612.16:612.592
612.2:612.592

THE EFFECT OF EXPOSURE TO COLD ON THE PULSE RATE AND RESPIRATION OF MAN.

By J. BARCROFT and F. VERZÁR.

(*From the Marine Biological Station, Woods Hole, Mass., and the Physiologische Anstalt, Basel.*)

Observations carried out by Izquierdo in collaboration with one of us [1931] indicated that whilst reduction of body temperature in cats caused a fall in the pulse rate when the cats were deeply under the influence of a narcotic, the effect was often reversed when the animals were only lightly anæsthetized. It might be expected that with no anæsthetic, were it practicable to carry out such experiments, the increase in the rate of heart beat when the body temperature is lowered just below the normal might be even more striking.

Whilst such experiments would be very difficult of conduct in cats they are very simple in man; moreover the effect of lowered body temperature on the pulse rate of man *qua* man is itself of great interest.

Method.

Four experiments were carried out; two in the cold storage room of the Woods Hole Laboratory, the temperature of which was 3–4° C. The other confirmatory experiments were carried out at Basel where the string galvanometer was conveniently accessible for counting the pulse—a process not always easy when the patient is shivering. There a bed was placed with an ample supply of bed-clothes. Each experiment was divided into three periods.

Period I. The subject of the experiment was naked and lay in comfort covered with the bed-clothes until his pulse became steady.

Period II. The bed-clothes were then removed. He was exposed for about half an hour to the cold, his pulse rate and his rectal temperature being observed at frequent intervals. The occurrence of shivering was also noted. In the second of the Woods Hole experiments observations were also made with the Du Bois spirometer which registered the volume of each respiration and the total metabolic rate.

Period III. After a sufficient length of exposure the bed-clothes were replaced over the patient and the observations continued for a time. It had been our intention to proceed with this phase of the experiment until the temperature rose to its original reading, but this was not persisted in for the reason that the temperature showed so little inclination to rise once it had been forced down by even a small amount. A short calculation would show that this is not surprising. The heat production of the

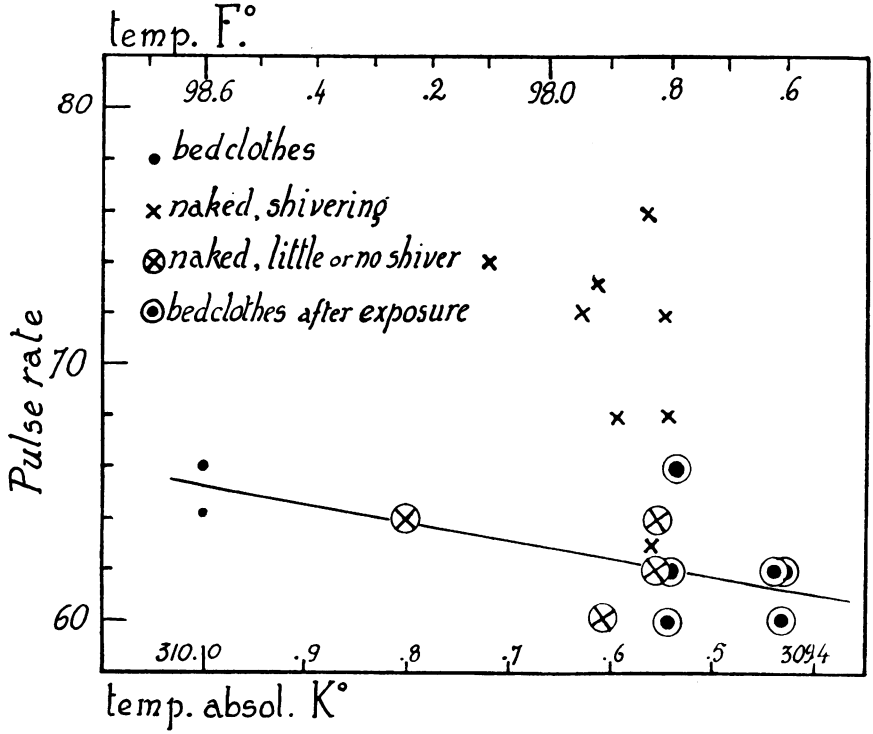


Fig. 1.

subject was of the order of 90 cal. per hour, his body weight 73 kg. Making allowance for the fact that a certain quantity of heat was lost through the evaporation from the lung, it will appear that about an hour's heat production would be required to raise the temperature of the body 1° C. even if no heat were lost from the body surface.

