THE PHYSIOLOGICAL COST OF MUSCULAR WORK MEASURED BY THE EXHALATION OF CARBON DIOXIDE.*

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AND
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THE following observations form part of a survey, upon which we have been engaged during the last three years, of the physiological cost of muscular work measured by the expiratory discharge of CO₂. The expenses of the inquiry have been in part met by grants received from the Royal Society and from the Medical Research Board, and during the last year from the Industrial Fatigue Research Board. Our results have been reported from time to time in the form of communications to the Royal Society and to the Physiological Society, and during the past year to this JOURNAL and to the Académie Royale de Médecine de Belgique.

These last communications, which are of the nature of reports to the Industrial Fatigue Research Board, have in our view a prospective medical as well as an industrial application, since our method of observation is, we believe, practicable in hospitals under conditions of abnormal metabolism as well as in factories and on the road under normal conditions. The method was described last year in this JOURNAL (April 17th, 1920) for the express purpose of enabling any unskilled observer to acquire and utilize it if so inclined, and need not therefore be redescribed now. The same paper contains the summary account of a week's observation made by Miss G. De Decker at the printing rooms of the BRITISH MEDICAL JOURNAL upon four compositors, showing as the average rate of energy output (gross) 103±2 kilo-calories per man per hour—that is, approximately 100 calories per hour (vide table below).

Our communication to the Belgian Academy of Medicine gave an account of the physiological cost of route marching upon four Belgian soldiers under service conditions, and showed as the average rate of energy output (net) 1/10th cubic centimetre of CO₂ per kilogram body weight per horizontal metre traversed.

Otherwise—if less precisely expressed—an average "fit" soldier (Belgian) marches under service conditions, with a load of 28 kilos, 16 kilometres (= nearly 10 miles) in four hours (= 50 minutes marching + 10 minutes rest per hour), at a net physiological cost of 1,000 calories, or 250 calories per hour.

The present communication deals with the energy output (A) of colliers during their work at the coal face; (B) of shoemakers during their work in the factory.

A. COLLIERIES.

Our observations were taken at the Cwm Colliery, near Pontypridd, by courtesy of the Great Western Colliery Company, and our thanks are due to Mr. Rees, the manager, who made arrangements enabling us to take hourly observations upon two colliers, D. O. and H. K.,

* The substance of a report to the Industrial Fatigue Research Board.

during their actual work at the coal face in "getting coal" and loading it on trucks. Our procedure consisted in the hourly collection of expired air for 30 seconds; this was

FIG. 2.—D. O. (Friday, October 8th.) Pulse frequency and CO₂ discharge taken simultaneously at hour intervals during seven hours' work at the coal face.

hardly felt as an interruption of work by the colliers, who lent themselves to the proceeding with the utmost goodwill. The work being "piece-work"—that is, the wage

TABLE I.—Showing Rate of Pulmonary Exhalation of CO₂ (c.cm. per second) and Pulse Frequencies of two Colliers at Cwm Colliery during three days' work at the Coal Face (Wednesday, Thursday, and Friday, October 6th, 7th, and 8th, 1920).

Date and Subject.	Time: A.M.					P.M.			
	7	8	9	10	10.20	11	12	1	2
October 6th.									
D. O. ...	2.8	6.0	14.0	5.8	—	12.9	17.5	19.0	21.0
Pulse: ...	76	112	112	100	—	112	120	120	133
H. K. ...	—	3.0	12.0	7.8	—	10.6	15.2	16.0	23.9
Pulse: ...	—	72	88	76	—	100	100	100	100
October 7th.									
D. O. ...	2.5	8.4	11.2	6.0	—	10.9	14.0	18.6	20.6
Pulse: ...	76	88	96	84	—	96	110	120	110
H. K. ...	2.0	5.0	9.0	4.5	—	9.4	13.5	16.2	20.0
Pulse: ...	72	80	80	72	—	84	100	100	100
October 8th.									
D. O. ...	2.7	7.2	9.9	13.6	4.5	9.0	14.0	17.5	15.7
Pulse: ...	80	96	100	100	84	96	104	112	100
H. K. ...	3.0	6.1	10.3	13.4	4.1	8.2	11.6	15.2	14.0
Pulse: ...	72	76	84	96	76	84	86	96	86

From 10 to 10.20 a.m. there was an interval for lunch; on the third day samples were collected at beginning and end of this interval. The pulse frequencies were taken during collection of samples.

