Some Effects of High Air Temperatures and Muscular Exertion upon Colliers.

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(Plate 11.)

This paper deals with the work undertaken by the author while he was Tyndall Research Student of the Royal Society. The investigations fall under the following four distinct headings :—

1. The Food Consumption of Colliers and its relation to Underground temperature conditions.
2. Respiratory Exchange of a Collier during work.
3. Relation of High Temperatures and Work to Sweating.
4. Miners' Cramp.

Each branch of investigation is related to underground temperature conditions, and has in consequence a bearing upon each of the other sections.

Part I.—Food Consumption.

In order to obtain data as to food consumption a form [of which a copy with instructions attached accompanied the manuscript of this paper] was sent, together with a "trade" spring-balance weighing by quarter-ounces to four pounds, and a Fahrenheit thermometer, to seventy colliers working at the coal face in different parts of the country. Sixty forms were filled up in such a manner as to justify their inclusion in the records of this investigation. A surprising amount of trouble and care was taken in the filling up of these forms. The men selected had in every case a reputation for steadiness and good work, and wherever possible were also attending evening classes. The actual duration of the work at the face would be about $5\frac{1}{2}$ hours daily.

The total number of forms will appear few in comparison with the colliers available in the respective districts, but it is to be doubted whether any material difference would have resulted by obtaining many more. It is extremely difficult to induce even the best men to undertake the required task for seven to ten days. In fact, many more refused than accepted ; and often, when it was possible to find a man willing to fill up the form, his intelligence was not such that he could be trusted to obtain and record accurate information.

The calorie values of most foods, cooked and uncooked, were taken direct from the figures given by Graham Lusk in his book 'The Science of Nutrition' (1920), and a few were taken from 'Analysis and Energy Values of Foods' by Dr. R. H. A. Plimmer. It was necessary, however, to calculate the calorie value of a number of standard articles of dietary after first ascertaining the loss or gain in weight due to cooking. In this work the author was assisted by his wife.

Before giving a tabulated statement of the results obtained, it will be of interest to quote the following calorie values of food eaten by various manual workers, as estimated by Atwater from the general results of his well-known investigations :—

	Cals./day.
Men at moderate work consumed	3500
,, hard ,,	4500
,, severe ,,	5700

The following instances show, however, that sometimes the food consumption was still greater :—

	Cals./day.
Blacksmiths at hard work actually consumed	6905
Teamsters, etc., at severe work	7805
Brickmakers ,,	8805

Table I shows the average results obtained and the relationship which was found between the colliers' consumption of food and drink in relation to temperature. The forms were collected over a period of 24 months—March, 1920–1922—during which time changes in the wage rates took place. It is unlikely, however, that this could affect the results, because during periods of low wages the ration of the breadwinner must be maintained to enable him to carry out his daily work in the mine.

It appears from the figures shown that the workers in hot mines consumed more food than those working in cool places. The average daily calorie consumptions of the colliers working at the warmest colliery are shown in Table I to be 5925; but two of the forms returned gave very abnormal calorie values. Had they been excluded, the average for the colliery would have worked out at 4942 calories per man per day. Column 9 gives the calorie

Table I.

District.	1	2	3	4	5	6	7	8	9	10	11	12							
	No. of Forms Returned.	Average Period covered by each form in days.	Average Underground Temperature in ° F.	Month of Year in which forms were filled up.	Average Height of the Men in cm.	Average Weight of the Men in kg.	Average Body Surface Area in square metres.	Average Calorie Value of Food eaten per man/day.	Calories per square metre body surface.	Wages Standard on the basis of the highest.	Average Total Liquid drunk per day in pints.	Percentage Calorie Value of Principal Foods to Total Calorie Value of Food eaten per day.							
												Bread.	Butter, Margarine, Dripping.	Butcher's Meat.	Ham and Bacon.	Potatoes.	Pudding.	Cake.	Cheese.
Pendleton ..	6	10	99	May	172	62.7	1.75	5925	3386	82	11.9	32.6	15.5	13.8	9.6	5.5	1.4	0.8	3.1
Pendlebury ..	6	10	88	July	168	60.4	1.68	5114	3044	82	9.2	32.1	11.4	14.1	16.3	6.6	1.1	2.2	2.6
Hamstead ..	10	9.1	79	June–Sept.	170	70.0	1.81	4644	2566	80	8.5	31.9	7.8	15.8	18.6	7.2	1.0	1.3	5.7
Forest of Dean	12	7.2	68	Dec.–Jan.	169	63.1	1.72	4293	2494	55	3.6	33.4	11.1	11.9	6.6	9.3	5.6	4.5	4.3
Derbyshire ..	8	10	66	March	169	59.9	1.69	4211	2491	100	4.4	34.2	7.8	10.9	9.9	5.5	9.9	3.9	1.5
Yorkshire ..	8	7.6	59	Feb.–July.	169	65.0	1.75	4472	2555	90	4.6	37.5	15.0	7.3	4.0	5.4	8.7	3.5	0.4
South Wales	10	7.9	55	Dec.–Jan.	170	65.3	1.76	4320	2454	88	3.7	31.2	17.4	11.0	11.2	3.5	2.1	12.1	2.0
Mean figures for the whole							1.74	4711	2713	—	6.55	33.3	12.3	12.1	10.9	6.1	4.2	4.0	2.8

consumption for the respective districts worked out on the basis of calories per square metre body surface, as determined by Du Bois's formula. It will be noticed that the relative figures are not much altered on this basis of comparison. The percentage proportions on a calorie basis of the main foods eaten are interesting. The figures given in Columns 8, 9, 11 and 12 are the daily averages for the whole period covered by the forms and are, therefore, somewhat lower than the averages which would obtain had all the days covered by each form been work days. A collier at Pendleton, for example, drank 13·6 pints (17·0 lbs.) of liquid per working day, as against 11·9 pints (14·9 lbs.) shown in Table I.

