INFLUENCE OF THERMAL ENVIRONMENT ON THE CIRCULATION AND THE BODY-HEAT

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From the Author.

STUDIES ON THE INFLUENCE OF THERMAL ENVIRONMENT ON THE CIRCULATION AND THE BODY-HEAT

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WITH FIFTEEN CHARTS.

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PREFACE.

The observations set forth in the following pages are part of an inquiry commenced ten years ago into the heat-producing power of the heart. Some new and interesting points have emerged during the investigation, and through the kindness of Professor Starling, of University College, a paper on the "Effects of the Movement of Air and of Water upon the Pulse-rate in Man" was communicated to the Physiological Society in December, 1911.[1] This subject is dealt with more fully in the latter part of this little book.

My notes contain in all more than twenty-five thousand observations of the pulse-rate, the blood-pressure, and the superficial and deep temperature of the body, under various conditions. For recording the temperature the Fahrenheit degree, which being smaller than the Centigrade lends itself more conveniently to a minuter division, has been used throughout, and when the rectal temperature is being watched continuously with a delicate thermometer a change so small as 0·1 F. may be recorded with confidence.

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[1] See *Journal of Physiology*, vol. xliii.

The influence of exposure of the body to cold sufficiently intense to lower the deep temperature by overpowering the effect of the reactionary processes has not been studied; nor have I attempted to trace the practical application of the results described or their bearing on the subject of acclimatization.

London, 1913.

SUMMARY.

TEMPERATURE CHARTS.

Influence of Thermal Environment on the Circulation and the Body-heat.

INTRODUCTORY.

At ordinary temperatures of the air when the body is recumbent in bed the thermal environment can be altered by simply increasing or reducing the amount of the overlying coverings, and the consequent changes brought about in the state of the circulation and the heat of the body can be studied with ease. Under excessive covering the subject becomes uncomfortably hot (the Hot condition) and when the body is exposed to the air by removal of the clothing the Cold condition may be developed. The thermally comfortable stage between these opposites may conveniently be termed the Neutral state. The best time for such investigations is in the morning, the subject not having left his bed and fasting: the rectal temperature is then in its most stable condition.

The temperature of the rectum has been continuously observed by means of a non-registering thermometer, shaped so as to permit the part bearing the scale to lie upon the front of the abdomen, when the bulb of the instrument is *in situ*. A similar straight instrument,[1] having its spiral bulb applied to the surface of the abdomen and securely fastened, has been used for watching the behaviour of the superficial temperature. The site chosen for observation was about the middle of the triangle bounded by the left Poupart's ligament and lines drawn from the extremities of this to the umbilicus. With due care the changes of temperature here observed may be regarded as indicating the kind, if not the amount, of the alterations taking place elsewhere.

For observation of the blood-pressure, Dr. George Oliver's hæmodynamometer has been employed. Two sorts of measurement have been made over the radial artery at the wrist, that which brought out the amplest vibrations of the indicator (here termed simply "Vascular pressure") and that which obliterated the movement altogether (denominated "Systolic impulse pressure.") In observing the latter the method adopted was to press the instrument slowly down on to the vessel until the oscillations of the pointer ceased to be visible: the reading could be checked by gradually reducing the pressure of the instrument until the movement of the indicator reappeared. Both these

[1] These instruments were made for me by Mr. C. F. Casella, of 13, Rochester Row, S.W.

readings give results considerably higher[1] than those obtained in the usual way by means of an armlet placed over the brachial artery and a mercurial manometer: they cannot be regarded as giving absolute values of the blood-pressure but may be useful as showing relative changes taking place in the same individual within a short period of time.

The pulse-rate was taken in half-minute counts and doubled.

In an attempt to compound the observed changes of the blood-pressure with those of the pulse-rate the sum of the two pressures measured at the same time has been multiplied by the co-existing pulse-rate, and the resultant (for the sake of convenience termed "Kardiobars") has been taken as a rough guide to the amount of energy being expended by the heart during the given period. These calculations bring out some suggestive results.

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[1] In a few comparative tests my measurements came out at 23 per cent. higher for the point of amplest vibration, and 80 per cent. for the maximum pressure. The methods, however, cannot be regarded as simply comparable quantitatively.

THE DEVELOPMENT OF THE HOT CONDITION.

The following table summarizes the results of a number of investigations into the state of the circulation, and of the deep temperature made on six different occasions, on three boys during the development of the Hot condition. The initial pulse-rate and blood-pressures are given in the respective columns and the adjacent rows exhibit the changes per cent. brought about by the heat accumulation.

The pulse-rate rose in every instance, the vascular pressure fell in every instance, and, excepting one case, the systolic impulse pressure fell. The single exceptional rise of the impulse pressure was probably due to excitement. In the Hot condition this pressure behaves in a less regular manner than the vascular and is liable to occasional upward movements, owing probably to the discomfort arising from the heated skin.

Notwithstanding the increase of the pulse-rate the associated changes of the blood-pressure generally led to a fall of the kardiobaric result, and the figures suggest that in the Hot condition during a time unit the katabolic expenditure of the heart is ordinarily reduced in spite of the increased activity of the cardiac pulsation.

TABLE I.—SUMMARY OF CHANGES OBSERVED IN THE DEVELOPMENT OF THE HOT CONDITION.

