BULLETIN No. 98.

U. S. DEPARTMENT OF AGRICULTURE,

OFFICE OF EXPERIMENT STATIONS,

A. C. TRUE, Director.

THE EFFECT

OF

SEVERE AND PROLONGED MUSCULAR WORK

ON

FOOD CONSUMPTION, DIGESTION, AND METABOLISM,

BY

W. O. ATWATER, PH. D.,

AND

H. C. SHERMAN, PH. D.,

AND

THE MECHANICAL WORK AND EFFICIENCY OF BICYCLERS,

BY

R. C. CARPENTER, M. S.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1901.

Bulletin No. 98.

U. S. DEPARTMENT OF AGRICULTURE,
OFFICE OF EXPERIMENT STATIONS,
A. C. TRUE, Director.

THE EFFECT OF SEVERE AND PROLONGED MUSCULAR WORK ON FOOD CONSUMPTION, DIGESTION, AND METABOLISM,

BY

W. O. ATWATER, PH. D.,
AND
H. C. SHERMAN, PH. D.,

AND THE MECHANICAL WORK AND EFFICIENCY OF BICYCLERS,

BY

R. C. CARPENTER, M. S.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1901.

LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Office of Experiment Stations,
Washington, D. C., June 1, 1901.

Sir: I have the honor to transmit herewith a report on studies of the effect of severe and prolonged muscular work on food consumption, digestion, and metabolism. The experiments were made with bicycle racers in a six-day contest at the Madison Square Garden, New York City, in December, 1898. The investigation was conducted by W. O. Atwater, special agent in charge of nutrition investigations, and H. C. Sherman, lecturer in chemistry at Columbia University, New York City. In the nutrition investigations conducted by the Department under the auspices of the Office of Experiment Stations considerable attention has been paid to food in connection with muscular work. Numerous dietary studies of persons performing varying amounts of work under approximately normal conditions have been made. It was believed that the present investigation, in which a large amount of severe work was performed for a considerable period of time, would afford results interesting in themselves and valuable for interpreting the results of other investigations. These studies constitute part of the nutrition investigations in charge of this Office and were conducted in accordance with instructions by its Director. In carrying on the work valuable assistance was rendered by Messrs. A. P. Bryant, H. M. Burr, P. B. Hawk, E. H. Hodgson, R. D. Milner, and H. E. Wells. The success of the investigation depended in large measure upon the hearty cooperation of the American Cycle Racing Association, under whose auspices the contest was conducted, and of the trainers, Messrs. John West, Joseph Quirk, and Charles McGue, as well as the riders themselves, Messrs. C. W. Miller, F. Albert, and H. Pilkington. Acknowledgment should also be made to Dr. E. E. Smith, through whose kindness the laboratories of Fraser & Co., of which he is director and chief chemist, were available.

The supplement on mechanical work and efficiency was contributed by R. C. Carpenter, professor of experimental engineering at Cornell

University. Professor Carpenter in recent years has given much attention to the study of the energy expended in driving bicycles and has made many experiments. The data and deductions from these have been embodied, so far as was needful, in his present discussion.

The report is respectfully submitted, with the recommendation that it be published as Bulletin No. 98 of this Office.

Respectfully,

A. C. True,
Director.

Hon. James Wilson,
Secretary of Agriculture.

CONTENTS.

ILLUSTRATIONS.

FOOD CONSUMPTION, DIGESTION, METABOLISM, AND MECHANICAL WORK OF BICYCLERS.

FOOD CONSUMPTION, DIGESTION, AND METABOLISM OF BICYCLERS.

By W. O. Atwater, Ph. D., and H. C. Sherman, Ph. D.

INTRODUCTION.

One very important phase of the science of nutrition is the relation of food to muscular work. This involves such problems as the source of muscular energy and the economical production of useful work. While naturally the greater part of the experimenting along such lines has been conducted with animals, a considerable number of investigations conducted under the auspices of this Office and the earlier work at the Connecticut Storrs Station have had to do with the subject of muscular work in man. Dietary studies[1] have been made with (1) professional men and others performing little muscular work; (2) farmers, mechanics, and others performing a moderate amount of muscular work; (3) mechanics and others at severe labor; (4) men performing for experimental purposes rather more than their usual amount of work; and (5) college athletes. In some of the experiments made with the respiration calorimeter the effects of muscular work were studied,[2] as was also the case in the digestion and nitrogen metabolism experiments conducted at the University of Tennessee.[3]

In order to judge of the various factors which affect any such subject and to obtain data for comparison it is generally desirable to carry on experiments and make observations under unusual conditions. In December, 1898, a six-day bicycle race was held in Madison Square Garden, New York City, in connection with which it was found possible to study the food consumption of three of the contestants as well as the digestibility of a mixed diet, the metabolism of nitrogen, and

[1] For details of these studies see U. S. Dept. Agr., Office of Experiment Stations Buls. 21, 29, 31, 32, 35, 37, 38, 40, 46, 52, 53, 54, 55, 71, 75, and 84, and Connecticut Storrs Sta. Rpts. 1891–1899.

[2] U. S. Dept. Agr., Office of Experiment Stations Buls. 44, 63, and 69.

[3] U. S. Dept. Agr., Office of Experiment Stations Bul. 89.

other problems pertaining to the subject. The race necessitated severe and long continued muscular exertion. An unusual opportunity was thus offered to study food in its relation to muscular work, and it is believed the results will prove interesting in themselves as well as useful in interpreting the results of other investigations.

Before describing the experiments conducted with the bicycle racers a brief summary of the investigations with man upon the effect of severe or long continued muscular work on metabolism which have been conducted by other observers seems necessary. Those here cited have to do with muscular work and its effect on the metabolism of nitrogen and energy.

PREVIOUS INVESTIGATIONS ON MUSCULAR WORK AND THE METABOLISM OF NITROGEN.

Liebig, who divided foods into plastic (nitrogenous) and respiratory (nonnitrogenous) nutrients, maintained that the former were the sources of muscular energy. This view was contested on theoretical grounds by Mayer,[1] who held that the muscular system was a machine which used for its fuel the carbonaceous and not necessarily the nitrogenous materials brought to it by the blood. Frankland called attention to a paper by John Mayow entitled "De motu musculari et spiritibus animalibus,"[2] about a century before Priestly's discovery of oxygen, in which it is stated that muscular power arises from the combustion in the muscles of fat brought by the blood with a gas which the lungs take up in respiration.

Lawes and Gilbert in 1854[3] showed that with animals under uniform conditions as regards exercise the amount of excreted nitrogen depends upon the amount ingested, while C. Voit[4] a few years later demonstrated that under some conditions at least an animal with a uniform ingestion of protein may perform an increased amount of muscular work without increasing the excretion of urea. Lehmann held that the excretion of nitrogen was dependent mainly upon the diet, but that when the latter was uniform the elimination of urea was increased by muscular exercise.

Of the many investigations[5] on the effect of muscular work upon

[1] Die organische Bewegung in ihrem Zusammenhange mit dem Stoffwechsel. Heilbronn, 1845, p. 54 et seq.

[2] Opera omnia medico-physica. Hagau comitum, 1681.

[3] Chem. Centbl., 1867, p. 770.

[4] Untersuchungen über den Einfluss des Kochsalzes, des Kaffees und der Muskelbewegungen auf den Stoffwechsel, 1860; abs. in Chem. Centbl., 1867, p. 774.

[5] A concise summary of 186 experiments with men and 199 with animals in which the effects of muscular work upon the metabolism of nitrogen was studied (in a number of cases the observations included the metabolism of carbon and energy) may be found in U. S. Dept. Agr., Office of Experiment Stations Bul. 45, pp. 118–135, 268–283, 355–363, 398, 411.

the excretion of nitrogen we cite only those which are in some way similar to that here reported. These may be divided into two classes, (1) experiments in which the subject and his diet were under the control of the experimenter and the work was performed for the purpose of investigation, and (2) experiments in which the diet was not under control, the subjects being professional athletes performing feats of endurance in public, and not primarily for experimental purposes. A brief summary of the more important investigations of this nature which we have found follows.

EXPERIMENTS WITH SUBJECTS WORKING SPECIFICALLY FOR INVESTIGATION.

Fick and Wislicenus published in 1866[1] the account of their investigation upon the relation of exercise to the elimination of nitrogen. These investigators experimented upon themselves, the work performed being the ascent of the Faulhorn, about 6,500 feet. From noon on August 29 until 7 p. m., August 30, they consumed only non-nitrogenous food, the diet being made up essentially of fat, starch, sugar, tea, wine, and beer.

The experiments proper began at 6.15 p. m. on August 29, when the bladder was emptied. The urine formed from this time until 5.10 the following morning was collected and called "night urine." The following 8 hours and 10 minutes were occupied in the ascent and the urine formed during this time was called the "work urine." The urine for five hours and forty minutes after the ascent was collected as "after work urine," and that during the night following was also collected. The two subjects eliminated nearly the same amounts of nitrogen, as shown in the following table:

TABLE 1.—*Experiments of Fick and Wislicenus on elimination of nitrogen by the kidneys.*

Designation.	Period covered.	Nitrogen eliminated.	
		Subject A.	Subject B.
		Grams.	*Grams.*
"Night urine"	Aug. 29, 6.15 p. m., to Aug. 30, 5.10 a. m. (10 hours 55 minutes).	6.92	6.68
"Work urine"	Aug. 30, 5.10 a. m. to 1.20 p. m. (8 hours 10 minutes).	3.31	3.13
"After-work urine"	Aug. 30, 1.20 p. m. to 7 p. m. (5 hours 40 minutes).	2.43	2.42
"Night urine" *a*	Aug. 30, 7 p. m., to Aug. 31, 5.30 a. m. (10 hours 30 minutes).	4.82	5.35

a At the beginning of the period in which this urine was collected the subjects consumed a hearty meal, consisting largely of meat.

These authors calculated the consumption of protein corresponding to this excretion of nitrogen, and assumed that protein might yield on combustion an amount of energy equal to the sum of the heats of

[1] Vrtljschr. Naturf. Gesell. Zürich, 10 (1865), p. 317; abs. in Chem. Centbl., 1867, pp. 769–782.

combustion of the carbon and hydrogen contained in it. From this computation they concluded that the protein consumed could have yielded only from one-half to three-fourths of the energy required to lift the weights of their bodies to the height ascended, while if the work of forward progression and the internal work be taken into account the discrepancy would become much greater.

Frankland[1] having determined the actual heats of combustion of protein and urea, calculated the energy available from the consumption of protein by Fick and Wislicenus to be only about two-thirds as much as these investigators had supposed.

Thus it was clearly shown that the nitrogen eliminated during and immediately after the work could not account for enough protein to yield the required energy, and, indeed, that the muscular work did not cause an increased elimination of nitrogen during or immediately after the exertion. But it does not follow that such an increase does not normally occur. The conditions here were abnormal, in that the subjects were in a state of "nitrogen starvation," and the observations were not continued as long after the exercise as more recent experiments have shown to be necessary in order to obtain all of the extra nitrogen eliminated in connection with muscular work.

Parkes[2] published in 1867 the results of a series of experiments made with two soldiers on a uniform mixed diet, with and without muscular work. Each working period was of three days' duration, and was preceded and followed by periods of two or four days during which the subjects followed their usual occupations. We infer that the usual occupations required comparatively little muscular exertion. It was found that the work, which consisted in walking on level ground, and did not, by Parkes's computations, exceed 160,000 kilogram-meters per day, caused a small increase in the excretion of nitrogen. This increased excretion, however, continued for some time after the completion of the extra muscular work.

In 1882 North[3] experimented upon himself, taking great pains to secure uniformity in his diet, and doing on one day of each experiment a considerable amount of work, walking from 30 to 47 miles and carrying a load of about 27 pounds. As the weight of the body is not given the amount of work can not be calculated, but it is evidently considerably greater than that done in Parkes's experiments, which North considered not sufficiently severe. The increased elimination of nitrogen with the muscular work was more immediate and more pronounced than in Parkes's experiments.

---

[1] Phil. Mag., 4. ser., 32 (1867), p. 182. Reprinted in Experimental Researches in Pure, Applied, and Physical Chemistry. London, 1877, p. 938.

[2] Proc. Roy. Soc. [London], 16 (1867), p. 45. U. S. Dept. Agr., Office of Experiment Stations Bul. 45, pp. 119, 129.

[3] Proc. Roy. Soc. [London], 36 (1882), p. 14. U. S. Dept. Agr., Office of Experiment Stations Bul. 45, pp. 120, 131.

It is to be noted, however, that in both of these investigations, in which the diet was the same in the periods of work as in those of rest, the increased metabolism of nitrogenous material, indicated by the increased elimination of nitrogen, may have been due to the fact that no increase of fuel ingredients was supplied to meet the increased demand for energy when work was done.

Zasietski[1] made a number of experiments, each including a rest and a work period, in which milk was the only food allowed, but the quantity was not limited. The work consisted in walking from 9 a. m. to 9 p. m., with short rests. The subjects were mostly peasants or students, and probably had not trained for the exertion. In general no more milk was consumed on the working days than on the days of rest, while the average excretion of nitrogen was 9 per cent greater.

Practically all of the recent experimenting with men sustains the view that muscular work normally results in an increased excretion of nitrogen when the work is at all severe and there is not a corresponding increase in the fuel ingredients (fats or carbohydrates) of the diet. It also implies that the increased output of nitrogen continues after the work stops, so that if the experiment continues but one day the larger part of the increase may be found on the succeeding day. Among these investigations may be mentioned those of Oppenheim,[2] North,[3] Burkalov,[4] Argutinski,[5] Zuntz,[6] Krummacher,[7] Pflüger,[8] Paton,[9] and Punine.[10] Hirschfeld[11] found no change in the nitrogen excretion after exercise, but the amount of exercise taken was relatively small and the fuel value of the diet was high (3,700 to 3,800 calories).

All of the investigations above mentioned differ from those reported herewith in that the subjects were not professional athletes and did not perform an amount of work at all approximating to that done in the cases here reported. The same is true, to some extent, of the recent experiments of Dunlop, Paton, Stockman, and Maccadam,[12] but as the amount of work performed in these was quite large, and as one

---

[1] Vrach, 6 (1887), p. 866. U. S. Dept. Agr., Office of Experiment Stations Bul. 45, pp. 121, 122, 131.

[2] Arch. Physiol. [Pflüger], 23 (1881), p. 497.

[3] Proc. Royal Soc. [London], 36 (1884), p. 11.

[4] Vrach, 9 (1888), p. 66.

[5] Arch. Physiol. [Pflüger], 46 (1889–90), p. 552.

[6] Arch. Physiol. [Du Bois-Reymond], 1894, p. 541. It should be noted that Zuntz believes the increased proteid metabolism to occur only when the exercise is sufficiently severe to cause labored breathing.

[7] Arch. Physiol. [Pflüger], 47 (1890), p. 451; Ztschr. Biol., 33 (1896), p. 108.

[8] Arch. Physiol. [Pflüger], 50 (1891), p. 98.

[9] Lab. Reports Royal College Phys. Edin., 3 (1891), p. 241.

[10] Inaug. Diss. St. Petersburg, 1894; abs. in U. S. Dept. Agr., Office of Experiment Stations Bul. 45, pp. 123–126, 134.

[11] Arch. Path. Anat. u. Physiol. [Virchow], 121 (1890), p. 504.

[12] Jour. Physiol., 22 (1897), pp. 69–98.

of the objects was to study the effect of training, they are of special interest in this connection. A brief account of this investigation follows.

Five experiments were made, all with men. In three of these the effect of moderately severe muscular exercise was studied, in one the effect of sweating, and in one the effect of massage. The general arrangement was similar in all cases. The subject was put on a rigidly fixed diet of his own selection for a period of seven days, the muscular work, sweating, or massage occurring on the fourth day. This gave a sufficiently long fore period to show changes on the experiment day and a sufficiently long after period to show later changes.

Nitrogen was determined in the food, feces, and urine. In the urine, in addition to total nitrogen, sulphur, phosphorus, and uric acid were determined and in some cases sodium, chlorin, preformed ammonia and "extractive" nitrogen as well.

Massage produced no marked change in the metabolism and hence it was inferred by the experimenters that the changes observed to result from severe muscular exercise are not due to the physical effects of an increased lymph flow. The only marked effect of sweating upon the urine is a diminution of water and of sodium chlorid. Independently of sweating or of the condition of training, severe muscular exertion increased the excretion of nitrogen and sulphur, the increase of nitrogen being due mainly to increased urea, although some was due to increased creatinin and preformed ammonia. When the subject was in poor training there was also an increase in the excretion of uric acid, nitrogenous extractives, and phosphoric acid.

These changes in urine were held by these investigators to indicate that excessive muscular work causes an increased katabolism of protein, this being simply "muscle proteid" if the subject is in good training, while if the subject is in poor training "this consumption of muscle proteid is accompanied by the consumption of the proteid of other tissues which contain nucleo-proteids as shown by the increased excretion of uric acid, extractive nitrogen, and phosphorus. There may be a withdrawal of proteids from other structures to effect repair in muscles, similar to the transference of material seen in starvation, the proteid portion being retained while the nucleo-acid portion is excreted."

Of course it must be remembered that in these experiments the subject was not allowed to increase his diet upon the working day or the days following. This may in part account for the occurrence of phenomena similar to those of fasting.

EXPERIMENTS WITH PROFESSIONAL ATHLETES.

In the following pages are summarized the experiments of the second class, namely, those in which the diet was not under control, the subjects being professional athletes performing feats of endurance in public and not primarily for experimental purposes.

Flint's[1] studies with the professional pedestrian Weston, which were conducted in New York in 1870, are, so far as we know, the first, and in some respects the best, of investigations of this class. For three consecutive five-day periods, during the second of which he walked 317 miles, Weston was continuously under observation. The food, which during the walk consisted chiefly of beef extract, oatmeal gruel, and raw eggs, was carefully weighed and the nitrogen therein computed for the most part from Payen's tables, although some analyses were made. Nitrogen was determined in the feces, and urea, uric acid, sulphuric acid, and phosphoric acid in the urine. The method for determining the uric acid was faulty and gave too low results. Even had this not been the case there would have been an appreciable amount of undetermined nitrogen in the urine. But in spite of the imperfections of the analytical work, the investigation has great value, chiefly because of the long fore and after periods. The results are shown in the following table:

TABLE 2.—*Flint's observations on daily nitrogen metabolism by Weston.*

Period.	Occupation.	Duration of test.	Nitrogen.			
			In food.	In urine.	In feces.	Gain (+) or loss (−).
		Days.	*Grams.*	*Grams.*	*Grams.*	*Grams.*
Fore period	Comparative rest	5	22.0	18.7	1.4	+ 1.9
Working period	Walking 62 miles per day	5	13.2	21.6	1.6	−10.0
After period	Rest	5	28.6	22.0	2.2	+ 4.4

It will be seen that during the five days of comparative rest before the walk Weston consumed food containing (according to Flint's calculation) 22 grams of nitrogen per day and eliminated 18.7 grams in the urine and 1.4 grams in the feces, storing 1.9 grams per day in the body. During the walk he consumed only 13.2 grams of nitrogen per day but eliminated in urine and feces 23.2 grams, making a daily loss of 10 grams of nitrogen from the body. During the five days after the race he consumed 28.6 grams of nitrogen per day and eliminated 24.2 grams, so that 4.4 grams were stored in the body daily. This investigation shows in a striking manner how the body may draw upon its own protein for the performance of muscular work and afterwards replace the material thus used. It should be noted, however, that the amount of food consumed by Weston during his walk was small. The fuel value of the diet and the relation of this to the mechanical work performed are discussed beyond (see pp. 14 and 56).

Six years later Pavy[2] investigated Weston's metabolism during

[1] New York Med. Jour., 13 (1870), p. 653.
[2] Lancet [London], 1896, I and II passim.

three of his professional walks in England. The observations covered (1) a two-day walk without fore or after periods, (2) a three-day walk with fore and after periods of one day each, and (3) a six-day walk with fore and after periods of six days each. The food consisted largely of beef tea, eggs, sea moss farina, and jelly; some meat and bread were also taken and some amounts of brandy and champagne were used. An approximate record of the food was kept and its nitrogen content was calculated without analysis. During the after period of the third experiment the food was not recorded. Urea and uric acid were determined in the urine. The results are briefly summarized in the table herewith, the nitrogen in the urine being calculated by the present writers from the amounts of urea and uric acid found. The data are not sufficient to show the nitrogen balance.

TABLE 3.—*Summary of Pavy's observations on nitrogen metabolism by Weston.*

Period.	Occupation.	Duration of test.	Nitrogen per day.	
			In food.	In urine.
		Days.	*Grams.*	*Grams.*
First experiment	Walking 90 miles per day	2	7.4	32.8
Second experiment:				
Fore period	Rest	1	33.9	19.6
Working period	Walking 88 miles per day	3	45.9	34.8
After period	Rest	1	41.8	15.2
Third experiment:				
Fore period	Comparative rest	6	31.0	20.6
Working period	Walking	6	43.5	33.8
After period	Rest	6	(?)	19.7

It is noticeable that on the two days of the first walk, when the food consumed contained only 7.4 grams nitrogen per day, the nitrogen excretion was practically the same as on other walking days. While these experiments are not sufficiently complete to be very satisfactory, they agree with those of Flint in showing a large excretion of nitrogen on the walking days. In the second and third of these experiments, however, the food consumed contained so much protein that there appears to have been little if any loss of body nitrogen.