Table II gives figures showing the amount of sodium chloride eaten by the colliers in the various districts, apart from what they deliberately added to their food. Although this table does not pretend to give the total salt consumed it gives the approximate total salt content of the principal foods constituting the dietaries. This has a significant bearing upon the work to be reported on later in connection with the regulation of body temperature. It will be seen that the workers in the hot mines consumed much more of salted food (ham and bacon).

Table II.—Sodium Chloride consumption per day.

Food.	Per cent. NaCl Content Hamill, Plimmer, and K.N.M.	Districts.													
		Pendleton.		Pendlebury.		Hamstead.		Forest of Dean.		Derbyshire.		Yorks.		S. Wales.	
		Wt. in gms.	NaCl in gms.	Wt. in gms.	NaCl in gms.	Wt. in gms.	NaCl in gms.	Wt. in gms.	NaCl in gms.	Wt. in gms.	NaCl in gms.	Wt. in gms.	NaCl in gms.	Wt. in gms.	NaCl in gms.
Bread	1.0	762	7.6	624	6.2	567	5.7	550	5.5	558	5.6	632	6.3	510	5.1
Butter and margarine..	1.25	130	1.6	77	0.9	51	0.6	62	0.8	41	0.5	85	1.0	99	1.2
Bacon and ham	5.0	85	4.2	116	5.8	119	5.9	37	1.8	57	2.8	28	1.4	77	3.8
Meat	0.1	221	0.2	241	0.2	224	0.2	164	0.2	173	0.2	107	0.1	136	0.1
Cheese	2.0	40	0.8	34	0.7	62	1.2	42	0.8	14	0.3	3	0.1	20	0.4
Cake and biscuits ..	0.6	17	0.1	40	0.2	23	0.1	62	0.4	57	0.4	51	0.3	173	1.0
Potatoes, cooked	0.6	317	1.9	380	2.3	340	2.2	420	2.5	224	1.3	244	1.5	162	0.9
Vegetables ..	0.6	79	0.5	82	0.5	57	0.4	99	0.6	40	0.2	31	0.2	45	0.3
Total salt in gms.			16.9		16.8		16.3		12.6		11.3		10.9		12.8

The main conclusions may be summed up as follows :—

1. The mean daily calorie consumption of the colliers was 4711. This is in accordance with what might be expected from the observations of Atwater and others on the food consumption of men engaged in hard muscular work.

2. The food consumption increased with increase of temperature underground. This is not the result which was expected, since a high air temperature and particularly a high wet-bulb temperature tends to diminish a man's capacity for hard work. The increased physiological work involved in the extra sweating at the higher temperature may possibly account for the extra metabolism, though this seems hardly probable.
3. The workers in the hot mines consumed a larger amount of salted foods than those working under lower temperature conditions. As will be shown later this is probably related to the loss of salt in sweating. The proportion of butcher's meat eaten was also greater in the hot mines.
4. The amount of liquid drunk increased rapidly with increase of the temperature above 70°. This is, of course, related to the amount of sweating.

Part 2.—Respiratory Exchange of a Collier during work.

The collier upon whom the following experiments were conducted is a man 5 feet 7 inches high, 148 lbs. in weight (stripped), with a food consumption which was found to be 6028 calories per day. His basal metabolism was calculated from Du Bois's formula to be 1·2 calories per minute. The quantity of air breathed during a whole shift was first of all determined by letting him inspire air through a meter. The method employed was as follows :—

To the man's mouth was attached a rubber mouthpiece fitted with face straps and nose clip as used in mine rescue apparatus. To the mouthpiece was attached a Rosling valve, and on the inspiratory and expiratory sides of it were attached 3-feet lengths of flexible rubber tubing. On the inspiratory side an air meter was connected by means of which the quantity of air breathed by the man could be read to within a ten-thousandth of a cubic foot. When a sample of expired air was required a Douglas bag of 100 litres capacity was attached to the end of the expiratory tube. When the bag was nearly full it was disconnected, and after well mixing the contents by pressing the sides of the bag in and out, the air was expelled through a gas sampling tube, so that a representative sample was secured.

The time and reading of the meter when changes in work took place (as, for example, the change from loading to coal hewing) was noted, so that the air consumption per minute during any given piece of work was determinable.

Before the actual experiments were begun the subject was thoroughly accustomed to the use of the mouthpiece. The experiments were continuous over the whole of three working shifts, except for a short break each day which was allowed for a meal. The barometric and temperature conditions were noted, and in all cases the volumes recorded are reduced to N.T.P. The quantities of air breathed as shown below are the average results for the three experiments.

	Litre/min.
Quantity of air breathed during the whole shift, including periods of rest	28·4
Quantity breathed during actual work	30·975
,, ,, periods of rest	16·37
,, ,, cutting with pick in solid coal	35·333
,, ,, loading slack with basket and rake	36·2
,, ,, getting coal with pick	29·858
,, ,, timbering (hacking and setting)	28·04

On the third day samples of inspiratory and expiratory air were taken during specific pieces of work, the results of which are summarised in Table III as follows :—

Table III.—Analysis and Volumes of Inspired and Expired Air.

