	1st-12th experimental weeks ..	107	15	35	578	3,134	1.13	2.65	31.7
	13th-15th experimental weeks ..	149	17	49	804	4,403	1.53	3.75	46.9
	1st after week	126	77	157	551	4,242	1.37	2.44	28.8
	2nd after week	80	37	78	472	2,983	1.37	1.61	22.7
Miss W. ..	Preliminary week	65	47	96	255	2,200	0.81	1.12	12.1
	1st-3rd experimental weeks ..	55	20	36	259	1,620	0.68	1.21	14.9
	4th-13th experimental weeks ..	60	21	40	309	1,884	0.72	1.26	16.2
	14th-15th experimental weeks ..	75	23	56	386	2,423	0.98	1.57	21.9
	1st after week	103	56	117	357	2,978	0.98	1.98	21.8
	2nd after week	74	45	73	317	2,284	1.08	1.55	17.1
Miss B. ..	Preliminary week	72	56	124	195	2,248	0.83	1.20	10.3
	All experimental weeks	62	20	42	286	1,825	0.75	1.39	16.9
	After week	105	71	194	297	3,452	1.01	1.77	18.6
H.	Preliminary week	120	75	144	467	3,814	1.21	1.74	23.2
	1st-12th experimental weeks ..	116	21	52	581	3,381	1.22	2.71	34.3
	13th-14th experimental weeks ..	154	21	64	796	4,504	1.51	3.50	46.4
	1st after week	133	77	158	452	4,016	1.04	2.28	28.1
	2nd after week	102	60	122	358	3,128	1.36	2.07	18.1
R.	Preliminary week	94	71	105	334	2,730	1.14	1.66	18.1
	All experimental weeks	103	21	50	514	3,024	1.08	2.35	30.5
	1st after week	137	85	176	594	4,669	1.38	2.37	29.0
	2nd after week	111	68	148	386	3,420	1.65	2.35	26.7
C.	Preliminary week	103	68	154	460	3,767	1.24	1.74	14.6
	2nd and 3rd experimental weeks ..	131	21	56	664	3,809	1.20	3.16	39.7
Miss T. ..	Preliminary week	101	76	153	410	3,515	1.01	1.68	20.0
	1st and 2nd experimental weeks ..	69	21	42	305	1,923	0.80	1.51	19.0
Mrs. G. ..	Preliminary week	35	19	35	213	1,341	0.32	0.64	9.8
	1st and 2nd experimental weeks ..	31	16	27	133	923	0.41	0.70	6.3

Table VIII shows the percentage distribution of calories between protein, fat, carbohydrate and alcohol in the diets. The increase rather than decrease in protein during the rationed periods must again be emphasised. The low proportion of calories obtained from fat, and the high proportion from carbohydrate are evident. For 15 weeks, M. was taking only 10·4 per cent. of his calories in the form of fat.

TABLE VIII
Percentage Distribution of Calories

<i>Subject.</i>	<i>Period.</i>	<i>Per cent. Calories from protein.</i>	<i>Per cent. Calories from fat.</i>	<i>Per cent. Calories from carbo- hydrate.</i>	<i>Per cent. Calories from alcohol.</i>
M.	Preliminary week ..	10·2	38·3	51·5	0
	1st-12th experimental weeks	14·0	10·4	75·6	0
	13th-15th experimental weeks	13·9	10·4	74·8	0·9
	1st after week	12·2	34·5	53·3	0
	2nd after week	11·0	24·3	64·7	0
Miss W.	Preliminary week ..	12·1	40·6	47·3	0
	1st-3rd experimental weeks	13·9	20·6	65·5	0
	4th-13th experimental weeks	13·1	19·7	67·2	0·4
	14th-15th experimental weeks	12·7	21·4	65·5	0
	1st after week	14·2	36·5	49·3	0
	2nd after week	13·3	29·7	57·0	0
Miss B.	Preliminary week ..	13·2	51·2	35·6	0
	All experimental weeks ..	13·9	21·4	64·3	0·4
	After week	12·5	52·2	35·3	0
H.	Preliminary week ..	12·9	35·1	50·2	1·8
	1st-12th experimental weeks	14·1	14·3	70·5	1·1
	13th and 14th experimental weeks	14·0	13·2	72·4	0·4
	1st after week	13·6	36·6	46·2	3·6
	2nd after week	13·4	36·2	47·0	3·4
R.	Preliminary week ..	14·1	35·7	50·2	0
	All experimental weeks ..	13·9	15·4	69·9	0·8
	1st after week	12·0	35·2	52·2	0·6
	2nd after week	13·3	40·3	46·4	0
C. . .	Preliminary week ..	11·2	38·0	50·1	0·7
	2nd and 3rd experimental weeks	14·1	13·6	71·5	0·8
Miss T.	Preliminary week ..	11·7	40·4	47·9	0
	1st and 2nd experimental weeks.	14·7	20·3	65·0	0
Mrs. G.	Preliminary week ..	10·7	24·3	65·0	0
	1st and 2nd experimental weeks.	13·7	27·2	59·1	0

Excretions and Balances

The effect of the experimental restrictions on the food consumption of the various subjects has now been described, and an account has been given of the chemical composition of the diets. The biochemical aspects, however, would not have been complete unless an attempt had been made to follow the absorption and metabolism of the experimental food. To this end, therefore, M., R., Miss W. and Miss T. collected their urines and fæces for one week before the restrictions were imposed, and again for another week during the period of experimental rations. M., R. and Miss W. collected their "experimental" urines and fæces after they had been on the rationed diet for eight weeks, by which time they had made most of their adaptations and their calorie intakes were roughly the same as before the restrictions had been imposed. Miss T. collected her excreta during the second week of her experimental diet, when her adaptation was still very incomplete and her calorie intake 1,600 per day lower than it had been during her preliminary week (Table VII). Seven to ten days after M., R., and Miss W. had finished their main experiment, they returned to the special diet, for reasons shortly to be described, and collected their excreta for a further week. They had not lost their aptitude for eating bread, potatoes and green vegetables at this time, and slipped back at once into their experimental habits. Miss T. returned to the diet with the others for a final week of collections. She, however, had been living on ordinary food for a considerable time, and consequently was no better adapted than she had been before, and her calorie intake was again little more than half her normal one.

Unfortunately, it was not possible during these "collection" weeks to set aside duplicate portions of the food for analysis, so that for balancing intake against output it has been necessary to calculate the composition of the food from food tables. This can be done with reasonable confidence for some elements if the foods are carefully chosen, but it is scarcely justifiable with minerals such as calcium when the diets consist largely of green vegetables and the tapwater is "hard."

Urines.—Table IX shows the urinary volumes and nitrogen partition. The increased volumes during the experimental periods have already been mentioned (page 21). Miss T.'s output would undoubtedly have been higher during the experimental periods than it had been during the preliminary week if she had eaten comparable amounts of food. The total N excreted by these four persons bore a close relationship to their N intake. In fact, taking the fæcal N into account, the subjects were in N equilibrium, and, therefore, the differences between the urinary outputs during the preliminary and experimental periods merely express the differences in protein intake which have already been discussed (page 32 and Table VII). The changes in ammonia excretion were indefinite and in the creatine and creatinine excretion negligible. Neither requires discussion. There was an increased excretion of uric acid by all four subjects