Summary.

	Estimated Output of Coal per Man per 7 hours.	Total Cost gross CO ₂ Exhaled in 7 hours.	CO ₂ per hour (gross)	Calories per hour.
	Tons.	Litres.	Gross.	Net.
October 6th.				
D. O. ...	4.5	313.5	44.8	262
H. K. ...	4.5	315.0	45.0	264
October 7th.				
D. O. ...	4.0	290.3	41.5	243
H. K. ...	4.0	246.9	35.3	207
October 8th.				
D. O. ...	3.5	256.6	36.7	216
H. K. ...	3.5	230.4	32.9	193
Average net cost =				168

* Allowance made for the first hour when no observation was taken.

being dependent on the tonnage got, was practically maximal and constant. Its energy value came out lower than we had anticipated, a fact that must, we believe, be explained as being due to the skilled character of the work of coal getting. A pulse count was taken during each half-minute while the expired air was being collected, the plotted curve of pulse-frequencies proved to be remarkably similar to the plotted curve of CO₂ discharge throughout the day's work, which was from 7 a.m. to 2 p.m., with an interval of twenty minutes at 10 a.m. for "lunch" (bread and cold tea or water; no alcohol). (See Fig. 2.)

The CO₂ figures (c.cm. per second) and the pulse frequencies for the two colliers—D.O., aged 49, weight 61 kilos, and H.K., aged 43, weight 67 kilos—are recorded in Table I.

B. SHOEMAKERS.

By courtesy of Mr. Francis J. Clark we have taken the following hourly readings at the boot and shoe factory of Messrs. C. and J. Clark, at Street, upon two male operatives at work in the "finishing room." The work there is reputed to be the hardest in the factory, and by the workmen themselves is commonly termed "donkey work."

In our view, however, it must be classified as "light work." It is carried out under excellent conditions of light and ventilation as "piece-work"—that is, there is no liability to lose time—in a room 220 ft. by 120 ft. by 12 ft., intended to accommodate 400 workmen (64 square feet of floor space per man), but in which there are at present only half that number. By reason of the actual slackness of trade these men are working only three days per week, but earning all they can during their time of work, so that the actual pressure of work by the individual workman may be regarded as maximal. The results are tabulated below.

From the figures obtained we calculate as the average physiological cost (gross) per man 6.2 c.cm. CO₂ per second, or 124 calories per hour. We hesitate to give even an approximate estimate of net cost, since we did not take resting or basal values, and the error incurred by assuming average values might be very large. Nevertheless, in order to allow of their inclusion in our general table, we give with due reservation the approximate net values per man and per square metre of body surface for this work, which obviously, in comparison with the values for dock labourers and cold storage labourers, are exceedingly low, of the same order as the values observed for tailors and printers.

FIG. 3.—Shoemakers (gross cost of labour). (See also Table II.)

The CO₂ figures for the two subjects—C. S., aged 54, weight 70 kilos, and W. P., aged 49, weight 67 kilos—are recorded in Table II.

The relative energy output of colliers and of shoemakers comes out from our observations as three times greater for the former than for the latter—namely, 96 calories per hour per square metre of body surface in the case of

TABLE II.—Showing Rate of Pulmonary Exhalation of CO₂ (c.cm. per second) of two Male Operatives at the Boot and Shoe Factory of Messrs. C. and J. Clark, Ltd., Street, Somerset, during three days' work in the "Making-up Room" (Monday, Tuesday, and Wednesday, March 21st, 22nd, and 23rd, 1921). From 12.30 to 1.30 interval for dinner.