Nature of Work.	Bar.	Dry Bulb ° F.	Wet Bulb ° F.	Volume at N.T.P. dry air.	Inspired Air.		Expired Air.		O_2 consumed.	CO_2 expired.	CO_2 in litre/min. at N.T.P.	O_2 in litre/min. N.T.P. dry air.	R.Q.	Cals. expended per min./1 litre O_2=4.74 cals.
					O_2	CO_2	O_2	CO_2						
				litres/min.					Per cent.	Per cent.				
Cutting in bottoms for props	32.14	80.6	78.8	29.32	19.98	0.19	15.99	4.21	3.98	4.02	1.178	1.168	1.01	5.536
Loading slack	32.14	81.1	78.9	40.35	19.86	0.38	15.04	4.83	4.91	4.45	1.795	1.98	0.91	9.385
Cutting timber with axe and erecting	32.14	81.3	79.0	31.346	19.86	0.38	15.58	4.75	4.26	4.37	1.370	1.334	1.02	6.323
Loading slack	32.14	81.85	79.2	38.679	19.86	0.38	15.06	4.51	4.96	4.12	1.592	1.917	0.83	9.086

After the above data had been obtained under actual working conditions the same collier attended the University on three evenings, when experiments were performed, a summary of which is shown in Table IV.

Table IV.

No. of Experiment.	Nature of Occupation.	Temp. ° F. dry.	Temp. ° F. wet.	Air breathed in litre/min.	Work done in ft./lbs. min.	CO_2 expired in litre/min.	O_2 consumed in litre/min.	R.Q.
1	Rest in an arm-chair	63·5	59·0	11·46	—	0·323	0·362	0·893
2	Rest in an arm-chair	90·9	78·3	9·74	—	0·30	0·273	1·10
3	Working on a Martin's ergometer	98·7	78·3	15·96	960	0·665	0·735	0·905
4	Working on a Martin's ergometer	97·0	86·3	25·3	2596	1·088	1·138	0·956
5	Working on a Martin's ergometer	95·4	85·0	32·0	3576	1·296	1·38	0·94

It will be seen from experiments 3, 4 and 5 (Table IV) that the increase of oxygen consumption is 0·0246 c.cs. for every additional 100 ft./lbs. of work done per minute on the ergometer, above the basis figure 735 c.cs. oxygen for the expenditure of 960 ft./lbs. min. The ergometer equivalents for work done whilst carrying out specific pieces of work in the mine can, therefore, be deduced from the figures for oxygen consumption given in Table III, and are as follows:—

1. Cutting in bottoms (hewing coal in the floor)—

$$(1\cdot168-0\cdot735)\div0\cdot0246 = 1760+960 = 2720 \text{ ft. lb./min.}$$

2. Loading slack—

$$\left.\begin{array}{l}(1\cdot98\ -0\cdot735)\div0\cdot0246 = 5061+960\\(1\cdot917-0\cdot735)\div0\cdot0246 = 4806+960\end{array}\right\} = 5893 \quad ,,$$

3. Cutting and erecting timber—

$$(1\cdot334-0\cdot735)\div0\cdot0246 = 2435+960 = 3395 \quad ,,$$

The collier upon whom these experiments were conducted has the reputation for being the best worker in the colliery (a South Staffordshire one), his average for tub-filling being double the average for all underground fillers in the same pit. It is likely, therefore, that average figures for colliers as a class would more nearly conform with the following figures, which are mainly empirical, being based upon the author's experience of the work of this man in comparison with the average coal-getter—

1. Cutting in bottoms .... 2500 ft. lb./min.
2. Loading slack .... 4000 ,,
3. Cutting and erecting timber .... 3000 ,,

These figures are of interest in that they are the first to be determined, and will form a useful basis for comparison with work done in other industries. It must be understood, however, that they are merely the ergometer equivalents of the work done by one particular man.

Part 3.—*The Relation of High Temperatures and Work to Sweating.*

The preliminary part of this work was carried out in Prof. J. S. Haldane's laboratory at Oxford in June, 1920, and in August of the same year experiments were conducted in the experimental chamber at the Doncaster Coal Owners' Mine Rescue Station. The Oxford experiments can be summarised briefly as follows :—The writer sat in as restful a position as possible in the respiration chamber, which was heated electrically. The body was protected against radiant heat from the heaters, and apart from the convection currents set up, there was no circulation of air in the chamber.

The following Table I gives the results of a series of experiments conducted at rest, fasting, there being no passage of urine or fæces, and any increase in weight of clothing being counted as body loss.

Table I.

Chamber Temperatures.		Body loss in lbs. per hour.	Remarks.
Dry Bulb Temp. ° F.	Wet Bulb Temp. ° F.		
68	—	0·095	
81	—	0·139	
82	—	0·152	
98·6	75	0·240	
110	84	0·430	
118·4	85·6	0·85	
123	89·3	1·115	During this experiment the mouth temperature rose 2·2° F., indicating that sweating was being stimulated to a maximum extent.

A series of experiments was carried out to indicate the relation of sweat loss to work done. The work was performed on a Martin's bicycle ergometer placed in the laboratory, the air temperature of which varied between 60° and 67° F. Table II gives the results obtained :—

Table II.