TABLE IX
Nitrogen Partition in the Urine

<i>Subject.</i>	<i>Period.</i>	<i>Average daily volume c.c.</i>	<i>Total N. g./day.</i>	<i>Urea N. g./day.</i>	<i>Ammonia N. g./day.</i>	<i>Uric acid N. g./day.</i>	<i>Creatinine + creatine N. g./day.</i>
M.	Preliminary	2,690	10.30	8.71	0.23	0.16	0.61
	1st experimental	3,406	16.10	14.30	0.47	0.28	0.59
	2nd experimental	3,734	15.30	—	—	0.33	0.60
R.	Preliminary	1,536	12.70	10.80	0.44	0.16	0.60
	1st experimental	2,489	16.40	13.60	0.51	0.29	0.56
	2nd experimental	2,500	14.60	—	—	0.28	0.59
Miss W.	Preliminary	2,286	9.43	7.86	0.43	0.15	0.52
	1st experimental	2,861	9.43	7.91	0.39	0.24	0.48
	2nd experimental	3,240	9.71	—	—	0.17	0.54
Miss T.	Preliminary	1,443	12.40	10.60	0.40	0.17	0.55
	1st experimental	1,457	9.71	8.29	0.36	0.17	0.44
	2nd experimental	1,600	10.30	—	—	0.19	0.53

during the experimental periods, particularly by M., R. and Miss W. This was a surprise, for there was little meat in the experimental diets and only very small quantities of any foods generally considered to be rich in purines. Analysis, however, revealed that the wholemeal bread contained 0.025 per cent. of purine N, which was presumably derived from nucleic acid in the germ. Moreover, vegetables cannot be neglected as a source of purines when they constitute such a high proportion of a diet. We found that a mixed cooked sample of cabbage and Brussels sprouts contained 0.0127 g. purine N per 100 g. and a sample of the cooked potatoes used during the experiment 0.0036 g. per 100 g. Using these figures and those given by McCance and Widdowson (1940), and for a few foods those of von Fellenberg (1918), the purine nitrogen in the diets has been calculated. The results are shown in Table X, and it will be seen that for three of the subjects the purine nitrogen introduced into the diet by the large quantities of wholemeal bread and vegetables more than counterbalanced the purine nitrogen lost owing to the restrictions of meat, and satisfactorily explains the increased excretion of uric acid in the urine. Miss T. ate more

TABLE X
Purine Nitrogen Intakes and Uric Acid Nitrogen Excretions

<i>Subject.</i>	<i>Period.</i>	<i>Purine nitrogen from bread g. per week.</i>	<i>Purine nitrogen from other foods g. per week.</i>	<i>Total purine nitrogen intake g. per week.</i>	<i>Total uric acid nitrogen excretion g. per week.</i>
M.	Preliminary	0.04	1.05	1.09	1.12
	1st experimental ..	0.97	1.30	2.27	1.94
	2nd experimental ..	1.10	1.11	2.21	2.34
R.	Preliminary	0.18	0.79	0.97	1.09
	1st experimental ..	1.53	0.88	2.41	2.02
	2nd experimental ..	1.10	0.84	1.94	1.93
Miss W. . .	Preliminary	0.06	0.84	0.90	1.07
	1st experimental ..	0.31	1.24	1.55	1.68
	2nd experimental ..	0.26	0.91	1.17	1.20
Miss T. . .	Preliminary	0.03	1.03	1.09	1.19
	1st experimental ..	0.67	0.69	1.36	1.20
	2nd experimental ..	0.59	0.72	1.31	1.35

meat than the other subjects in her preliminary week, and in consequence had a high purine intake. She ate only small amounts of vegetables during her experimental periods, so that had it not been for the wholemeal bread her purine intake would have fallen. As it was, it rose slightly, as did her excretion of uric acid. It is quite evident that if persons with gout are being strictly dieted they should be told to avoid wholemeal bread and unlimited green vegetables.

Fæces.—Table XI shows the effect of the rationed diet upon the water and organic matter in the fæces. The changes are uniform and consistent. Each person excreted more water, more solids, more

TABLE XI

Composition of the Faeces : Water and Organic Substances

<i>Subject.</i>	<i>Period.</i>	<i>Water g./day.</i>	<i>Dry matter g./day.</i>	<i>Total N. g./day.</i>	<i>Total fat g./day.</i>	<i>Split fat g./day.</i>	<i>Total fat per cent. of dry matter.</i>	<i>Cellulose,* etc., g./day.</i>
M.	Preliminary	150	30	1.79	4.16	2.41	14.0	11.3
	1st experimental	355	64	3.21	6.30	2.28	9.9	29.1
	2nd experimental	418	70	4.07	6.62	1.90	9.5	28.8
Miss W.	Preliminary	36	17	1.09	3.23	0.96	19.0	5.0
	1st experimental	93	29	1.45	3.80	1.30	13.1	12.4
	2nd experimental	130	43	1.96	4.18	1.83	9.7	21.6
R.	Preliminary	81	27	1.32	5.90	2.47	22.0	11.0
	1st experimental	276	70	3.28	6.10	2.17	6.8	30.0
	2nd experimental	206	53	2.46	5.50	1.54	10.2	25.7
Miss T.	Preliminary	28	14	0.74	3.20	1.57	22.4	4.4
	1st experimental	85	31	1.13	4.12	1.64	13.5	14.6
	2nd experimental	60	22	0.82	3.20	1.26	14.5	11.3

* These figures were arrived at by subtracting the total protein ($N \times 6.25$) and the fat from the dry matter.

fat, N, and cellular debris in the fæces during the first experimental period than he had done during the preliminary week. The results of the second experimental period were very similar to the first, but the individual figures should be inspected and compared. It is evident that these bulky diets, full of bread, potatoes and green vegetables, completely altered the character of the fæces. Starch was occasionally found in them, but only in undigested fragments of beans and peas which had been swallowed without mastication. The quantities of fat excreted are particularly interesting. The percentage of fat in the fæcal dry matter always fell during the experimental periods, but the total fat excreted in these weeks was about the same as (R. and Miss T.) or greater than (M. and Miss W.) it had been before. The changes are shown in Table XII, where it will be seen that 7 to 23 per cent. of the fat in the experimental food escaped absorption. It is generally considered that 95-98 per

TABLE XII
Percentage of the Dietary Fat Excreted in the Fæces

<i>Subject</i>	<i>Preliminary (normal) period.</i>	<i>1st experimental period.</i>	<i>2nd experimental period.</i>
M.	3.2	22.8	21.4
Miss W.	3.5	10.3	12.6
R.	5.6	12.4	11.4
Miss T.	2.2	10.0	7.1

cent. of both animal and vegetable fats in a mixed diet are utilised. A superficial examination of the present figures therefore suggests that the fat in these particular foods was unusually poorly absorbed. The comparison is unfair, because the digestibility of fats has usually been investigated—as in the well-known experiments of Langworthy and Holmes (1917)—by incorporating 60 to 100 g. of the pure fats into an almost fat-free diet. The digestion and absorption of the small quantities of fat in natural vegetable foods is a problem which has been less considered. It might well be found that the present figures were by no means exceptional for such foodstuffs. A loss of 23 per cent. of the fat in the diet is a very high proportion, and some allowance should really be made for it in calculating the available fat in the diets, or the calories derived therefrom. The convention, however, in calculating diets is to neglect the fæces, and this convention was followed in compiling the tables and figures. The correction makes much less difference to the total calories, since so much of the energy value of the food was derived from carbohydrate. The high percentage of the food fat found in the fæces is likely to have been due more to the general increase in fæcal matter than to the fat in the bread being particularly indigestible, since Miss W.'s intake of bread was scarcely high enough to account for her excretions of fat during the experimental periods.

Urinary-fæcal ratios.—Table XIII shows the distribution of minerals and nitrogen between the fæces and the urines, and the total amounts of the elements excreted. Since the subjects were

TABLE XIII

The Excretion and Distribution between the Urine and Faeces of Nitrogen and Mineral Matter