In 1878 Jones[1] collected and analyzed the urine passed by the professional pedestrian Schmehl during four of six consecutive days in which he walked a total of 500 miles. The average daily excretion of nitrogen in the form of urea and uric acid was 25 grams. The amount and composition of the food were not recorded with sufficient accuracy to indicate whether the body gained or lost nitrogen.

In 1884 Weston undertook and finished successfully a walk of 50 miles per day for 100 consecutive days, Sundays excluded. The last 300 miles were walked on a level indoor track and the food consumed and the metabolism of nitrogen were observed by Blyth.[2] The food was weighed or measured and the nutrients calculated, as Blyth states,

[1] New Orleans Med. and Surg. Jour., 5 (1877–78), p. 856.
[2] Proc. Roy. Soc. [London], 37 (1884), p. 46.

from "analyses in my own work on 'Food,' supplemented by the mean numbers given in König's 'Nahrungsmittel,' and in two instances by analyses of the actual foods consumed." The urine for each day was collected and analyzed. The feces passed on the last five days, Tuesday to Saturday inclusive, were united and assumed to represent the food of the five days—Monday to Friday of the same week. The food on Saturday being somewhat exceptional, Blyth prefers to omit this day from the average, especially as the feces represent only the other five. The average nitrogen for these five days (Monday to Friday) was: In food, 37.2 grams; in urine, 25.5, and in feces, 9.8, leaving 1.9 grams per day apparently stored in the body. In addition to 235.8 grams of protein the average daily diet was estimated to furnish 64.6 grams of fat and 799.9 grams of carbohydrates. This, according to our usual method of calculation, would furnish 4,850 calories of energy per day. This experiment differs from any of the others in that when it was begun the subject had already been undergoing the same severe exercise for a long time—nearly four months.

Bryant[1] has calculated, from estimates furnished by Miller's trainer, the nutrients consumed by Miller during the six-day bicycle race at New York in 1897, a year before the present experiment. According to this estimate the diet contained on an average 262 grams of protein and 6,100 calories per day. Nothing is known of the nitrogen excretion during these days, but there is no reason to suppose that any considerable part of this large amount of protein was stored in the body. "That in this case the diet was not greatly at variance with the needs of the body is indicated by the fact that there was but little change in body weight during the six days."

In general all of these observations indicate that well-trained professional athletes when engaged in severe muscular exertion metabolize relatively large amounts of protein, the body tissue being drawn upon unless the protein of the food is very abundant. Of course the amounts of carbohydrates and fats in the diet will have a most important influence, a fact which was not fully appreciated by the earlier investigators.

PREVIOUS INVESTIGATIONS UPON MUSCULAR WORK AND THE METABOLISM OF ENERGY—EFFICIENCY OF MAN AS A PRIME MOTOR.

Hirn,[2] as early as 1856–57, attempted an investigation of the source of muscular energy and the mechanical efficiency of the human organism. For this latter purpose he employed a sort of calorimeter to measure the heat given off from the body. The calorimeter was a

[1] Diet. and Hyg. Gaz., 15 (1899), p. 393.

[2] L'Equivalent mécanique de la Chaleur, 1858. Rewritten under the title La Thermodynamique et l'étude du travail chez les êtres vivants. Paris, 1887.

small room or chamber inside of which the subject was placed during the experiment. Within the calorimeter was a treadwheel turned by power from outside. The muscular work was done and measured by treading the wheel, the arrangements being such that the work done by the subject during one revolution of the wheel was estimated to be equivalent to that required to raise his body through a distance equal to the circumference of the wheel. This was "positive" work. There was also a provision for so-called "negative" work, which is not included in the discussion.

The total energy metabolized by the body during the experiment was assumed to be represented by the sum of the heat given off from the body as measured by the calorimeter and the heat equivalent of the muscular work as determined by the treadwheel. The heat equivalent of the work done divided by this sum was taken as the measure of the mechanical efficiency of the subject. The mechanical efficiency was thus measured in percentage of the total energy metabolized in the body. At the beginning of the experiment the subject worked and breathed in the calorimeter chamber until the temperature had become constant, when the remeasurements were commenced. Each experiment lasted from 40 to 60 minutes, according to the ability of the subject to sustain the labor without discomfort. Experiments were made upon five subjects—three men, a lymphatic youth of 18, and a strong young woman of the same age. The efficiencies varied from 17 per cent in the case of the "very lymphatic" youth to 25 per cent in the case of a strong laborer 47 years old. These calculations evidently make no allowance for the heat given off from the body when in a state of rest. If such allowance were made, the figures for efficiency would of course become higher. Naturally the experimental methods used at this time were not very accurate. Hirn himself recognized this fact and wished to repeat his experiments. Chauveau[1] has also criticised the work and pointed out the modifications which should have been introduced, and with which he hopes to repeat the work. Nevertheless the investigation is of decided interest as being the first, and for many years the best, of its kind.

Blyth,[2] in reporting his observations on Weston, gives estimates of the amount of work performed by the latter, but does not calculate the fuel value of the diet nor discuss the question of mechanical efficiency.

Zuntz and his associates have given considerable attention to the subject of muscular work and metabolism, experimenting upon different animals, including man, and with different forms of work. The general method in all cases involved the determination, by means of

---

[1] Arch. Physiol. Norm. et Path., 5. ser., 9 (1897), p. 229.

[2] Proc. Roy. Soc. [London], 37 (1884), p. 46.

the Zuntz respiration apparatus, of the kinds and amounts of material oxidized in the body, and the calculation of the total energy liberated. The external muscular work was either measured directly or calculated from the weight of the subject, including in some cases the weight of a burden carried, and the horizontal and perpendicular distance walked or climbed. A careful distinction was made between the energy metabolized in the performance of the ordinary functions of the body, i. e., internal or physiological work, and the extra energy metabolized in connection with the external work. The latter was calculated by taking the total amount of energy metabolized during a period of work and subtracting from it the amount metabolized by the body during a corresponding period of rest. The difference was taken as representing the amount of energy metabolized for the performance of the external work. Dividing the energy of this external muscular work by the energy especially metabolized for its performance gives the percentage mechanical efficiency of the subject.

In a comparatively recent summary of the investigations Zuntz[1] has stated that about 35 per cent of the extra energy of the food used in connection with the external muscular work is available for that work, practically the same value being obtained for horses and dogs as for men. Kellner and Wolff,[2] experimenting with horses by a radically different method, have reached practically the same result.

This interesting agreement is the more surprising in view of the conclusion reached by Kronecker and his associates, Schnyder, and others, in studying the relation of muscular work to the production of carbon dioxid, that the amount of the latter produced depends less upon the amount of work performed than upon the intensity of the exertion, and that the efficiency varies greatly with the condition of the subject and his familiarity with the work. Schnyder[3] gives an excellent digest of the work of this character as well as that of Zuntz and his followers.

Bryant,[4] using a modification of Carpenter's[5] formula for computing the work done in driving a bicycle, and reducing the fuel value of Miller's diet by the amount believed to be necessary to maintain the body at rest, concludes that this rider maintained during six days of almost continuous bicycle racing an efficiency of 36 per cent.

Atwater and Rosa[6] have determined the mechanical efficiency of a man not accustomed to severe exercise who worked in this case eight hours a day on an ergometer, which consisted of a stationary bicycle

[1] Experiment Station Record, 7 (1895–96), p. 547.

[2] Landw. Jahrb., 24 (1895), p. 125; Experiment Station Record, 7 (1895–96), p. 611.

[3] Ztschr. Biol., 33 (1896), pp. 289–319.

[4] Diet. and Hyg. Gaz., 15 (1899), p. 393.

[5] L. A. W. Bulletin 27 (1898), pp. 401, 445, 466.

[6] Phys. Rev., 9 (1899), p. 248.

belted to a small dynamo. The whole was placed in a respiration calorimeter,[1] in which the subject remained for several days. The total amount of heat given off was accurately measured by means of the calorimeter. The work done was determined by measuring the current produced by the dynamo. The electrical energy was then transformed into heat and its amount was included in the total heat measured by the calorimeter. In addition to these heat measurements the total income and outgo of nitrogen, carbon, hydrogen, and water were determined. In these particular experiments the average work done was about 40 watts per day, or 109,000 kilogrammeters, equivalent to 256 calories per day. Dividing this by the total number of calories measured by the calorimeter, 3,726 per day, they obtain an average mechanical efficiency of 7 per cent of the total energy metabolized. But after deducting the average amount of energy metabolized by the same man when at rest, which had been found by several experiments to be about 2,500 calories, the remainder, which was assumed to be the energy metabolized for the performance of the work, is 1,226 calories per day, and the mechanical efficiency becomes, for these experiments, 21 per cent.

OCCASION AND PLAN OF THE PRESENT INQUIRY.

The six-day bicycle race held in the Madison Square Garden in New York in December, 1898, offered an opportunity for observations on the food consumption and metabolism of trained athletes under conditions of unusually prolonged as well as severe exertion. It was hoped at the outset that arrangements would be possible for determining the amount of work done and the mechanical efficiency of their bodies, considered as prime motors, with some approach to accuracy. Considerable material was gathered for such computations and was used by Professor Carpenter in the preparation of the appended report on the mechanical work and efficiency of the riders. Circumstances have not permitted the direct experimenting with a bicycle dynamometer, which was originally planned.

It was reasonably certain that the contestants, stimulated by the professional importance of the race, the value of the prizes offered, and the size and enthusiasm of their audiences, would perform an amount of work far greater than could be expected of a man working alone for purely experimental purposes, and probably greater than was accomplished by the professional pedestrian observed by Flint, Pavy, and Blyth. It was also believed that the measurements of income and outgo of matter could be made with considerable more accuracy and completeness than was attained in the experiments which these investigators reported. On the other hand, it was evident that the observations

[1] U. S. Dept. Agr., Office of Experiment Stations Bul. 63.

would have to be made under considerable disadvantages and that many of the conditions would be beyond control, since no attempt was to be made to regulate the diet or movements of the contestants under observation, and they were not to be subjected to any inconvenience or delays on account of the experiments. It could not be expected, therefore, that the results would be capable of as strict interpretation as in the case of ordinary metabolism experiments, nor was it feasible to observe the metabolism of the men before and after the race, as Flint was able to do in the case of Weston in 1870.

The general plan adopted involved the determination of (1) the amount and composition of the foods and beverages used and (2) the amount and composition of the urine and feces excreted. Records of the time occupied in rest and in riding, the approximate number of hours of sleep, and the general changes in body weight were also obtained.

Thirty-one contestants entered, and twelve finished, the race. The observations were made upon three, one of whom withdrew early in the fourth day, while the others continued until the close of the race, winning the first and fourth places, respectively. The race began a little after midnight on Sunday night and ended a little after 10 p. m. on the following Saturday night, thus continuing one hundred and forty-two hours. The observations were continued during the whole time, day and night. A number of chemists connected with the nutrition investigations in progress at Middletown shared with the writers in the observations made on the race track, there being usually three observers present at a time. The labor of making the observations was exacting and practically continuous, as the contestants spent nearly the whole of the time—often twenty-two to twenty-three hours of each day—on the track.

The samples were prepared for analysis in a neighboring laboratory. The analyses were made at Middletown, Conn., in the chemical laboratory of Wesleyan University.

THE SUBJECTS OF THE EXPERIMENTS.

All of the subjects had been trained for the race, and two of them were experienced in contests of this sort. Although natives of other countries, all had lived for a number of years in the United States and were in the hands of American trainers, so that there is no reason to doubt that in dietary and most other habits they fairly represent American professional athletes. There are many reasons for believing that in this race Miller was the best representative of the well-trained, well-managed athlete. In the descriptions which follow the data regarding Miller and Pilkington were furnished for the most part by Mr. West, their trainer, while the description of Albert is based mainly on data supplied by himself.

C. W. Miller.—Age, 24; height (without shoes), 5 feet 5 inches; weight in ordinary clothing when not in special training, about 172 pounds; in riding costume at the beginning of the race, 157 pounds 12 ounces; at the same time stripped, 153 pounds 14 ounces; waist measure, 34 inches; chest measure, 38 inches; expansion, 37–42 inches. Although a native of Germany, he had lived for six years in Chicago, where, previous to taking up athletics, he was engaged in business. For four years he had devoted himself mainly, and for over two years entirely, to bicycle racing.

Mr. Miller always obeyed his trainer and manager without question and never allowed himself any anxiety regarding business affairs or arrangements of any kind. This circumstance is believed to have been of some advantage to him in his work. According to the statements of his trainer, he never uses alcohol or tobacco in any form, and his system of training involved no special deprivations, and therefore did not wear upon him, his usual habits being such as to necessitate no essential change in preparing for a race. Three or four weeks before the present contest he went with his trainer to Cape Girardeau, Mo., to secure the advantage of warmer weather for his training. Here for two or three weeks he trained by riding 40 or 50 miles per day on an outdoor track. Six days before the race he started for New York, and from then until the race took very little exercise. During both these periods he lived in hotels and took his meals with his trainer, who limited his diet only by restricting the quantities of pastry and pork consumed. Reaching New York on Friday afternoon before the race, he remained quietly in his hotel nearly all of the intervening time, going out only once to the garden to try the track for a few minutes.

Frank Albert.—Age 28; height (without shoes) 5 feet 8½ inches; weight in ordinary clothing when not in special training, about 150 pounds; in riding costume at the beginning of the race, 138 pounds 8 ounces; waist measure, 30 inches; chest measure, 35 inches; expansion, 33–37 inches. Born in Canada of Scotch-Irish parents, he had lived in New York City since boyhood. He early took up athletics and at the time of these experiments had been devoting himself to foot and cycle racing for at least ten years and had once held a world's record in the latter.

He was his own manager, and thus had many more arrangements to look after than did Miller. He also attended entirely to his own training, employing a trainer only at the beginning of the race. He states that while temperate in all his habits, he habitually smokes in moderation and is not a total abstainer. During the two or three weeks previous to the race he lived in a private family in New York City, not limiting his diet except to avoid veal and fat meats. His exercise consisted in walking several miles every day and riding for a couple of hours, more or less, on a "home trainer," or on a rather small indoor track in the city. He took pains to secure at least eight hours of sleep every night. During training he continued to smoke occasionally. He took little exercise on the Friday before the race began and practically none on Saturday and Sunday. From noon of the Thursday to noon of the Saturday before the race it was possible to observe his diet and collect the urine. This covers practically the last day of active training and the first day of comparative rest before the race.

Henry Pilkington.—Age 25; height 5 feet 7½ inches; weight in ordinary clothing when not in special training, about 150 pounds; in riding costume at the beginning of the race, 141 pounds 4 ounces; waist measure, 31 inches; chest measure, 36 inches; expansion, 34–39 inches. Born in Ireland, he had lived four years in this country. For five years he had given much time to athletics, but this was his first attempt to ride an endurance race. He had trained with Miller and in a similar manner. In disposition he resembled Albert rather than Miller.

SURROUNDINGS AND EXPERIMENTAL CONDITIONS.

The Madison Square Garden, in which the race here described was held, is practically a covered inclosure occupying nearly the whole of

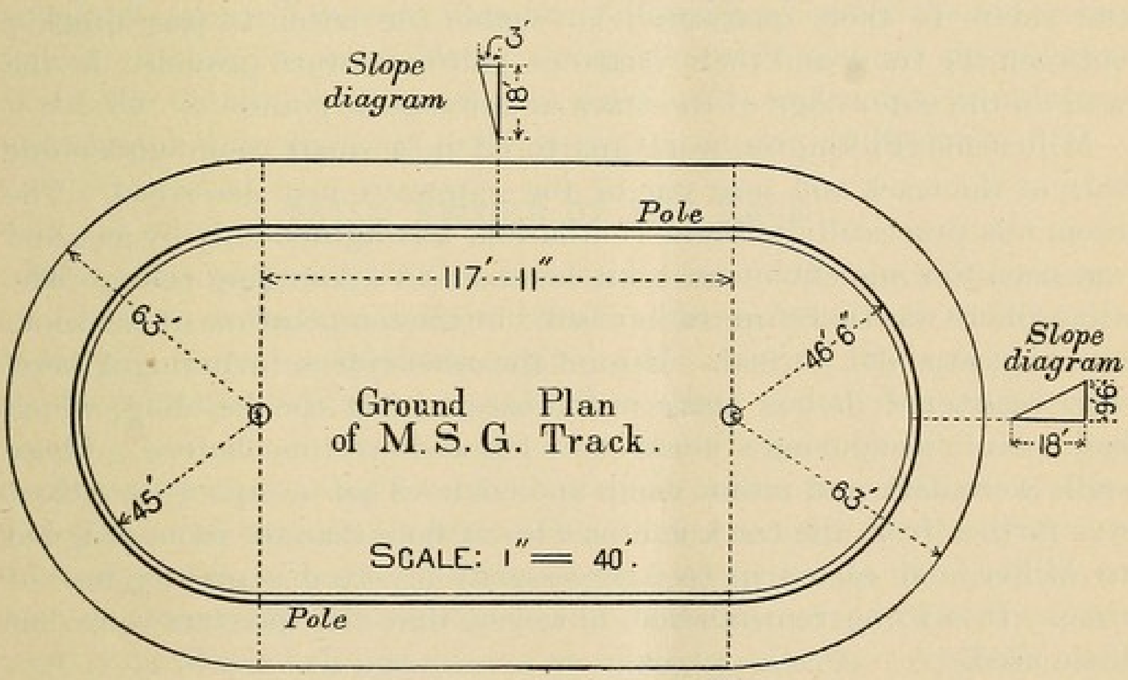

FIG. 1.—Diagram of track used for six-day race, Madison Square Garden, New York City, December, 1898.

a city block. It has seats around the sides for spectators and a great court in the center. Around this court a pine plank track was constructed for the special purpose of the six-day bicycle race (fig. 1). This track was straight at the sides and semicircular at the ends. The horizontal width was 18 feet, but at all points the outer edge was raised. This elevation of the outer edge was 3 feet at the lowest point (midway of the straight side) and 9½ feet at the highest (midway of the semicircular end). The "banking" here adopted was said to be somewhat greater than had been used in previous six-day contests, but decidedly less than is usually found on tracks constructed for racing at high speed.

A heavy black line, the "pole," was drawn around the track 18 inches from the inside edge, as close as it would be practicable to ride at a moderate rate of speed, and served as a sort of guide for the riders. The length of this line was intended to be exactly one-tenth of a mile and was so considered in making up the official record (fig. 1). The contestants, however, did not follow the pole exactly and were apt to ride outside of it, especially when attempting to pass one another. In consequence the distance actually covered was somewhat greater than the records show.

Inside the track, along one of its straight sides, was a level space about 6 feet wide. A portion of this space was assigned to each rider. Here his food and drink were brought and handed to him, as described beyond (p. 32). The chemists who made the observations here reported occupied places in this space and had their balances and other apparatus for weighing and sampling the food on tables here. While engaged in the observations they did not leave this space except to accompany the riders to their quarters. To enable the latter to pass quickly between the track and their quarters, gateways were provided in the wall on the outer edge of the track at convenient points.

Miller and Pilkington were quartered in a small room under one turn of the track and near one of the gateways just described. The room was practically without ventilation, was lighted only by gas, and was used to some extent as a kitchen and as a lounging room. The atmosphere was therefore rather bad, but the temperature of the room was kept at about normal. Most of the other riders, including Albert, were quartered in box stalls in the basement of the building, which had been in use during a horse show but a short time before. These stalls were dark and rather damp and cold. That occupied by Albert was farther from the track and on a lower floor than the room assigned to Miller, and each trip to it necessarily involved a greater loss of time. It is to be remembered, however, that the quarters were but little used.

In none of the quarters was there running water, and usually only the hands, face, and feet of the riders were bathed. This is notable in contrast to the frequent bathing usually practiced by amateur athletes or those whose exertions are of short duration. Miller's legs were massaged at frequent intervals, and not infrequently, especially in the last half of the race, his head, neck, and legs were bathed with hot water, this being believed to induce wakefulness.

As a result of frequent though not altogether systematic observations, the average temperature on the track was estimated as 58° to 60° F. The variations in temperature were sufficient at times to be very noticeable. Sometimes it was cold enough to cause the riders to complain. It was noticeable that even during the hardest riding none of the racers under observation perspired as freely as would be expected of a man at such severe work. When they came off the track their clothing was usually damp, but never actually wet. So far as observed, none of the men complained of becoming warm when riding. The clothing was of such nature that it absorbed and retained considerable perspiration, the amount being great enough to prevent the weight of the subjects being ascertained with accuracy when, as was usually necessary, they were weighed dressed. The riders wore, as a rule, two jerseys and two or three pairs of tights or trunks.

The glare of the lights in the evenings on the light-colored wooden track and the dust which had gathered before the end of the week affected the eyes of the riders slightly, especially on the last days.