Ft./lbs. of work per minute.	Loss in lbs. per hour.
709	0·18
2443	0·53
3420	0·736
5130	1·45

The loss shown in Tables I and II represents the gross loss by weight, almost the whole of which is due to the evaporation from the skin and lungs and moisture caught by the clothing. The weight of oxygen taken in compensates almost completely for the weight of carbon dioxide exhaled.

The Doncaster experiments conducted by Mr. J. Ivon Graham and the writer demonstrated the inability of unacclimatised persons to sweat to anything like the extent to which, as will be shown later, a collier acclimatised to high temperature can sweat. It was, in fact, found impossible to produce by sweating a loss of as much as 1½ lbs. per hour, as shown in the following table :—

Table III.

Subject.	Experiment No.	Chamber Temperature.		Body Temperature.	Air Velocity in ft. per min.	Loss in lbs./hour.
		Dry Bulb ° F.	Wet Bulb ° F.			
J. I. G.	1	106·5	82·8	97·9— 99·9	—	0·594
	2	105·0	82·0	98·2— 98·4	185	1·125
	3	107·6	85·0	98·4— 99·2	183	1·437
	4	108	89·2	99·8—101·6	790	1·2
	5	110·5	81·0	99·0—100·1	800	1·437

Experiments Nos. 4 and 5 were interesting in that the hot air current of approximately 800 feet per minute dried up the skin, so that J. I. G., unable to evaporate moisture fast enough, felt very uncomfortable, and experienced a sharp rise in body temperature.

Owing to the move of the Doncaster Coal Owners' Research Laboratory to the Mining Department of Birmingham University, and the time taken in erecting a new respiration chamber, the experiments were postponed until July, 1922. In the meantime, however, information was obtained showing the actual loss in weight by sweating of colliers working in hot mines. This was determined by weighing the men dressed, plus their full water bottles and snap, before they entered the pit. They were reweighed after the shift's work, and the difference in weight, less the amount of urine passed plus the amount of moisture absorbed by the boots and clothing (if worn), gave the amount of moisture lost by perspiration and respiration. The moisture in the working clothes and boots was determined by weighing them dry and wet. The results for Hamstead Colliery are as follows :—

Table IV.—Hamstead Colliery Results.

Underground Temperature.	Subjects.	No. of separate observations.	Max. loss of weight in lbs.	Min. loss of weight in lbs.	Average loss of weight in lbs.	Loss of weight in lbs./hr. on the basis of a $5\frac{1}{2}$-hr. working period.
82° F. dry 77° F. wet	D. T.	28	11·81	8·25	9·35	1·7
	A. C.	1	—	—	10·19	1·85
	R. S.	5	9·25	7·12	7·81	1·42
	W. T.	4	7·25	5·19	6·44	1·17
	C. P.	3	9·06	5·94	7·31	1·33
	W. D. G.	1	—	—	6·62	1·20
	K. N. M.	1	—	—	4·69	0·85

The man, D. T., had the reputation for being the best worker in the pit. The cases K. N. M., with a student assistant W. D. G., are interesting in that both were unaccustomed to manual work; and in order to compare the effects of work with that of a collier, each loaded five tubs of coal and four tubs of slack, which is a fair day's work. During the first two hours of the work period, each perspired visibly and freely, but afterwards the body appeared quite dry, although the body temperatures remained normal in each case.

Another interesting observation was made in connection with the experiments upon D. T., who worked for one shift in a thick cloud of coal dust. The dust collected on his body and formed a thin covering which throughout the shift appeared fairly dry. On this occasion he lost nearly 1 lb. less in weight than on the previous day, although he worked equally hard, if not harder. He stated that when his body was covered with coal dust he did not perspire so freely. It seems probable that the layer of coal dust on his skin prevented sweat from dripping off him and so being wasted as regards its cooling influence. Another interesting observation by the same man was to the effect that when he recommenced work after several weeks' holiday he was unable to maintain his normal rate of sweating, with the result that during the last two hours of the shift he was good for nothing. His temperature had presumably risen. This condition only lasts two days at the most.

The results for Pendleton Colliery are shown in the following table :—

Table V.—Pendleton Colliery.

Underground Temperature ° F.	Case No.	Loss from skin and lungs in lbs.		Hours worked.		Average loss by evaporation in lbs. per hour for the two shifts.
		1st day.	2nd day.	1st day.	2nd day.	
98° to 100° F. dry bulb, and 85° F. wet bulb.	1	18·56	15·25	5	5·75	3·175
	2	10·44	12·94	5	5·75	2·168
	3	18·75	18·0	5·5	6·25	3·145
	4	13·25	11·62	5·5	6·25	2·135
	5	15·44	16·12	5	6·25	2·695
	6	12·12	12·44	5	5·75	2·28
	7	12·68	10·81	5	5·75	2·205
	8	9·68	13·75	5	5·75	2·16
	9	13·68	12·75	5	5·75	2·475
	10	9·31	9·37	5	5·75	1·76
	11	11·31	12·12	5	5·75	2·185
	12	10·56	10·12	5	5·75	1·93
	13	11·81	17·12	5	5·75	2·67

It will be seen that of the 13 men the maximum individual loss from the skin and lungs amounted to 18·56 lbs. for five hours' work, and the minimum loss amounted to 9·375 lbs. for 5·75 hours' work; or, in other words, the loss in lbs. per hour was 3·7 and 1·66 respectively.