	Duration of obs.—minutes	Temperature of Rectum		Pulse-rate		Blood-pressure				Kardiobars p.c. change
						Vascular		Impulse		
		Initial	Change	Initial	P.c. change	Initial	P.c. change	Initial	P.c. change	
1	90	99·1°	+ 0·1	79	+ 6	100	−15	140	− 14	− 8
2[1]	120	98·6	− 0·4	69	+ 6	102	− 9	150	− 3	0
3	40	99·8	− 0·2	83·5	+ 8	82	−14	140	+11	+ 10
4	75	99·1	− 0·6	83	+12	85	−41	140	− 28	− 25
5	72	98·8	+ 0·2	62·8	+ 6	105	−42	160	− 18	− 23
6[1]	15	99·0	?	66	+ 4	100	−10	140	− 14	− 8

Investigations Nos. 1 and 2 were made on a boy aged 14, Nos. 3, 4 and 6 on a boy aged 11, No. 5 on a boy aged 15.

The temperature of the skin ascends in the Hot condition and may approximate to the level of the rectal temperature: the amount of the elevation depends chiefly upon the previous state of the skin as regards warmth. In the second case the cutaneous temperature (97·2°) gained 0·8° before the outbreak of perspiration induced a fall (*cf.* chart

[1] In these the investigation was made in the morning, fasting.

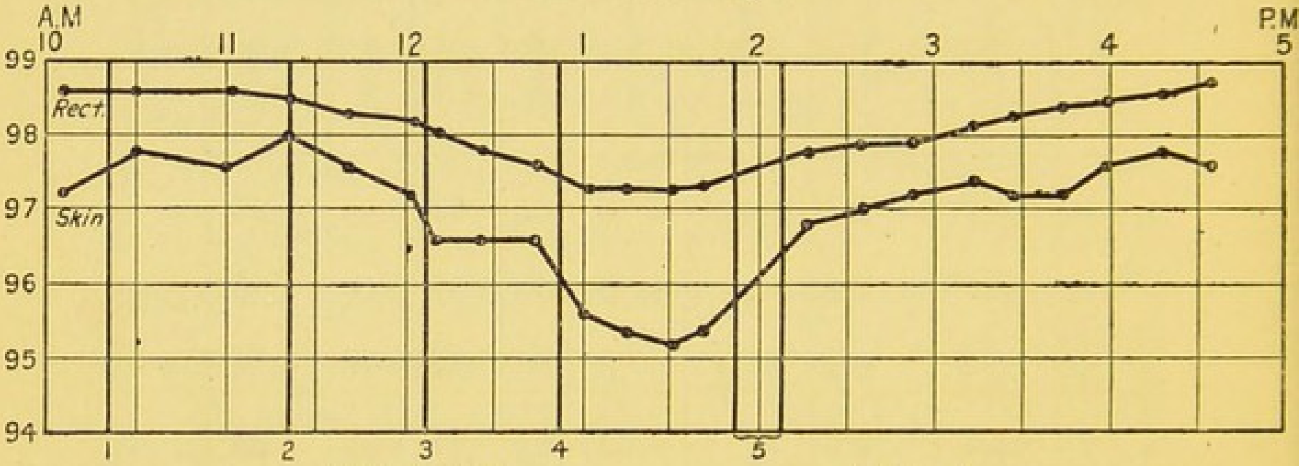
No. 1) and the chart No. 2 exhibits an ascent nearly twice as great. The cutaneous temperature has reached levels as high as 97° to 99°.

CHART 1.

HOT CONDITION: UNCOVERING: FOOD.

BOY AGED 14. Case 2 in Tables I and II.

Air T. 66—69°.



1. "So hot."
2. Perspiration.
3. Two blankets off.
4. Skin dry.
5. Breakfast.

The cutaneous temperature first ascended with accumulating heat: a fall of the cutaneous and the rectal temperature followed in association with perspiration, prior to the removal of the coverings; and a further and greater descent occurred after two blankets had been taken away.

Subsequently both temperatures rose after the ingestion of food.

The blankets were not replaced: the remaining coverings were a night-dress and one sheet. The boy complained of heat before the uncovering, when the escape of heat was impeded; but made no such complaint about 4 p.m., although the abdominal cutaneous temperature had risen to about the same level as before.

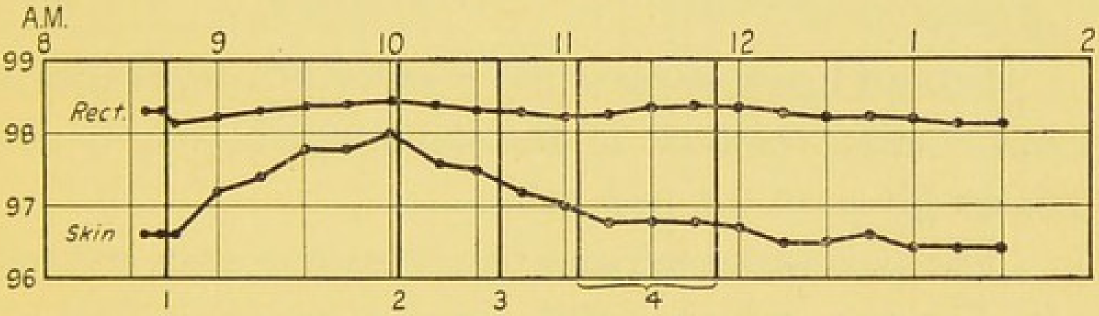
The rectal temperature may be made to ascend from heat accumulation. The elevation shown in the chart No. 2 was in part due to this cause and the slight elevations exhibited in two instances in the table may have been of this nature. In Case 2 perspiration led to a fall of the deep temperature and in Cases 3 and 4 the rectal temperature was falling from antecedent causes. These examples are of interest as demonstrating that acceleration of the pulse-rate may occur in the Hot condition apart from any warming, and even with a possible cooling, of the cardiac tissue (*cf.* also chart No. 15).

CHART 2.

HEAT ACCUMULATION.

SELF IN BED: FASTING.

Air T. 67—70°.