Date and Subject.	Time: A.M.				P.M.					
	9	10	10.30	11	12.30	1.30	2.30	3	4	4.30
March 21st.										
C. S.	...	3.4	5.6	7.0	7.0	3.3	4.1	5.8	6.8	7.0
W. P.	...	2.0	2.7	3.5	5.0	2.3	5.0	5.4	7.1	7.5
March 22nd.										
C. S.	...	3.0	5.0	—	4.0	5.4	4.1	—	7.5	8.0
W. P.	...	2.3	4.2	—	3.8	5.0	2.9	—	5.4	8.0
March 23rd.										
C. S.	...	5.0	5.6	—	7.5	8.2	6.6	—	8.7	8.7
W. P.	...	4.2	5.0	—	6.3	7.5	6.0	—	6.7	7.5

* The pulse frequencies of C. S. = 83 during the morning and 100 during the afternoon; those of W. P. = 72 throughout the day.

colliers, and 32 calories in the case of shoemakers. The relation of their energy output to that of other workers whom we have measured during the last two years is exhibited in the following table and graphs (Fig. 4). For purposes of strict comparison it is necessary to state the cost of work by individuals of different bulk in units per kilo of body weight, or preferably in units per square metre of body surface. But for practical purposes during investigation we find it useful to think in terms of CO₂ (gross) per second, which we translate at once into calories per hour by using the factor $\times 20$. Our data have been presented under both of these forms in the graphs given below. In the left-hand graph the gross results are given in c.cm. CO₂ per second (and calories per hour); the basal or subsistence values assumed at 1 c.cm. per 20 kilos of body weight are shaded black; the remaining portions shaded grey indicate net cost per individual. In the right-hand graph these net values per individual are reduced to the common denomination of net values per square metre.

In connexion with this last table in which we have summarized the results of all the observations we have taken of various classes of "manual workers" during the last

REFERENCES.	BODY-WEIGHT (kilocal.)	BODY-SURFACE (square metres)	OCCUPATION.	NUMBER OF DAYS OR HOURS OBSERVED.	CO ₂ c.c.s. per sec. gross	Do basal	net.	CALORIES (gross) per hour per man	CALORIES (net) per hour per man	CALORIES (gross) per hour per person.				CALORIES (net) per hour per square metre of body surface.	
										(black-basal; shaded-net).					
										I II III IV					
										SEDENTARY	LIGHT	MEDIUM	HEAVY	per sec. ccCO ₂	per hour CAL.
										5	10	15	20	per sec. ccCO ₂	per hour CAL.
1	86'0	2'0	DOCK LABOURERS. Time-work.	DAY. 6	14'3 - 13'0	286	100	100	100	100	200	300	400	100	200
			Piece-work.	DAY. 3	21'8 - 13'17'5	436	175	286	175	286	436	588	740	175	700
2	67'0	1'8	COLD STORAGE LABOUR. Piece-work.	DAY. 6	10'3 - 3'3	7'0	206	77	206	206	206	206	206	77	308
	74'0	1'8	Do (Smithfield). Piece-work.	DAY. 6	14'7 - 3'7	11'0	284	123	284	284	284	284	284	123	492
	74'0	1'8	Do Do Piece-work	NIGHT. 6	14'4 - 3'7	10'7	288	119	288	288	288	288	288	119	476
3	62'3	1'7	TAILORS (men).	DAY. 17	5'85 - 3'1	2'75	117	32'4	117	117	117	117	117	32'4	1300
	48'2	1'3	Do (women).	DAY. 7	5'15 - 2'4	2'75	103	36'6	103	103	103	103	103	36'6	1464
4	73'0	1'9	PRINTERS (men).	DAY. 12	7'0 - 3'6	3'4	140	35'5	140	140	140	140	140	35'5	1420
	48'0	1'4	Do (women).	DAY. 6	4'9 - 2'4	2'3	98	35'9	98	98	98	98	98	35'9	1436
5	65'3	1'7	Do B.M.J.	DAY. 24	5'3 - 3'3	2'0	106	24'0	106	106	106	106	106	24	984
6	73'6	1'9	TIMES PRINTING HOUSE.	NIGHT. 8	8'1 - 3'7	4'4	162	47'0	162	162	162	162	162	47	1880
	60'5	1'8	Composers.	NIGHT. 12	10'0 - 3'0	7'0	200	77'0	200	200	200	200	200	77	3080
	69'0	1'8	Casters.	NIGHT. 12	10'9 - 3'5	7'4	218	82'0	218	218	218	218	218	82	3280
	60'1	1'75	Readers.	NIGHT. 12	3'0 - 3'0	0	60	0	60	60	60	60	60	0	240
	65'0	1'74	Founders.	NIGHT. 12	9'3 - 3'2	6'1	186	70'0	186	186	186	186	186	70	2800
	66'2	1'77	Machinists.	NIGHT. 9	8'0 - 3'3	4'7	160	33'0	160	160	160	160	160	33	1320
7	64'0	1'70	COLLIERS	DAY. 6	11'6 - 3'2	8'4	232	96'0	232	232	232	232	232	96	3840
8	72'0	1'75	BELGIAN SOLDIERS (route march)	DAY. 4	16'1 - 3'6	12'5	322	143	322	322	322	322	322	143	5720
9	68'0	1'73	SHOE-MAKERS	DAY. 6	6'2 - 3'4	2'8	124	32	124	124	124	124	124	32	1280