The average loss per hour by skin and lungs for the 13 men during the two days will be seen to be 2·38 lbs., and the average work period 5½ hours. The average volume of urine passed per man was 155 c.c. This is only half the average passed during ordinary conditions at normal temperature, and the water drunk during the shift amounted on the average to 7½ lbs. so that it did not compensate for the loss by skin and lungs, nearly all of which must, of course, have been from the skin.

As the sweat contains a very appreciable amount of chloride it is evident that the miners were losing much chloride during this work. It is obvious that this subject is of sufficient importance to merit thorough scientific investigation.

Further investigations on sweating have been commenced in the respiration chamber erected in the Mine Rescue Room, Birmingham University, in connection with the Mining Research Laboratory. This chamber of 268¾ cubic feet capacity can be heated electrically by radiators to a temperature above 130° F. (Plate 11).

The photographs show (fig. 1) outside view of chamber and (fig. 2) ergometer. The fan, which can be regulated to run at various speeds, circulates a current of air in the chamber which can be varied from 0 to 17 cubic feet per minute. The water bottle A is filled with warm distilled water and connected by rubber piping to a hose which is put through the air exit to enable a man to wash himself down inside the chamber. By this means a man can cease work, wash down, dry and recommence work in just over 10 minutes. A Martin bicycle ergometer is used for accurate work measurement. Underneath the ergometer is placed a mackintosh sheet to catch all sweat dropping from the man whilst peddling. After each experiment the ergometer and stand is thoroughly washed down with distilled water, which collects in a large galvanised iron tray. The man himself is also washed down into the tray, the total washings measured, and the chlorides estimated as sodium chloride, determined by Volhard's method. It has often been assumed that the chloride in sweat is almost entirely sodium chloride, since sodium predominates very greatly over potassium and other basic substances in the blood plasma. An analysis made by Mr. J. Ivon Graham in connection with one of these experiments showed, however, that 59·3 per cent. of the chloride was sodium chloride and the remaining 40·7 per cent. potassium chloride.

Before commencing an experiment the subject is washed down very thoroughly with hot water, dried and weighed after first passing urine. The work is performed in thin cotton shorts, washed in distilled water, dried and weighed before use. Exact weights are taken of food eaten, water drunk and urine passed during any given experiment. The volume of air expired is measured by an air meter during the performance of a given amount of work and also during rest. This information enables one to estimate approximately the moisture loss by respiration and obtain the loss due to perspiration only. The loss of perspiration in lbs. per hour, as shown in the table, is, therefore, actual; the respiration loss having been deducted. The latter loss was, however, very small.

The experiments were carried out upon the three following subjects:—

A. P. V., who is a member of the teaching staff of the Mining Department. He cycles 14 miles each day and, therefore, can be considered fit, but not accustomed to manual work. F. R., a mechanic assistant in the Mining Department, a man of good physique and standard of intelligence much above the average. S. C., a young collier, who for the past $4\frac{1}{2}$ years has worked in

Pendleton pit, the last year having been spent filling tubs at the coal face in the hottest district. This man is fully acclimatised to heat, and forms an interesting contrast with F. R. and A. P. V.

From these experiments the following conclusions result (see Table pp. 194 and 195).

1. The sodium chloride content of the sweat as determined is much lower than the figure generally given in text-books. Thus Luciani, who in his 'Physiology' gives a full account of existing knowledge in relation to sweating, gives the percentage of sodium chloride in sweat as about 0·6. The maximum and minimum percentage contents as determined in these experiments will be seen to be 0·325 and 0·118 respectively, with an average of 0·224 per cent. This result confirms the findings of Dr. E. H. Hunt in experiments conducted by him at Oxford. Dr. Hunt collected sweat with careful precautions to prevent errors from evaporation and previous contamination of the skin. (See 'Journal of Hygiene,' vol. 12, p. 479 (1913).)

2. For fixed conditions of temperature and humidity an increase in the work output is accompanied by an increase in the sweat loss, and apparently also of its sodium chloride concentration. Also, if the work output be maintained constant, an increase in the loss of sweat and its sodium chloride content accompanies an increase in temperature. Where there is much sweating the loss of chloride from the body is very large and may be enormously greater than the loss by the urine. This great loss of chloride by sweating is evidently related to the extra quantity of salt in the diet of miners working in hot mines. It also throws clear light on the requirements for salt and the incidence of a salt tax in a hot climate.

3. There is a marked difference in the amount of sweating between the man acclimatised to hard manual work under high temperature conditions, and men who take just sufficient exercise to keep fit. It will be seen that for the same work output under nearly equal conditions of temperature and humidity the collier loses more than twice as much weight by sweating as does A. P. V. When, in a further experiment, the collier was pressed by an increase in the dry and wet bulb temperature he lost 5·8 lbs. per hour by sweating, which is a remarkable figure. I am enabled to quote evidence from Dr. Hunt in the same direction. In a letter from Singareni, India, to Dr. J. S. Haldane he gives the following information: (1) While taking violent exercise, such as a hard single at tennis, in an air temperature of, say, 102° F., or a little more, the loss of body weight is 4 lbs. per hour, as against the loss of 2 lbs. in the Oxford Turkish Bath. (2) A healthy 110-lb. weight Dravidian coolie can