1. Turned to right side.
2. Too warm; turned to back, arms out.
3. Blanket removed.
4. Reading.

The cutaneous temperature gained 1·2° in one and a quarter hours, and sank after partial exposure and removal of a blanket.

The rectal temperature dropped 0·2 with change of position (? from shifting of the instrument), but regained this amount in half an hour, and added 0·15 more up till 10 o'clock. After partial exposure and removal of a blanket the temperature sank 0·2 in the next hour. The rise of 0·15 (from 11 a.m. till 12) I attribute to reading the newspaper (with associated movement of the arms). After the reading ceased the temperature fell 0·3 in the next hour and a half.

Other phenomena associated with the Hot condition may be mentioned. The subject complains

"I feel hot" and is tempted to put out his arms or to throw off the coverings. If he is not too wide awake there may be a tendency to drowsiness or sleep and later to wakefulness and restlessness. The respiration is quickened[1] and becomes shallow and sighs are frequently drawn. There may be a sense of oppression and of weakness which is speedily relieved by exposure to cold. The pulse is large and soft and may at times not be easily felt, and the quickened rate is irregular (*i.e.*, the counts vary considerably) and is liable to rapid acceleration on movement. The advent of the Hot condition may be hastened by the recent ingestion of food.

Table II summarizes the results of observations made after removal of the coverings in five of the cases given in the first table.

The pulse-rate fell and the pressures rose, except in Case 3, which exhibited the peculiar rise of impulse pressure during the development of the Hot condition : this pressure now reverted to its initial level. The diminution of the pulse-rate was very rapid, beginning immediately.

In three instances the observations were continued after the clothing in whole or in part had

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[1] This quickening of the respiration seems to be a distinct effort to aid the escape of heat and the sighing must have a similar effect. When lying still in bed I have reduced the rectal temperature as much as 0·2° by breathing deeply and quickly for several minutes in air having a temperature 38·5°.

TABLE II.—Effects observed after Removal of the Coverings in the Hot Condition.

	Air temperature	Duration of exposure—minutes	Rectal temperature change	Pulse-rate		Blood-pressure				Kardiobars p.c. change
						Vascular		Impulse		
				Previous	P.c. change	Previous	P.c. change	Previous	P.c. change	
1	70°	25	+0·1	84·5	−10	85	+23	120	+33	+15
2	68	23	−0·4	73·7	− 5	92	+19	145	+10	+ 8
3	61	34	−0·1	90·5	− 7	70	+14	156	−10	−10
4	57	6	+0·05	93·6	−17	50	+60	100	+50	+26
5	56	61	−0·2	67·1	−11	60	+83	130	+42	+37

been replaced and yielded the results shown in Table III. The changes actual (not per cent.) are given, and for the purpose of comparison the actual alterations induced by the previous uncovering are added.

In two cases the characteristic changes of the Hot condition began to reappear, the change of the pulse-rate being most marked in Case 4, which had the shortest period of exposure. In Case 3 (anomalous throughout) sleep supervened at the time the clothes were replaced and led to a fall of the pulse-rate as well as of the pressures. In this instance the exposure had been of longer duration than in the other two.

TABLE III.—EFFECTS OF RE-COVERING AFTER A SHORT EXPOSURE IN THE HOT CONDITION.

	Duration of obs. after re-covering	Rectal temperature change	Pulse-rate		Blood-pressure				Kardiobars	
					Vascular		Impulse			
			Change during exposure	Change after re-covering	Change during exposure	Change after re-covering	Change during exposure	Change after re-covering	Change during exposure	Change after re-covering
1	35	**−0·2**	− 8·8	**+1·4**	+20	**−20**	+40	**−30**	+2700	−3500
3	34	**−0·1**	− 7·1	**−5·4**	+10	**− 5**	−16	**− 5**	−2200	−2000
4	5	?	−16·3	**+7**	+30	**−15**	+50	**−10**	+3700	−500

The cutaneous temperature fell after removal of the coverings. In Case 2 the temperature 97·2° in the hot state (having already dropped 0·8° in association with perspiration while the body was covered) sank, after removal of two blankets, 1·8° in seventy minutes (chart No. 1). After replacement of the coverings, Case 1, which had lost 0·8° during the exposure, regained 0·4° in twenty-four minutes (chart No. 3).

The rectal temperature sinks during the exposure. This was the rule (at least at the commencement), but not always the case. Two instances showed a slight ascent. In Case 4 the temperature (as stated above) was falling from antecedent causes and the short exposure appeared to interrupt the descent. Case 1, in spite of the fact that free perspiration was going on when the coverings were removed, exhibited no fall but began to ascend towards the end of the exposure (chart No. 3). These results seem conflicting, but I regard the upward change as a genuine ultimate result of the exposure, and it will be seen to correspond with similar effects occurring when the exposure to mild cold takes place while the skin is in a warm (but not hot) condition.

After replacement of the coverings the rectal temperature showed a slight descent within half an hour well marked in Case 1 (chart No. 3). This early fall of the deep temperature is interesting, and has a close relation with the simultaneous warming of the skin. It is due to an internal redistribution of heat and corresponds with the slight preliminary fall of the rectal temperature sometimes found to occur in a warm bath. The superficial parts are being warmed at the expense of the heat of the blood and of the deeper structures. This lowering influence on the deep temperature exerted by a cold surface by means of the returning circulation of the blood is a fact of great importance in the economy of the body heat (*cf.* chart No. 6).