FIG. 4.

two years, we desire to call particular attention to the grading we have been led to adopt in accordance with nature of work. Expressed in terms of cubic centimetres CO₂ exhaled per second (gross) and of the approximate caloric expenditure thereby signified, our grading is as follows:

	C.cm. CO ₂ per Second.	Calories per Hour.
I. Sedentary work	Below 5	Below 100
II. Light... ..	5 to 10	100 to 200
III. Medium	10 to 15	200 to 300
IV. Heavy	15 to 20	300 to 400
(Heaviest)	(Above 20)	(Above 400)

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3. *Proceedings Physiological Society*, December 20th, 1919.
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INTERMITTENT ALBUMINURIA IN CHILDREN.

BY

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By the term intermittent albuminuria is meant the condition in which a specimen of urine passed at one time of day is found to contain albumin, whereas a specimen from the same patient at another time of day is free from it. This condition is well known, and has been called by several names, of which cyclic, postural, orthostatic, lordotic, functional, and physiological are the commonest. Albuminuria is present only if the patient is up and about, and is absent if he remains in bed.

Etiology and Pathology.

Albuminuria is much more common in children than is generally supposed.

Samuel West¹ quotes the following figures for boys between 10 and 18 years of age:

Author.	Number Tested.	Percentage with Albuminuria.
Stirling	369	20.8
Ribbert	240	22.0
Dukes	Many years' experience	22 at least
Grainger Stewart... ..	100	17.0

Stirling also shows that the incidence increases from the age of 12 to 15, and then decreases. Leslie Thorne Thorne² states that out of 1,890 boys between 9 and 16 years 9.1 per cent. had albuminuria; of these only fifteen (or 0.8 per cent.) had definitely hypertrophied hearts and increased arterial tension.

On examining the urine of 397 boys between 8 and 14 years of age at Vauxhall Street Elementary School I found albumin in 91 of the specimens (that is, 23 per cent.). The tests were carried out between 10 and 12 o'clock in the morning, the method employed being to add four drops of a concentrated solution of salicyl sulphonic acid to half an inch of urine in a test tube. The following table gives the age incidence in this series; no attempt was made to discover how many of these cases were intermittent.