Summary

Observed Data.	Water drunk during Experiments.								
	A. P. V., University Lecturer.			F. R., Mechanic.		S. C., Collier.			
Ft./lbs. of work done per minute	2682	3353	3687	3353	4695	2816	3353	4024	5365
Dry bulb temperature ° F.	95	95.2	95.6	113.8	112	111.4	104.2	103	102.8
Wet bulb temperature ° F.	70.1	70.5	70.2	79.5	80.7	81.8	82.8	85.2	85
Average loss of sweat in lbs. per hour	1.14	1.18	1.09	1.43	1.62	2.24	2.42	3.28	3.84
Average weight in lbs. of water drunk during experiment.	3.16	3.69	4.83	4.64	1.125	5.56	6.31	8.69	7.81
Average period worked in hours......	3	3	3	3.33	2	3	3	3	2
Average weight in grams of salt taken	—	—	—	—	—	—	—	—	—
Average volume of urine passed in cubic cm.	146	919	1039	330	83	74	94	55	77
Average percentage of chloride (NaCl) content of sweat.	0.223	0.289	0.165	0.207	0.325	0.189	0.187	0.259	0.199
Average percentage of chloride (NaCl) content of urine.	0.778	0.204	0.258	0.613	0.88	0.676	0.546	0.389	0.282
Average total salt content of sweat..	3.473	4.668	2.448	3.913	4.364	5.867	6.410	11.575	6.936
Average total salt content of urine..	1.136	1.804	1.715	1.232	0.731	0.482	0.577	0.257	0.327
Average total salt loss during experiment.	4.609	6.472	4.163	5.145	5.095	6.349	6.987	11.832	7.263
Ratio between salt excretion of sweat glands and that of kidneys.	3.06	2.6	1.43	3.17	5.97	12.2	11.1	45.0	21.2

lose 10 lbs. weight in five hours without any apparent symptoms, though this represents 10 per cent. of his total body weight (109 lbs. to 99 lbs.). He could doubtless lose more before he commenced to suffer badly.

4. The distribution of chloride excretion between the kidneys and the sweat glands is of considerable interest. It will be seen that in the cases of F. R. and more particularly S. C. there was a very marked relative increase in the excretion of chloride by the sweat glands with increase of work at high temperatures, whereas in the case of A. P. V. there was no such increase.

The subject of this part of the paper is receiving further attention in order to clear up points not sufficiently established. For this reason a fuller statement of a number of the data obtained is withheld for the present.

Part 4.—*Miners' Cramp.*

Miners' Cramp has hitherto been observed only among the workers in hot mines where the temperature varies between 98 and 102° F. dry bulb and 83° to 87° F. wet bulb. In fact, the writer does not know of pits other than Agecroft and Pendleton where cases have been reported. There seems to be no doubt, however, that even where cases of severe cramp do not occur, miners may be partially disabled in respect of working capacity by the same *of Results.*

No Water drunk during Experiments.										Salt Water drunk.				
A. P. V., University Lecturer.						F. R., Mechanic.			S. C., Collier.	A. P. V., University Lecturer.			F. R., Mech.	S. C., Collier
2682	2682	3353	3353	3687	3687	2213	3353	4695	3353	2682	3353	3687	—	5365
71.6	94.7	71.0	95.3	69.5	96	108	115.5	114	103	94.9	96.3	95.3	—	101
59.2	69.3	57.0	69.8	57.1	69.7	79.7	79.7	81	85	70.0	70.3	70.0	—	85
0.31	1.05	0.42	1.10	0.46	1.09	1.02	1.29	1.718	2.45	1.07	1.16	1.05	—	3.08
—	—	—	—	—	—	—	—	—	—	3.43	3.68	3.62	—	6.56
3	3	3	3	3	3	3	3	2	3	3	3	3	—	2
—	—	—	—	—	—	—	—	—	—	4.61	6.47	6.0	—	0.32
165	110	212	122	195	170	150	65	60	100	350	130	126	—	75
0.118	0.286	0.144	0.256	0.196	0.24	0.200	0.28	0.305	0.227	0.224	0.223	0.182	—	0.246
1.33	1.614	1.556	1.538	1.591	1.158	1.121	1.287	0.50	1.392	0.585	1.52	1.584	—	0.234
0.502	3.473	0.828	3.843	1.238	3.577	2.573	4.568	4.36	7.58	3.266	3.533	2.596	—	6.871
2.2	1.136	3.3	1.896	3.102	1.968	1.666	0.836	0.30	1.392	2.047	1.976	2.005	—	0.175
2.702	4.609	4.128	5.739	4.34	5.545	4.239	5.404	4.66	8.972	5.313	5.509	4.601	—	7.046
0.228	3.06	0.25	2.03	0.40	1.82	1.54	5.46	14.5	5.45	1.6	1.8	1.3	—	39.3

cause as leads finally to attacks of cramp. This subject is of general importance, therefore, in connection with deep mining problems of the future, and in connection with other industries where men are performing hard work at high temperatures.

The number of cases severe enough to warrant the carrying of the men out of the pit was only nine in two years, but minor attacks of cramp occurred more frequently, and would no doubt have developed into severe cases had not the men ceased work immediately.

The evidence taken from sufferers and non-sufferers working in the same district leads one to attribute cramp to the following causes :—

(*a*) High air temperatures.
(*b*) Excessive drinking of water due to (*a*).
(*c*) Continued hard work.