Subject.	Element.	Preliminary period.					1st experimental period.					2nd experimental period.				
		Urine g./day.	Faeces g./day.	Total g./day.	Urine per cent. total.	Faeces per cent. total.	Urine g./day.	Faeces g./day.	Total g./day.	Urine per cent. total.	Faeces per cent. total.	Urine g./day.	Faeces g./day.	Total g./day.	Urine per cent. total.	Faeces per cent. total.
M.	Na	7.54	0.15	7.69	98.0	2.0	12.10	0.49	12.59	98.1	3.9	14.40	0.44	14.84	97.5	2.5
	K	5.00	0.75	5.75	87.0	13.0	6.05	1.90	7.95	76.2	23.8	8.72	2.49	11.21	78.0	22.0
	Ca	0.25	0.82	1.07	23.4	76.6	0.14	1.15	1.29	10.7	89.3	0.15	1.45	1.60	9.4	90.6
	Mg	0.16	0.28	0.44	36.4	63.6	0.20	0.98	1.18	17.0	83.0	0.23	0.89	1.12	20.5	79.5
	P	0.71	0.49	1.20	59.0	41.0	1.27	1.67	2.94	43.2	56.8	1.23	1.93	3.16	39.0	61.0
	Cl	11.70	—	—	—	—	18.30	—	—	—	—	23.60	—	—	—	—
	N	10.30	1.79	12.09	85.5	14.5	16.20	3.21	19.41	83.5	16.5	15.30	4.07	19.37	79.0	21.0
Miss W.	Na	3.21	0.01	3.22	99.7	0.3	5.37	0.07	5.44	98.7	1.3	6.50	0.18	6.68	97.5	2.5
	K	3.67	0.38	4.05	90.6	9.4	4.80	0.71	5.51	87.1	12.9	6.35	0.93	7.28	87.4	12.6
	Ca	0.14	0.71	0.85	16.5	83.5	0.11	0.83	0.94	11.7	88.3	0.08	0.96	1.04	7.7	92.3
	Mg	0.12	0.19	0.31	38.7	61.3	0.07	0.36	0.43	16.3	83.7	0.14	0.45	0.59	23.7	76.3
	P	0.61	0.38	0.99	61.6	38.4	0.61	0.72	1.33	45.8	54.2	0.65	0.95	1.60	40.6	59.4
	Cl	4.60	—	—	—	—	8.72	—	—	—	—	9.75	—	—	—	—
	N	9.40	1.09	10.49	89.6	10.4	9.40	1.46	10.86	86.6	13.4	9.70	1.96	11.66	83.2	16.8
R.	Na	3.80	0.03	3.83	99.2	0.8	5.83	0.10	5.93	98.3	1.7	8.80	0.08	8.88	99.0	1.0
	K	2.61	0.63	3.24	80.6	19.4	5.09	1.93	7.02	72.6	27.4	5.42	1.50	6.92	78.5	21.5
	Ca	0.32	0.98	1.30	24.6	75.4	0.29	1.16	1.45	20.0	80.0	0.25	1.27	1.52	16.4	83.6
	Mg	0.14	0.28	0.42	33.3	66.7	0.17	0.80	0.97	17.5	82.5	0.18	0.58	0.76	23.7	76.3
	P	1.09	0.59	1.68	65.0	35.0	1.26	1.41	2.67	47.1	52.9	1.25	1.35	2.60	48.2	51.8
	Cl	5.85	—	—	—	—	9.50	—	—	—	—	14.20	—	—	—	—
	N	12.70	1.32	14.02	90.6	9.4	16.40	3.29	19.69	83.3	16.7	14.60	2.49	17.09	85.4	14.6
Miss T.	Na	2.47	0.02	2.49	99.2	0.8	3.08	0.04	3.12	98.7	1.3	5.20	0.03	5.23	99.3	0.7
	K	3.21	0.28	3.49	88.8	11.2	2.81	0.91	3.72	75.4	24.6	3.16	0.70	3.86	82.0	18.0
	Ca	0.24	0.68	0.92	26.1	73.9	0.17	0.81	0.98	17.3	82.7	0.17	0.46	0.63	27.0	73.0
	Mg	0.11	0.14	0.25	44.0	56.0	0.10	0.41	0.51	19.6	80.4	0.11	0.32	0.43	25.5	74.5
	P	0.90	0.40	1.30	69.2	30.8	0.86	0.92	1.78	48.3	51.7	0.78	0.63	1.41	55.3	44.7
	Cl	3.62	—	—	—	—	4.80	—	—	—	—	7.95	—	—	—	—
	N	12.30	0.74	13.04	94.4	5.6	9.70	1.21	10.91	88.9	11.1	10.30	0.82	11.12	92.6	7.4

adults and probably in approximate mineral balance, the total amounts excreted may be taken to be roughly equal to the total amounts in the food. We may, therefore, use the changes in the total *excretions* to gauge the effect of the experimental diets upon the *intakes* of those minerals (sodium, chlorine, potassium and magnesium), which for various reasons have not been calculated from the food tables. On doing so, it is evident that the experimental diets contained far more salt. This was due to the fact that practically all the food either had salt in it, or was eaten with salt. There were no pastries, puddings, cakes, jams, sugars and fats which contribute calories but little or no salt to a typical mixed diet. The same general reasons go to explain why there was so much more potassium and magnesium in the experimental diets. The restrictions in sugar and fats, which are almost free of these minerals, increased the consumption of other foods (*e.g.*, wholemeal bread) which are rich sources of both. The calcium, phosphorus and nitrogen in the foods have already been discussed.

The distributions of the minerals and nitrogen between the urine and faeces is interesting. It is to be noted that each person had his own characteristic ratios during the preliminary week, and that the experimental diet modified these individual ratios in the same direction and in a most orderly manner. R., for example, excreted 24.6 per cent. of his calcium by the kidney during the preliminary week, Miss W. 16.5 per cent. In the first experimental week R.'s percentage fell to 20.0 and Miss W.'s to 11.7. This is a feature of the results which technicians and investigators will agree makes them carry conviction.

The increased amounts of sodium in the experimental faeces are readily explained by the fact that there was more fluid in them. The extracellular secretions had been less completely reabsorbed. The extra potassium may have been due to the increased quantities of cellular debris found in the experimental faeces (Table XI), to the increased fluid, or to both. The calcium excretions are worthy of special note. If the preliminary and first experimental periods are compared, it will be found that the change of diet decreased the amount of calcium in the urine, and the percentage of the element so excreted. This was at first taken to mean that we were suffering from a mild vitamin D deficiency or, at any rate, that more vitamin D would restore the distribution of calcium between the urine and faeces to its pre-experimental level. Since this question of D deficiency was a very important one, we decided to saturate ourselves with the vitamin, and then to collect excreta for a second experimental period. Accordingly, after finishing the main experiment, M., R. and Miss W. arranged to take 2,500 international units of vitamin D every day for a fortnight, and Miss T. 5,000 international units a day for three days. All four subjects then returned to the experimental diet and reduced the vitamin intake to a dose which was intended to be 500 units a day. After three preliminary days they began to collect their urine and faeces

for a third week. As will be seen in Table XIII, M., Miss W. and R. excreted a still lower percentage of their calcium by the kidney in the second experimental period. Only Miss T. showed a reversion to her pre-experimental ratio, and there are reasons for suspecting that the results for her faeces in the second experimental period may be wrong. She fell ill towards the close of the week with a septic throat and had to go to bed. Her bowels became irregular, and although she took carmine at the appointed time and thought the faeces were correctly demarcated, an inspection of her results shows that every one of her faecal figures is lower than in the first experimental period. We communicated these unexpected findings to Messrs. Glaxo, Ltd., from whom the vitamin D had been obtained, and they at once offered to re-assay biologically the vitamin preparation which had been used. This took some time and the conclusion finally reached was that there had been some deterioration in the preparation. Our dosages, therefore, had all been smaller than planned, but should still have been generous. Taking the evidence together, one must accordingly conclude that vitamin D in reasonable dosage did not restore our calcium ratios to their pre-experimental levels, and that, therefore, we were wrong to suppose that the excretion ratios in the first experimental period suggested that we required more vitamin D. These present results indeed should probably be regarded as a confirmation of those of Buttner (1939), who found that the administration of 100 international units of vitamin D per day to two normal persons—*i.e.*, persons not in need of vitamin D—did not alter their urinary/faecal calcium ratios. The increased faecal/urinary ratios may have been due—and this would bring calcium into line with sodium, potassium and other minerals—to the increased bulk of the faeces caused by the rough food and the resulting hyperperistalsis and increased intestinal secretion. Althausen *et al.* (1939) have concluded that the increased and abnormal faecal excretion of calcium by rats with hyperthyroidism is due to causes such as these. It can scarcely be due to a deficiency of vitamin D, for Tibbetts *et al.* (1932) have made a limited study of this matter in patients with hyperthyroidism, and found that the administration of large amounts of the vitamin neither depressed the abnormal excretion of calcium by the bowel nor raised the urinary/faecal ratios.