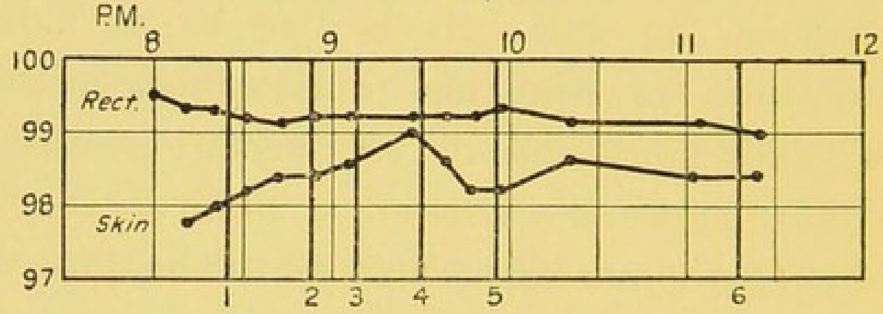
To sum up the changes of the body heat: The difference between the rectal and the cutaneous temperature reduced to the smallest amount in the Hot condition becomes increased during the exposure, for the skin is cooled more than the deeper parts, and if the rectal temperature proceeds ultimately to ascend the difference will be further enhanced. After replacement of the coverings the deep and the superficial temperature again approach each other, the rectal first falling and then rising (if heat accumulation again occurs), while the cutaneous temperature rises throughout and gains on the rectal.[1] Chart No. 3 illustrates all these changes except the final, the early stages of the Hot condition being reproduced after the re-covering and then soon becoming modified by sleep.

CHART 3.

HOT CONDITION: UNCOVERING: RE-COVERING.

BOY AGED 14. Case 1 in Tables I, II, and III.

Air T. 70°.



1. Perspiration beginning.
2. "Very hot."
3. Extra clothing.
4. Clothes removed.
5. Clothes replaced.
6. Asleep.

Dinner finished, 7.30 p.m.
In bed, 7.40 p.m.

The surface temperature (already high) gained 1·2 in one and a quarter hours, dropped after the uncovering and rose again after the clothing was replaced.

The rectal temperature, falling initially from rest, rose 0·1 before 9 p.m. (? accumulating heat) and stood. After the uncovering it stood for some time, then gained 0·1 towards the latter part of the exposure. After re-covering the temperature fell 0·2 (while the skin was becoming warmer), and finally was beginning to sink in association with sleep.

Perspiration made little impression on the rectal temperature, probably owing to the recent dinner—perhaps it arrested the incipient rise from accumulating heat.

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[1] Perspiration apparently may modify these events by depressing both the superficial and the deep temperature.

THE DEVELOPMENT OF THE COLD CONDITION.

Small changes of the pulse-rate, especially when slowly developing, are difficult of detection and necessitate a large number of observations for their satisfactory determination. A yawn may have a distinct influence, and a slight stretch a yet more powerful effect, in temporarily quickening the rate. The slowing of the rate after momentary stimulation, as observed in the immediately succeeding counts, may sometimes be quite marked—as after a slight cough or momentary movement of the body. The generally consistent results which emerge from the investigations recorded lead one to believe that the changes described below, though small, are real and characteristic.

Five investigations into the conditions obtaining when the body in a Neutral state was exposed to moderately cold still air were made on two of the boys (short of the induction of shivering). The changes observed are set forth in Table IV.

The vascular pressure, though now considerably higher than in the Hot condition, rose by percentages not greatly inferior to those in Table II, and the systolic impulse pressure (also now higher) was augmented, though to a less proportionate extent

TABLE IV.

Effects observed after Removal of the Coverings in the Neutral State.

	Air temperature	Duration of exposure—minutes	Rectal Temperature		Pulse-rate		Blood-pressure				Kardiobars p.c. change
							Vascular		Impulse		
			Previous	Change	Previous	P.c. change	Previous	P.c. change	Previous	P.c. change	
1	57°	30	99·0°	+ **0·2**	65	– **4·5**	87	+ **20**	150	+ **20**	+ 14
2	55	24	...	...	67	– **3·0**	90	+ **27**	163	+ **10**	+ 13
3	53	60	98·4	{ + **0·1** / – **0·1**	57·3	– **0·5**	102	+ **29**	149	+ **20**	+ 23
4	50	40	98·4	+ **0·1**	68·6	– **0·7**	86	+ **57**	172	+ **8**	+ 23
5	42	27	98·4	+ **0·1**	64·6	– **4·0**	90	+ **38**	210	+ **9**	+ 13

The subjects had had no food since the previous day, except in Case 2, when breakfast had been taken over an hour beforehand. Investigation No. 1 was made on the boy aged 11. Nos. 2 to 5 on the boy aged 15.

than was the vascular. The pulse-rate fell slightly, thus contrasting distinctly with the large falls observed on exposure in the Hot condition. In one or two instances after falling in the early period of the exposure the rate showed a tendency to a slight elevation later.

The changes observed after replacement of the coverings are shown in Table V. The actual alterations are given together with the changes induced by the previous exposure.

TABLE V.—Effects of re-covering after Exposure in the Neutral State.