Men are generally affected by cramp during the second half of the shift and always in the muscles actually being strained at the time. Sufferers are generally men of poor physique. If a man is attacked whilst lifting a full tub on to the rails, cramp might occur in the arms, legs or abdomen ; if the latter, the man is put out of action immediately, the contortion of the abdominal muscles being so great as to form a lump the size of a cricket ball. In severe attacks of cramp it may take half a dozen men to hold down a sufferer and straighten out the affected limbs. Such treatment produces excessive exhaustion of the sufferer, and sal volatile is usually administered to revive him. The evidence collected from the men in the pit was submitted to Prof. J. S. Haldane, who suggested that cramp may depend upon excessive loss of chloride by continued sweating. The matter was then investigated by Mr. J. B. S. Haldane, who accompanied the writer and Prof. A. V. Hill, F.R.S., to a deep coal face at Pendleton Colliery and examined the urine. A sample of urine obtained at the end of the shift from one of the colliers who was subject to cramp was found to be practically free from chloride, though very little urine was being passed. It gave not even the slightest cloudiness with silver nitrate, though only 5 c.c. were secreted during $4\frac{1}{2}$ hours. This phenomenon, which is never met with under normal conditions, and hardly ever at any time, made it quite clear that there was excessive shortage of chlorides in the blood. This condition must have been brought about, under the circumstances, by a combination of excessive sweating and drinking of water. Sweating by itself could have no such effect, as follows from the fact that sweat contains only about $0 \cdot 2$ per cent. of chloride, so that sweating by itself would tend to concentrate the chloride in the blood plasma. Mr. Haldane also directed my attention to recent investigations by Rowntree ('American Journal of Physiology,' vol. 59, p. 451 (1922)) on water poisoning produced in animals by ingestion of large quantities of water into the stomach through a tube. The animals showed the severest symptoms, including twitching of muscles, passing on into convulsions. For the theoretical connection between water poisoning due to excessive diffusion pressure of water in the blood, and shortage of salts in the body I may refer to p. 175 of Prof. J. S. Haldane's book on 'Respiration' (1922). It has, moreover, been shown recently by Dr. Priestley ('Journ. of Physiol.,' vol. 55, p. 305 (1921)) that when excess of water is voluntarily drunk the excretion of chlorides by the kidneys falls very markedly, in spite of the enormous excess of urine passed. Miner's cramp, and with it the symptoms of fatigue referred to below, must thus apparently be attributed to water poisoning.

A probable explanation of why the miners drink too much is that thirst depends, to a large extent at least, on dryness of the mouth and throat. In hot and relatively dry air, as at Pendleton, this dryness will tend to be excessive during muscular exertion and the associated increased breathing, and consequently a miner will tend to drink far too much water. The work of Prof. Pembrey and his pupils recently referred to in a preliminary communication to the Physiological Society, but not yet published in full, shows that with hard work there is complete, or almost complete, cessation of kidney excretion, doubtless owing to the blood being diverted to the muscles. With a big circulation through the skin, as in a hot mine, this effect would probably be produced more easily—that is, with less work. If the kidneys were functioning normally the excess of water would be excreted, but the kidneys are out of action for the reason just mentioned, and the excess of water in the body thus becomes formidable.

On the theory just stated it ought to be possible to prevent the symptoms of water poisoning by supplying the miners with a drink containing just sufficient salt to balance the loss of salt by sweating, and it was decided to experiment upon a few selected colliers by giving them 10 grams of sodium chloride in a gallon of water. The results are extremely interesting and of importance.

The men chosen were sufferers and non-sufferers of good and poor physique. The results are, of course, varied. Some like salt, others dislike it, as is the case with pit ponies. Some pit ponies will lick away in a short time the rock-salt placed in their mangers, whereas others will not touch it. The results obtained are as follows :—

Case 1.—E. C., of poor physique, who drinks 8 pints of water during the shift. He has been a frequent sufferer, but since taking salt each day for the past three months has had no sign of cramp. His evidence was as follows : (1) Appetite much improved ; (2) feels quite fresh after a shift's work, where formerly he was obliged to cease work at about 12.30 p.m. each day owing to excessive fatigue ; (3) his life at home was changed from one of laziness and sleep to one full of energy ; (4) in general feels a changed man.

Case 2.—T. M., poor physique, but a non-sufferer. Took salt for two weeks only and felt much better for doing so.

Case 3.—H. C., a well-built and athletic collier. Took salt for three weeks with the following results : (1) Passed small quantities of urine from 10 to 12 times in the shift instead of twice under normal conditions ; (2) he did not feel anything like so tired after the shift's work ; (3) drank less—about three-quarters of his normal quantity.

Case 4.—J. N., of average physique, a non-sufferer. This man only took one-third of the quantity prescribed and was very half-hearted about the experiment. He stated it had not affected him in any way.

Case 5.—Of average physique ; a non-sufferer. This man took one-half of the quantity prescribed because the full quantity made him feel sick. He drinks 5 pints of water per shift. He found that the salt water prevented attacks of dizziness from which he was accustomed to suffer towards the end of a shift's work.

Case 6.—J. W., of average physique; non-sufferer. Drinks 5 pints per shift. The salt water did not affect him for better or worse.

Case 7.—E. C., of poor physique; sufferer. Was affected similarly to Case 1.

The manager of the mine has discharged all but two of the sufferers so that it was impossible to experiment upon other cramp cases.

Cramp is not confined to miners alone. Ship stokers and iron workers, who also have frequently to work at high temperatures, are liable to it. The writer is obliged to the Assistant Secretary of the Royal Society for calling Dr. Haldane's attention to a graphic description of stokers' cramp in 'The Little Red Captain,' by C. J. Cutcliffe Hyne, of which the following is an extract:—

"Driven half lunatic by the heat and the work, he kept dipping his lips in the water-bucket and drinking heavy draughts. As a consequence that unpoetical complaint cramp in his stomach overtook him at last, and tied him into those ungainly knots of torture which he had so frequently observed upon scientifically in others."