The following is the protocol of Exp. 1.

There are two general inferences from it, the first is that the increase in the pulse rate which takes place in exposure to cold—spasmodic and uneven—is associated with the existence of shivering and the

Time a.m.		Rectal temp. °F.	Pulse rate	Respirations
9.26	*Period I* commences. Patient undresses, lies down, right arm free. Body and legs covered			
9.31	—	—	78	—
9.32	—	—	—	18
9.35	—	—	79	—
9.39	—	—	76	—
9.40	—	—	—	16
9.41	Sleepy, hand cold	—	—	—
9·49	Rectal temperature read. Thermometer in rectum 9.39–9.49	98·7	—	—
10.2	—	—	64	—
10.6	Pulse arhythmic	—	68	—
10.8	Thermometer read (9.58–10.8)*	98.4	—	—
10.9	—	—	66	—
10.13	*Period II* commences			
10.14	Goose skin, shivering commences	—	64	—
10.19	Shivering, legs and thorax	—	74	—
10.19	Thermometer (10.9–10.19)	98·6	—	—
10.25	—	—	72	—
10.26	Deep respirations	—	—	10
10.28	—	—	73	—
10.30	Thermometer (10.20–10.30)	97·9	—	—
10.30	Strong shivering arm, thorax, abdomen, feet	—	—	—
10.32	Shivering passes off largely. Feels now quite comfortable, less goose skin	—	—	—
10.33	—	—	60	—
10.35	Occasional shivering, goose skin more marked	—	68	15†
10.38	Shivering	—	76	—
10.42	Shivering	—	63	—
10.45	Little shivering, speaks. Uneasy	—	64	—
10.46	—	—	62	—
10.48	Thermometer (38–48)	97.8	—	—
10.52	Shivering returns (49–54)	—	72	—
10.54	—	97·8	—	—
10.54	—	—	68	—
10.55	*Period III* commences			
10.56	Says he feels much worse	—	—	—
11.3	Shivers again and worse than before	—	—	—
11.5	No shivering	—	66	—
11.8	Nails no more blue	—	60	—
11.19	—	—	62	—
11.20	Thermometer (10–20)	97·7	—	—
11.21	—	—	—	—
11.24	Goes to own room, lies on table. Speaks	—	—	—
11.30	Lies quiet	—	—	—
11.37	—	—	60	14
11.42	—	—	62	—
11.43	—	—	62	—
11.45	Thermometer (35–45)	97·6	—	—
11.51	Thermometer (46–51)	97·6	—	—

* The reading is placed on the protocol at the time that it was made. The figures in brackets are those at which the thermometer was put into and removed from the anus. The temperature observed (as the temperature was falling) probably corresponds to about 1 minute after the insertion of the thermometer.

† Respiratory cramp difficult to count.

second that, apart from these attacks, there is a fundamental decline in pulse rate corresponding to the fall in temperature and represented roughly by the straight line in Fig. 1. This experiment and Exps. 2, 3 and 4 which confirmed it, give a general support to the view held by Magnus and Liljestrand [1922] that shivering is closely associated with skin temperature. These authors adopted the ingenious plan of taking cold baths, in which the water on occasion contained a considerable quantity of CO_2. The CO_2 caused dilatation of the skin vessels and consequent maintenance of the skin temperature, and although the body temperature fell, shivering did not take place.