Age	...	8	9	10	11	12	13	14
No. of cases	...	82	63	65	54	63	62	8
Percentage with albuminuria	...	12.5	17	22.5	24.5	31	39	50

With regard to sex incidence, it is generally assumed that albuminuria is commoner in boys, but there does not seem to be any evidence on the subject; out of 16 cases of intermittent albuminuria studied at the Evelina Hospital

for Children, only 4 were boys. In regard to age, the youngest case I have seen was a girl of 5½; the condition is said to be very rare after 20.

Most authors agree that children with intermittent albuminuria are debilitated, and some French physicians³ ascribe the condition to "pretuberculosis." Others lay stress upon the presence of lordosis in these cases, and Jelle⁴ goes so far as to say that he can produce albuminuria in normal children or prevent it in orthostatic children by mechanical means. In 6 cases in which I made special note of the spinal curvature, lordosis was present in 4 and absent in 2.

As intermittent albuminuria is not a fatal disease very few accounts of *post-mortem* findings have been published. Langstein⁵ describes a case of orthostatic albuminuria, which died of cerebral tumour, in which no abnormality was found in the kidneys either macroscopically or microscopically.

Several theories have been advanced to account for this condition, but each of them has the disadvantage of not explaining all the cases; the following are some of the best known:

1. That it is due to congestion of the kidneys, either by pressure on the renal veins or from some vasomotor abnormality.
2. That it is due to diminished coagulability of the blood, and is related to chilblains and urticaria, and may be cured by administration of calcium lactate for a few days.
3. That it is an early manifestation of tuberculosis.
4. That it is one of the neuroses of childhood.

Character of the Urine.

The amount of urine passed in two cases admitted as in-patients to the Evelina Hospital was found to be normal, more being secreted by day than by night.

The specific gravity varies between wide limits in individual cases. The albumin also varies in amount, but is seldom more than 0.05 per cent. by Esbach's method. It is generally absent from the morning specimen, and absent if the patient remains in bed; but in one of the cases treated as an in-patient a cloud of albumin was present in the morning specimen on one occasion, and the child had a temperature of 100° the same evening, for which no cause could be found; neither the morning albuminuria nor the pyrexia recurred. The other case admitted to hospital developed a very severe attack of gastro-enteritis, passing blood in the stools; one of the specimens obtained during this illness contained albumin although the patient was in bed. In patients who are up and about the amount of albumin increases to a maximum during the day, the time at which this is reached being constant in any individual case, so that one child would always have a trace at midday and a cloud in the evening, whilst another would always have a cloud at midday and none in the evening. In some cases a precipitate is formed in the cold by adding a few drops of acetic acid to the urine; some authors state that this is pathognomonic of intermittent albuminuria, but it is not present in all cases, and is sometimes found in other conditions such as cyclic vomiting and cardiac failure of diphtheria. The formation of this precipitate is slow, so in all probability it is often overlooked. Probably more than one substance is precipitated in this way, for in most specimens the cloud thus formed is increased by boiling, but in a few cases it disappeared on heating to re-form very slowly after cooling.

Casts are sometimes found in cases that appear to be simple intermittent albuminuria; hyaline types are commonest, although granular and epithelial are sometimes seen. Out of nineteen specimens of urine containing albumin from boys at Vauxhall Street School epithelial casts were found in one specimen, granular in four, and hyaline in one. Blood was not found in any of these cases, nor in any of those seen at Evelina Hospital.

Symptoms and Signs.

There can be no doubt that many cases occur without symptoms. There does, however, seem to be a syndrome associated with intermittent albuminuria which is quite characteristic but difficult to describe. Heubner says: "There is considerable atony and lassitude, which deprive these children of all joyfulness, alacrity, and pleasure of work." The patient generally cries when examined, and whimpers or "grizzles" a great deal at home; he is easily tired, and prefers sitting down to playing about. These children are subject to headaches and "bilious attacks," but are not constipated; they sleep well, and do not want to get up in the morning.

The children are asthenic and their pupils are unusually large; beyond this nothing was constantly found among the 16 cases at Evelina Hospital. The heart was enlarged in 2 cases only and the exercise tolerance was normal in