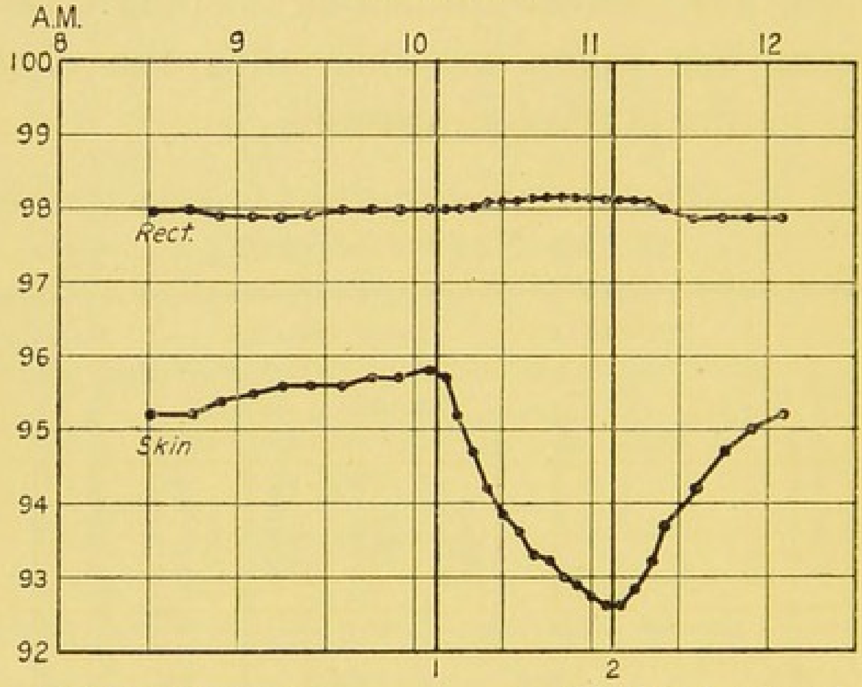
	Duration of obs. after re-covering—minutes	Rectal temperature change	Pulse-rate		Blood-pressure				Kardiobars	
			During exposure	After re-covering	Vascular		Impulse		During exposure	After re-covering
					During exposure	After re-covering	During exposure	After re-covering		
1	61	– 0·4	– 3	– 0·6	+18	– 15	+30	– 40	+2200	– 3500
2	19	...	– 1·9	– 1·1	+25	– 25	+17	– 20	+2300	– 3200
3	33	– 0·1	– 0·3	– 1·6	+30	– 27	+31	– 25	+3400	– 3400
4	39	– 0·1	– 0·5	– 4·9	+49	– 35	+15	– 17	+4200	– 4900
5	29	– 0·1	– 2·6	– 4	+35	– 10	+20	– 20	+2600	– 3200

The blood-pressures fell in every instance and the pulse-rate (which had already fallen during the exposure) now showed a *further* fall. On some occasions this early fall was succeeded by a slight elevation in the later period.

The changes of the rectal temperature have been stated in the tables, and the concurrent behaviour of the superficial and the deep temperature in similar circumstances is illustrated in chart No. 4.

CHART 4.

EXPOSURE TO MILD COLD IN NEUTRAL STATE.
SELF: FASTING: RECUMBENT IN BED.
Air T. 60°.



1. Clothes removed. 2. Clothes replaced.

The slight initial fall of the rectal temperature and the early elevation of the surface temperature were due to the recovery from the previous respective elevation and fall caused by the effort and exposure associated with placing the instruments.

After the uncovering, the rectal temperature gained 0·15 and the surface temperature fell 3·2.

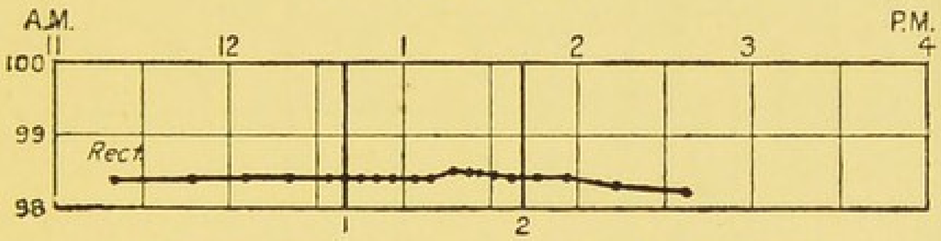
After the re-covering the rectal temperature sank 0·25 and the cutaneous temperature rose 2·6.

After removal of the clothing the rectal temperature stood for a time (it might first show a minute fall) and then ascended. In my own case, I have seen it rise 0·3° in twenty-six minutes (without shivering). After the re-covering the rectal temperature stood temporarily and then fell. Case 3, which during the somewhat prolonged exposure had fallen back to its previous level, showed, like the rest, a final fall; the deep temperature was thus reduced below its pre-exposure level. This final result occurred also in Case 1.

The observations from which the figures under Case 5 in the two first tables and under Case 3 in the fourth and fifth were collected are summarized on page 18, and the temperature chart is appended (No. 5).

CHART 5.

EXPOSURE IN NEUTRAL AND HOT CONDITIONS.
BOY AGED 15: FASTING.
Air T. 52—53·5°.

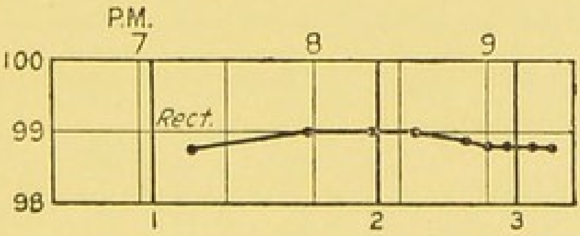


1. Uncovered. 2. Re-covered.

The rectal temperature was stationary for eighty minutes before exposure; during exposure rose slowly 0·1, then sank an equal amount; after re-covering fell 0·2 in the next hour.

Dinner finished about 5 p.m.: later reading in bed till 7 p.m.

Air T. 56·5°.



1. Lying quiet in gown under bedclothes. 2. Bedclothes removed. 3. Gown off.

The rectal temperature ascended 0·2 (? heat accumulation), then stood. After removal of the bedclothes the temperature sank 0·2.

SUMMARY OF OBSERVATIONS ON THE BOY AGED 15.