In Exp. 1 the shivering was intense and continuous in period II from 10.14 to 10.32, and occasional for the rest of period II, but of the last part of period II more must be said later. On the other hand, during period III when the skin was covered and relatively warm there was little shivering even though the body temperature did not rise. To revert to the latter part of period II. Both in Exps. 1 and 2 there was a moment (in Exp. 1 at 10.32) when the mental outlook and the aspect of the subject underwent a remarkable alteration. Till that time, there had been acute consciousness of the cold, discomfort and flexing of the limbs, with, as mentioned in this protocol, intense goose skin and shivering. Quite suddenly the limbs were extended, the shivering and the goose skin tended to disappear, the skin probably (though no skin temperatures were taken) became warmer and the patient experienced a sensation of pleasure which could here be described as "basking in the cold."

Details of Exp. 2 are so similar to those of Exp. 1 that little need be said about it save for the discussion of the spirometer records. These were taken continuously throughout the experiment up to the end of period II and at intervals in period III.

Section III of the record is a fair sample of the type of respiration and metabolic rate in period I. Sections I and II are not reproduced, being essentially similar to section III.

Section IV at the very commencement of period II shows little difference from section III save that the respiration is somewhat more irregular.

Section V shows the commencement of the onset of shivering respiratory spasms. These rather give the impression of being caused by deficiency in the expiratory phase of respiration. The rate of respiration is not notably altered nor, apart from shivering fits at *a* and *b*, is the depth of inspiration increased. The considerable inflation of the chest is caused by either an inhibition of expiration or a cutting in of the next inspiration

before the expiration is complete. It is difficult to describe what takes place in words which do not seem to presuppose some theory of the

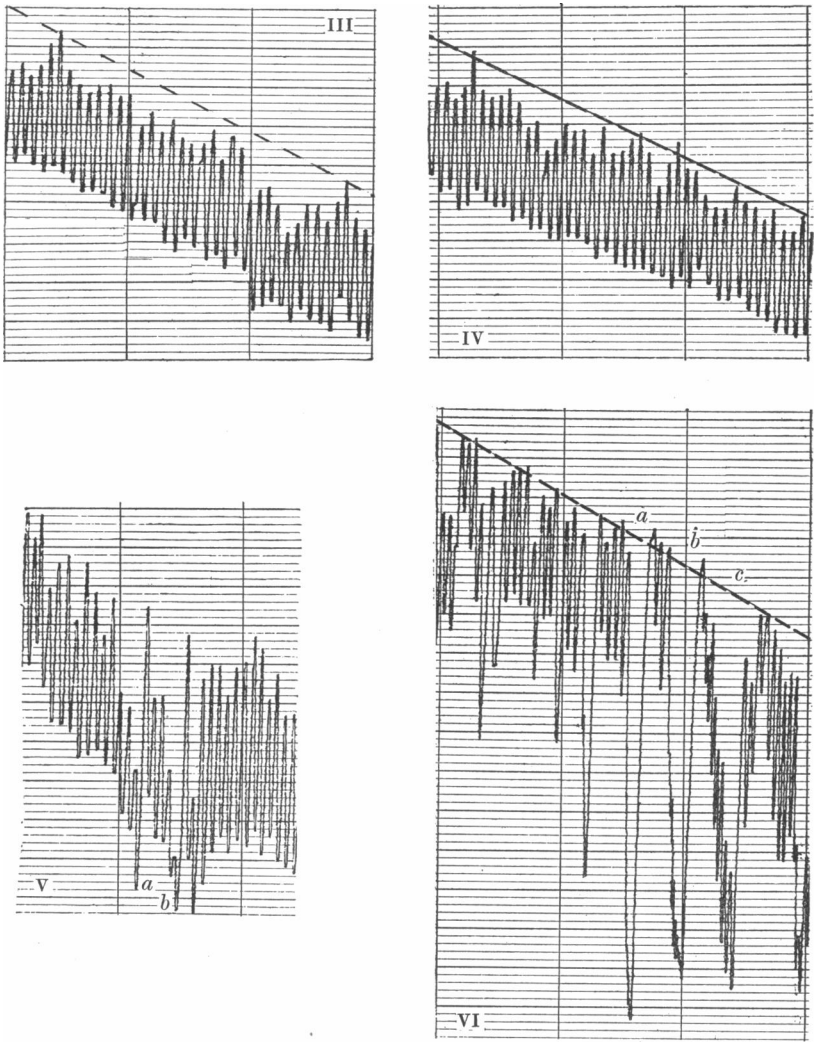
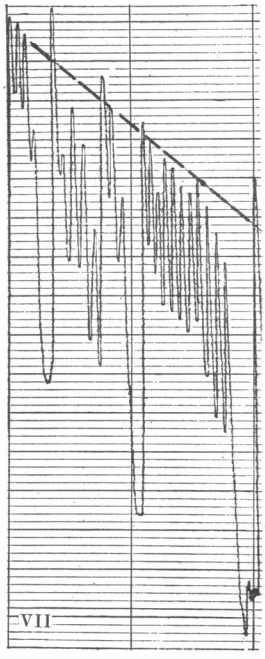
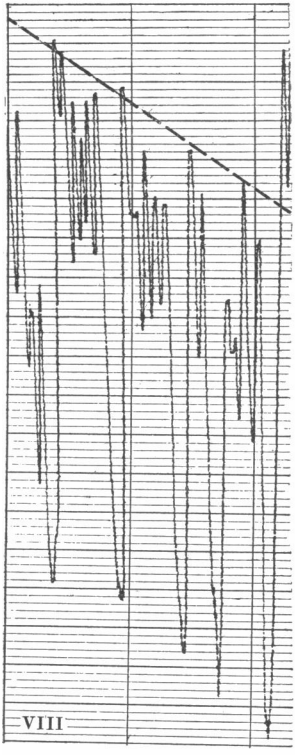