Another disagreeable feature, and one of which the riders made the most complaint, was the presence of tobacco smoke, which kept the atmosphere always tainted and often made it very bad.

How great was the loss of sleep and how irregular were the habits of even the best managed and most successful of the contestants during the race will be seen from the following record of the two men studied. Owing to unavoidable circumstances it was not possible to obtain the details of Pilkington's record. He was not a prominent contestant and dropped out early in the fourth day of the race.

DAILY RECORD OF THE RACE.

Before the beginning of the race each contestant was subjected to a medical examination, special attention being given to the heart. Physicians were on hand throughout the race for the purpose of watching the riders, examining all who seemed greatly exhausted and stopping any whom they saw fit. Some of these physicians were employed by the racing association, while others were officers of the New York City board of health and had been detailed for this duty.

Monday, December 5.—The contestants, thirty-one in number, were started at 8 minutes 20 seconds after 12 on the morning of December 5.

At 12.44 Miller lost one minute by changing wheels. At 3.35 a.m. Albert left the track, feeling unwell, but returned after a rest of 15 minutes. After riding 7 miles he again rested 5 minutes.

From the start the effort of all the leading contestants, especially Miller and two others who were not included in the investigation, was to maintain a high speed, in the hope of wearing out their rivals as early as possible and then to hold the advantage thus won.[1] Most of

[1] Even in the earliest part of the race the spirits of the riders seemed largely influenced by their relative positions among the contestants. It is partly for this reason that the daily progress of Miller and Albert is here given in considerable detail. Inasmuch as Pilkington did not complete the race, details of his record are omitted.

the time during the first half day Miller set the pace, and at the end of 12 hours he was in the lead with a score of 236 miles. At 12.28 p. m. he dismounted and went to his quarters; changed some of his clothing; remained off his wheel for 12 minutes. At about the same time Albert was off the track for 11 minutes. At 5.10 p. m. he again left the track for 10 minutes. At 5.16 Miller left the track for 11 minutes' rest and rubbing. He appeared none the worse for his riding and was in excellent spirits. He was also off his bicycle for 1 to 2 minutes at 6.15, 9.30, 9.45, and 10.10 p. m. The last dismount was due to a fall. Albert was off for 16 minutes at about 10 p. m. An hour later he was again off for 21 minutes, and at 1.26 a. m. on Tuesday he left the track to sleep and was off nearly an hour, sleeping most of the time. Miller had a 20-minute rest about midnight.

At the end of the day Miller had ridden 23 hours and 10 minutes and covered 441.8 miles; Albert, 22 hours and 40 minutes, covering 402 miles.

Tuesday, December 6.—At 2.20 a. m. Miller left the track and was off 70 minutes, sleeping about an hour. When he returned he rode for 7 hours without dismounting, keeping, as on the first day, usually at the head of the fastest group of riders. At 10.30 Miller went to his room for 45 minutes, most of which was spent in sleep. On returning he rode hard, with only three stops of 10 to 20 minutes each, until after midnight. During this time both of his opponents had been forced to rest, so that when he stopped, shortly after midnight, he was only 4 miles behind the leader and was 30 miles ahead of the third. Miller's trainer insisted on his sleeping a second time before noon of this day. Later in the day he secured the lead.

Throughout the day Albert kept up a steady, strong pace, and by taking little rest succeeded in covering more distance (371 miles) than any other rider. From 2 a. m. until after noon he did not dismount. During the afternoon he made five stops, aggregating about an hour. When he stopped to sleep, at about 11 p. m., he held third place. He was off from 11.05 p. m. to 12.33 a. m. and had a little over an hour's sleep.

The day's score was: Miller, 21 hours 10 minutes, 366.7 miles; Albert, 21 hours 17 minutes, 371.3 miles.

Wednesday, December 7.—Miller and Albert both went on in good spirits and excellent condition. At 2 a m. the former was second and the latter fifth. At 4 a. m. Miller rested half an hour, and then returning, rode rapidly and steadily, gaining the lead early in the morning and holding it most of the day. He made occasional stops, the longest being at 6 p. m., when he was off for an hour and slept most of the time. During the day he rode 20 hours 11 minutes, covering 334.1 miles.

Albert rode all day at a steady pace. Every hour or two he would dismount for 5 to 20 minutes for a little rest and massage, and he usually ate at these times instead of on his wheel. The dust, smoke, and glare had slightly irritated his eyes. He was unwilling to stop for sleep. At midnight (after 72 hours) he held fourth place. He had ridden during the day 20 hours 41 minutes, covering 352.7 miles.

Thursday, December 8.—At 2.27 a. m. Miller left the track for 40 minutes, sleeping most of the time. Three hours later he was again off for 48 minutes. Albert, who had been without sleep for 30 hours, but with a short rest every hour or two, left the track at 5.45 for 2½ hours, getting 2 hours of sleep. Returning, he rode on the same plan as the day before, keeping a good pace, usually in the wake of one of the leading racers, sprinting little, and stopping every hour or two for 5 to 15 minutes. He maintained fourth place all day, gradually increasing his lead over the fifth.

Miller, from the time of his return at 6.35 a. m. until 5.50 p. m., lost about 1 hour in five stops, and during the time he was on his wheel kept up a pace of about 18 miles an hour. By noon he had regained first place, but lost it again during one of his short rests. When he went to his room at 5.50 he was partially bathed and well rubbed, and then rested about 1 hour. During the evening he tied for first place with his principal competitor, and they sprinted frequently.

During the day Miller rode 19 hours 43 minutes, covering 316.5 miles; Albert, 17 hours 13 minutes, covering 285.3 miles.

Friday, December 9.—Soon after midnight Miller's chief competitor left the track for some time. Miller gained the lead and then rested for about 50 minutes. Four times before noon he stopped for 15 to 30 minutes for short rests and massage, but when riding he kept up a pace of 17 or 18 miles per hour. Between 12 and 1 the official score shows that he covered 20.5 miles. He took a 40-minute rest at 2.30 and again at 8 p. m., with half a dozen short stops at various times during the day. By midnight he had a lead of 37 miles. He had ridden 1,786.9 miles in 120 hours, of which he had spent 103.9 hours on his wheel, making the average rate, when riding, 17.2 miles per hour. Out of the total of about 16 hours spent off his wheel it was estimated that he had slept about 5 hours. The outside estimate of sleep up to this time would be 6 or 6½ hours.

A little after midnight Albert left the track for 2½ hours. When he returned he rode much as on the previous day, stopping sixteen times before 9.45 p. m., when he again rested for nearly 2 hours. His riding was steady and his spirits and appetite good.

The score for the day was: Miller, 327.8 miles in 19 hours 37 minutes; Albert, 229.4 miles in 14 hours 30 minutes.

Saturday, December 10.—Miller stopped at 1.24 a. m. and took 1¼ hours' sleep. Before 2 p. m. he made six shorter stops. Then he rested an hour, after which he rode 20 minutes, then was off the track 1½ hours. During the remaining 6 hours of the race he rode only 36.7 miles, but it was evident that he could easily have ridden much more had he wished. On several occasions he rode a mile in less than 3 minutes, sometimes keeping pace with the short-distance exhibition riders for several laps. His record for the day was 220.5 miles in 14 hours 14 minutes, and for the six days was 2,007.4 miles in 118 hours 5 minutes.

Until 3 p. m. Albert rode on much the same plan as on the other days, except that his speed was lower and his rests longer. As a rule, he would ride 8 to 12 miles in 40 to 50 minutes and rest the remainder of the hour. After 3 p. m. he rode only 21 miles in all. His record for the day was 181.9 miles in 12 hours 23 minutes, and for the six days was 1,822.6 miles in 108 hours 44 minutes. At the end of the race he walked without difficulty to his lodgings, a distance of about a quarter of a mile.

While the race ended officially at 10.08, the contestants had practically stopped racing some time before. At no time after noon did any one of the leading riders appear to be trying to pass the one next ahead of him, and late in the afternoon practically all of them were off the track for some time.

Sunday, December 11.—Both Miller and Albert were seen near the middle of the day. There was nothing in the appearance of either to indicate that he had been through an unusual experience.

Miller gave public exhibitions upon his bicycle during the succeeding weeks. Both Miller and Albert took part in a twenty-four-hour race in New York the following month and in a six-day race in San Francisco two months later, Miller winning the latter and breaking his New York record.

The physical strength and endurance manifested by these men is brought out more clearly in the following tabular recapitulation:

TABLE 4.—*Recapitulation of score of Miller and Albert.*

Subject.	Riding.		Rest.		Sleep. [a]		Distance covered.
	Hrs.	*Min.*	*Hrs.*	*Min.*	*Hrs.*	*Min.*	*Miles.*
MILLER.							
Monday	23	10	0	50	0	0	441.8
Tuesday	21	10	2	50	1	40	366.7
Wednesday	20	11	3	49	1	35	334.1
Thursday	19	43	4	17	1	10	316.5
Friday	19	37	4	23	1	5	327.8
Saturday, till 10 p. m	14	14	7	46	2	30	220.5
Total for six days	118	5	23	55	8	0	2,007.4
Average for six days	19	41	3	59	1	20	334.6
Total for first five days	103	51	16	9	5	30	1,786.9
Average for first five days	20	46	3	14	1	6	357.4
ALBERT.							
Monday	22	40	1	20	0	0	402.0
Tuesday	21	17	2	43	1	30	371.3
Wednesday	90	41	3	19	0	20	352.7
Thursday	17	13	6	47	2	0	285.3
Friday	14	30	9	30	3	40	229.4
Saturday, till 10 p. m	12	23	9	37	2	0	181.9
Total for six days	108	44	33	16	9	30	1,822.6
Average for six days	18	7	5	33	1	35	303.8
Total for first five days	9[illegible]	21	23	39	7	30	1,640.7
Average for first five days	19	16	4	44	1	30	328.1

[a] Approximate estimate.

As already stated, Pilkington did not complete the race, and the data of his work were not obtained in full detail. He withdrew early on the fourth day. His score for the first three days was 863.2 miles.

Changes in body weights during the race.—As already stated, the weighings of the riders were not accurate because they were necessarily made without removal of the clothing which contained varying and sometimes considerable amounts of moisture. The following general statements are, however, believed to be reasonably near the truth:

Miller lost about 4 pounds in weight on the first day of the race. During the remaining five days the gains and losses were not great and so nearly equaled each other that the weight at the close of the race was practically the same as at the end of the first day. In other words, the net change in weight for the six days is accounted for by the loss observed on the first day, the net change for the following five days being practically nothing.

Albert lost only about 2 pounds on the first day. The first and second days taken together show a loss of about 3½ pounds, which was regained during the remaining four days of the race. The weight at the end of the race was almost exactly the same as at the beginning.

Pilkington lost about 3 pounds on the first day of the race and showed no change in weight on the second and third days.

Thus each of the riders lost weight at the beginning of the race. In two cases the weight remained about constant after this, while in one case the initial loss was recovered during the following days of the contest.

ANALYSES OF FOOD MATERIALS AND FECES.

As previously stated, the investigation with the bicyclists included (1) dietary studies, (2) digestion experiments, and (3) determinations of the balance of income and outgo of nitrogen. In connection with the dietary studies most of the food materials used were analyzed. This was the more desirable since a few of the articles used were somewhat unusual, and the composition of many of the cooked foods could not be calculated readily from the tables showing the average composition of American food materials. Whenever practicable a sample was taken from each lot of food purchased or prepared, composite samples being made when different lots of the same food were used. In other cases, especially those of the prepared foods, analyses were made of duplicate samples, which were purchased in New York at the time of the race except as otherwise stated in the description of samples beyond. The fruits were not analyzed, as the quantities of nutrients furnished by them were small and the average composition was fairly well known.

The analytical methods followed were those adopted by the Association of Official Agricultural Chemists[1] with such minor modifications as have been found desirable in the experience of this laboratory and have been described in previous publications.[2]

Such samples as could not conveniently be transported in the fresh state were partially dried in New York. All analyses were made in the chemical laboratory of Wesleyan University, at Middletown, Conn.

In connection with the three studies made during the race the feces were collected and analyzed. These samples follow those of the food materials in the description and tabulation which follow.

DESCRIPTION OF SAMPLES OF FOOD AND FECES ANALYZED.

No. 2979. Roast leg of lamb.—Rather well-done leg of lamb from which most of the visible fat had been removed. Used in dietary study No. 256.

No. 2983. Beefsteak.—This was rather rare round steak containing some visible fat. Used in dietary study No. 257.

No. 2982. Chicken broth.—Prepared in the usual way by the trainer immediately before using. Used in dietary study No. 257.

No. 2995. Mutton broth.—This was rather thin broth prepared immediately before using by stewing the mutton in water. Used in dietary study No. 257.

No. 2996. Beef tea.—Prepared by the trainer from round steak. Used in dietary study No. 257.

No. 3014. Vigoral.—A commercial preparation apparently consisting of a concentrated beef extract mixed with some pulverized beef and strongly flavored with celery salt. Used in dietary study No. 257. It was assumed that the vigoral used in dietary studies Nos. 255 and 258 had the same composition.

No. 3019. Beef-tea tablets.—A commercial preparation of beef extract and vegetables in solid form. This sample was purchased in Middletown and assumed to have the same composition as that used in dietary study No. 257.

No. 3020. Beef juice.—Very rare round steak was cut into small pieces and pressed by hand. The sample for analysis was prepared in Middletown in the same manner as that used in dietary study No. 257.

No. 2976. Soup.—A thin soup prepared with mixed vegetables. Used in dietary study No. 256.

No. 2997. Milk.—This was milk purchased from a cart and not bottled. Used in dietary study No. 256.

No. 2998. Milk.—Bottled milk purchased from a New York City dairy. Used in dietary study No. 257.

No. 2999. Milk.—Bottled milk from a New York City dairy. Used in dietary studies Nos. 255 and 258.

No. 3001. Koumiss.—A commercial preparation made from cow's milk. A duplicate sample was purchased for analysis. It contained 0.52 per cent alcohol assumed as isodynamic with 0.9 per cent carbohydrates.[3] Used in dietary studies Nos. 255 and 258.

No. 3002. Matzoon.—A commercial preparation made from cow's milk. It contained 0.81 per cent alcohol assumed as isodynamic with 1.4 per cent carbohydrates.[3] Used in dietary study No. 255.

---

[1] U. S. Dept. Agr., Division of Chemistry Bul. 46, revised.

[2] See especially Connecticut Storrs Sta. Rpt. 1891, p. 47.

[3] Based on their relative heats of combustion per gram, 1 gram of alcohol is isodynamic with 1.7 grams of carbohydrates ($7.1 \div 4.2 = 1.7$).

No. 3000. Butter.—Purchased in a New York City market. Used in dietary study No. 257.

No. 3013. Malted milk.—A commercial preparation. Used in dietary study No. 257.

No. 3016. Calf's-foot jelly.—A commercial preparation of gelatin sweetened and flavored with wine. It contained 2.44 per cent alcohol assumed as isodynamic with 4.1 per cent carbohydrates.[1] Used in dietary study No. 257.

No. 2984. White bread.—Homemade. Used in dietary studies Nos. 256 and 257.

No. 2985. Graham bread.—This was what is commonly known as graham gems. Used in dietary study No. 257.

No. 2986. Biscuit.—These were the sort of wheat bread known as "raised" biscuit, i. e., leavened with yeast. They were unusually dry from having been kept for some time in a paper bag at the track. Used in dietary study No. 257.

No. 2978. Oatmeal, boiled.—Prepared in the usual manner. Used in dietary study No. 256.

No. 2988. Oatmeal, boiled.—Prepared in the usual manner. Used in dietary study No. 257.

No. 2994. Oatmeal, boiled.—Prepared in the usual manner. Used in dietary studies Nos. 255 and 258.

No. 2981. Rice, boiled.—Prepared in the usual manner. Used in dietary study No. 257.

No. 2993. Rice, boiled.—Prepared in the usual manner. Used in dietary studies Nos. 255 and 258.

No. 2989. Cake.—Sugar cakes purchased from a local bakery. Used in dietary study No. 255.

No. 2990. Custard pie.—Purchased from a local bakery. Used in dietary study No. 255.

No. 2991. Charlotte russe.—Purchased from a local bakery. Used in dietary study No. 255.

No. 2975. Rice pudding.—Homemade. Used in dietary study No. 256.

No. 2992. Rice pudding.—Used in dietary study No. 255.

No. 2980. Tapioca pudding.—Homemade. Used in dietary study No. 257.

No. 2977. Mashed potatoes.—Boiled and mashed with the addition of a little butter and milk. Used in dietary study No. 256.

No. 2987. Stewed prunes.—From a jar of stewed dried prunes prepared in a private family and brought to the track. The sample represents total edible portion including liquor. Used in dietary study No. 257.

No. 3017. Ginger ale.—One of the commercial brands commonly sold in New York City. A duplicate sample was purchased for analysis. No alcohol was found. Used in dietary study No. 257.

No. 3018. Cocoa wine.—A commercial preparation commonly sold under this name. A duplicate sample was purchased for analysis. It contained 17.36 per cent alcohol assumed as isodynamic with 29.5 per cent carbohydrates.[1] Used in dietary study No. 257.

No. 3010. Feces from Miller.—Representing food eaten during the six days of the race.

No. 3011. Feces from Albert.—Representing food eaten during the six days of the race.

No. 3012. Feces from Pilkington.—Assumed to represent food consumed during first three days of the race.

---

[1] Based on their relative heats of combustion per gram, 1 gram of alcohol is isodynamic with 1.7 grams of carbohydrates ($7.1 \div 4.2 = 1.7$).

TABLE 5.—*Percentage composition of food materials and feces analyzed in connection with these studies.*

Laboratory number.	Reference number.	Materials.	Water.	Protein.	Fat.	Carbohydrates.	Ash.	Heat of combustion per gram.
		ANIMAL FOOD.						
			Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Calories.*
2979	1	Roast leg of lamb	60.86	29.62	6.79	....	1.62	2.308
2983	2	Beefsteak	57.58	28.69	12.91	....	1.27	2.754
2982	3	Chicken broth	92.74	3.56	2.05	....	1.58	.350
2995	4	Mutton broth	95.10	1.08	3.26	....	.52	.361
2996	5	Beef tea	94.93	2.51	1.69	....	.76	.266
3014	6	Vigoral	41.81	*a* 13.81	1.84	*b* 8.90	16.01	*c* 1.350
3019	7	Beef-tea tablets	10.76	*a* 16.06	.24	....	26.74	*c* .960
3020	8	Beef juice	....	*a* 6.13	....	....	....	*c* .350
2976	9	Soup	90.98	1.36	1.77	4.74	1.15	.410
2997	10	Milk	86.75	3.15	4.66	4.68	.76	.790
2998	11	.....do	88.40	2.86	3.91	4.13	.70	.686
2999	12	.....do	87.65	3.08	3.79	4.70	.78	.721
3001	13	Koumiss	88.33	3.62	2.58	4.52	.95	.625
3002	14	Matzoon	90.35	3.08	3.16	2.67	.74	.571
3000	15	Butter	10.57	1.12	86.04	....	2.27	8.005
3013	16	Malted milk	2.46	14.69	8.70	70.25	3.90	4.302
3016	17	Calf's-foot jelly	81.38	5.31	....	14.83	.19	.900
		VEGETABLE FOOD.						
2984	18	White bread	35.79	10.65	.59	51.42	1.55	2.797
2985	19	Graham bread	26.24	10.49	.58	60.75	1.94	3.182
2986	20	Biscuit	16.74	8.66	9.84	62.16	2.80	3.870
2978	21	Oatmeal, boiled	81.52	2.94	1.10	13.58	.86	.833
2988	22	.....do	88.92	1.58	.64	8.54	.32	.501
2994	23	.....do	86.18	1.99	.52	10.37	.94	.604
2981	24	Rice, boiled	77.62	2.85	1.80	17.29	.44	.998
2993	25	.....do	88.45	.69	.06	10.55	.25	.478
2989	26	Cake	23.80	7.59	12.71	54.73	1.17	3.773
2990	27	Custard pie	56.60	5.67	9.88	26.40	1.45	2.306
2991	28	Charlotte russe	47.28	4.81	21.89	25.29	.73	3.231
2975	29	Rice pudding	73.98	3.22	2.52	19.62	.66	1.200
2992	30	.....do	70.67	3.15	2.62	22.73	.83	1.390
2980	31	Tapioca pudding	81.05	5.00	5.26	7.93	.76	1.114
2977	32	Potatoes, mashed	74.10	2.27	6.42	15.81	1.40	1.316
2987	33	Stewed prunes	78.05	.73	.38	20.13	.71	.975
		UNCLASSIFIED FOOD.						
3017	34	Ginger ale	89.30	.06	....	10.58	.06	*c* 450
3018	35	Cocoa wine	72.04	....	....	35.88	3.23	*c* 1.500
		FECES.						
3010	......	Miller	....	26.95	27.08	18.95	27.02	5.070
3011	......	Albert	....	42.76	10.19	34.82	12.23	5.204
3012	......	Pilkington	....	22.55	38.24	9.54	29.67	5.480

a The proteid nitrogen was determined by Mallet's method (U. S. Dept. Agr., Division of Chemistry Bul. 54) and multiplied by 6.25. In our hands Mallet's method gave slightly higher and somewhat more concordant results for proteid nitrogen than did the bromin method. (See Bul. 54, above.)

b As these preparations contained some carbohydrates which could not be satisfactorily determined by direct estimation, they are calculated by difference in the usual way. The result thus obtained is obviously inaccurate, but is comparable to the so-called "carbohydrates" of other analyses. In estimating the carbohydrates by difference the total nitrogeneous matter was computed by multiplying the total nitrogen by 6.25.

c Heat of combustion estimated from percentage composition by use of the factors proposed by Atwater and Bryant in Connecticut Storrs Sta. Rpt. 1899, p. 104.