The changes described in our calcium excretions naturally raise the question of whether the calcium balance was affected adversely by the diet. As already stated, our calcium intakes were not measured with sufficient accuracy to enable us to balance intake against output for these few experimental weeks. Even if they had been, the periods were not long enough and the subjects were not numerous enough for really good metabolic work. The present investigation, in short, was not designed for this purpose, and it is better therefore to leave the matter open till further work has been done (*see* McCance and Widdowson, *J. Physiol.*, 1942, 101 *et seq.*). It would clearly be unwise to recommend any diet which was likely to lead to negative calcium balances.

Magnesium behaved rather differently from calcium, in that the total amount in the urine did not necessarily fall. The proportion of the total magnesium excreted by the kidney, however, did fall; and clearly magnesium, like calcium, was less readily absorbed from the experimental than from the preliminary diets. The experimental food increased the absolute amounts of phosphorus in M.'s and R.'s urines, did not alter the amounts in Miss W.'s, and decreased those in Miss T.'s. Since, however, the amount of phosphorus in the faeces was always greatly increased, each person excreted a larger percentage of this element by the bowel than he had done before. The increased excretion of magnesium, phosphorus and calcium by the bowel may have been due not only to the increased bulk of the faeces and to the causes which were operating in the case of other elements, *e.g.*, potassium and nitrogen, but also, more specifically, to the large amounts of phytic acid in the experimental food (Harrison and Mellanby, 1939; McCance and Widdowson, 1935).

Taking these faecal and urinary excretions together, it is clear that the faecal/urinary ratios were invariably increased by the experimental diets; and it follows that this food was not so well absorbed nor so completely utilised as the preliminary diets had been. It would be unwise, however, to use this as an argument against the experimental diets for adults, except possibly as regards calcium, for they contained more minerals and sometimes more nitrogen, and the present work as a whole leads us to believe that a sufficiency was absorbed. They could not be recommended for children, however, without further investigation.

At intervals up to Christmas the long-term subjects were examined for signs of vitamin deficiencies. Their daily excretion of aneurin, and of ascorbic and nicotinic acids were measured, and found to be completely satisfactory. The excretions of the two former were, in fact, very high (Table XIV), and figures of this magnitude for aneurin have not been obtained in more recent experiments involving somewhat similar diets. The large amounts of aneurin presumably came from the bread and green vegetables, and those of ascorbic acid

TABLE XIV
Vitamin Excretions

Subject.	Ascorbic acid mg. per day.		Aneurin µg. per day.		Nicotinic Acid mg. per day.	
	Control.	Experi- mental.	Control.	Experi- mental.	Control.	Experi- mental.
M. ..	87	132	150	1,550	—	4.3
H. ..	28	75	183	1,183	3.4	4.1
R. ..	18	77	220	1,225	3.5	2.7
Miss W. ..	43	101	173	439	—	1.8
Miss B. ..	19	61	208	555	3.4	1.7

Vitamin tests were made on two consecutive days, before, after one month and after two months on the diet. The results after the first month were so like those after the second month that all four figures have been averaged.

from the potatoes and green vegetables. Tests for the subjects' powers of dark adaptation revealed no indication of vitamin A deficiency. There was considerable variation from one subject to another, but the readings obtained after one and two months on the special diet agreed within experimental error with the same person's results before the diet was started. Since the diets contained very little vitamin A, we conclude that the subjects were synthesising this vitamin for themselves from the precursor carotene, which they were obtaining from their green vegetables and carrots.

Effects of the Restrictions upon Health and Physical Fitness

The general health of all the subjects was good throughout this experiment. They were able to carry out their normal work without any loss of efficiency. R. was suffering from a cold when the experiment began. H. had a bad one very soon after it started, and H. and Miss W. had very mild colds at Christmas time. M. had a similar mild cold in January. R. has never had a winter so free from infections of the upper respiratory tract. One of the subjects who was prone to acne and allied infections, noted that her skin was unusually, if not completely, clear during the experiment, and that the spots reappeared after a few weeks on normal food.

M., H., R. and Miss W. tested their physical fitness by strenuous exercise. Miss B. was unable to do so, since she abandoned her allegiance and went home on the 21st December.

After some shorter preliminary cycle rides, R. and M. went for a long run near Cambridge on the 22nd December. It was sunny but very cold, with continuous hard frost. R. rode 73 miles, M. 102 miles.

On the 27th December, at 5.30 a.m., R. and M. set out to cycle from Barrington, Cambs., to Langdale, Westmorland. The weather was very cold, and the roads were in places covered with ice. The wind, which was north, was against them. They covered 92 miles on the first day and put up at Tuxford. The next day was cloudy and not quite so cold. The wind was very light but still against them. They reached Skipton at tea time—a distance of 80 miles—and found there a few inches of new snow on the roads. They left Skipton at 6.30 a.m. on the 29th, an intensely cold morning, and reached their destination in Langdale, 63 miles farther on, at 1.55 p.m. For the whole of this distance the roads were snow-covered and for the most part ungravelled. Each fell off once owing to the slippery surfaces.

On the 30th December M., H., R. and Miss W. walked over Scafell Pike to Mickledore and back, a distance of 15 miles over track and boulders, involving 3,900 feet of climbing. The wind was north and the weather very cold with several inches of new snow underfoot, and there were periods of mist and falling snow.

To appreciate R.'s performances during these last four days it is essential to judge them in the light of his upbringing and psychology. Reared from childhood under the sentence of a weak

heart, R. spent his boyhood and university life almost "in cotton wool," never played any games or took part in sports of any kind. A chance illness in 1936 led him to visit a consulting physician, who discovered that there was, after all, nothing wrong with his heart. Suddenly emancipated in this way at the age of 22, R. made little use of his freedom for some time. He took up no games, but after about a year he bought a bicycle and gradually began to extend himself on it. Till this experiment began, however, his longest ride had been of the order of 70 miles in summer weather, and he had never ridden distances of that magnitude on two successive days. Not only was he unaware that he could do so, but he believed that he could not. He had never walked for more than a few hours at a time on level ground, and he had never been on a mountain in his life. He had therefore in all probability never experienced real physical fatigue under trying conditions, and his performance must be reckoned a psychological as much as a physical triumph. After these tests R. was passed as fit, and although he stayed on with the party, he was absolved from further long days of exceptional exertion.

M. was forced to rest on the 31st December and 1st January by a bursitis of his right heel which had been troubling him for 10 days.

On the 31st December H. ascended Bow Fell by the Band from the gate of Stool End Farm in 53 minutes. Atmospheric conditions were perfect, but there was some hard frozen snow underfoot. This test involved a climb of 2,600 feet in a distance of $2\frac{1}{2}$ miles. Carrying a load of a few pounds, M. made this ascent on the 10th January in 51 minutes, but the ground conditions were probably slightly better, and by the 10th January M. was in excellent mountaineering training.

On the 2nd January M. and H., carrying loads of 8 and 9 lbs. respectively, left their base at 6 a.m., crossed into Borrowdale by Stake Pass and thence over the Honister, Scarf Gap and Black Sail Passes to reach Wasdale Head at 11.45. After a pause of 35 minutes they went over Eskdale Fell to Boot, where they stopped for 10 minutes to put through a telephone call, and returned home over Hardknott and Wrynose Passes and by Elterwater, to arrive at 5.25 p.m. This was a distance of 36 miles, involving 7,000 feet of ascent and descent, and it was covered at an average speed—including stops—of about 3.2 miles per hour. The weather was perfect, but there were a few inches of snow on the ground and a considerable amount of ice on both sides of the Honister Pass. Most of the way was over very rough foot paths; the only stretches of metalled road were in the Langdale valleys and over the Honister Pass.

On the 4th January H. ascended Coniston Old Man from Coniston Church in 88 minutes, carrying a rucksack weighing 42 lbs. On the same day M. did the same climb in 82 minutes. He took a slightly shorter route, but carried a rucksack, 100 feet of rope and an ice axe, giving a total weight of 45 lbs. The ascents therefore were not comparable. The conditions were excellent. This test meant a

climb of 2,400 feet in a distance of approximately $2\frac{3}{8}$ miles. M.'s pulse-rate five minutes after reaching the top was 88.