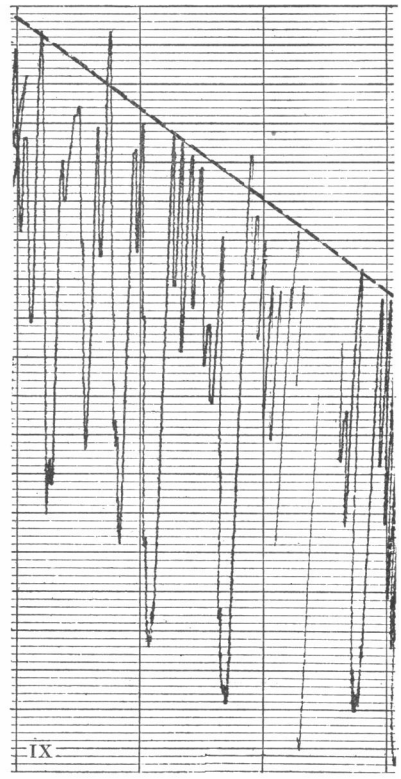
Fig. 2. Section of tracing of Du Bois spirometer. Ordinate rulings = 2 mm. Abscissa; vertical lines = minutes. 1 mm. in 6 minutes on the diagonal = 1 calorie per hour.

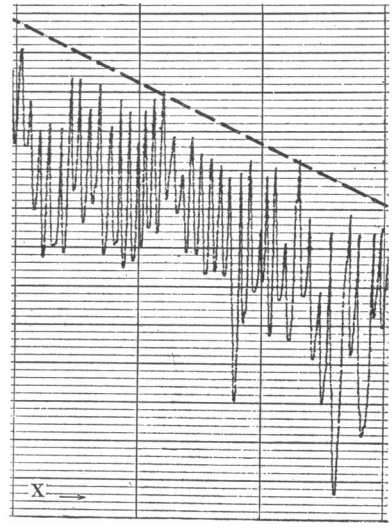
causation of the respiratory rhythm, but it is our express intention not to postulate any theory.