A few of the food materials consumed were not analyzed. These were such as previous investigations had shown to be of nearly uniform composition or were used in very small amounts. It was assumed that their composition could be calculated with sufficient accuracy from available data. The values used for this purpose are shown in the following table, together with the calculated heats of combustion per gram.[1]

[1] The heats of combustion were computed by use of the factors proposed by Atwater and Bryant in Connecticut Storrs Sta. Rpt. 1899, p. 104.

TABLE 6.—*Assumed percentage composition of foods not analyzed.*

Reference number.	Food materials.	Refuse.	Water.	Protein.	Fat.	Carbohydrates.	Ash.	Calculated heat of combustion per gram.
	ANIMAL FOOD.							
	Beef:	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Calories.*
36	Steak (all lean)		73.50	23.20	2.50		1.20	1.550
37	....do		70.00	21.30	7.90		1.10	1.950
	Lamb:							
38	Chops		47.60	21.70	29.90		1.30	4.070
39	Gravy		13.70	4.70	81.80		.30	8.040
40	Poultry: Chicken		59.90	27.00	11.50		1.30	2.620
41	Fish: Salmon, canned		63.50	21.80	12.10		2.60	2.380
42	Eggs		73.70	13.40	10.50		1.00	1.770
43	Butter		11.00	1.00	85.00		3.00	7.920
	UNCLASSIFIED FOOD.							
44	Soup: Tomato, canned		90.00	1.80	1.10	5.60	1.50	.430
	VEGETABLE FOOD.							
	Cereals:							
45	Bread, Vienna		34.20	9.40	1.20	54.10	1.10	2.920
46	Bread, graham		35.70	8.90	1.80	52.10	1.50	2.870
47	Cake, wedding (as average of fruit cakes)		17.30	5.90	10.90	64.10	1.80	3.980
48	Crackers, graham		5.40	10.00	9.40	73.80	1.40	4.550
49	Crackers, soda		5.90	9.80	9.10	73.10	2.10	4.480
50	Doughnuts		18.30	6.70	21.00	53.10	.90	4.570
	Sugars, starches, and oils:							
51	Sugar					100.00		3.960
52	Licorice drops (as coffee sugar)					95.00		3.750
	Vegetables:							
53	Celery, edible portion		94.50	1.10	.10	3.30	1.00	.200
54	Lettuce		94.70	1.20	.30	2.90	.90	.210
55	Peas, stewed *a*		73.80	6.70	3.37	14.57	1.50	1.200
56	Potatoes, plain boiled		75.50	2.50	.10	20.90	1.00	1.010
57	Tomatoes, raw		94.00	1.20	.20	4.00	.60	.250
58	Tomato pickles, green		93.80	1.10	.40	4.00	.70	.260
	Fruits:							
59	Apples		84.60	.40	.50	14.20	.30	.630
60	Apples, as purchased	25.00	63.30	.30	.30	10.80	.20	.470
61	Bananas		75.30	1.30	.60	22.00	.80	1.000
62	Grapes, Malaga		77.40	1.30	1.60	19.20	.50	.980
63	Oranges, edible portion		86.90	.80	.20	11.60	.50	.520
64	Pears		84.40	.60	.50	14.10	.40	.640
65	Peaches		88.10	.70	.10	10.80	.30	.480

a Composition assumed from that of sample analyzed in connection with dietaries of university boat crews.

DIETARY STUDIES—STATISTICS OF FOOD CONSUMED.

The statistics of the amounts and composition of the foods used by the several men under observation were gathered, and are reported as far as possible, in accordance with the methods for dietary studies which have been elaborated and followed in the series of studies of food and nutrition to which these experiments belong.[1] In some cases special methods were necessary on account of conditions under which the observations were made.

No regular meals were eaten. The food was taken at such intervals and in such amounts as suited the convenience of the subject and the judgment of his trainer. The food was prepared in part outside the building, in part at the quarters of the several subjects, and in part at their stands, which were in the space beside the track, which is

[1] U. S. Dept. Agr., Office of Experiment Stations Buls. 21, 29, etc.; and Connecticut Storrs Sta. Rpts. 1891–1897.

described above. Especially during the earlier days of the race most of the food was administered in a liquid or semiliquid form. Whenever a rider desired food he called to his trainer in passing the stand. The food was then put into a small tin cylinder of known weight, and the whole weighed by the chemist in attendance. A signal was then given to the rider, who diminished his speed so that the cylinder could be handed to him, and caught in his hand as he rode by. He swallowed the food while riding, and returned the cylinder when passing the stand again. The rider and attendants were very careful to avoid spilling any of the food in handling it after it had been weighed. In a few cases, however, there was a slight loss of food in handing the cylinder to the moving rider or receiving it from him. In such cases it was necessary to deduct the amount which appeared to be thus lost. Such accidents were very rare, and can not be regarded as introducing serious errors. When the cylinder was returned it was weighed, and this weight subtracted from that of cylinder and contents to determine the amount actually eaten.

The residue in the can was usually quite small, and in cases in which mixtures were fed the composition of this small residue was assumed to be the same as of the original mixture. When fruit was given the edible portion was weighed and handed directly to the rider, who always consumed it completely.

The results of the several dietary studies are tabulated beyond. Following each entry of the amount of a food material is a number in parentheses which corresponds with the number given the same food material in Tables 5 and 6, thus indicating the figures used in computing the nutrients in the food. For example, the figure 42 in parentheses after the first food material in Table 7, eggs 43 grams, refers to reference No. 42 in Table 6 and shows the assumed composition of the eggs. The fuel values were calculated as explained beyond, p. 52.

The numbers of the dietary studies 255–258 are those used in the series of such studies made in connection with the general nutrition investigations to which these studies belong.

DIETARY STUDY NO. 255, C. W. MILLER.

This study covered the entire period of the bicycle race—December 5 to 10, inclusive. Each portion of food, excepting the meat extract, the supply of which was weighed daily, was weighed immediately before being eaten. Most of the weighings of food were made on a torsion balance, with metric beam graduated to 5 grams and sensitive to 1 gram. This balance was mounted on a small table at the side of the track. As already noted, the foods taken during the greater part of the time were mostly liquid or semiliquid, and were eaten as a rule without dismounting. Toward the end of the race, when Miller dismounted more frequently and spent more time in his quarters, he ate a considerable part of his food there. This food was weighed on a spring balance, sensitive to one-half ounce, but as the quantities taken at a time on these occasions were relatively large, and the weighing could be done at leisure, the proportional error was probably not much greater than at the track side.

The amount and composition of the food consumed each day, and during the whole period, as well as the averages per day, are shown in the following table:

TABLE 7.—*Foods and nutrients consumed by C. W. Miller, December 5–10, inclusive.*

Date.	Kinds and amounts of food consumed.	Nutrients and fuel value.			
		Protein.	Fat.	Carbohydrates.	Fuel value.
	ANIMAL FOOD.				
1898.		*Grams.*	*Grams.*	*Grams.*	*Calories.*
Dec. 5	Eggs, raw, 43 gms. (42); milk, 690 gms. (12); koumiss, 7,138 gms. (13). Total animal food	285.4	214.9	355.0	4,624
	VEGETABLE FOOD.				
	Boiled rice, 360 gms. (25); sugar, 72 gms. (51); raw apples, edible portion, 480 gms. (59). Total vegetable food	4.4	2.6	178.2	773
	Total food	289.8	217.5	533.2	5,397
	ANIMAL FOOD.				
Dec. 6	Vigoral, 127 gms. (6); eggs, 173 gms. (42); milk, 2,779 gms. (12); koumiss, 482 gms. (13). Total animal food	143.8	138.3	163.7	2,547
	VEGETABLE FOOD.				
	Boiled oatmeal, 418 gms. (23); boiled rice, 225 gms. (25); sugar, 92 gms. (51); apples, 300 gms. (59); oranges, 699 gms. (63). Total vegetable food	16.7	5.2	282.7	1,276
	Total food	160.5	143.5	446.4	3,823
	ANIMAL FOOD.				
Dec. 7	Vigoral, 311 gms. (6); milk, 4,937 gms. (12). Total animal food	195.1	192.8	259.7	3,658
	VEGETABLE FOOD.				
	Bread, Vienna, 35 gms. (45); charlotte russe, 142 gms. (28); boiled oatmeal, 280 gms. (23); boiled rice, 371 gms. (25); rice pudding, 226 gms. (30); sugar, 53 gms. (51); apples, 320 gms. (59); oranges, 1,683 gms. (63). Total vegetable food	40.2	44.1	467.9	2,493
	Total food	235.3	236.9	727.6	6,151
	ANIMAL FOOD.				
Dec. 8	Beef extract, 43 gms. (6); matzoon, 476 gms. (14); milk, 581 gms. (12). Total animal food	38.5	37.8	43.8	689
	VEGETABLE FOOD.				
	Charlotte russe, 71 gms. (28); rice pudding, 737 gms. (30); apples, edible portion, 798 gms. (59); oranges, edible portion, 661 gms. (63). Total vegetable food	35.1	40.1	375.5	2,056
	Total food	73.6	77.9	419.3	2,745

TABLE 7.—*Foods and nutrients consumed by C. W. Miller, Decembe. 5–10, inclusive*—Continued.

Date.	Kinds and amounts of food consumed.	Nutrients and fuel value.			
		Protein.	Fat.	Carbo-hydrates.	Fuel value.
	ANIMAL FOOD.				
1898.		*Grams.*	*Grams.*	*Grams.*	*Calories.*
Dec. 9	Beef extract, 9 gms. (6); eggs, edible portion, 94 gms. (42); milk, 823 gms. (12). Total animal food.	39.1	41.3	39.5	706
	VEGETABLE FOOD.				
	Charlotte russe, 170 gms. (28); custard pie, 839 gms. (27); boiled oatmeal, 86 gms. (23); boiled rice, 300 gms. (25); canned tomato soup, 113 gms. (44); sugar, 25 gms. (51); apples, edible portion, 870 gms. (59). Total vegetable food	65.1	126.5	459.8	3,329
	Total food	104.2	167.8	499.3	4,035
	ANIMAL FOOD.				
Dec. 10	Beef extract, 5 gms. (6); milk, 1,985 gms. (12). Total animal food	61.8	75.4	93.6	1,339
	VEGETABLE FOOD.				
	Charlotte russe, 170 gms. (28); custard pie, 867 gms. (27); boiled rice, 252 gms. (25); rice pudding, 170 gms. (30); sugar, 19 gms. (51); sugar cakes, 57 gms. (26); wedding cake, 85 gms. (47); apples, 1,296 gms. (59); Malaga grapes, 865 gms. (62). Total vegetable food	90.1	164.1	791.1	5,138
	Total food	151.9	239.5	884.7	6,477
	Average per day, animal food	127.3	116.7	159.2	2,260
	Average per day, vegetable food	41.9	63.8	425.9	2,510
	Average per day, total food	**169.2**	**180.5**	**585.1**	**4,770**

In addition to the food, Miller consumed on the different days the following quantities of coffee infusion: December 5, 767 grams; December 6, 1,446 grams; December 7, 693 grams; December 8, 820 grams; December 9, 2,147 grams; and December 10, 798 grams. Numerous analyses in this laboratory have indicated that the quantity of nitrogen in coffee infusion is so minute as to have no appreciable effect upon the nitrogen balance.

DIETARY STUDY NO. 256, F. ALBERT (PREVIOUS TO THE RACE).

This study covered two days shortly before the race. It began with dinner December 1 and closed with breakfast December 3. The meals were taken at Albert's home. There was no special diet. The foods eaten were those prepared for the family. As previously noted, Albert avoided an excess of fats and sweets. The food served him at each meal was weighed on a spring balance similar to that used in dietary study No. 257. Due account was taken of uneaten residues. The details of the dietary study are shown in the following table:

TABLE 8.—*Foods and nutrients consumed by Frank Albert, December 1-3.*

Date.	Kinds and amounts of food consumed.	Nutrients and fuel value.			
		Protein.	Fat.	Carbo-hydrates.	Fuel value.
	ANIMAL FOOD.	*Grams.*	*Grams.*	*Grams.*	*Calories.*
1898. Dec. 1-2	Sirloin steak, lean, 142 gms. (36); roast leg of lamb, 170 gms. (1); gravy from lamb, 14 gms. (39); eggs, 170 gms. (42); butter, 71 gms. (43); milk, 964 gms. (10). Total animal food	137.9	149.6	45.1	2,141
	VEGETABLE FOOD.				
	White bread, 198 gms. (18); graham bread, 28 gms. (46); boiled oatmeal, 397 gms. (21); rice pudding, 213 gms. (29); sugar, 28 gms. (51); lettuce, 85 gms. (54); stewed peas, 85 gms. (55); prepared mashed potatoes, 213 gms. (32); tomato pickles, green, 57 gms. (58); apples, as purchased, 99 gms. (60); bananas, edible portion, 85 gms. (61); canned peaches, 142 gms. (65). Total vegetable food	56.6	29.5	335.7	1,883
	Total food	194.5	179.1	380.8	4,024
	ANIMAL FOOD.				
Dec. 2-3	Round steak, lean, 99 gms. (37); sirloin steak, lean, 99 gms. (36); canned salmon, 57 gms. (41); eggs, 114 gms. (42); butter, 78 gms. (43); milk, 255 gms. (10). Total animal food	80.5	107.4	11.9	1,377
	VEGETABLE FOOD.				
	Bread, 283 gms. (18); boiled oatmeal, 354 gms. (21); rice pudding, 184 gms. (29); sugar, 57 gms. (51); stewed peas, 113 gms. (55); plain boiled potatoes, 100 gms. (56); tomato pickles, 71 gms. (58); vegetable soup, 298 gms. (9); canned peaches, 142 gms. (65). Total vegetable food	62.4	19.9	356.3	1,902
	Total food	142.9	127.3	368.2	3,279
	Average per day, animal food	109.2	128.5	28.5	1,759
	Average per day, vegetable food	59.5	24.7	346.0	1,892
	Average per day, total food	**168.7**	**153.2**	**374.5**	**3,651**

DIETARY STUDY NO. 257, F. ALBERT (DURING THE RACE).

This study covered the six days of the race (December 5 to 10, inclusive). Some of the subject's food was brought from his home; the rest was prepared at his stand by the track side. The conditions attending the dietary study were less favorable for accuracy than were those in the study made with Miller. The space available for the work was very small, the table was in a crowded corner where it was frequently shaken, and the weighings had to be made very quickly. For these reasons it did not seem practicable to make the weighings on anything more delicate than a spring balance. A very accurate spring balance was obtained which was usually read to one-fourth ounce, but when time allowed could be made to indicate one-eighth ounce. At first each lot of food was weighed, but as the amount taken at a time was usually quite small it was soon seen that there was a possibility of considerable error in the weighings. As soon as practicable (on the second day) it was arranged to have most of the articles of food used by the rider kept separate from that of his attendants. The rider's foods were then weighed at the beginning and end of each day, thus greatly reducing the number of weighings and the probable error. Even afteı this was done, however, the amounts of food eaten were probably less accurately determined than in dietary studies Nos. 255 and 258. During the last half of the race Albert consumed the greater part of his food while resting at his stand beside the track. The details of this dietary study are given in the following table:

TABLE 9.—*Foods and nutrients consumed by Frank Albert, December 5–10.*

Date.	Kinds and amounts of food consumed.	Nutrients and fuel value.			
		Protein.	Fat.	Carbohydrates.	Fuel value.
	ANIMAL FOOD.	*Grams.*	*Grams.*	*Grams.*	*Calories.*
1898. Dec. 5	Beefsteak, lean, 85 gms. (36); beef tea, 440 gms. (5); eggs, 241 gms. (42); butter, 142 gms. (15); milk, 531 gms. (11). Total animal food	79.9	177.8	21.9	2,071
	VEGETABLE FOOD.				
	Bread, 368 gms. (18); graham bread, 85 gms. (19) graham crackers, 6 gms. (48); boiled oatmeal, 694 gms. (22); boiled rice, 241 gms. (24); sugar, 63 gms. (51); celery, 78 gms. (53); apples, 376 gms. (59). Total vegetable food	68.9	14.0	465.2	2,320
	UNCLASSIFIED FOOD.				
	Ginger ale, 1,680 gms. (34); calf's-foot jelly, 42 gms. (17); malted milk, 91 gms. (16). Total unclassified food	16.7	7.9	247.9	1,158
	Total food	165.5	199.7	735.0	5,549
	ANIMAL FOOD.				
Dec. 6	Beefsteak, lean, 28 gms. (36); beef juice, 128 gms. (8); lamb chops, 78 gms. (38); chicken, 42 gms. (40); chicken broth, 170 gms. (3); eggs, 57 gms. (42); butter, 64 gms. (15); milk, 116 gms. (11). Total animal food	60.4	97.9	4.8	1,178
	VEGETABLE FOOD.				
	Bread, 198 gms. (18); graham crackers, 6 gms. (48); boiled oatmeal, 347 gms. (22); sugar, 119 gms. (51); licorice drops, 18 gms. (52); celery, 78 gms. (53); raw tomatoes, 220 gms. (57); raw apples, edible portion, 269 gms. (59); California grapes, 99 gms. (62); oranges, edible portion, 135 gms. (63); stewed prunes, 376 gms. (33). Total vegetable food	37.0	9.0	431.8	2,005
	UNCLASSIFIED FOOD.				
	Ginger ale, 1,248 gms. (34); calf's-foot jelly, 99 gms. (17); malted milk, 82 gms. (16). Total unclassified food	18.1	7.1	204.3	978
	Total food	115.5	114.0	640.9	4,161
	ANIMAL FOOD.				
Dec. 7	Beefsteak, lean, 50 gms. (36); beef juice, 14 gms. (8); beef-tea tablets, 10 gms. (7); vigoral, 18 gms. (6); lamb chops, 14 gms. (38); chicken, 85 gms. (40); chicken broth, 283 gms. (3); eggs, 369 gms. (42); butter, 78 gms. (15); milk, 142 gms. (11). Total animal food	107.0	132.7	7.5	1,704
	VEGETABLE FOOD.				
	White bread, 177 gms. (18); graham gems, 184 gms. (19); boiled oatmeal, 532 gms. (22); sugar 177 gms. (51); celery, 78 gms. (53); raw tomatoes, 29 gms. (57); vegetable soup, 191 gms. (9); apples, edible portion, 192 gms. (59); Malaga grapes, 138 gms. (62); oranges, edible portion, 326 gms. (63); stewed prunes, 170 gms. (33). Total vegetable food	56.8	13.6	563.7	2,670

TABLE 9.—*Foods and nutrients consumed by Frank Albert, December 5-10*—Continued.