These performances are not records in any sense of the term, but they could not have been carried out by people who were not physically fit, and they are beyond the capabilities of many who consider themselves healthy and who have never been the victims of any dietary restrictions whatsoever. Through the kindness of Mr. G. R. Speaker, some of these walks and climbs were submitted to Mr. Unna of the Alpine and Scottish Mountaineering Clubs for comment. He considered that the Coniston climb was probably the most searching, but he also pointed out that the time for the round walk of the 2nd January was 28 per cent. faster than the time calculated by Naismith's rule. He added that, although the route was a favourable one for high speeds, this was "distinctly good; and, what is perhaps more informative, the ratios of the times for the three sections of the walk do not show any tendency to slow down towards the end."

On the 4th of January Miss W. made the ascent of Coniston Old Man beside H., but carrying no load, and on the 5th January they left the cottage in Langdale at 8.5 a.m., crossed into Borrowdale by Stake Pass, and thence to the tops of Green Gable and Great Gable via Honister summit, and home over Esk Hause, getting in about 6 p.m. This was a distance of 22 miles, involving ascents and descents of 5,250 feet; and in spite of the slow time it was a good performance, for Miss W. had injured her knee on the 1st January. It was bruised and swollen when she started but had given her no trouble the day before. Owing to a further strain, however, it began to give her considerable pain soon after starting, slowed up all her descents and made them most uncomfortable. Atmospheric and ground conditions were fair.

It has been implied by critics that our tests of physical fitness were no tests at all, and could be considered so only if the same rides and climbs had been carried out before the experiment began. Such criticism is too facile. It would carry weight only if human beings were machines or if the alteration in the diet had been undetectable, so that half the subjects, unknown to themselves, could have been made to serve as controls. From the nature of the experiment these were unattainable exactitudes. The tests described were the best approximations which could be devised, and it is hoped that no unjustifiable claims have been based upon them. Better performances *might* have been put up by the same people on their normal food (or indeed on the experimental food), but we made no attempt to investigate the finer points of the matter. These tests were only incidents in a fortnight of considerable activity, the bare data of which are given in Table XV. A point we would stress here is that on this food we were all not only physically fit, but mentally vigorous, and anxious to take advantage of the fine weather to make the very best of what was to us a most enjoyable holiday.

TABLE XV
Exercise and Calorie Consumption

Date.	Subject M.		Subject R.		Subject H.		Subject Miss W.	
	Exercise.	Calorie intake.	Exercise.	Calorie intake.	Exercise.	Calorie intake.	Exercise.	Calorie intake.
26.12	L	3,664	T	3,139	T	4,310	T	2,671
27.12	R92 ..	4,873	R92 ..	3,138	T	3,820	T	2,075
28.12	R80, W4	5,272	R80, W4	4,382	W4	3,294	W4	1,759
29.12	R63, W4	5,308	R63	3,045	W4, C1000	4,094	W4	2,119
30.12	W15, C3900	4,507	W15, C3900	3,390	W15, C3900	4,027	W15, C3900	1,756
31.12	T	3,319	W5, C1000	2,904	W11, C3250	4,232	W11, C3250	1,827
1.1	T	4,046	W8, C2650	3,723	W8, C2650	3,919	W8, C2650	1,917
2.1	W36, C7000	5,850	W10, C2615	2,828	W36, C7000	4,941	O	2,125
3.1	W5, C2100	4,151	W8.5, C2200	3,589	W8.5, C2200	4,759	W8.5, C2200	2,497
4.1	W8, C3000	3,815	W8, C1923	2,699	W8, C3000	4,213	W8, C3000	2,277
5.1	W21.5, C5250	5,245	W5, C1200	3,347	W21.5, C5250	4,911	W21.5, C5250	2,509
6.1	R53, C2530	5,007	W10, C1959	3,347	T	4,104	T	1,959
7.1	W8, C900	3,640	O	2,955	T	3,831	O	2,491
8.1	W11, C4500	5,045	R22	3,579	W11, C4500	5,189	T	2,590
9.1	W11, C5400	4,852	W10, C1000	3,598	W11, C5400	4,982	W10, C1000	2,548
10.1	W4, C2600	4,263	—	—	—	—	L	2,520
11.1	W6, C1900	4,430	—	—	—	—	W6, C1900	2,562
12.1	W7, C2300	3,773	—	—	—	—	W4, C2000	2,573

L = little.

W = walked (miles).

T = trifling.

R = cycled (miles).

O = a day spent indoors.

C = climbed (feet).

Correlation between Physical Exercise, Calorie Intakes and Food

In Figs. 3, 4, 5 and 6 the weeks marked with the solid horizontal line below the weight curve were those in which the various tests of physical fitness were carried out. These involved hard exercise, sometimes for many hours a day, and M., H. and Miss W. met this by increasing their calorie consumption. R. did not. We have made a further analysis of these weeks to see how close the correlation was between the severity of the exercise and the daily consumption of calories.

Table XV gives a record of the distances cycled or walked, the heights climbed and the calorie intakes of M., H., R. and Miss W. from the 26th December till the party left Langdale. M.'s correlation between exercise and calorie consumption is quite obvious. He may be reckoned to have had nine big days (27th, 28th, 29th, 30th December and 2nd, 5th, 6th, 8th and 9th of January), on all of which his daily calorie intake was over 4,850 and ranged up to 5,850. His highest intake on days reckoned as moderate was no higher than 4,430. The others showed less obvious correlation, and Miss W. clearly tended to eat more and more the longer she stayed at Langdale. On re-arranging the data (Table XVI) H.'s figures suggest a correlation. R.'s correlation is much less con-

TABLE XVI

Correlation of Exercise with Calorie Consumption

<i>Subject.</i>	<i>Classification of exercise, number of days and dates.</i>			<i>Average daily consumption of calories.</i>
M. ..	Light (3)	Dec. 26, 31; Jan. 1	3,676
	Moderate (6)	Jan. 3, 4, 7, 10, 11, 12	4,012
	Heavy (9)	Dec. 27, 28, 29, 30; Jan. 2, 5, 6, 8, 9	5,107
H. ..	Light (5)	Dec. 26, 27, 28; Jan. 6, 7	3,872
	Moderate (4)	Dec. 29; Jan. 1, 3, 4	4,246
	Heavy (6)	Dec. 30, 31; Jan. 2, 5, 8, 9	4,714
R. ..	Light (2)	Dec. 26; Jan. 7	3,047
	Moderate (9)	Dec. 31; Jan. 1, 2, 3, 4, 5, 6, 8, 9	3,290
	Heavy (4)	Dec. 27, 28, 29, 30	3,489
Miss W. ..	Light (9)	Dec. 26, 27, 28, 29; Jan. 2, 6, 7, 8, 10	2,256
	Moderate (5)	Jan. 1, 3, 9, 11, 12	2,420
	Heavy (4)	Dec. 30, 31; Jan. 4, 5	2,092

vincing, as a closer examination of Tables XV and XVI will reveal, and Miss W. showed no correlation at all. Personal idiosyncrasies lie behind these differences. R. was never really happy under difficult and unpleasant climatic conditions. He liked his soup, his creature comforts and a good sit-down meal at mid-day, and he could not adapt himself to eating large amounts of food in

the open air, sheltering from a snowstorm behind an ice-covered boulder. R. therefore ate far more on the days when he was at the cottage for lunch. M. and H. ate large quantities when they were out on whole-day expeditions, and if it was too cold to sit down for more than a few minutes, they ate their bread while on the move. We give these results to show in a quantitative way how differently people may react to the same surroundings and yet appear to achieve equally satisfactory results. It is only when conditions become really severe that weaknesses are revealed. Thus, R. would probably have lost much weight had he been forced to take the prolonged exercise in the open air which M. took on the first nine days of January; H. could probably have taken much more without losing an ounce.

It is only fair to note that R. was not the only subject whose calorie intake was affected by comfort and good cheer. Table XVII shows the effect of Christmas Day on M.'s, H.'s, R.'s and Miss W.'s calorie consumption. There were extras at the evening meal, in the shape of a plum pudding made from ingredients saved from the rations during the previous weeks, and a few nuts; but M. ate more potatoes on the 25th December than he had ever eaten in one day before (51 oz.). There were, however, extenuating circumstances, for M. had cycled 52 miles during the day.