Time	Period--minutes	Pulse-rate		Blood-pressure				Kardio-bars	
				Vascular		Impulse			
		No. of obs.	Average	No. of obs.	Average	Average	No. of obs.		
A.M. 11.8 to 11.59 ...	51	16	56·5	2	100	155	2	14400	Fasting. Lying awake.
12.0 ,, P.M. 12.39 ...	39	19	57·3	8	101	148	8	14300	Awake, except a few minutes.
12.40 ,, 1.10 ...	30	15	53·9	7	122	175	7	16000	Uncovered.
1.10 ,, 1.40 ...	30	12	57·0	5	132	180	5	17800	,,
1.40 ,, 1.55 ...	15	10	51·5	3	108	166	3	14100	Re-covered.
1.56 ,, 2.10 ...	14	10	55·4	2	105	155	2	14400	,,
2.49									Drank egg and milk.
2.50 ,, 3.20 ...	30	18	58·2	4	110	172	4	16400	
3.20 ,, 3.50 ...	30	20	62·9	5	110	170	5	17600	
5.0									Dinner finished.
7.9 ,, 7.17 ...	8	6	62·8	1	105	160	1	16600	In gown under bedclothes.
8.0 ,, 8.21 ...	21	10	67·1	3	63	130	3	12900	Hot, perspiring.
8.21 ,, 9.8 ...	47	15	64·2	7	61	138	6	12800	Bedclothes off.
9.11 ,, 9.21 ...	10	4	59·5	3	95	175	3	16000	Gown off.

THE SIGNIFICANCE OF THE CHANGES OBSERVED IN THE STATE OF THE CIRCULATION.

THE VASCULAR PRESSURE.

The changes of the vascular pressure observed in these investigations were commonly more extensive than those of the systolic impulse. The variability of these measurements under thermal influences is illustrated by the following figures taken from the foregoing investigations.

Vascular Pressure.

	In Hot condition	In Neutral state	In Neutral state	In Cold condition
Boy aged 15 ...	60	105	102	132
Boy aged 11 ...	50	85	87	105

Systolic Impulse Pressure.

	In Hot condition	In Neutral state	In Neutral state	In Cold condition
Boy aged 15 ...	130	160	163	180
Boy aged 11 ...	100	140	140	180

It thus appears that in the case of a boy when the body passes from a Hot to a Cold condition the vascular pressure may be more than doubled and the impulse pressure may be increased 80 per cent. These figures cannot be held to exhaust the limits of such variation, for on no occasion was the investigation pushed to an extreme point in either direction.

The table also brings out the remarkable fact that the level to which the impulse pressure may sink when the body is in a Hot condition may be equalled, if not exceeded, by the vascular pressure when the body is under the influence of cold ; thus suggesting that when the body is cold the circulation of the blood within the radial artery may be carried on continuously at a level of pressure which is only momentarily attained during the climax of the systolic impulse when the body is hot.

Though the ratio of the vascular pressure to the impulse pressure when the body is in the Neutral condition, fasting and at rest, is liable to great variation, the vascular ordinarily ranging from 30 to 60 per cent. lower than the impulse pressure; inasmuch as thermal influences commonly affected the former in a more marked degree, heat usually reduced, and cold usually increased, its relative proportion. The elevation of the blood-pressure may commence almost at once on exposure of the body to cold. I have noted considerable changes of both measurements in the space of four minutes. The reverse changes after the re-covering may be more gradual. The behaviour of the vascular pressure was throughout more regular than that of the systolic impulse.

The elevation of the vascular measurement observed to result from exposure to cold in the investigations recorded must have been due, in so far as it was not owing to the immediate effect of thermal influences upon the tissues, to an *increased contraction of the muscular coats of the arteries, especially of the peripheral vessels*, for the pulse-rate commonly fell at the same time: conversely, the diminution of the pressure associated with accumulating heat must have been largely due to a *relaxation of these vessels*, for when it was most marked there co-existed a more frequent beating of the heart.

Such vascular changes are not confined to the cutaneous region, for on digital examination the radial artery gives distinct indications of alteration in the condition of its coats. In the Hot state the pulse here (as before remarked) is large and soft, and may at times not be easily felt. On exposure of the body to mild cold the size of the vessel appears to be reduced: the pulse becomes harder and the vessel more readily defined. These changes in their development may take place in an irregularly rhythmic manner, the artery being felt to contract under the examining finger and then to relax somewhat and again to contract until a more settled state becomes established. While the artery is actively contracting, the pulse-rate may, simultaneously, become accelerated for some beats.

The use of the hæmodynamometer brings out some minuter differences which the finger is unable to detect. In the Hot condition the indicator swings with an ample and beautiful sweep, it shoots up with the systolic impulse, immediately falls freely to rise with a large dicrotic wave and then drops in a group of diminishing oscillations. During the exposure to cold, when sufficient time has elapsed, the pointer, after reaching the systolic climax, remains elevated for an appreciable period, and the dicrotic wave is almost lost in a series of rapid quiverings which disappear as the indicator sinks to its lowest level: the whole vibration is less extensive than before. In the Hot condition the instrument responds readily at pressures considerably below the point of widest oscillation; in contrast to this, when the body is under the influence of cold, at the lower pressures no oscillation of the indicator is apparent and the pointer does not begin to vibrate until the pressure of the instrument is made to approach nearer to the existing level of the vascular pressure. Doubtless, alterations of the skin and subjacent tissues developed by the agency of heat and cold respectively, enhance these peculiarities of the pulse, but at most they can be regarded as contributory only, and there can be no doubt as to the reality of the vascular adaptation to thermal influences.

A double result is thus brought about by each agent—**heat leading to an enlarged peripheral and cutaneous area of circulation by relaxing the blood-vessels and coincidently inducing a diminution of the mean vascular pressure; and cold, by increasing the vascular constriction,**

reducing the field of irrigation at the surface and at the peripheral parts, and synchronously raising this pressure.