Date.	Kinds and amounts of food consumed.	Nutrients and fuel value.			
		Protein.	Fat.	Carbohydrates.	Fuel value.
	UNCLASSIFIED FOOD.	*Grams.*	*Grams.*	*Grams.*	*Calories.*
1898. Dec. 7	Cocoa wine, 170 gms. (35); ginger ale, 2,459 gms. (34); calf's-foot jelly, 213 gms. (17); malted milk, 78 gms. (16). Total unclassified food	24.2	6.8	407.5	1,833
	Total food	188.0	153.1	978.7	6,207
	ANIMAL FOOD.				
Dec. 8	Beefsteak, lean, 71 gms. (36); beefsteak, 71 gms. (2); beef juice, 11 gms. (8); beef-tea tablets, 5 gms. (7); vigoral, 27 gms. (6); mutton broth, 539 gms. (4); chicken, 64 gms. (40); chicken broth, 340 gms. (3); eggs, 283 gms. (42); butter, 198 gms. (15); milk, 312 gms. (11). Total animal food	126.2	255.8	15.3	2,959
	VEGETABLE FOOD.				
	Bread, 170 gms. (18); "raised" biscuits, 43 gms. (20); doughnuts, 49 gms. (50); graham gems, 397 gms. (19); sugar, 142 gms. (51); apples, 390 gms. (59); bananas, 92 gms. (61); Malaga grapes, 99 gms. (62); oranges, edible portion, 64 gms. (63); pears, 283 gms. (64). Total vegetable food	73.0	23.4	665.2	3,245
	UNCLASSIFIED FOOD.				
	Cocoa wine, 198 gms. (35); ginger ale, 1,581 gms. (34); calf's-foot jelly, 269 gms. (17); malted milk, 36 gms. (16). Total unclassified food	20.5	3.1	303.5	1,357
	Total food	219.7	282.3	984.0	7,561
	ANIMAL FOOD.				
Dec. 9	Beefsteak, lean, 170 gms. (36); chicken (cooked) capon, 156 gms. (40); chicken broth, 305 gms. (3); eggs, 56 gms. (42); butter, 220 gms. (15); milk, 149 gms. (11). Total animal food	106.7	229.5	6.1	2,597
	VEGETABLE FOOD.				
	Bread, 553 gms. (18); soda crackers, 28 gms. (49); graham gems, 128 gms. (19); tapioca pudding, 170 gms. (31); sugar, 135 gms. (51); celery, 49 gms. (53); apples, 418 gms. (59); Malaga grapes, 156 gms. (62); oranges, 234 gms. (63); pears, 319 gms. (64); stewed prunes, 319 gms. (33). Total vegetable food	93.8	23.5	758.3	3,712
	UNCLASSIFIED FOOD.				
	Cocoa wine, 43 gms. (35); ginger ale, 1,623 gms. (34); calf's-foot jelly, 156 gms. (17); malted milk, 21 gms. (16). Total unclassified food	12.4	1.8	225.0	990
	Total food	212.9	254.8	989.4	7,299
	ANIMAL FOOD.				
Dec. 10	Beefsteak, 64 gms. (2); lamb chops, 71 gms. (38); mutton broth, 276 gms. (4); chicken, 85 gms. (40); chicken broth, 425 gms. (3); eggs, 114 gms. (42); butter, 92 gms. (15); milk, 269 gms. (11). Total animal food	98.8	158.6	11.1	1,925
	VEGETABLE FOOD.				
	Bread, 142 gms. (18); biscuits, 57 gms. (20); soda crackers, 28 gms. (49); graham gems, 269 gms. (19); tapioca pudding, 142 gms. (31); sugar, 241 gms. (51); apples, edible portion, 85 gms. (59); Malaga grapes, 78 gms. (62); pears, edible portion, 510 gms. (64). Total vegetable food	62.3	22.2	643.6	3,101

TABLE 9.—*Foods and nutrients consumed by Frank Albert, December 5-10*—Continued.

Date.	Kinds and amounts of food consumed.	Nutrients and fuel value.			
		Protein.	Fat.	Carbo-hydrates.	Fuel value.
	UNCLASSIFIED FOOD.				
1898.		*Grams.*	*Grams.*	*Grams.*	*Calories.*
Dec. 10	Cocoa wine, 113 gms. (35); ginger ale, 914 gms. (34); calf's-foot jelly, 220 gms. (17); malted milk, 7 gms. (16). Total unclassified food	13.2	0.6	174.7	770
	Total food	174.3	181.4	829.4	5,802
	Average per day, animal food	96.5	175.4	11.1	2,072
	Average per day, vegetable food	65.3	17.6	588.0	2,842
	Average per day, unclassified food	17.5	4.5	260.5	1,182
	Average per day, total food	**179.3**	**197.5**	**859.6**	**6,096**

The amount of coffee infusion consumed on the different days was as follows: December 5, 857 grams; December 6, 1,951 grams; December 7, 1,707 grams; December 8, 2,431 grams; December 9, 1,427 grams, and December 10, 1,638 grams. On December 5, 517 grams of tea infusion was consumed. None was drunk on the following days.

As previously noted, it was possible to observe the diet and collect the urine of this subject from noon of the Thursday to noon of the Saturday before the race. This period covered practically the last day of active training and the first day of comparative rest before the contest. The results of observations of food consumption for these two days are shown in Table 8, above. On the first day the food contained 195 grams of protein (31.2 of nitrogen) and 4,025 calories of energy; on the second, 143 grams of protein (22.9 of nitrogen) and 3,280 calories. During the two days the subject eliminated 24.5 and 14.1 grams of nitrogen, respectively, in the urine (see p. 50). Thus, while the potential energy of the diet was but very little above the averages found for farmers, mechanics, and professional men, and considerably less than the average of college athletes in studies made in the United States,[1] the protein was considerably higher than in the former and rather higher than in the latter. It appears, however, that a considerable portion of this protein was stored in the body, since the urine contained much less nitrogen than the food, and the amount in the feces could account for more than a part of this difference.

DIETARY STUDY NO. 258, H. PILKINGTON.

This study covered the first three days of the bicycle race (December 5 to 7, inclusive). The food was prepared in the same way as that served Miller (No. 255), and the same methods were followed in weighing the food consumed and collecting the samples. The details of the dietary study follow:

[1] U. S. Dept. Agr., Office of Experiment Stations Buls. 21 and 75; also U. S. Dept. Agr. Yearbook, 1898, p. 450; Connecticut Storrs Sta. Rpt. 1897, p. 153.

TABLE 10.—*Foods and nutrients consumed by Henry Pilkington, December 5–7, inclusive.*

Date.	Kinds and amounts of food consumed.	Nutrients and fuel value.			
		Protein.	Fat.	Carbo-hydrates.	Fuel value.
	ANIMAL FOOD.				
1898.		*Grams.*	*Grams.*	*Grams.*	*Calories.*
Dec. 5	Eggs, 79 gms. (42); milk, 1,600 gms. (12); koumiss, 4,522 gms. (13). Total animal food	223.6	185.6	279.6	3,789
	VEGETABLE FOOD.				
	Boiled oatmeal, 506 gms. (23); boiled rice, 574 gms. (25); sugar, 89 gms. (51); apples, 19 gms. (59). Total vegetable food	14.2	3.0	204.8	926
	Total food	237.8	188.6	484.4	4,715
	ANIMAL FOOD.				
Dec. 6	Vigoral, 85 gms. (6); eggs, 46 gms. (42); milk, 1,496 gms. (12); koumiss, 3,233 gms. (13). Total animal food	181.0	146.5	224.0	3,023
	VEGETABLE FOOD.				
	Boiled oatmeal, 131 gms. (23); boiled rice, 756 gms. (25); sugar, 85 gms. (51); oranges, 255 gms. (63). Total vegetable food	9.8	1.7	208.0	909
	Total food	190.8	148.2	432.0	3,932
	ANIMAL FOOD.				
Dec. 7	Vigoral, 156 gms. (6); butter, 28 gms. (43); milk, 4,165 gms. (12); koumiss, 175 gms. (13). Total animal food	156.5	189.0	217.6	3,291
	VEGETABLE FOOD.				
	Bread, 307 gms. (45); boiled oatmeal, 768 gms. (23); boiled rice, 350 gms. (25); sugar, 80 gms. (51); apples, 150 gms. (59); oranges, 85 gms. (63). Total vegetable food	47.8	8.9	393.7	1,893
	Total food	204.3	197.9	611.3	5,184
	Average per day, animal food	187.0	173.7	240.4	3,368
	Average per day, vegetable food	23.9	4.5	268.8	1,242
	Average per day, total food	**210.9**	**178.2**	**509.2**	**4,610**

The amount of coffee infusion consumed on the different days was as follows: December 5, 552 grams; December 6, 457 grams, and December 7, 605 grams.

In the preceding tables the fuel value of the diet was calculated by Rubner's factors, which are in common use. According to these each gram of protein in the average mixed diet has a fuel value of 4.1 calories, each gram of fat 9.3, and each gram of carbohydrates 4.1 calories. These factors were proposed by Rubner in 1885,[1] and were based upon such data as were available at the time. A large amount of experimental research has, however, accumulated within recent years which makes it possible to determine these factors with a closer approach to accuracy. Atwater and Bryant recently published an article which contains a general summary[2] of the data bearing upon the determinations of factors for estimating the fuel value of the

[1] Ztschr. Biol., 21 (1885), p. 377.

[2] Connecticut Storrs Sta. Rpt. 1899, p. 73.

various nutrients in different kinds of food materials and in ordinary mixed diet. In the article referred to the factors 4.0, 8.9, and 4.0 are proposed as expressing much more clearly the average fuel value of 1 gram of protein, fats, and carbohydrates, respectively, than do the corresponding factors of Rubner.

In deducing these factors the results of a considerable amount of late experimental inquiry were summarized, including (1) analyses of over 4,000 specimens of American food materials; (2) a large number of European and American determinations of the nitrogen factor of protein and of the heats of combustion of food materials and of the proteids, fats, carbohydrates, and other compounds occurring in them; (3) a considerable number of determinations of the ratio of the heat of combustion of solids of urine to the amount of nitrogen present including 46 late American determinations of the urine of men subsisting upon different diets, made chiefly in connection with digestion experiments; (4) the proportion of different kinds of food materials and of nutrients in the ordinary mixed diet, as shown by the results of 185 dietary studies lately made in the United States; and (5) the digestibility of the nutrients of different food materials, as indicated by European and American digestion experiments, including nearly 100 experiments lately made in the United States on the digestibility of a mixed diet by healthy men.

Most of these data have accumulated since Rubner made his estimates in 1885. Thus for the heat of combustion of urine, which is an important factor in determining the fuel value of the protein, he had only the results of a small number of determinations on the urine of dogs. Moreover, Rubner's estimates were based upon determinations of heats of combustion by the Thompson-Stohmann calorimeter, which has been found to give lower results than are obtained by the more highly developed bomb calorimeter now commonly used.

In discussing the factors for fuel value as proposed by Rubner and those as proposed by Atwater and Bryant, it is necessary to carefully define the terms used. The sense in which the expression "fuel value" is here used is stated in the following definition:

"By fuel value is understood the energy (heat of combustion) of the material of the food which is capable of oxidation in the body. For the total food it is the total energy less that of the corresponding unoxidized materials of the feces and urine. For the protein it is likewise the total heat of combustion less that of the corresponding unoxidized residues of these excretions. For the fats and carbohydrates it is the total energy of the food less that of the corresponding unoxidized material of the feces."

Rubner's fuel value or "Wärmewerth" of protein was obtained in practically the same way as the new factor for the fuel value of protein. In his "Wärmewerth" of fats and carbohydrates, however, no allowance was made for the amounts lost in the feces. The difference, therefore, between Rubner's "Wärmewerth" and the term fuel value here used is: For the fats and carbohydrates, Rubner's "Wärmewerth" is the total heat of combustion, whereas the fuel value is that amount less the heat of combustion of the corresponding compounds of the feces. For the protein the "Wärmewerth" and the fuel value both represent the heat of combustion of the total protein, less the sum of the heats of combustion of the protein of the feces and the solids of the urine. Aside from this difference there is a further variation between Rubner's estimates for "Wärmewerth" and those here given for fuel value, which has already been referred to, namely, the smaller values for heats of combustion as determined by the Thompson-Stohmann calorimeter upon which Rubner first based his factors.

Nevertheless, it is only just to say that considering the paucity of Rubner's data and the fact that he made no allowance for either the undigested material or the metabolic products of the feces properly belonging to the carbohydrates and fats, the results are certainly very close to those arrived at by the use of the more extensive data now available.

The data given in some detail in Tables 7, 9, and 10 are summarized in Table 11. This table also gives the fuel value of the food as computed by the old and the new factors. In addition, there are added for purposes of comparison, the fuel values actually found by experiment. These latter values are in every instance slightly lower than those computed by use of the new factors, and are very much lower than the values as computed by use of the old factors. They indicate that in these particular cases even the new factors are somewhat too large. These factors, however, were applied to the results obtained in twenty-seven experiments made in connection with investigations with the respiration calorimeter, and were found on the average to give results differing by only one-tenth of 1 per cent from the actual fuel values as determined by experiment.

TABLE 11.—*Summary of nutrients and fuel value of food consumed each day by the different riders.*

Subject and day.	Protein.	Fat.	Carbohydrates.	Fuel value. By old factors.	Fuel value. By new factors.
MILLER.	*Grams.*	*Grams.*	*Grams.*	*Calories.*	*Calories.*
First day, Dec. 5	290	218	533	5,397	5,232
Second day, Dec. 6	160	144	446	3,823	3,706
Third day, Dec. 7	235	237	728	6,151	5,961
Fourth day, Dec. 8	74	78	419	2,745	2,666
Fifth day, Dec. 9	104	168	499	4,035	3,907
Sixth day, Dec. 10	152	240	885	6,477	6,284
Average of 6 days	169	181	585	4,770	4,626
Fuel value as actually determined					4,583

TABLE 11.—*Summary of nutrients and fuel value of food consumed each day by the different riders*—Continued.

Subject and day.	Protein.	Fat.	Carbohydrates.	Fuel value. By old factors.	Fuel value. By new factors.
ALBERT.	*Grams.*	*Grams.*	*Grams.*	*Calories.*	*Calories.*
First day, Dec. 5	165	200	735	5,549	5,380
Second day, Dec. 6	116	114	641	4,161	4,043
Third day, Dec. 7	188	153	979	6,207	6,030
Fourth day, Dec. 8	220	282	984	7,561	7,326
Fifth day, Dec. 9	213	255	989	7,299	7,078
Sixth day, Dec. 10	174	181	829	5,802	5,623
Average of 6 days	179	198	859	6,096	5,913
Fuel value as actually determined					5,878
PILKINGTON.					
First day, Dec. 5	238	189	484	4,715	4,570
Second day, Dec. 6	191	148	432	3,932	3,809
Third day, Dec. 7	204	198	611	5,184	5,022
Average of 3 days	211	178	509	4,610	4,467
Fuel value as actually determined					4,323

FOOD CONSUMPTION OF THE BICYCLE RACERS COMPARED WITH THAT OF OTHER ATHLETES.

The food consumption of these bicycle racers is compared with that of other athletes and of different classes of men at severe and at ordinary occupations in Table 12, which follows:

TABLE 12.—*Comparison of average daily food consumption of persons with severe muscular work.*

Reference number.		Protein.	Fat.	Carbohydrates.	Fuel value.	Nutritive ratio.*a*
		Grams.	*Grams.*	*Grams.*	*Calories.*	*1:*
1	Miller during 6-day race, 1898	169	181	585	4,770	5.9
2	Pilkington during 3 days of the 6-day race, 1898	211	178	509	4,610	4.3
3	Albert during 6-day race, 1898	179	198	859	6,095	7.3
4	Albert during preliminary period, 1898	169	153	375	3,650	4.2
5	Weston, 5-day preliminary to 5-day walk, 1870 *b*	149	141	226	2,850	3.6
6	Weston during 5-day walking race, 1870 *b*	94	66	154	1,635	3.2
7	Weston, 5 days following 5-day walking race, 1870 *b*	197	168	454	4,230	4.2
8	Weston, ninety-fifth to ninety-ninth day of 100-day walk *b*	236	65	780	4,770	3.9
9	Weston, 3-day walking race, 1877 *c*	294	195	941	6,877	4.7
10	Weston, 6-day preliminary to 6-day walking race, 1877 *d*	218	102	462	3,735	3.1
11	Weston, 6 days of walk, 1877 *d*	300	158	606	5,185	3.2
12	Miller during 6-day bicycle race, 1897 *e*	262	192	791	6,100	4.6
13	Sandow in time of exhibitions of strength *f*	244	151	502	4,460	3.5
14	Harvard University boat crew, Cambridge, 1898 *g*	162	175	449	4,130	5.2
15	Harvard freshman boat crew, Cambridge, 1898 *g*	153	223	468	4,620	6.1
16	Harvard University boat crew, New London, 1898 *g*	160	170	448	4,075	5.2
17	Harvard freshman boat crew, New London, 1898 *g*	135	152	416	3,675	5.7
18	Captain of Harvard freshman crew, New London, 1898 *g*	155	181	487	4,315	5.7
19	Yale University boat crew, New Haven, 1898 *g*	145	170	375	3,705	5.1

a Calculated by dividing the sum of carbohydrates and $2\frac{1}{4}$ times the fat by the amount of protein.
b Flint, New York Med. Jour., 13 (1870), 653. See also p. 13, above.
c Blyth, Proc. Roy. Soc. [London], 37 (1884), pp. 46–55. See also p. 16, above.
d Pavy, Lancet, 1896, I, II, passim. See also p. 13, above.
e Bryant, Diet. & Hyg. Gaz., 15 (1899), p. 393. See also p. 14, above.
f Langworthy and Beal, Connecticut Storrs Sta. Rpt. 1896, p. 158.
g U. S. Dept. Agr., Office of Experiment Stations Bul. 75.

TABLE 12.—*Comparison of average daily food consumption of persons with severe muscular work*—Continued.

Reference number.		Protein.	Fat.	Carbohydrates.	Fuel value.	Nutritive value.
		Grams.	*Grams.*	*Grams.*	*Calories.*	*1:*
20	Yale University boat crew, New London, 1898 *a*	171	171	434	4,070	4.6
21	Foot-ball team, Connecticut, 1889 *b*	181	292	557	5,740	6.8
22	Foot-ball team, California, 1897 *c*	270	416	710	7,885	6.1
23	Dock laborers, Cronstadt, Russia *d*	216–220	95	931	5,595	5.3
24	New York builder (large and muscular), average of 2 studies *e*	195	242	718	5,995	6.5
25	Average of 14 mechanics' families *f*	103	150	402	3,465	7.2
26	Average of 10 farmers' families *f*	97	130	467	3,515	7.8
27	Average of 14 professional men's families *f*	104	125	423	3,325	6.6

a U. S. Dept. Agr., Office of Experiment Stations Bul. 75.
b Connecticut Storrs Sta. Rpt. 1891, p. 128.
c U. S. Dept. Agr., Office of Experiment Stations Bul. 84.
d Vestnik Obsh. Hig. Subed. i Prakt Med., 31 (1896), No. 1, Pt. VIII, p. 4; abs. in U. S. Dept. Agr., Experiment Station Record, 10 (1898–99), p. 678.
e U. S. Dept. Agr., Office of Experiment Stations Bul. 46, p. 51.
f U. S. Dept. Agr. Yearbook, 1898, p. 450.

It will be seen from this table that the bicycle racers' dietaries are high both in protein and energy. On the other hand, they did more than two ordinary days' work in one. Taking into account the nitrogen metabolized in excess of the amount supplied by the food,[1] we may say that the total protein metabolized was about twice as much as the available protein of the food of the average American mechanic or professional man and the average energy about 50 per cent greater. Here, however, we must note that Albert's diet supplied 25 to 30 per cent more energy than Miller's or Pilkington's. The college boat crews (studied in summer) stand about midway between the average of men of ordinary occupations and the professional bicycle racers here reported. Weston's diet showed such great variations in the different studies made with him that an average of the results would be of doubtful value. Perhaps, however, it may be safe to assume that his diet during the last days of his 100-day walk would represent the demands of his body when worked almost up to its capacity for physical exertion. At this time his dietary supplied a little more protein than that of any of these bicycle racers here reported, although the amount actually metabolized in the body was probably more nearly equal to that observed with them. As regards energy, his supply was about the same as that of Miller and Pilkington and less than that of Albert.

The nutritive ratios shown in Table 12 are seen to vary greatly. In studies of the kind here reported it seems hardly proper to attach great importance to this ratio, for it would seem that these athletes were able to supply during the few days of the race considerable protein from their own bodies, and that the food was selected with a view to easy digestibility rather than to its proportion of protein. In

[1] See discussion of nitrogen balance, p. 50.

other words, it seemed that during the days of the race the question of a well-balanced ration became subordinate to that of an easily digested and agreeable one. As the results show (see p. 50), deficiencies in the supply of protein were apparently made good by utilizing material of the body tissue without injury, but it is evident that any marked disturbance of the digestive apparatus would have been fatal to the prospects of any contestant.

If the nutritive ratio of Miller's diet be calculated for each day it will be found to be narrow at first (1:3.5 for the first day) and gradually widening as the race progressed, until at the end it was decidedly wide (1:9.4 for the last day). This is, of course, accounted for by the fact that at first almost the only foods were milk and koumiss, while later large quantities of cereals were used, and toward the last the rider was allowed to indulge in fruits and pastry. The trainer's reason for thus regulating the diet was to insure good digestion and regular movements of the bowels. Whether the change in nutritive ratio was of any advantage it is impossible to say. No such change was found in the case of Albert.

Notwithstanding these variations a consideration of the nutritive ratios is not without interest. Albert shows little difference in this respect from the average American families, while Miller has a narrower ratio, not far from the average of the college boat crews. Pilkington, who remained in the race for only three days, shows a still narrower ratio; about the same as Miller's ratio for the same days. Miller's average ratio is considerably wider than any ratio found for Weston, but had the former not been allowed to indulge in fruit and pastry toward the end of the race there would have been little, if any, difference.

In general these results seem rather to confirm the impression that intense exertion is best supported by a diet with a narrow nutritive ratio; that is, by a diet with a large amount of protein in proportion to the fat and carbohydrates.

It is interesting to note that Albert consumed considerable amounts of sugar, taking it principally in the form of ginger ale. The use of sugar in the diet of soldiers and others whose work is heavy and prolonged is being much discussed. It is sometimes recommended also for athletes, whose exertions are intense but of short duration. For the latter cases, however, it has been more generally believed that a diet consisting largely of animal food, and furnishing more protein, is preferable. This subject will be found discussed in previous bulletins of this Office.[1]

[1] U. S. Dept. Agr. Farmers' Bul. 93, and U. S. Dept. Agr., Office of Experiment Stations Bul. 75.

DIGESTION EXPERIMENTS.