TABLE XVII
The Calorie Consumption on Christmas Day

Subject.	Average daily calories during previous week.	Calorie consumption on Christmas day.
M.	3,487	5,597
H.	3,610	4,464
R.	3,253	4,430
Miss W. .. .	1,995	2,988

The actual foods consumed during some of these long days are shown in Table XVIII. The table demonstrates very well the large amounts of bread which had to be eaten to satisfy the physiological demand for calories. The meal arrangements were fairly characteristic of the individual subjects. Miss W., for instance, never ate bread with her evening meal or took porridge for breakfast, but the autolysed yeast was really more characteristic of M. than of R. H.'s meal "after getting in" was really two meals—tea, at which he ate 8½ oz. bread, and supper, at which he ate the rest. R. and Miss W. also had tea on the days when they were home in time, but on the days illustrated they were not.

The vegetable breakfasts with home-made chutney may interest some, and even stimulate them to try the same. Anyone who wishes to gain a rapid idea of what these diets were like is strongly recommended to weigh out any one of the meals and compare it with his own!

TABLE XVIII
Foods Consumed during Days of Strenuous Exercise

Subject and date:— Exercise:—	<i>M.—2.1.40</i> Walked 36 miles Climbed 7,000 ft.	<i>R.—3.1.40</i> Walked 9 miles Climbed 2,200 ft.	<i>Miss W.—5.1.40</i> Walked 21½ miles Climbed 5,250 ft.	<i>H.—8.1.40</i> Walked 11 miles Climbed 4,500 ft.
Before starting	Porridge 20½ oz Bread 4½ ..	Porridge 8 oz Bread 8½ .. Autolysed yeast .. ½ ..	Boiled potato .. 9 oz Cabbage 9 .. Chutney 1½ .. Bread 1 ..	Boiled potato .. 4 oz Brussels sprouts .. 4 .. Chutney ¾ .. Bread 8½ ..
While out	Bread 38 .. Vegetable soup .. 7 ..	Bread 10 .. Vegetable soup .. 30 ..	Bread 7½ .. Pea soup 13 .. Fish paste 1 ..	Bread 21 .. Curry soup .. 7½ ..
After getting in	Vegetable soup .. 12 .. Bread 12 .. Boiled potato .. 34 .. Boiled swedes .. 22 .. Stewed beef .. 2 .. Gravy 25 ..	Baked potato .. 19 .. Cheese 2 .. Cabbage 18 .. Bread 6 ..	Boiled potato .. 16½ .. Curried butter beans 22 .. Cabbage 16½ ..	Boiled potato .. 20½ .. Boiled dried peas .. 12 .. Boiled rice 16 .. Kipper 4 .. Bread 17½ ..
Extras	Milk 5 ..	Milk 5 .. Margarine ½ .. Jam 1½ ..	Milk 5 .. Margarine ½ .. Marmalade 1½ ..	Milk 5 .. Margarine ½ .. Jam and marmalade 1½ ..

Effect of Return to a Freely Chosen Diet on the Quantities and Chemical Composition of the Food Consumed

This was a most interesting section of the experiment and it is well worth careful consideration, for it illuminates an aspect of human nutrition which has been somewhat neglected. There were two after-periods of one week each. One followed the experimental periods without a break, and the other came five weeks later. To understand the findings it is essential to realise something of the circumstances in which the studies were carried out. On the 21st December Miss B., with undisguised relief, gave up an experiment which had been worrying her for $2\frac{1}{2}$ months, and went home to eat. Ten days later she posted to us an account of her first week of gastronomic freedom. The results were really rather remarkable. Some are shown in Fig. 7 and there it will be seen that her calories rose from an experimental level of 1,780 per day to 3,450. She ate no potatoes, not many green vegetables, and her bread intake did not rise. Whence then the extra calories? These came mostly from meat (60 oz. in the week), butter 14 oz., cream $5\frac{1}{4}$ oz., chocolate 21 oz. and cake 30 oz. It is evident that she lost no time in obliterating most of the traces of the experimental routine, but several still persisted. She wrote to say that she had missed the wholemeal bread and had been forced to eat a very pale substitute which was all the household could provide. Moreover, her bread/butter ratio (Table XIX), of which she was probably quite unconscious, had not been restored to its preliminary value. R., H., M. and Miss W. went back to ordinary food with hearty appetites, immediately after a fortnight of strenuous exercise. R. returned to the bosom of a family which had been saving up Christmas and New Year fare for a starving hero! His food therefore was largely pre-arranged. His daily calorie intake (Fig. 6) rose by over 1,000. This was mainly due to the consumption of chocolate, $15\frac{1}{2}$ oz., cake 43 oz., puddings 26 oz., jam, etc., 20 oz. and sugar as such 10 oz., and bread, potatoes and vegetables well in excess of his preliminary week. H. went home to a family with ordered dietary habits. He had been eating much more than R. and taking much more exercise. He showed (*cf.* p. 48) a much better exercise-calorie adaptation than R., for he reduced his calories, although only by a little. His bread intake (Fig. 5) fell to near its preliminary level, but he ate 61 oz. of potatoes during the week, which was rather an achievement for a person living in an ordinary household. In his preliminary week he had eaten 16 oz. Meat $66\frac{1}{2}$ oz., cake $30\frac{1}{4}$ oz., puddings 19 oz. and fruit 40 oz. compensated for the fall in bread and green vegetables. M. and Miss W. returned to households where the menus were theirs to command. They were therefore much freer than the others, and their results are rather more instructive. M. reduced his consumption of bread, potatoes and vegetables, but to varying degrees, retaining them all at about twice their preliminary levels (Fig. 3). He ate large quantities of fruit (Table XIX) and 58 oz. of meat and

TABLE XIX
Consumption of Certain Foodstuffs before, during and after the Experiment
(Arranged to show the persistence or otherwise of experimental influences)

Food.	H.				Miss W.			
	Preliminary week. oz /week.	Last experimental week. oz /week.	1st week after giving up experimental food. oz /week.	6th week after giving up experimental food. oz /week.	Preliminary week. oz /week.	Last experimental week. oz /week.	1st week after giving up experimental food. oz /week.	6th week after giving up experimental food. oz /week.
Milk	69	35·0	47·0	100·0	103·0	35·0	68·0	84·0
Meat	41	5·7	67·0	31·0	35·0	16·0	35·0	21·0
Meat + fish	62	16·0	69·0	36·0	35·0	16·0	47·0	21·0
Potatoes	16	201·0	61·0	32·0	80·0	198·0	164·0	152·0
Bread	60	261·0	76·0	94·0	30·0	68·0	55·0	30·0
" Butter " (on bread)	12	4·0	5·0	5·7	6·5	3·7	5·0	3·4
Jam	15	10·0	11·0	16·0	8·0	9·6	4·8	3·2
Fruit	76	3·5	4·0	26·0	64·0	0	42·0	65·0
Cheese	17	4·0	11·0	16·0	0	4·0	9·0	12·0
	R.				M.			
Milk	140	35·0	151·0	163·0	178·0	35·0	108·0	81·0
Meat	39	6·0	36·0	28·0	52·0	7·2	45·0	10·0
Meat + fish	52	14·0	53·0	28·0	52·0	11·2	58·0	20·0
Potatoes	32	148·0	41·0	56·0	96·0	282·0	188·0	191·0
Bread	26	128·0	65·0	45·0	21·0	256·0	41·0	5·2
" Butter " (on bread)	8	4·0	6·5	8·7	7·0	0	3·9	0·2
Jam	11	10·0	19·0	5·0	15·0	0	9·0	1·7
Fruit	51	4·7	53·0	24·0	200·0	0	227·0	220·0
Soup	0	326·0	52·0	62·0	—	—	—	—
Chocolate	6	0	16·0	4·7	—	—	—	—

fish in the week, but less than his experimental rations of "butter," *i.e.*, fat for bread, and jam. His calories fell slightly. Miss W. had got so much into the habit of eating potatoes and green vegetables that she scarcely reduced them at all (Fig. 4). She did not eat up her ration of "butter" or jam, but she added some puddings and biscuits to her dietary and increased her consumption of meat and fish to 47 oz., of fruit to 42 oz. and of cheese to 8.7 oz., with the result that her calories rose from 2,520 per day to 2,980.