So long as the pulse-rate remains steady, or provided any alteration of it is in a direction opposite to that of the change in the vascular pressure, alteration of the latter manifestly points to modification of the vascular conditions.

THE SYSTOLIC IMPULSE PRESSURE.

The systolic impulse pressure, on the contrary, points more immediately to the force of the heart-beat, and with care one may often observe variations in the strength of individual contractions as transmitted by the blood to the radial artery at the wrist, for when in using the hæmodynamometer the obliterating pressure has just been reached, if the instrument be held steady for a short time one or two succeeding beats may manifest themselves and their effect on the indicator may not be equal, or perhaps a second trial of the instrument may show that the first ascertained pressure was too high: this is ordinarily the case when psychical disturbance of the heart's functions (as from excitement) is passing off.

Though the two measurements of pressure obtained over the radial artery in the conditions dealt with broadly followed a similar course, their behaviour was by no means exactly concurrent, for either might take precedence, whether in ascending or descending, and the respective amounts of change showed no regular relationship: sometimes they moved in opposite directions (*cf.* Case 3 in Tables I and II); besides, ordinarily, the impulse pressure was relatively greater in proportion to the vascular when the latter was at its lower levels (*cf.* Table, p. 19). The systolic impulse pressure therefore exhibits an independent character of its own; its nexus, moreover, with augmenting psychical influences appears to be more intimate than is that of the vascular pressure, for excitement seems to affect it more speedily. In view of these considerations it is fair to regard the observed rise of the impulse pressure, owing to the influence of cold, and its fall consequent on exposure of the body to warmth, largely as direct results of variations in the force of the ventricular contractions and these variations as due to a *reflex influence upon the heart itself* arising from the operation on the skin of thermal stimuli. This conclusion is supported by the associated alterations observed to take place in the pulse-rate (*c.f.* also p. 53).

THE PULSE-RATE.

The behaviour of the blood-pressure gives the key to the interpretation of the alterations noted in the pulse-rate.

In the Hot condition when the peripheral vascular channels are enlarged the heart beats more rapidly and with less force, the resistance to its output having been reduced, but it does not beat fast enough to maintain the pressure of the blood at its previous level, and the vascular pressure falls. The kardiobaric calculations suggest that the expenditure of energy by the heart may thus be reduced by more than 20 per cent. After removal of the coverings the exposure to cold by stimulating contraction of the peripheral vessels raised the vascular pressure, and the heart meeting with greater resistance reduced the number of its pulsations[1] while contracting with increased force. As the vessels were previously in a state of free dilatation the reduction of the pulse-rate was considerable.

In the Neutral state when the peripheral vessels would not be greatly dilated, the vascular contraction following exposure to cold would lead to only a slight fall in the pulse-rate, while raising the vascular pressure to yet higher levels. It is obvious that the work of the heart must have been increased, and if the kardiobaric sums are an indication of the amount of the cardiac katabolism it would appear that this may be increased by half as much again when the recumbent body of a resting boy in a hot condition is exposed to moderately cold still air for a sufficient length of time. During the later period of the exposure when the peripheral vessels would be more firmly contracting (as

[1] But not sufficiently to permit the pressure of the blood to remain at its previous level—the heart, therefore, was being stimulated to more energetic though less mobile activity.

indicated by the enhanced vascular pressure) the stimulating effect of cold apparently showed itself in a tendency to a slight acceleration of the pulse-rate (*cf.* table p. 18). As will be seen later the responsive power of the heart when the body is exposed to a cold wind (or to cold water) is much greater than the foregoing investigations in still air indicate.

After the re-covering the pulse-rate fell at first in every instance. This would be a ready means of lessening the cardiac katabolism before the more tardy vascular changes could bring about a reduction of the blood-pressure. Such a fall of the rate is most vividly brought out by the replacement of a small part only of the coverings. On one occasion after uncovering a boy I chanced to replace one sheet only: the effect on the pulse-rate was remarkable, the next counts dropping four beats per minute lower than any recorded during the preceding investigation. The re-covering after the exposure to cold thus appears to have brought about a diminution of the katabolic activity of the circulatory apparatus in three ways; by lessening the number of the pulsations of the heart and by reducing the contracting force of both the heart and the blood-vessels.

At a later stage after the replacement of the coverings a slight elevation of the pulse-rate was observed in some instances. By this time the vascular pressure had dropped considerably, and as doubtless the arterial relaxation would now permit some enlargement of the channel and an easier passage of the blood, the heart could slightly quicken its beating to adjust the circulation to the newly established state of the vessels without necessitating an increased katabolic expenditure. The stage in fact marks the initial development of those changes which when more advanced have been seen to characterize the hot condition.

The changes of the circulation which have been described, plainly connote important functional results in regard to the discharge of heat. In the Hot condition there will be an increased capacity for discharging heat from the body when in a hotter environment,[1] for the blood is brought nearer the surface and the acceleration of the pulse-rate involves a more rapid current. Cold will reverse these processes by greatly reducing the pulse-rate and also by cutting off the supply of blood to the skin, and thus the body will endeavour to conserve the internal heat.

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[1] The amount of heat actually discharged is not necessarily increased.

REDISTRIBUTION OF INTERNAL HEAT AFTER EXPOSURE TO COLD.