In order to determine the outgo of nitrogen through the intestine, and incidentally the digestibility of the diet under the conditions of unusually severe work, the feces from each of the subjects were collected and the portions corresponding to the food eaten during the race were separated and analyzed. The methods followed in these digestion experiments were such as have been used in other studies of the series to which these belong.[1] The separations were made by means of lampblack given with the last meal before the race and the first meal after. These separations were not very satisfactory, the differences in color being less pronounced than is usual. This was probably due to the fact that the subjects did not take meals at regular intervals, but ate small quantities of food very frequently, so that the lampblack would be more likely to be mixed with the residues of preceding or succeeding meals than under ordinary circumstances. While these errors in separation may be sufficient to somewhat affect the results when considered simply as those of digestion experiments, they can not have any very serious influence upon the main question studied, since neither the balance of income and outgo of nitrogen nor that of energy could be much altered by such small errors as may have occurred in the separation of the first and last portions of feces in a six-day metabolism experiment.

The weight of the dry matter of the feces excreted by each man corresponding to the food eaten during the days covered by the experiment was as follows: Miller (six days), 252 grams; Albert (six days), 235.6 grams, and Pilkington (three days), 179.1 grams. The composition of the dry matter of the feces is shown in Table 5.

The results of the digestion experiments are shown in Tables 13–15. The amounts of the different nutrients and the heats of combustion are calculated from the total quantities of the different kinds of food materials consumed and their composition and potential energy per gram, as shown in Tables 5 and 6. The difference between the amounts of nutrients in the total food eaten and the amounts rejected in the feces gives the amounts actually available[2] to the body. The proportion of any given nutrient thus digested is termed its coefficient of digestibility under the given conditions. The heat of combustion of the incompletely oxidized matter excreted in the urine ranged from 1.32 to 1.23 calories

[1] U. S. Dept. Agr., Office of Experiment Stations Bul. 21, p. 57, and Bul. 53, p. 25; also Connecticut Storrs Sta. Rpt. 1896, p. 163.

[2] It is of course understood that the feces contain not only the undigested residue of the food, but considerable quantities of metabolic products, so that the results of experiments of this kind show, not the quantities of nutrients actually digested, but rather the approximate amounts which are actually available to the body for the building of tissue and the yielding of energy. For discussion of this subject see Connecticut Storrs Sta. Rpt. 1897, p. 156.

per gram of protein metabolized. In digestion experiment No. 95 the value for the "heat of combustion of urine" is computed from the available protein (946 grams), allowing 1.32 calories of energy from each gram of this protein as unavailable for use in the body owing to its excretion in the incompletely oxidized material of the urine. In experiment No. 96 the corresponding value is obtained by multiplying the available protein by 1.28, and in experiment No. 97 by multiplying the available protein by 1.23, these being the factors found by actual determinations of heat of combustion of the urine of each of the subjects.

TABLE 13.—*Details of digestion experiment No. 95, Miller.*

Laboratory No. of sample.	Food materials.	Weight of material.	Protein (N.×6.25)	Fat.	Carbohydrates.	Heat of combustion (determined).
		Grams.	*Grams.*	*Grams.*	*Grams.*	*Calories.*
3014	Vigoral	438	60	8	39	587
(*a*)	Beef extract	57	8	1	5	76
(*a*)	Eggs, raw	310	41	33	....	549
2999	Milk	11,795	363	447	554	8,504
3001	Koumiss	7,620	276	197	344	4,763
3002	Matzoon	476	15	15	13	272
(*a*)	Bread	35	3	....	19	98
2994	Oatmeal	784	16	4	81	474
2993	Rice	1,508	10	1	159	721
2992	Rice pudding	1,133	36	29	258	1,575
2991	Charlotte russe	553	27	121	140	1,787
2989	Sugar cake	57	4	7	31	215
	Wedding cake	85	5	9	55	338
2990	Custard pie	1,703	97	168	450	3,927
(*a*)	Tomato soup	113	2	1	6	49
(*a*)	Sugar	261	....	....	261	1,034
(*a*)	Apples	4,064	16	20	577	2,560
(*a*)	Grapes	865	11	14	166	848
(*a*)	Oranges	3,043	24	6	353	1,582
	Total	34,900	1,014	1,081	3,511	29,959
3010	Feces (water free)	....	68	68	48	1,278
	Urine	....	....	....	....	1,183
	Amount digested	....	946	1,013	3,463	27,498
	Coefficients of digestibility (per cent)	....	93.3	93.7	98.6	91.8

a Composition assumed from previous analysis of similar materials.

TABLE 14.—*Details of digestion experiment No. 96, Albert.*

Laboratory No. of sample.	Food materials.	Weight of material.	Protein (N.×6.25)	Fat.	Carbohydrates.	Heat of combustion (determined).
		Grams.	*Grams.*	*Grams.*	*Grams.*	*Calories.*
	Beefsteak	404	94	10	....	626
2983	.....do	135	39	17	....	372
3020	Beef juice	153	9	....	....	54
2996	Beef tea	440	11	7	....	117
3019	Beef-tea tablets	15	2	....	....	14
(*a*)	Lamb chops	163	35	49	....	663
2995	Mutton broth	815	9	27	....	294
(*a*)	Chicken	432	117	50	....	1,132
2982	Chicken broth	1,523	54	31	....	533
(*a*)	Eggs	1,120	150	118	....	1,982
3000	Butter	794	9	683	....	6,356
2998	Milk	1,519	43	59	63	1,042
3014	Vigoral	45	6	1	4	60
3016	Calf's-foot jelly	999	53	....	148	899

a Composition assumed from previous analysis of similar materials.

TABLE 14.—*Details of digestion experiment No. 96, Albert*—Continued.

Laboratory No. of sample.	Food materials.	Weight of material.	Protein (N.×6.25)	Fat.	Carbohydrates.	Heat of combustion (determined).
		Grams.	*Grams.*	*Grams.*	*Grams.*	*Calories.*
2976	Soup	191	3	3	9	78
2988	Oatmeal	1,573	25	10	134	788
2981	Rice	241	7	4	42	241
(*a*)	Crackers, graham	12	1	1	9	55
2985	Gems, graham	978	103	6	594	3,112
2985	Bread, graham	85	9	....	52	270
(*a*)	Soda crackers	56	5	5	41	251
2986	Biscuit	100	8	10	62	387
(*a*)	Bread	1,608	171	9	827	4,497
(*a*)	Doughnuts	49	3	10	26	224
2980	Tapioca pudding	312	16	16	25	348
(*a*)	Sugar	877	....	....	877	3,473
(*a*)	Celery	283	3	....	9	57
(*a*)	Tomatoes	249	3	....	10	62
(*a*)	Apples	1,730	7	9	246	1,090
(*a*)	Bananas	92	1	1	20	92
(*a*)	Grapes	570	7	9	109	559
(*a*)	Oranges	759	6	2	88	395
(*a*)	Pears	1,112	7	6	157	712
(*a*)	Prunes	865	6	3	174	843
(*a*)	Ginger ale	9,505	6	....	1,006	3,992
(*a*)	Licorice drops	18	....	....	17	68
(*a*)	Cocoa wine	524	....	....	188	749
(*a*)	Malted milk	315	46	27	221	1,355
	Total	30,661	1,074	1,183	5,158	37,842
3011	Feces (water free)	236	101	24	82	1,229
	Urine	....	....	....	....	1,343
	Amount digested	....	973	1,159	5,076	35,270
	Coefficients of digestibility (per cent)	....	90.6	98.0	98.4	93.2

a Composition assumed from previous analysis of similar materials.

TABLE 15.—*Details of digestion experiment No. 97, Pilkington.*

Laboratory No. of sample.	Food materials.	Weight of material.	Protein (N.×6.25)	Fat.	Carbohydrates.	Heat of combustion (determined).
		Grams.	*Grams.*	*Grams.*	*Grams.*	*Calories.*
3014	Vigoral	241	33	4	21	323
(*a*)	Eggs	125	17	13	....	221
(*a*)	Butter	28	....	24	....	222
2999	Milk	7,261	224	275	341	5,234
3001	Koumiss	7,930	287	205	358	4,856
(*a*)	Bread	307	29	4	166	896
2994	Oatmeal (boiled)	1,405	28	7	146	849
2993	Rice (boiled)	1,680	12	1	177	803
(*a*)	Sugar	254	....	....	254	1,006
(*a*)	Apples	169	1	1	24	106
(*a*)	Oranges	340	3	1	39	177
	Total	19,740	634	535	1,526	14,693
3012	Feces (water free)	179	40	68	17	981
	Urine	....	....	....	....	742
	Amount digested	....	594	467	1,509	12,970
	Coefficients of digestibility (per cent)	....	93.7	87.3	98.9	88.3

a Composition assumed from previous analysis of similar materials.

The results tabulated above show that the digestion was normal, at least as regards quantity; in other words, the proportions of nutrients digested and made available by these men with severe and almost continuous muscular exercise were not essentially different from those found with men under ordinary conditions.[1]

[1] Connecticut Storrs Sta. Rpt. 1899, p. 87.

METABOLISM OF NITROGEN.

Collection and analysis of urine.—The urine of each twenty-four hours was collected in glass jars, sealed, and carried to the laboratory, where it was measured and the specific gravity and nitrogen content determined. The volume was measured by use of an accurately graduated and calibrated glass cylinder of 2 liters capacity. The specific gravity was determined by a carefully calibrated spindle. The weight was calculated from the volume and specific gravity as thus found. The nitrogen was determined by the Kjeldahl method in weighed samples of about 5 grams each. The heat of combustion was determined by burning in oxygen on filter blocks in a bomb calorimeter, as elsewhere described.[1]

Tests for albumin and sugar in urine.—In addition to the quantitative determinations already mentioned, each day's urine of each subject was tested for albumin and sugar. No trace of either was found in any of the samples.

Nitrogen lag.—Since the men urinated only at long intervals, it is probable that in many cases a considerable quantity of the urine formed on one day may have been carried till the next, so that the excretion of any particular day may indicate very little as regards the actual metabolism of that day. The excretion for the six days, however, probably represents more accurately the nitrogen metabolism for that period. In the experiments of Dunlop, Paton, Stockman, and Maccadam, referred to above, the greater part of the extra excretion of nitrogen was found in two cases on the day following that on which the work was done, and in one case on the second day following. If there had been a similar lag in the excretion of nitrogen by the subjects studied in the bicycle race, the figures would show less than the total amount of body protein actually metabolized. Such a discrepancy is not improbable, but there are two reasons for thinking that it may not have been great. In the first place, it seems probable that the extra metabolism of body protein may very likely have taken place mainly in the earlier part of the race, when the amount of work was greatest. If this were true the excretion of this extra nitrogen would be practically complete before the end of the week. In the second place, as the severe muscular work continued for so long a period, there would probably be a tendency toward equilibrium of total nitrogen metabolism and total nitrogen excretion, in which event the nitrogen lag would continue for a shorter time after the end of the experiment, and might be largely covered by the last twelve hours of the race, in which the amount of work done by each of the subjects was comparatively small.

---

[1] U. S. Dept. Agr., Office of Experiment Stations Bul. 69, p. 23.

This view is strongly confirmed by the results obtained by Flint[1] and by Pavy[1] in studying the metabolism of Weston during the days of walking and the days which followed the walks. In the study made by Flint the ingestion of nitrogen was more than doubled in the days following the race while the excretion was not noticeably increased. Pavy found that on the days following the severe exercise there was a very marked diminution in the amount of nitrogen excreted while the amount ingested apparently was not greatly changed.

The following tables show the quantitative data determined regarding the urine of each of the subjects:

TABLE 16.—*Statistics of urine—Miller, December 5–10, inclusive.*

Date.	Volume.	Specific gravity.	Calculated weight.	Nitrogen.		Heat of combustion.	
				Per cent.	Total.	Per gram.	Total.
1898.	*C. c.*		*Grams.*		*Grams.*	*Calories.*	*Calories.*
December 5	1,845	1.028	1,897	1.85	35.1	0.143	271
6	2,520	1.027	2,588	1.65	42.7	.148	383
7	2,375	1.029	2,444	1.89	46.2	.148	362
8	2,080	1.027	2,136	1.67	35.7	.138	295
9	1,605	1.028	1,650	1.86	30.7	.156	257
10	1,385	1.029	1,425	1.89	26.9	.152	217
Total	11,810	....	12,140	....	217.3	....	1,785
Average per day	1,968	....	2,023	....	36.2	....	298

TABLE 17.—*Statistics of urine—Albert, December 1–3. (Previous to the race.)*

Date.	Volume.	Specific gravity.	Calculated weight.	Nitrogen.		Heat of combustion.	
				Per cent.	Total.	Per gram.	Total.
1898.	*C. c.*		*Grams.*		*Grams.*	*Calories.*	*Calories.*
December 1	1,670	1.0275	1,716	1.43	24.5	....	....
2	960	1.026	985	1.43	14.1	....	....
Total	2,630	....	2,701	....	38.6	0.114	308
Average 1 day	1,315	....	1,351	....	19.3	....	154

TABLE 18.—*Statistics of urine—Albert, December 5–10, inclusive.*

Date.	Volume.	Specific gravity.	Calculated weight.	Nitrogen.		Heat of combustion.	
				Per cent.	Total.	Per gram.	Total.
1898.	*C. c.*		*Grams.*		*Grams.*	*Calories.*	*Calories.*
December 5	1,340	1.031	1,382	1.83	25.3	0.145	200
6	1,560	1.030	1,607	2.04	32.8	.159	256
7	1,680	1.031	1,732	2.25	39.0	.186	322
8	1,945	1.031	2,005	2.25	45.1	.133	267
9	910	1.030	937	2.14	20.0	.192	180
10	2,565	1.027	2,634	1.51	39.8	.125	329
Total	10,000	....	10,297	....	202.0	....	1,554
Average 1 day	1,667	....	1,716	....	33.7	....	259

[1] See p. 13.

TABLE 19.—*Statistics of urine—Pilkington, December 5-10, inclusive.*

Date.	Volume.	Specific gravity.	Calculated weight.	Nitrogen.		Heat of combustion.	
				Per cent.	Total.	Per gram.	Total.
1898.	*C. c.*		*Grams.*		*Grams.*	*Calories.*	*Calories.*
December 5	1,880	1.026	1,929	1.70	32.8	0.118	228
6	2,720	1.022	2,780	1.57	43.6	.116	322
7	2,220	1.029	2,264	1.78	40.3	.142	322
Total	6,820	....	6,973	....	116.7	....	872
Average 1 day	2,275	....	2,324	....	38.9	....	291

BALANCE OF INCOME AND OUTGO OF NITROGEN.

From the data already given regarding food, feces, and urine, the balance of income and outgo of nitrogen can be calculated. In the table which follows are given the average amounts of nitrogen per day in the food, feces, and urine of each of the subjects. The accuracy of each balance of income and outgo of nitrogen is proportional to that of the corresponding dietary study. As the bladder was not emptied regularly at midnight, it is believed that any attempt to state the balance by days would be misleading. The average amounts of nutrients consumed are also shown in the table:

TABLE 20.—*Nutrients and energy of food and nitrogen balance in the three experiments. Average per day.*

Subject.	Duration of experiment.	Income in food.				Nitrogen.			
		Protein, *a*	Fat.	Carbohydrates.	Fuel value.	In food.	In urine.	In feces.	Loss.
	Days.	*Grams.*	*Grams.*	*Grams.*	*Calories*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
Miller	6	169	181	585	4,770	*b* 29.4	36.2	1.8	8.6
Albert	6	179	198	559	6,095	*c* 29.1	33.7	2.5	7.1
Pilkington	3	211	178	509	4,610	*d* 36.0	38.9	2.2	5.1

a This does not include the nonproteid nitrogenous constituents of meat extracts and vigoral. See note on p. 30.

b This includes 2.3 grams of nonproteid nitrogen in meat extract and beef juice omitted in table of food consumed, p. 33.

c Includes 0.4 grams of nonproteid nitrogen in meat extract and beef juice omitted in table of food consumed, p. 36.

d Includes 2.3 grams of nonproteid nitrogen in meat extract and beef juice omitted in table of food consumed, p. 39.

It will be noted that notwithstanding the large amounts of protein and energy in the dietaries each of the subjects lost a considerable amount of nitrogen during the period of the race. In addition to the large amount of protein in his food, averaging 211 grams, the rider who continued in the race three days (Pilkington) metabolized about 33 grams of body protein, equivalent to about 4¾ ounces of lean flesh per day. That is to say, the total nitrogen excreted in urine and feces exceeded the total nitrogen of the food by 5.1 grams per day, which (multiplied by 6.25) corresponds to 33 grams of protein, which must have been supplied from the store in the body. The body protein was thus reduced by 33 grams per day. Assuming lean flesh to contain 25 per cent protein, this would correspond to 132 grams, or about 4¾ ounces per day.

The subjects who rode six days (Miller and Albert) had average daily incomes of 169 and 179 grams of protein, respectively. In addition to this Miller metabolized about 54 grams of body protein, equivalent to about 8 ounces of lean flesh, and Albert about 44 grams of body protein, equivalent to about 6¼ ounces of lean flesh per day. It will be remembered that Weston, when studied by Flint, lost an even greater amount of nitrogen per day (10 grams, equivalent to 62.5 grams of protein), while the same pedestrian, when studied by Pavy a few years later under similar conditions as regards exertion, consumed much larger amounts of proteid food, and thus apparently received more nitrogen than he excreted. The experiments upon Weston seemed to show that whenever he subjected himself to severe exertion he metabolized large amounts of protein, body protein being drawn upon in some cases while in others sufficient food was consumed to protect the tissues from such loss.

In the present experiments none of the three subjects consumed sufficient food to avoid this loss of body protein, although all were supplied with as much food as they wished, and could have had any desired quantity of readily available protein. Why the body should use its own substance under such circumstances is a question which at present can not be satisfactorily answered. The fact that such was the case, each of the contestants who finished the race consuming during the period body protein equivalent to 2 or 3 pounds of lean flesh, and that no injury resulted therefrom, would seem to indicate that these men had stores of protein which could be metabolized to aid in meeting the demands put upon the body by the severe exertion, without robbing any of the working parts, and at the same time relieving the system of a part of the labor of digestion. Possibly the ability to carry such a store of available protein is one of the factors which make for physical endurance.

There is, however, one source of outgo of nitrogen which has not been taken into account in these experiments, and which may be of considerable importance, namely, the elimination of nitrogen in the form of urea in the perspiration. The quantity of nitrogen which may thus be eliminated may be considerable. Schaefer[1] cites various determinations of the quantity of urea and nitrogen excreted in the perspiration. Thus Favre found 0.044 gram urea per 1,000 cubic centimeters of perspiration, and Funke 1.55 grams urea in 1,000 cubic centimeters of perspiration. Argutinsky found 0.363 and 0.410 gram of urea in 225 and 330 cubic centimeters of perspiration, respectively. The same

[1] Text-book of Physiology, Vol. I, pp. 671–673.

investigator also found 0.7 gram of nitrogen by extracting with distilled water the clothes worn by subjects actively walking or climbing during a considerable portion of the day. In experiments with the respiration calorimeter[1] the amount of nitrogen found in the clothes by extraction with distilled water varied from 0.2 to 0.4 gram per day. C. C. Easterbrook[2] found in some experiments carried on upon himself that the perspiration contained from 0.1 to 0.3 per cent urea.

A still more pronounced elimination of nitrogen in the perspiration was found by Eijkmann[3] in experiments carried on in the tropics upon some Malay medical students. Three experiments were made. The first lasted 12 hours, during which 0.222 gram of nitrogen was excreted. The second experiment continued 24 hours, during which time there was found in the perspiration 0.761 gram of nitrogen. The third experiment likewise continued 24 hours, and there was an elimination of nitrogen in the perspiration amounting to 1.362 grams. The subjects were engaged in light occupation.

It is possible, therefore, that the loss of body nitrogen may have been appreciably greater than we have calculated—perhaps one-fifth greater.

METABOLISM OF ENERGY.

Total energy metabolized.—The total income of energy in the food and the outgo in urine and feces in the different experiments has already been shown in Tables 13–15. The difference between the income and outgo has been called the available energy of the food. The energy of the material actually oxidized in the body may be greater or less than the available energy of income according as the subject is losing or storing body protein and fat.

The nitrogen lost by the subjects during the time of the investigation is taken as a measure of body protein metabolized in excess of the protein in the food consumed. The energy which the body obtained from this protein may be calculated and the estimate for the energy of the food increased by a corresponding amount.

As regards the energy obtained by the body in these experiments from the combustion of its nonnitrogenous constituents—fat and perhaps carbohydrates—we have no positive knowledge. It might be supposed that changes in the weight of the body would be due to gain or loss of lean flesh or of fat. If this were the case the amount of fat gained or lost would be indicated by the change in weight after making allowance for the change in lean flesh, corresponding to the gain or loss of nitrogen. The changes in weight of the men studied were

[1] U. S. Dept. Agr., Office of Experiment Stations Bul. 69, and unpublished material.

[2] Scottish Med. and Surg. Jour., 6 (1900), p. 120.