Five weeks later these last four subjects again weighed their food. By this time they had been living for some weeks under conditions closely resembling those of the preliminary week, and the tests were comparable. R.'s calories were still at their holiday level (Fig. 6), and he had put on a good deal of weight. He had lost most of his obvious experimental habits, but this was largely a matter of circumstances and he was still taking saccharine in his coffee and eating brown bread. H. had also put on weight (Fig. 5) and had probably been eating much more than he ate during this final week. His potato intake was still at twice its preliminary level, and his "butter" intake half. This last was an obvious legacy of the experiment and one which all the subjects showed, as a reference to Table XIX will indicate. H.'s meat intake was about half what it had been before the experiment and in the week after it. During this final week M. was found to be still eating almost experimental amounts of potatoes and other vegetables, but his bread consumption had fallen to near zero. His fruit intake was 220 oz. in the week, but he ate negligible quantities of butter and jam, and his meat and fish together were only a few ounces above the experimental allowance. His animal protein was coming from cheese (4.7 oz.), eggs and milk. Miss W.'s potato intake was still at the experimental level. Her bread and vegetable consumption had fallen, her calories also. Her intake of meat was very much below its pre-experimental level and cheese had taken its place as a source of animal protein.

The chemical composition of the diets during the after-periods are shown in Table VII, and it will be seen that during the first after-period all four subjects raised their fat intakes to very high levels. This was largely unconscious, for they were not eating much butter and the source was fat used in cooking. R. raised his carbohydrate intake during this period largely by his increased consumption of sugar. These excesses had disappeared by the second after-period. The percentage distribution of calories between protein, fat and carbohydrate is worth considering (Table VIII). It shows, as always, the relative constancy of the proportion derived from protein; and unmistakable relics of the experiment are to be found in the percentage of their calories which M. and Miss W. were obtaining from fat in the second after-period.

If these after-periods be regarded as the converse of the first few weeks of the experiment, all the results fall into line. It will be recalled that when the experiment first began everyone's calorie intake fell, owing to the dryness and bulk of the food, its lack of fat,

and to the fact that the food took a long time to eat. In subsequent weeks, however, adaptation enabled all the subjects to recover their original calorie intakes. At the close of the experiment, four persons with holiday appetites, and accustomed to very bulky food, found themselves free to eat what they chose or what was set before them. They liked the food they had been having, but the relaxation was exhilarating and the new food a pleasant change. Consequently, they continued to eat up to the anatomical capacity of their stomachs, but all replaced some of their cereals and vegetables with foodstuffs like fat and sugar, of high calorific value but negligible bulk. The result was that when the day of reckoning came both R. and Miss W. found that they had been guilty of calorie intakes wholly unsuspected by themselves. This is shown by the fact that two days after leaving the experimental diet R. made the following note in his diary: "Appetite seems to be adjusted to the changed food." H. and M. avoided such excesses as these, but ate far more than they required as judged by their exercise records. Miss B. had the biggest rise in calories, without the excuse of a fortnight's heavy exercise! By the second period bodily requirements had regained control of appetite—except possibly in the case of R.—and the results are chiefly interesting as showing in what respects the experimental influence had persisted, or had reasserted itself after being temporarily submerged in the exuberance of the first week of freedom. These trends of food consumption are summarised in Table XIX. The butter/bread ratios have been tabulated separately (Table XX), and they show very well the persistence of new habits acquired during the experiment. Other consumption trends indicate complete obliteration of the experimental influences: M.'s fruit consumption is a good example.

These after-periods indicate that food habits, even of a strange and unconventional type, are not easily lost once they have been acquired.

TABLE XX

Proportions of Bread to Butter eaten by Five Subjects before, during and after the Experiment

Subject.	Preliminary week.	Last experimental week.	1st week after giving up experimental food.	6th week after giving up experimental food.
H.	5/1	65/1	15/1	16/1
M.	3/1	*	10/1	26/1
R.	3·3/1	32/1	10/1	6/1
Miss W. ..	4·6/1	18/1	11/1	9/1
Miss B. ..	2/1	19/1	3·4/1	—

* M. ate no butter for the last 12 weeks of the experiment.

Cost of the Experimental Diet

The food used in this experiment was purchased in shops in Cambridge. Potatoes were bought by the hundredweight, all other

foods in smaller amounts as required. The average weekly cost of the food per head was worked out separately for the months of October, November and December, and the results were almost identical. The food cost 7s. per head per week. Of this, 31 per cent. was spent on vegetables, including potatoes, 24 per cent. on bread, 7 per cent. on milk and 38 per cent. on the remainder of the diet.

Summary of Results

The present experiment was carried out to discover whether normal English men and women could live and thrive mentally and physically if they were suddenly subjected to a feeding régime in which fat, sugar, flesh foods and other articles of diet were severely restricted. It was found that all the subjects required a little time in which to adapt themselves to the changed conditions. This they did by increasing their consumption of unrationed foods till they had roughly adjusted their calorie intakes to their pre-experimental levels. The unrationed foods were essentially potatoes, green and root vegetables, and bread made from a flour containing 92 per cent. of the original wheat and fortified with calcium carbonate. Each was nutritionally valuable and possibly indispensable. The degree, form and extent of the adaptation demanded of each subject naturally varied with the diet to which he had been accustomed. Some failed to make the complete compensations within the time for which they were under observation, but this is probably because they were only taking part in the experiment for two to four weeks. All who were tested for three months made satisfactory adjustments. One person, who made quite a good physical adaptation, was apprehensive and worried about the effects of the new diet upon her health, and she must be regarded as a failure in psychological adaptation.

Once the subjects had adjusted themselves they were satisfied and content. They liked the food, they approached it with gusto and did not find it monotonous. They would have been quite happy to have continued eating it beyond the limits of the experiment. Five weeks after their return to normal food their diets still showed unmistakable traces of the habits they had acquired during the experiment. Their health was particularly good all the time they were eating this restricted dietary, and at the end of three months they were able to take prolonged and severe physical exercise without undue fatigue.

The diets themselves contained quite enough protein, although they were inevitably low in animal protein. They had very little fat in them, but correspondingly large amounts of carbohydrate, most of which was in the form of starch. They were therefore bulky, tended to be laxative and to give rise to quantities of flatus. The faeces were more bulky than before, and contained much more water, nitrogen and mineral matter. They also contained

more undigested cellulose and sometimes even more fat. The food, particularly the bread, demanded thorough mastication and took a relatively long time to eat. Nevertheless, it proved to be satisfactory for persons requiring 4,000 to 6,000 calories per day. The diets provided as much calcium as the normal ones, plenty of phosphorus, iron and other minerals, and much more vitamin B₁ and C than most English diets. A study of the excretions showed that the urines contained about the same amounts of magnesium and phosphorus as before. They contained less calcium, suggesting that less was absorbed, and this was at first attributed to a vitamin D deficiency, but it was found to be impossible to alter the urinary/fæcal ratios by giving moderate doses of calciferol.

We inevitably came to the conclusion that—once an adult had become accustomed to it, which he did easily enough—this diet was satisfactory for all ordinary purposes.

DISCUSSION

Justification of the Experiment

Throughout this experiment we have had the most gloomy pronouncements made about our present sanity and our future health. We quote a few in illustration. Many were made by persons who had either spent their lives working on nutrition or had received a special training in the subject. The following is an extract from a colleague's letter received early in the experiment: "I think one of the most interesting things about your diet will be whether it fulfils a prophesy X made to me the other day, when I suggested to him that we could exist for a long time during war on practically no fat, provided the vitamins were supplied separately, if we had sufficient protein and enough calories. He said that he agreed, but that we should all become pot-bellied. I have often wondered whether this admittedly frequent effect of war-time rations on the civilian population was really to be attributed to the low fat content and the consequent high bulk of the diet, or whether it was not rather some more specific inanition that could be avoided on a low fat diet, provided other dietary requirements were met."