The following description sent to Prof. Haldane by Surgeon-Commander A. Fairley, R.N., may be regarded as typical of a sharp attack of "stokers' cramp":—

"During hard steaming in a hot climate, *e.g.*, Mediterranean in summer, a young stoker is brought up from the boiler room with severe cramp in the muscles of his abdomen and limbs. He walks or is partly assisted to the 'Sick Bay.' The Stoker Petty Officer who brings him has already diagnosed the case and informs you the man is suffering from 'stokers' cramp,' and that his warnings against drinking too much water have been disregarded. Presently the cramp recurs, the abdominal muscles and those of the arms, legs and thighs may together or in turn become bunched up, with hard knots standing out on the muscle due to violent tonic local contraction. The condition is obviously extremely painful, the man writhing and yelling out during the more acute spasms. In such a case massage and warmth alone will not speedily end the attacks, which follow one another almost continuously. A hypodermic of morphia gives him relief, and by his next watch he is well enough to carry on as usual. The condition is not seen so often these days owing to the transition from coal to oil fuel, with its lessened labour and consequently lessened consumption of water while working. The amount of water drunk is sometimes surprisingly great. During a four-hour watch 10 to 12 pints is not uncommon, but this is unusual among the older and more experienced hands, among whom the condition is seldom met with. As further proof of the condition being not only painful but avoidable, I cannot recall any case of a man having had more than one attack."

Mr. Wallace Thorneycroft, of Glasgow, was good enough to obtain and forward to Dr. Haldane particulars concerning the occurrence of cramp among steel workers exposed to the heat of the furnaces, and the following extracts were taken from several reports submitted by him :—

"In hand-charging days cramp did not often happen with men at work, although men did get cramp when at home. I do not recall half a dozen cases of men having to be taken home owing to cramp."

"Steel melters sweat freely, but experienced hands do not suffer from stomach cramp, as they refrain from drinking when sweating . . . . Their practice is to swill out their mouths with water without swallowing it. Inexperienced men, who drink water when in a heated condition, take cramp and become incapacitated for a day or so."

"Cramp, according to our experience, almost entirely depends on the men's own physical condition, and we have heard it freely stated among the men themselves that those who suffer from cramp are those who have had a big supply of alcoholic liquor the night before."

"It is not our experience that excessive sweating produces cramp, and we have never had this fact demonstrated to us in our melting shops, even at the hand-charged furnaces. As a rule this depends very largely on the physical condition of the men themselves. We have been told, however, by experienced and intelligent melters that any distress of this description they experienced arose chiefly from their being called upon unexpectedly to charge their furnaces after having partaken of a very heavy meal . . . ."

A common feature of all the reports is that the men drink from 2 to 4 pints of water during work.

The experiments conducted upon A. P. V. and recorded in Part 3 of this paper have a bearing upon this subject. Mr. Veale studied the effects of drinking salt water during work periods, and found that when salt was taken he felt less the fatiguing effects of the work than when abundance of salt-free water was drunk. This bears out the results obtained by the Pendleton colliers who have experimented with the drinking of salt water.

The writer is particularly indebted to Prof. J. S. Haldane for extremely valuable guidance given throughout, and to Mr. J. B. S. Haldane, Mr. J. Ivon Graham, various mining friends and members of his own staff, for their valuable co-operation. Part of the expenses have been defrayed by the Safety in Mines Research Board.

Further experiments by Mr. A. P. Veale and the writer are at present being carried out on the subjects dealt with in the last two parts of this paper.

Studies in the Fat Metabolism of the Timothy Grass Bacillus. II.—The Carbon Balance-sheet and Respiratory Quotient.

By Marjory Stephenson and Margaret Dampier Whetham.

(Communicated by Prof. F. Gowland Hopkins, F.R.S. Received June 18, 1923.)

(A Report to the Medical Research Council, from the Biochemical Laboratory, Cambridge.)

It was shown in a previous communication [Stephenson and Whetham, 1922 (1)] that the Timothy Grass Bacillus can be cultivated on a synthetic medium containing potassium phosphate (KH_2PO_4: 0·4 per cent.), and magnesium sulphate ($MgSO_4 . 7H_2O$: 0·07 per cent.), with ammonium phosphate ($(NH_4)_2 . HPO_4$: 0·4 per cent.) as the sole source of nitrogen, and glucose (1 per cent.) as the sole source of carbon. The cultivation was carried out in Roux bottles, and the hydrogen ion concentration was kept constant at $P_H = 8 \cdot 0$ by the presence of excess of calcium carbonate. Under these conditions, the glucose was completely used in about 21 days; no breakdown products other than carbon dioxide were found; the protein nitrogen and lipoid contents of the bacillus were estimated at intervals and found to attain a maximum immediately before the glucose was used up; the fat of the organism then rapidly fell off, though no decrease was detected in the protein as estimated by Kjeldahl's method. It therefore appeared that while growing in a medium containing a sufficiency of glucose, the organism stored fat, which was oxidised when the glucose was exhausted—the organism living at the expense of its fat and saving its protein.

More recently, somewhat similar work on *Aspergillus niger* has been reported by Terroine, Wurmser and Montané [1922 (2)], who deprived the fully grown fungus of both nitrogenous and carbon-containing foodstuffs, and found a