[3] Arch. Path. Anat. u. Physiol. [Virchow], 131 (1893), p. 170. Also abstracted in U. S. Dept. Agr., Office of Experiment Stations Bul. 45.

approximately determined by weighing the men daily (usually in riding costume) as nearly at midnight as possible. Making the calculation just indicated and computing the liberation or storage of energy which would correspond to the apparent loss or gain of fat we reach impossible results, the indicated metabolism of energy sometimes being a negative quantity and at other times exceeding 25,000 calories in a day. In view of this and of the well-known fact that the water content of the body, as well as that of the clothing, is subject to considerable variations, we are forced to regard the fluctuations of body weight as being chiefly due to gain or loss of water. That the riders may have lost some fat during the race is certainly not improbable; but as we have no means of determining its amount we are forced to neglect this source of energy in computing the amount metabolized. Assuming that all the available energy of the food was metabolized and adding to this energy the estimated heat of combustion of the protein contributed by the body, we obtain the results given in the following table:

TABLE 21.—*Computation of energy of material metabolized exclusive of body fat lost.*

Subject.	Duration of experiment.	Total energy metabolized.	Average per day.
	Days.	*Calories.*	*Calories.*
Miller	6	28,917	4,820
Albert	6	36,441	6,074
Pilkington	3	13,391	4,464

The figures in Table 21 thus show the actual energy metabolized according to the data obtained for the total energy of income and outgo as determined by the heats of combustion of foods, feces, and urine and the estimated energy from the body protein used.

It is much to be regretted that the data do not show how much of other body material than protein was lost during the experiment. Of course the only way to determine this loss would be by a respiration apparatus. The ideal experiment would be made in a respiration calorimeter with a bicycle ergometer to show the balance of income and outgo of energy as well as material. Such experiments are being made with the respiration calorimeter at Wesleyan University, although not with athletes capable of such exertion as the leading contestants in the race here referred to.

SUMMARY.

The bicycle race at the Madison Square Garden in 1898 covered 142 consecutive hours, from 12.08 a. m. on Monday, December 5, to 10.08 p. m. Saturday, December 10. During this time the chief contestants took only such rest or sleep as was absolutely necessary, working on an average of about five-sixths of the whole day, and sleeping very little. Of the three contestants in the race who served as subjects for the investigation reported in this bulletin, two were experienced and held out to the end, while the third withdrew on the fourth day of the race. During the first 72 hours of the race he had ridden 863 miles.

The subjects who continued in the race until its close won first and fourth places, respectively. The winner, C. W. Miller, was, as previously stated, rather short but very muscular. During the first five days of the race he rode about 21 hours and slept about 1 hour each day. On the last day he rested and slept more, but even when this day is included he worked, on an average, 20 hours out of the 24, and of the 4 hours of rest only about 1 hour and 20 minutes was spent in sleep. His tremendous endurance is shown, not only by his riding 2,007 miles during the week, but perhaps even more strikingly by the fact that the fatigue and strain produced no sign of either physical or mental weakness.

The second subject, Frank Albert, was older than Miller, 2 or 3 inches taller, and weighed several pounds less. His labor was not quite so intense and severe, since he rode about 185 miles per day less and did not have such close rivals for his position in the latter part of the race as did Miller. Nevertheless, the feat of riding 109 of 142 consecutive hours and covering 1,822 miles within this period is sufficiently remarkable. His condition at the end of the race was apparently as good as at the end of the first day.

The kind of food consumed by Miller was determined by his trainer, and for the most part was carefully planned in advance of the race in accordance with experience gained in similar contests, and consisted of simple foods, most of them liquid or semiliquid. No water was drunk during the contest. No alcoholic beverage, except in so far as the very small quantities of alcohol in koumiss might entitle it the appellation, was used. Considerable quantities of coffee were also consumed after the first day, but no other stimulant or beverage.

Albert's food was much more varied than Miller's and not so strictly governed by his trainer.

The foods eaten by Pilkington on the three days during which he remained in the race were similar to those which Miller consumed on the same days. The amount of each food used by each rider was determined by weighing, and, unless its composition was already fairly well known, each food was sampled and analyzed. Thus the actual nutrients consumed by each subject were determined.

The urines and feces were collected and their amounts and compositions determined. Thus the availability of the nutrients of the food and the outgo of nitrogen from the body were found. By comparing the amount of nitrogen thus eliminated with the amount ingested in the food, the gain or loss of nitrogen is found.

Some of the more important of the quantitative data of the experiments are summarized in the following tables:

TABLE 22.—*Summary of average time spent on the wheel and distance covered per day.*

Rider.	Duration in days.	Working time per day.			Distance covered per day.		
		Maximum.	Minimum.	Average.	Maximum.	Minimum.	Average.
		h. m.	*h. m.*	*h. m.*	*Miles.*	*Miles.*	*Miles.*
Miller	6	23 10	14 14	20 1	441.8	*a*220.5	334.6
Albert	6	22 40	12 23	18 27	402.0	*a*181.9	303.8
Pilkington	3	....	....	....	....	....	287.7

a Saturday, see p. 26.

TABLE 23.—*Summary of average daily income and outgo of nitrogen and loss of body protein.*

Rider.	Nitrogen.				Equivalent loss of body protein.
	In food.	In feces.	In urine.	Loss.	
	Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*
Miller	*a*29.4	1.8	36.2	8.6	53.8
Albert	*b*29.1	2.5	33.7	7.1	44.4
Pilkington	*c*36.0	2.2	38.9	5.1	31.9

a This includes 2.3 grams of nonproteid nitrogen in meat extract and beef juice omitted in table of food consumed.

b Includes 0.4 gram of nonproteid nitrogen in meat extract and beef juice omitted in table of food consumed.

c Includes 2.3 grams of nonproteid nitrogen in meat extract and beef juice omitted in table of food consumed.

TABLE 24.—*Summary of average daily amounts of protein and energy in the food eaten available for use and actually metabolized.*

Rider.	Protein.			Energy.		
	In total food.	In available food.	Metabolized.	In total food.	In available food.	Metabolized. *a*
	Grams.	*Grams.*	*Grams.*	*Calories.*	*Calories.*	*Calories.*
Miller	169	158	223	4,957	4,547	4,789
Albert	179	163	223	6,300	5,871	6,066
Pilkington	211	197	243	4,898	4,323	4,464

a Exclusive of that derived from body fat.

These tables, which summarize only the more important data reported and discussed in the different sections of this bulletin above, show some facts which seem to us of considerable interest. Among these are (1) the long duration of the periods of work—often 22 to 24 hours per day and averaging 18½ to 20 hours; (2) the great amount of work performed, averaging a ride of over 300 miles per day; (3) the fuel values of the dietaries which, although high (about 50 per cent above the average found for American farmers and mechanics), are not greater than have been found in a number of dietaries of men doing only a small fraction of the amount of work; (4) the proportion of protein in the dietaries, which is rather high in each case, averaging 169 to 211 grams per day, or nearly twice as much as is ordinarily found in the dietaries of farmers or mechanics; and (5) the fact that the subjects, although ingesting such large amounts of protein, drew upon that stored in the body to such an extent as to lose considerable quantities of nitrogen, the amounts thus lost averaging, respectively, 8.6, 7.1, and 5.1 grams per day exclusive of the nitrogen eliminated in the perspiration.

The only previous studies which we have found in which the work was similar are those conducted by different investigators upon the professional pedestrian Weston. Taking Miller as being in some respects the most satisfactory and typical of the subjects studied by us, and the one regarding whom our data are the most nearly accurate, a comparison with Weston may be of interest.

So far as we can judge from the data available, Miller, while under our observation, worked a greater proportion of the time and exhibited a greater amount of mechanical power than did Weston in any of the periods during which his metabolism was observed. His diet furnished considerably more protein and much more energy than did Weston's in 1870, but in 1876, when Weston took sufficient food to keep his body from losing nitrogen, his dietary was considerably larger than Miller's, both as regards protein and energy. The total nitrogen metabolized by Miller was not greatly different from what was found for Weston during his three walks in 1884. In 1870 Weston metabolized considerably less nitrogen.

The nutritive ratio in Weston's dietaries was quite narrow, 1:4.2 to 1:5.7. In Miller's dietary the ratio is narrow for the earlier and wide for the later days of the race and for the whole period is 1:5.9, or somewhat narrower than the averages found in American families and near the average found for boat crews. Albert's dietary shows a ratio of 1:7.3, which is very close to that of the average of American dietary studies. As explained above (p. 43), the nutritive ratio may be greatly influenced by the use of certain foods which are selected because of their effects upon digestion rather than nutrition.

These experiments would seem to favor the following inferences: (1) That trained athletes undergoing unusually severe exertion demand a largely increased supply of easily digested food of such kinds as "agree" with the subject, and that the availability of such food is not greatly affected by the loss of sleep and almost continuous muscular exertion; (2) that under such circumstances the metabolism of nitrogen as well as that of energy is increased, body protein being drawn upon unless the food is very abundant; and (3) that trained athletes appear to be able to lose relatively large amounts of body nitrogen without any apparent ill effects.

It is conceivable that equally severe and prolonged exertion might perhaps be undergone without increased metabolism of nitrogen, provided the supply of fuel material was very abundant. This question, however, can be settled only by experiments in which the diet is under control.

MECHANICAL WORK AND EFFICIENCY OF BICYCLERS.

By R. C. Carpenter, M. M. E.,
Professor of Experimental Engineering, Cornell University, Ithaca, N. Y.

No dynamometrical measurement was made of the mechanical work performed by the various riders who were the subjects of the investigations recorded in this bulletin; consequently an exercise of judgment is required in order to determine the probable conditions which affected the resistances to be overcome.

The various external resistances can be discussed under two general heads: (1) That of the air, and (2) that of the wheel.

AIR RESISTANCE.

Resistance of flat surfaces.—Authorities are not entirely in harmony as to the resistance produced by a body moving through the air with a definite velocity. Smeaton,[1] in 1750, published a table showing the relation between wind pressures and velocities which had been obtained by experimenting. This table corresponded to the formula $p = 0.005\ av^2$, in which p equals the pressure produced per square foot, a the area exposed in square feet, and v the velocity in miles per hour. This formula was used extensively to aid in the design of large windmills, in the construction of which Smeaton was very expert. A. R. Wolff[2] deduces from theoretical considerations a table substantially like that given by Smeaton for a temperature of 45° F., but would indicate a pressure 10 per cent greater at 0° F. and 10 per cent less at 100° F. Allen Hazen[3] states that experiments with whirling arms, with plates exposed to direct wind and on locomotives, have shown that the formula $p = 0.0058\ av^2$ is correct up to a velocity of 40 miles per hour. Professor Kernot, of Melbourne, in some recent experiments obtains $p = 0.005\ av^2$, which agrees with Smeaton's formula. Various other authorities have given different values for the wind pressure, probably because of some condition not noticed or corrected which affected the

[1] Kent's Mechanical Engineer's Pocket Book, p. 492.
[2] The Windmill as a Prime Mover, p. 9.
[3] Engineering News, July 6, 1890.

results. Thus, Marton[1] gives $p = 0.004\ av^2$; Whipple and Dies, $p = 0.0029\ av^2$; and Crosby[2] $p = 0.\ fav$, in which f is a constant to be determined.

The weight of evidence would indicate that the wind pressure on plane bodies is very nearly equal to the amount represented by the formula, $p = 0.005\ av^2$.

The pressure on a rounded body is considerably less than on a flat body; thus the pressure on a cylinder or cone is equal to one-half that of its diametrical planes.

Air resistance of riders.—The air resistance which a rider must overcome depends upon his body exposure. The data given on pages 20 and 21 show that Miller was 5 feet 4 inches in height, and had a waist measure of 34 inches, while Albert was 5 feet 8½ inches in height with a waist measure of 30 inches. One of these men being somewhat the taller and the other somewhat the broader, it seems quite probable that the exposure of each was about the same. This exposure would depend to a considerable extent upon the position in which they rode, it being noticeably smaller in the scorching position than when riding bolt upright. These men are reported to have ridden in a semiupright position, as would probably be necessary because of the prolonged time of the race. The total exposure of a man of similar dimensions riding bolt upright has been found to be about 6½ square feet, in the semiupright position 6 square feet, and in a scorching position a little over 5 square feet. The resistance on account of the rounded nature of the body is considered by the best authorities about equal to one-half of that of a plane of equal dimensions. From the author's best calculations the exposed surface in the semiupright position would be equivalent to a plane of about 3 square feet.[3] At times it is doubtless equivalent to as much as 4 square feet, and during short intervals of scorching was doubtless much reduced. In some previous calculations the author concluded that a small man riding for a short distance could bend his body into such a form that the resistance due to the air would not exceed 1.5 square feet of plane surface.[4] In the following calculations it has been assumed that the exposure of the riders was equivalent to 3 square feet of plane surface.

The work done in overcoming the wind resistance is equal to the pressure multiplied by the distance passed through in a given time.

---

[1] Kent's Mechanical Engineer's Pocket Book, p. 492.

[2] Kent's Mechanical Engineer's Pocket Book, p. 493.

[3] According to unpublished results obtained by A. P. Bryant, at Middletown, Conn., the total exposure of a bicycle rider of about the build of Albert, when in different positions, as ascertained by measuring the shadow area, was as follows: When sitting bolt upright it was equal to 6.4 square feet; when sitting semiupright, 5.9 square feet, and in the "scorching" position, 5.2 square feet.

[4] See L. A. W. Bulletin, May, 1898, and Sibley Journal, Dec., 1899, p. 58.

Thus if the pressure is expressed by the formula $p = 0.005\ av^2$, the work done in foot pounds per minute, w, is expressed by the formula $w = 0.005\ av^2\ d$. From this latter formula the following table of air resistance is constructed, showing the total amount of work done

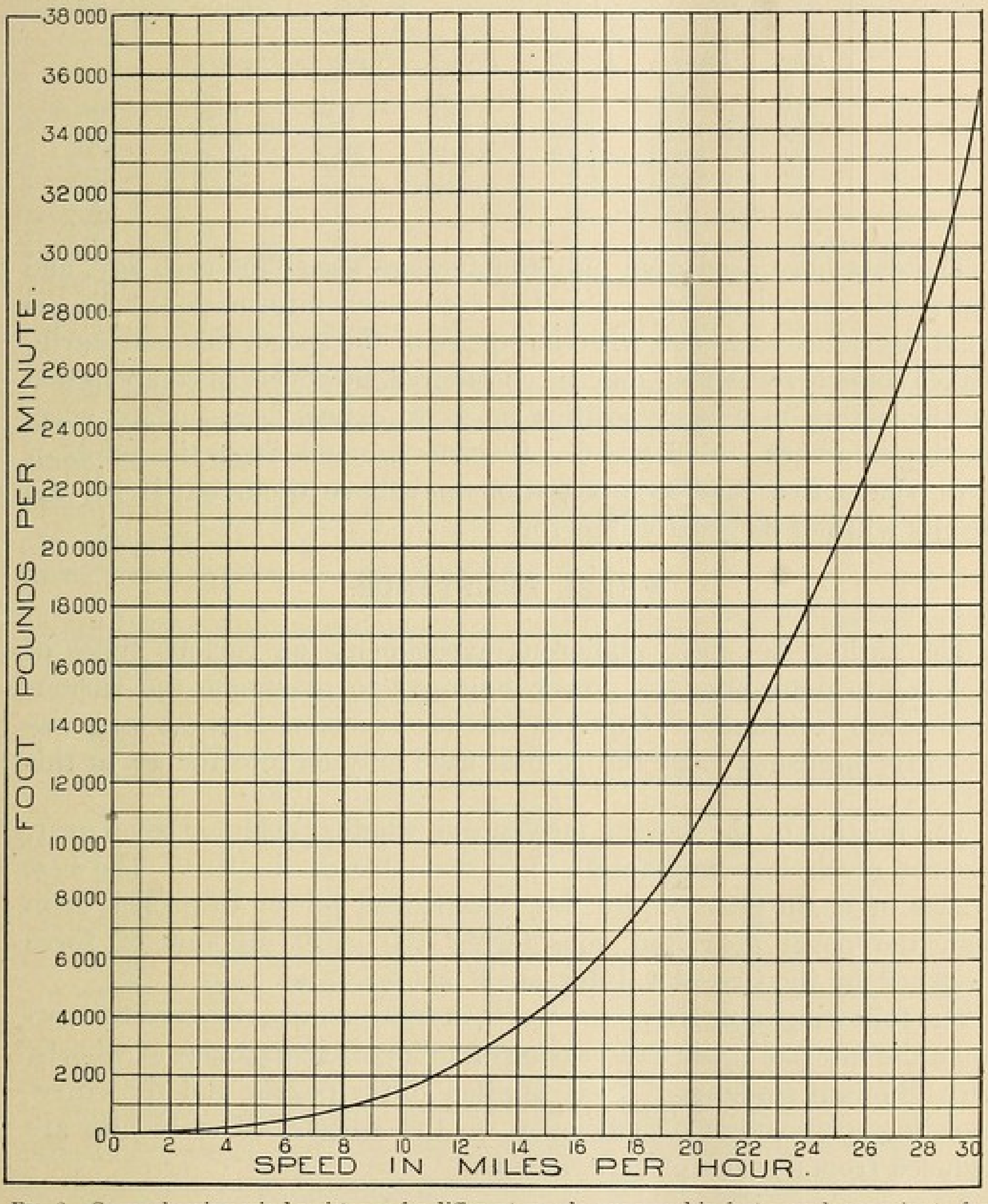

FIG. 2.—Curve showing wind resistance for different speeds, expressed in foot-pounds per minute, for 3 square feet of exposed plane surface.

per minute with an equivalent exposure of 3 and of 4 square feet. The results expressed in the last two columns of this table are shown graphically in fig. 2. This diagram is more convenient for actual use than the values in the table, as the amounts of work done at rates intermediate between those given in the table are readily found.

TABLE 1.—*Total air resistance overcome by riders at different speeds.*

Speed per hour.	Wind pressure per square foot.	Wind pressure against riders.		Work done by riders per minute.	
		Exposure equivalent to 4 square feet.	Exposure equivalent to 3 square feet.	Exposure equivalent to 4 square feet.	Exposure equivalent to 3 square feet.
Miles.	*Pounds.*	*Pounds.*	*Pounds.*	*Ft. pounds.*	*Ft. pounds.*
5	0.125	0.5000	0.375	220	165
$7\frac{1}{2}$	.281	1.125	.843	743	562
10	.500	2.000	1.500	1,760	1,320
15	1.125	4.500	3.375	5,940	4,455
20	2.000	7.000	6.000	14,040	10,530
25	3.125	12.500	9.375	27,500	20,625
30	4.500	18.00	13.500	47,520	35,640

The data here used give only the average speed for each day, and the results are therefore computed from such information. As the wind resistance increases with the square of the speed, this necessarily makes some error, which may be considered, however, as compensated for by riding in a bent position so as to expose less surface when moving at a high rate of speed. It seems probable from the habits of most riders that such compensation may have occurred; if so, the results will not be greatly in error.

WHEEL RESISTANCE.

The author has made numerous experiments on various types of bicycles to determine the power required to overcome the various mechanical resistances. Quite an extended account of these tests was recently published[1] and the results need only be referred to in this article.

The friction of the driving mechanism, whether chain or bevel gear, absorbs much less mechanical force than that of the tire. The best grades of chain gear require less mechanical power to propel them than the bevel gear, but considering the great amount of force absorbed by the tire, this difference is not material.

The following table shows the work, in foot-pounds, required to overcome the internal (gear and bearing) friction of five grades of wheels, with different amounts of force applied to the pedals, and the corresponding percentage of efficiency of the wheels. The results are deduced from a series of experiments.

[1] Sibley Journal, Nov. and Dec., 1899, pp. 58, 94.

TABLE 2.—*Friction involved in the driving of various chain and chainless bicycles at a speed of 15 miles per hour.*

Total work per minute.	Mean pedal pressure. *a*	Chain gear A.		Chain gear B and best chainless.		Chain gear C.		Chainless gear No. 1.		Chainless gear No. 2.	
		Friction per minute.	Efficiency.	Friction per minute.	Efficiency.	Friction per minute.	Efficiency.	Friction per minute.	Efficiency.	Friction per minute.	Efficiency.
Ft. lbs.	*Ft. lbs.*	*Ft. lbs.*	*Per ct.*	*Ft. lbs.*	*Per ct.*	*Ft. lbs.*	*Per ct.*	*Ft. lbs.*	*Per ct.*	*Ft. lbs.*	*Per ct.*
2,500	10.2	50	98	150	94.0	250	90.0	208	91.6	783	67.5
5,000	20.4	57	98.8	241	95.8	332	94.3	288	94.25	813	83.8
7,500	30.6	64	99.2	271	96.4	414	94.5	367	95.1	842	88.8
10,000	40.8	71	99.3	331	96.7	496	95.1	469	95.3	893	91.0
12,500	51.0	78	99.4	392	96.9	578	95.4	549	96.6	923	92.6
15,000	61.2	86	99.4	453	97.0	660	95.6	640	95.7	965	93.6
17,500	71.4	93	99.5	514	97.1	742	95.7	723	95.85	997	94.4
20,000	81.6	100	99.5	575	97.2	825	95.8	812	95.94	1,037	94.8
25,000	102.2	107	99.6	636	97.3	907	96.2	875	96.5	1,040	95.9

a Mean pedal pressure for wheel with 6¾-inch crank and with 70⅝ gear.