Section VI shows much larger inspiratory spasms (*a*, *b* and *c*). The


VII


VIII

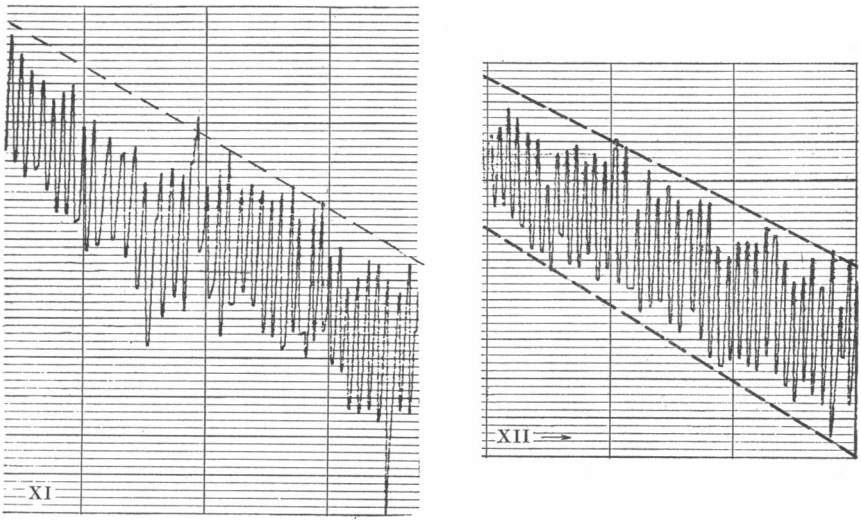

IX


X

comparison of these spasms is interesting, as showing the degree to which the inspirations are built upon one another.

These inspiratory spasms present a similarity, superficially at all events, to the apneuses of Lumsden [1923] and are even more like some of the phenomena obtained by Taylor [1930] in HCN poisoning.

Sections VII–IX show the period at which the shivering rigors were most strongly established. The metabolic rate so far as it could be measured was increased and variable, the pulse was also varied between 64 and 80, having been 66 at the end of period I. Section X was immediately after the "basking" phase commenced. The pulse (64–59) had now dropped below that in period I. The respiration has become quiet with only slight



and occasional irregularities. The metabolic rate (again so far as it could be measured) had fallen at least as low as, if not lower than in period I.

Sections IX and XII are 3 and 25 minutes respectively after the bedclothes had been replaced on the subject. There was no appreciable rise in the body temperature, and 23 minutes after section XII it had only risen in 1/10° C. Yet in record XI there is only the merest suggestion of shivering, and in record XII there is only a slight irregularity in the respiration with a little stop at the close of two inspirations. The pulse during the later part of period III varied between 62 and 66.

The following additional data may be given with regard to the respiration in the above experiment.

Section of record	Period	Respirations per min.	Calories per hour	Remarks
III	I	13	91	Rest
IV	I	13	94	„
VI	II	15–11*	106	Cold*
VII	II	8–12	159	Shivering
VIII	II	8*	135	„
IX	II	8*	146	„
X	III	13	92	Skin warm
XI	III	10–13	111	„
XII	III	13	114	„

* Means rigors.

The effect of shivering was to raise the heat production from 50 to 75 p.c.

The Exps. 3 and 4 on students confirmed the results obtained on the pulse and the psychology, indeed the effect on the pulse was greater in the case of the students than of the subject (J.B.) of Exps. 1 and 2. In Exp. 3 the pulse rose from an average value of 82·5 to a maximal value of 98 (dropping when the clothes were replaced to 81·5) and in Exp. 4 from 70 to a maximum of 98 during the period of respiratory spasms, and falling back to 68, 68, 72.

Conclusions.

1. Apart from spasmodic rises in the pulse rate associated with shivering, the pulse rate in man falls with fall of body temperature.

2. The spasmodic rises associated with shivering may amount to 40 p.c. of the original pulse rate.

3. The respiration shows marked summation of inspiratory movements during the rigors which had very deep and sustained inspirations.

4. The oxygen consumption increases during the shivering fits by as much as 75 p.c. of its value during rest.

We have to thank the authorities at Woods Hole Marine Station for the hospitality extended to us, and in particular Dr W. E. Garrey for his kindness in helping us with the observations.

REFERENCES.

Barcroft, J. and Izquierdo, J. J. (1931). (Paper immediately preceding this.)
Lumsden, T. (1923). *J. Physiol.* **57**, 153, 354; **58**, 81, 111.
Magnus, R. and Liljestrand, G. (1922). *Pfluegers Arch.* **193**, 527.
Taylor, H. (1930). *J. Physiol.* **69**, 124.