It has also been suggested that we should get famine œdema from protein deficiencies, scurvy, anæmia, night-blindness, constipation, and even rheumatoid arthritis—besides a number of other bizarre ailments which are too fantastic to mention. Opinions of this sort fully justify an experiment such as this at the present time, for we have been able to refute our critics on every point, and to demonstrate, moreover, the bearing of such work on the present national and international situation.

We have been criticised for stopping this experiment after three-and-a-half months. We justify this action on three grounds:—(1) Three months should be long enough to reveal whether a diet becomes unbearably monotonous or unpalatable. (2) If no signs of deficiency appear under clinical test, and if all the biochemical tests are normal, it is obvious that many more months would be

required to bring out the unknown, hypothetical—and possibly non-existent—deficiencies, which form the critics' main armamentarium. (3) Anyone who has weighed all his food for 18 weeks will appreciate that "*fixité du milieu interieur*" is not the sole "*condition de la vie libre.*" In other words, we wanted a holiday, a break from the discipline of the prolonged experiment, and we felt that after it we could do more useful work by directing our energies into other channels.

Implications of the Experiment

It is essential to realise at the outset of this discussion that any generalisation made on the strength of our results is based upon the reactions of a very few individuals. It is perhaps as well to recognise at once in what way our material and the conditions of our experiment have differed from any situation likely to arise in practice. Our numbers were small, we were all healthy adults and we had more men than women in the long-term party. Populations are reckoned in millions, half of their numbers are children, the adults are not all healthy and there are more women than men. These differences are important, but the children and the sick require special consideration in any case, and the variation in the sex ratios probably does not matter. In our experiment the onset was sudden: full restrictions were imposed overnight, as it were. This would never happen to the country as a whole. We feel satisfied that a sudden onset was the correct experimental approach, because it exaggerated the difficulties of adaptation and enabled us to study them more easily. A real situation involving similar restrictions would develop slowly and enable adaptation to take place almost imperceptibly. Our experimental rations applied with equal force to each individual subject. This made the conditions easier for the small eater and more difficult for the large eater than would be the case in practice, where adjustments within the family circle would certainly facilitate the application of national *per caput* rations to individual citizens. The Germans have anticipated this difficulty and overcome it by issuing supplementary rations for heavy workers and for persons in special occupations. A further difference lies in the rations themselves. The experimental rations were a matter of design; the national ones will be a question of necessity. They will never be the same. Nevertheless, we have established certain general principles which may confidently be predicted to apply to whatever system of rationing may be in force. If the nation were to be rationed as we have been rationed, we could naturally make more predictions and make them with greater certainty. There must always be other differences of a psychological and quite imponderable type between the experimental and actual exigencies. In the former, the subjects are handicapped by the fact that they are surrounded, often at their very meals, by people still living lives of plenty, who regard all dietetic experimenters as half mad and frequently say so. In the latter, the country is likely to be united

by common endeavour. All would be sufferers alike, and this would be a great help. On the other hand, the experimental subjects have the zest of their work, and they know they are being well looked after. Fully alive, therefore, to these and other differences, and to the dangers of making deductions from a single experiment, we can proceed to consider in what way the present study bears upon the food situation in this and other countries.

The first generalisation we wish to make is that if rationed in certain directions, people will certainly try to keep up their calories from unrationed foods. It is right that they should do so, for a dietary restriction in calories would without doubt rapidly lead to a general deterioration in the health and strength of the population (Jansen, 1917-18; Bach, 1919; Loewy and Brahm, 1919; Lusk, 1921). If this be accepted it follows that partial rationing, *i.e.* restrictions in the supplies of certain commodities, will not limit total consumption as reckoned in calories. It will rather direct consumption towards the foods which remain unrationed, and the demand for these will increase. Those responsible for the imposition of rations should be prepared for this event. Furthermore, if the present quantitative dietary habits of an individual or of the nation are known—and if the proposed restrictions are also known—it should be possible to make a forecast of what the increased consumption of the unrationed foods will be. The more foods it is proposed to ration, *i.e.* restrict, the easier it becomes to make the forecast about the increased demand which will arise for the unrationed foods. These statements are true of any system of rationing. Taking the present experiment as an example, the restrictions imposed upon our consumption of meat, fats, sugar, etc., forced us to increase our consumption of wheat and potatoes 2-8 times, and of green vegetables 2-5 times. If these restrictions were felt to be necessary over the whole country, the Government should be prepared for the demand for these three commodities to increase to about this extent, and act accordingly beforehand. A more accurate forecast could probably be made if there were justification for doing so.

We have enjoyed the experimental diet and it has maintained us in good health, but we do not think that at the moment the British people would readily accept it. Sudden imposition of such restrictions would be alarming; for the public has not been prepared psychologically to face a régime of this degree of severity. We had an excellent example among our own subjects of how some of the population would undoubtedly behave if faced with rations such as ours. Nevertheless, education and confident reassurance based on facts can do much to remove misgivings; and if the public could once be persuaded to accept restrictions which were not prejudicial to health, the power of habit is so great where food is concerned that we do not believe there would be any further trouble. This is an important point, and one where the Germans have the advantage over us, for their rations have been imposed and accepted since the

beginning of the war, and, in our opinion, no complaints should now be anticipated in that quarter unless their physical nutrition begins to fail. If this country is to face severe restrictions, the problem will be to effect their introduction and get them accepted. How it might be done should be thought out now. Arrangements should be made beforehand as to which foods should be obtained and made available, and the public prepared for them.

We would not necessarily recommend our diets as they stand, for they would be much improved by the addition of fat and sugar, but they have at least stood up to the test of experiment, and we would strongly recommend certain features of them. The three staples, wholemeal bread, potatoes and green vegetables—were all of the greatest value to us. In a crisis, not only should everything possible be done to leave them unrationed, but it should be arranged that rich and poor can alike command them. This raises the very difficult question of economics, which it is outside our province to discuss. We would, however, mention in passing that the more foods are rationed, the more the diets of rich and poor must conform to a uniform pattern. It has been pointed out to us that if we had done this experiment in the spring it would have been difficult or impossible to obtain green vegetables. No doubt this is true after a very severe winter, but there are always substitutes such as nettles, which are excellent, though not often used in this country. Moreover, it is probable that our nutrition would have been quite satisfactory without so many green vegetables during the few months of shortage.

For *emergency* rations, only flour containing about 92 per cent. of the original wheat should be considered. Nutritionally our diets would have been very much inferior if we had used a 70 per cent., *i.e.* a white flour. Wholemeal breads are frequently preferred to white, once the consumers have acquired the taste. We would not recommend the adulteration of wheat flours with oatmeal, soya bean meal or potato starch, as was done in the last war. From the points of view of palatability and health it is much better to have the bread made of unadulterated wheaten flour, and to eat the potatoes as such. We consider, however, that if a milk shortage be envisaged at any time, calcium should certainly be added to the bread. We all very much appreciated the cheese in our rations, and suggest that if there is to be any shortage of flesh foods—or, indeed, in any case—the importation and consumption of cheese should be encouraged.

We feel quite strongly that these experiments should be extended to children, whose requirements, tastes and powers of endurance are so different from those of adults. It might be of immense value if, as the result of such tests, we could prescribe with confidence very simple diets which children as well as adults could reasonably be expected to eat, which would maintain perfect health, and which it was within the country's means to provide.

The success with which we have been able to carry out severe

physical work under wintry conditions raises the question of whether diets such as ours would not be quite as satisfactory for soldiers as their present ones. We believe that they would, but again we would not advocate them without modification, and preferably not without trial. We can see no justification, however, for the enormous amounts of meat in the rations of the British soldier, and we consider that troops, in this country at any rate, would be just as well served with bread made from a lightly milled flour, more potatoes if necessary, and less meat.

In conclusion, we would draw attention to the value of experiments such as this in planning relief diets for starving populations in stricken areas.

One experiment can never settle every question. While, therefore, in the meantime we make our deductions and suggestions with reserve, we feel that we have established one point with certainty, namely, that these problems of national nutrition in times of stress can be tackled by experimental methods. We do not expect our studies to have provided more than a first approximation to the truth. Other experiments, however, can easily be designed to cover, to check, and so to confirm or refute every statement we have made.

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