The following table shows in a similar manner the amount of work lost because of the friction of the tire on a single wheel when working under conditions similar to those under which the data in the preceding table were obtained. In estimating the total resistance of the bicycle, the results in this table should be doubled and added to the internal resistances as given in the preceding table.

TABLE 3.—*Tire friction of rear wheel at a speed of 15 miles per hour, with different amounts of total work.*

Total work per minute.	Mean pedal pressure. *a*	Very thin racing tire.		Heavy racing tire.		Light road tire.		Ordinary road tire.	
		Friction per minute.	Efficiency.	Friction per minute.	Efficiency.	Friction per minute.	Efficiency.	Friction per minute.	Efficiency.
Ft. lbs.	*Ft. lbs.*	*Ft. lbs.*	*Per ct.*	*Ft. lbs.*	*Per ct.*	*Ft. lbs.*	*Per ct.*	*Ft. lbs.*	*Per ct.*
2,500	10.22	525	79.0	1,156	53.8	1,625	35.0	2,000	20.0
5,000	20.4	608	87.8	1,219	76.7	1,696	66.0	2,108	57.8
7,500	30.6	691	90.8	1,282	82.8	1,767	75.5	2,216	70.6
10,000	40.8	774	92.3	1,345	86.6	1,838	81.6	2,324	76.7
12,500	51.0	858	93.2	1,408	88.8	1,909	84.8	2,432	80.6
15,000	21.2	941	93.7	1,471	90.2	1,980	86.8	2,541	83.2
20,000	81.6	1,025	94.8	1,534	92.2	2,150	89.2	2,650	86.7
25,000	102.2	1,108	95.6	1,596	93.6	2,221	91.9	2,758	88.9

a Mean pedal pressure for wheel with crank 6¾ inches long and with 70⅝ gear.

The above results were obtained by deducting from the friction of the entire wheel, with tire, the friction of the same wheel without tire.

It is quite probable that the riders in the six-day races would select the best grades of bicycles and those which were propelled with the least expenditure of power. The author has found that riders are generally expert in selecting wheels which have the least friction. Hence it appears that it is fair to assume that the force required to propel the wheels would correspond to the lowest results in Table 3, and those next lowest in Table 2. This latter supposition is believed to be rather more probable, for the reason that the lowest results in Table 2 are to be considered as exceptional.

For the purpose of facilitating computations of results a diagram (fig. 3) has been prepared, on which is shown the resistance in foot-pounds per minute due to gearing and also to the best racing tire, corresponding to a total resistance which is given at the bottom of the diagram. This diagram is constructed for a speed of 15 miles per hour. For a speed greater than 15 miles the resistance is increased in each case by an amount which was determined by test and was equal to the amount given in the table multiplied by one-ninetieth of the increase in speed. Thus, if the amount in excess of 15 miles per hour be denoted by x, the increased resistance would be that given in the diagram times x, which is to be added to the value obtained from the diagram. Experiments made in Sibley College laboratory show that for a difference in weight of 15 pounds the total resistance does not increase more

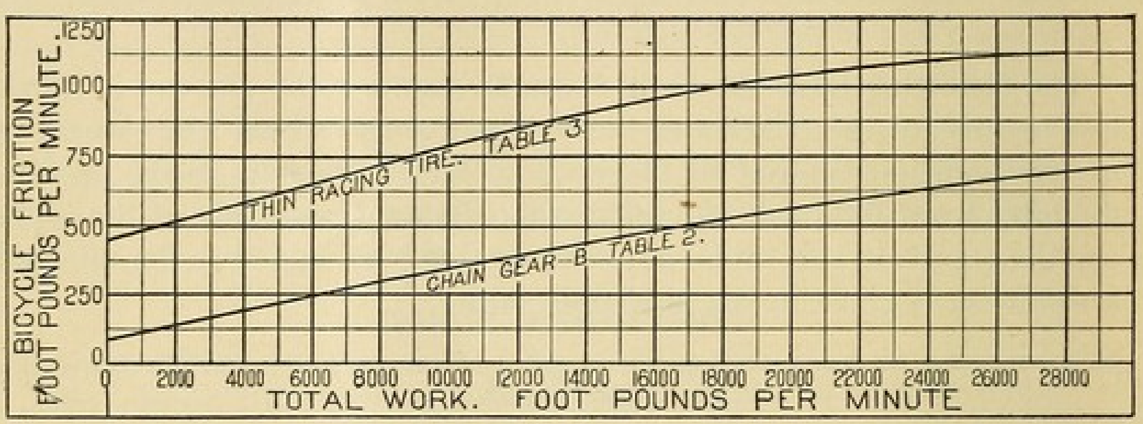

FIG. 3.—Curves showing bicycle resistance, speed 15 miles per hour.

than 2 per cent. As this correction is smaller than the probable error of computation, it has not been considered best to make use of it.

From data given earlier in this bulletin (pp. 23–27) we know the distance ridden each day and the time spent in riding, from which we may compute the average speed per hour. By use of figs. 1 and 2 the total resistance due to gear and tire friction and to wind pressure may be computed. These results are shown in Tables 4 and 5. The values in the fifth column for resistance due to wind pressure are taken directly from fig. 2 at the average speed per hour. Those in the fifth column, bicycle resistance, are found from fig. 3 in the following manner: The total resistance will be equal to the wind resistance plus the gear resistance and the tire resistance[1] of both wheels.

[1] In the computation for the total resistance of the bicycle the friction work of the gearing and the friction work of the two wheels have been added. In a previous calculation, to which reference has been made, the total wheel resistance was taken as that of the gearing plus that shown by the dynamometer for one wheel, it being at that time thought that the work of friction of the rear wheel when running on the dynamometer was nearly equal to that of two wheels on a level surface, for the reason

The total resistance in foot-pounds per minute multiplied by 60 gives the amount of work done each hour, and this latter quantity multiplied by the number of hours spent on the wheel gives the total amount of work done during the day. The heat equivalent of the work done is computed by dividing the total number of foot-pounds of work by the mechanical equivalent of 1 calorie—3,088 foot-pounds. From the data and computations given in Table 4 it would appear that the heat equivalent of the average amount of work done by Miller per day was 3,102 calories, while the total energy of the food was only 4,957 calories. Even allowing for a considerable consumption of body fat, the ratio of heat equivalent of work done to total energy of food and body tissue consumed must be extremely large. It will be noted that the "work done" is the extreme muscular work, i. e., the mechanical energy applied to the pedals of the wheels.

TABLE 4.—*Energy supplied and work done (a) by C. W. Miller.*

Date.	Distance covered each day.	Time spent on wheel each day.	Average speed per hour.	Resistance overcome per minute.			Total work done each day.	Heat equivalent of work done.	Total energy in food.
				Bicycle.	Wind.	Total.			
	Miles.	*Hours.*	*Miles.*	*Foot-pounds.*	*Foot-pounds.*	*Foot-pounds.*	*Foot-pounds.*	*Calories.*	*Calories.*
Dec. 5	441.8	23.16	19.07	1,927	9,000	10,927	15,184,159	4,917	5,900
6	366.7	21.16	17.32	1,692	6,750	8,442	10,717,963	3,471	4,108
7	334.1	20.18	16.55	1,590	5,850	7,440	9,008,352	2,917	6,577
8	316.5	19.72	16.05	1,542	5,325	6,867	8,125,034	2,631	2,890
9	327.8	19.62	16.71	1,587	6,000	7,587	8,931,416	2,892	4,238
10	220.5	14.23	15.46	1,508	4,950	6,458	5,513,840	1,786	6,788
Average 6 days	334.6	19.68	17.00	....	....	....	9,580,127	3,102	*b* 4,993
Average 5 days	357.4	20.77	17.20	....	....	....	10,393,385	3,366	....

a Exposure assumed to be equivalent to 3 square feet.

b The energy in the food for individual days is computed by use of factors as explained above (p. —). The average for the six days was determined by burning samples of the foods in the bomb calorimeter, and hence differs slightly from the computed average.

that the power was absorbed by a wheel of about the diameter of the bicycle wheel on which the rear wheel rested and which was put in motion by the rear wheel. Subsequent investigation seems to indicate that the track friction is practically independent of the size of the dynamometer wheel which absorbed the work, and consequently to obtain the full resistance of the bicycle it is necessary to add that caused by the gearing to twice that due to one wheel as shown by the dynamometer. This hypothesis may be slightly in error and may make the tire resistance greater than that actually overcome, but the correction is not relatively a large one, although sufficient to reduce the total resistance about 7 per cent and make a corresponding reduction in the efficiency of the rider.

TABLE 5.—*Energy supplied and work done (a) by Frank Albert.*

Date.	Distance covered each day.	Time spent on wheel each day.	Average speed per hour.	Resistance overcome per minute.			Total work done each day.	Heat equivalent of work done.	Total energy in food.
				Bicycle.	Wind.	Total.			
	Miles.	*Hours.*	*Miles.*	*Foot-pounds.*	*Foot-pounds.*	*Foot-pounds.*	*Foot-pounds.*	*Calories.*	*Calories.*
Dec. 5	402.0	22.66	17.75	1,745	7,200	8,945	12,161,622	3,938	5,862
6	371.3	21.28	17.40	1,703	6,870	8,573	10,946,006	3,545	4,387
7	352.7	20.68	17.10	1,683	6,550	8,233	10,215,506	3,308	6,563
8	285.3	17.21	16.60	1,602	5,925	7,527	7,772,380	2,517	7,977
9	229.4	14.50	15.85	1,550	5,250	6,800	5,916,000	1,916	7,704
10	181.9	12.38	14.60	1,420	4,125	5,545	4,118,826	1,334	6,124
Average 6 days	303.8	18.11	16.80	....	....	....	8,521,723	2,760	*b* 6,307
Average 5 days	328.1	19.26	17.05	....	....	....	9,402,303	3,045	....

a Exposure assumed to be equivalent to 3 square feet.

b The energy in the food for individual days is computed by use of factors as explained above. The average for the six days was determined by burning samples of the foods in the bomb calorimeter, and hence differs slightly from the computed average.

The figures in the last column of Tables 4 and 5 show the total energy in the food. The values for the individual days are computed by use of factors for heats of combustion of the different nutrients in mixed diet which were proposed by Atwater and Bryant,[1] which allow 5.65 calories of energy for every gram of protein in the food, 9.4 calories for every gram of fat, and 4.1 calories for every gram of carbohydrates. The average energy in the food for the six days was found by actual determination of the heat of combustion of the foods consumed, but the computations were not made for individual days. The average for the six days of the study is therefore that actually determined, while the amounts for the individual days are computed approximately by use of the factors. By reference to Table 4 it will be observed that the total work done by Miller is computed to have been over 15,000,000 foot-pounds, or 7,500 foot-tons, on the first day, and 5,500,000 foot-pounds, or 2,750 foot-tons, on the last day of the race. The corresponding heat equivalent of the work done is computed by dividing the total number of foot-pounds of work by the mechanical equivalent of one calorie, i. e., 3,088 foot-pounds, and ranges from 4,917 calories on the first day of the race to 1,786 calories on the last day. The average heat equivalent of the work done in the six days amounted to 3,102 calories. At the same time, the food consumed furnished 4,957 calories, making an apparent efficiency of over 60 per cent. It is probable, however, that there was a greater or less consumption of body fat during the experiment, the energy of which should be added to that of the food consumed in estimating the total income, thus diminishing the apparent efficiency. How much this loss of body fat amounted to can not be estimated for the reasons already pointed out (see p. 52). If we assume that the equivalent exposure of the bicycle rider was 4 square feet, computations similar to those recorded in

[1] Connecticut Storrs Sta. Rpt. 1899, p. 73. These factors differ from those more recently determined. See p. 39.

Table 4 serve to show that the total work done each day ranged from nearly 20,000,000 to nearly 7,000,000 foot-pounds, and the corresponding heat equivalent from 6,381 to 2,256 calories, averaging 3,994 calories.

The amount of work done by Albert was slightly less than that by Miller, ranging from 12,000,000 to 4,000,000 foot-pounds per day with a corresponding range in heat equivalent from 3,938 to 1,334 calories. The average heat equivalent of the work done per day during the six days is 2,760 calories, and the average energy in the food as found by actual determination of the heat of combustion is 6,307 calories, making an apparent efficiency of nearly 45 per cent. The same uncertainty as to the amount of body fat consumed exists in this as in the previous case, so that we can reach only a very approximate value for the efficiency of the rider. If the equivalent exposure of the rider is assumed as equal to 4 square feet, the total amount of work done each day varied from nearly 16,000,000 to a little over 5,000,000 foot-pounds, with a corresponding range in heat equivalent from 5,088 to 1,686 calories, with an average for the six days of 3,547 calories.

Regarding the probable error of the computations given in Tables 4 and 5 the author is prepared to say but little. The factors determining the wind pressure upon subjects are not definitely known, and the pressure may have been greater or less than that assumed. When one rider followed another it would be less. On the other hand, it is extremely probable that the recorded distance traveled is less than the actual distance, since the riders, much of the time, especially when riding in bunches, were a greater or less distance outside of the "pole" or line which was taken for the measurement of the track. Furthermore, the calculations make no account of increase of work that must have occurred in ascending the slight grade at each end of the course which would be brought about by the travel of the rider on a track some distance from the pole. These conditions should not change the efficiency more than 10 per cent. One thing seems certain; the amount of work performed each day by the riders was very large indeed, and the efficiency appears to have been noticeably greater than that obtained by the best steam or oil engines. The best record of any heat engine is probably that of the Deisal motor. This has produced, in a test by James Denton, 1 horsepower on the brake for a consumption of 0.54 pound of kerosene oil. This would be equivalent to 8,300 heat units per horsepower, the oil being valued at 18,604 heat units per pound; in this case we should have an efficiency of transformation equal to about 33.7 per cent. The best record of a steam engine is the Nordberg pumping engine at Pittsburg, which shows an efficiency per indicated horsepower, on the basis of total heat supplied, of 22.7 per cent. Per delivered horsepower this amount would probably be 10 per cent less.

With the exception of the Deisal motor the best record of any oil engine per delivered horsepower is about 16.5 per cent efficiency.

From this comparison it would seem that the human machine is decidedly superior to any heat engine which has been developed in form so as to be of any value for practical use.

CONCLUSIONS AND REMARKS.

The calculations would indicate that both Miller and Albert possessed great physical strength and endurance and that Miller must have been a remarkable physical giant. His results seem unprecedented, especially when expressed numerically. Dr. R. H. Thurston[1] states that the average work of a man is to be considered as about 2,000,000 foot-pounds per day, rising occasionally to an amount 50 per cent greater. Considering 2,000,000 foot-pounds per day as the work of an average man, it will be noted that the energy exerted by Miller during five days of the race was more than five times greater than this amount, and that exerted by Albert was nearly as much. It is quite possible that the calculated results make the energy expended greater than it should be, although a reexamination of the calculations fails to show any reason for reducing the results. It is possible that the wind exposure may have been less than assumed, although it is not believed that the equivalent plane surface could have been less than 2.6 square feet. Had the exposure been as small as this, which is hardly probable, the resistance due to the wind would have been reduced slightly over 13 per cent. The wheel resistance, as previously remarked, may be slightly high. The total of these corrections would reduce the energy expended by about 11 per cent. It is believed, however, that the results given are the most probable.

As before stated, the only accurate measurement of the energy developed by the bicycle riders would be that obtained with a dynamometer applied to the pedal of the bicycle, and at the present time such data are not available.

Most of the data which are published pertaining to the work accomplished by a man relate to the energy which can be applied day after day under usual working conditions and is much less than might be applied when a man was exerting himself to the utmost. Under the conditions of the race the amount of energy exerted can be considered about the limit of human strength and endurance. This is reasonably many times greater than would be exerted by the ordinary laborer working under the routine of his usual occupation.

Believing that additional data regarding the average energy equivalent to the day's work of a man would be interesting, the statement of

[1] The Animal as a Prime Mover, Smithsonian Report for 1896.

a few authorities relating to this subject is presented in the following table:

TABLE 6.—*Power of men.*

Kind of work.	Foot-pounds per minute for short periods.	Foot-pounds per day (average).	Authority.
Bicycle riding, 10 seconds	19,000	....	J. B. Denton *a*.
Bicycle riding, 15 seconds	9,080	....	Do.
Bicycle riding, 96 seconds	8,750	....	Do.
Bicycle riding, 1 hour	6,000	....	R. C. Carpenter *b*.
Walking backward and forward on a tilting lever	6,640	3,984,000	Trautwein *c*.
Soldier carrying knapsack (Ruhlman)	5,000	3,000,000	Thurston *d*.
Men raising beetle	4,080	1,224,000	Trautwein *c*.
Climbing stairs for 8 hours	4,032	1,935,360	Weisbach *d*.
Man walking for 10 hours	3,987	2,394,000	Do.
Man lifting heavy hammer 5 hours	3,808	1,142,400	Do.
Pushing on lever in circular path	3,667	2,200,000	Trautwein *c*.
Working on treadmill 7 hours	3,360	1,480,000	Do.
Average work of man	3,330	2,000,000	Thurston *e*.
Raising water with pump	2,400	1,000,000	Trautwein *c*.

a Iron Age, Oct., 1897, p. 14.
b Sibley Journal, 1899, p. 59.
c Trautwein's Engineer's Pocketbook, p. 607.
d Mechanics of Engineering, 2 (1877), p. 74.
e The Animal as a Prime Mover, Smithsonian Report, 1896.

It is quite generally believed that the amount of energy expended by a laborer is nearly inversely proportional to the length of the working-day, taken, of course, with certain limitations. This would indicate that the amount of energy expended during a day of twenty-four hours might be uniform, which is, of course, scarcely ever true.

O

LIST OF PUBLICATIONS OF THE OFFICE OF EXPERIMENT STATIONS ON THE FOOD AND NUTRITION OF MAN—Continued.

Bul. 67. Studies on Bread and Bread Making. By Harry Snyder and L. A. Voorhees. Pp. 51. Price, 10 cents.
Bul. 68. A Description of Some Chinese Vegetable Food Materials and Their Nutritive and Economic Value. By W. C. Blasdale. Pp. 48. Price, 10 cents.
Bul. 69. Experiments on the Metabolism of Matter and Energy in the Human Body. By W. O. Atwater and F. G. Benedict, with the cooperation of A. W. Smith and A. P. Bryant. Pp. 112. Price, 10 cents.
Bul. 71. Dietary Studies of Negroes in Eastern Virginia in 1897 and 1898. By H. B. Frissell and Isabel Bevier. Pp. 45. Price, 5 cents.
Bul. 75. Dietary Studies of University Boat Crews. By W. O. Atwater and A. P. Bryant. Pp. 72. Price, 5 cents.
Bul. 84. Nutrition Investigations at the California Agricultural Experiment Station, 1896–1898. By M. E. Jaffa. Pp. 39. Price, 5 cents.
Bul. 85. A Report of Investigations on the Digestibility and Nutritive Value of Bread. By Chas. D. Woods and L. H. Merrill. Pp. 51. Price, 5 cents.
Bul. 89. Experiments on the Effect of Muscular Work upon the Digestibility of Food and the Metabolism of Nitrogen. Conducted at the University of Tennessee, 1897–1899. By C. E. Wait. Pp. 77. Price, 5 cents.
Bul. 91. Nutrition Investigations at the University of Illinois, North Dakota Agricultural College, and Lake Erie College, Ohio, 1896–1900. By H. S. Grindley and J. L. Sammis, E. F. Ladd, and Isabel Bevier and Elizabeth C. Sprague. Pp. 42. Price, 5 cents.

FARMERS' BULLETINS.

Bul. 23. Foods: Nutritive Value and Cost. By W. O. Atwater. Pp. 32.
Bul. 34. Meats: Composition and Cooking. By C. D. Woods. Pp. 29.
Bul. 74. Milk as Food. Pp. 39.
Bul. 85. Fish as Food. By C. F. Langworthy. Pp. 30.
Bul. 93. Sugar as Food. By Mary H. Abel. Pp. 27.
Bul. 112. Bread and the Principles of Bread Making. By Helen W. Atwater. Pp. 38.
Bul. 121. Beans, Peas, and other Legumes as Food. By Mary H. Abel. Pp. 32.
Bul. 128. Eggs and Their Uses as Food. By C. F. Langworthy. Pp. 32.

CIRCULAR.

Cir. 46. Foods for Man. By C. F. Langworthy. Pp. 10.

SEPARATES.

Food and Diet. By W. O. Atwater. Reprinted from Yearbook of Department of Agriculture for 1894. Pp. 44.
Some Results of Dietary Studies in the United States. By A. P. Bryant. Reprinted from Yearbook of Department of Agriculture for 1898. Pp. 14.
Development of the Nutrition Investigations of the Department of Agriculture. By A. C. True and R. D. Milner. Reprinted from Yearbook of Department of Agriculture for 1899. Pp. 16.