The chart No. 6 well illustrates the powerful influence which coldness of the superficial and remoter parts may exert upon the rectal temperature when these are being warmed by the returning blood after exposure of the body to cold. Some loss of heat, especially in cold weather, is commonly associated with the placing of the instruments. Hence on this occasion the abdominal surface temperature was unusually low at the beginning of the investigation. This explains the early elevation of the cutaneous temperature, which took place in spite of the greater exposure associated with going out into the open air. The instruments had been *in situ* for over twenty minutes before the observations were begun. On each occasion of walking after the exposed ride the rectal temperature fell and the surface temperature ascended thus :—

1st occasion	...	rectal − 0·2	...	cutaneous	+ 0·5
2nd ,,	...	,, − 0·5	...	,,	+ 2·4
3rd ,,	...	,, − 0·65	...	,,	+ 0·8

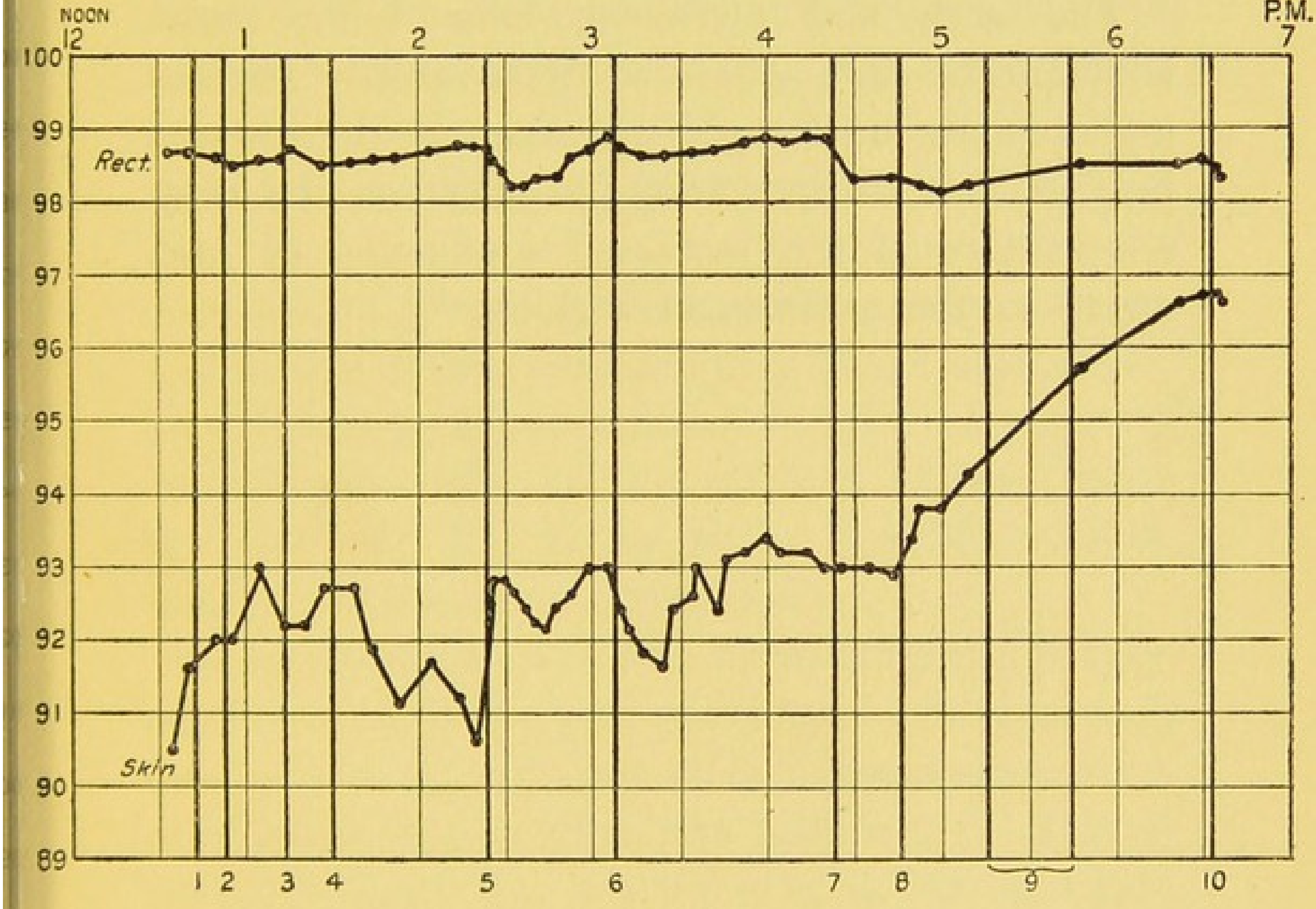
On the second occasion of walking (which occupied about three quarters of an hour) the rectal

CHART 6.

Continuous Observation of the Superficial and Deep Temperatures under Various Conditions.

Self.

Open-air T. 11.50 a.m., 27°; 4.56 p.m., 33°.



1. Went out of doors.
2. Riding on outside of electric tram.
3. Walking.
4. Riding on outside of electric tram.
5. Walking.
6. Riding on outside of electric tram.
7. Walking.
8. At home.
9. Meat tea.
10. Went up to bedroom.

temperature after the initial fall began to ascend in the later period. Such is the typical behaviour of the deep temperature according to my observations during a walk if the weather is cold and the exercise is of sufficiently long duration. The early fall of the superficial temperature on this occasion was due to a cold wind.

The early and increasing falls of the rectal temperature here observed were chiefly due, in my opinion, to the redistribution of the internal heat at first overpowering the effect on the deep temperature of the increased production of heat owing to the exertion of walking.

EQUILIBRATION OF LOSS AND PRODUCTION OF HEAT.

The rectal temperature need not at any moment represent the balance between the total amount of heat being produced and discharged. Apart from the consideration that there must inevitably be some delay between the production and the discharge of heat, equilibration may be postponed owing to the comparative thermal independence of the skin, as well as to internal redistribution of the heat of the body following *after* exposure to cold. Hence the mutual relationship of the amounts of heat being produced and lost at the same moment must be subject to considerable variation.

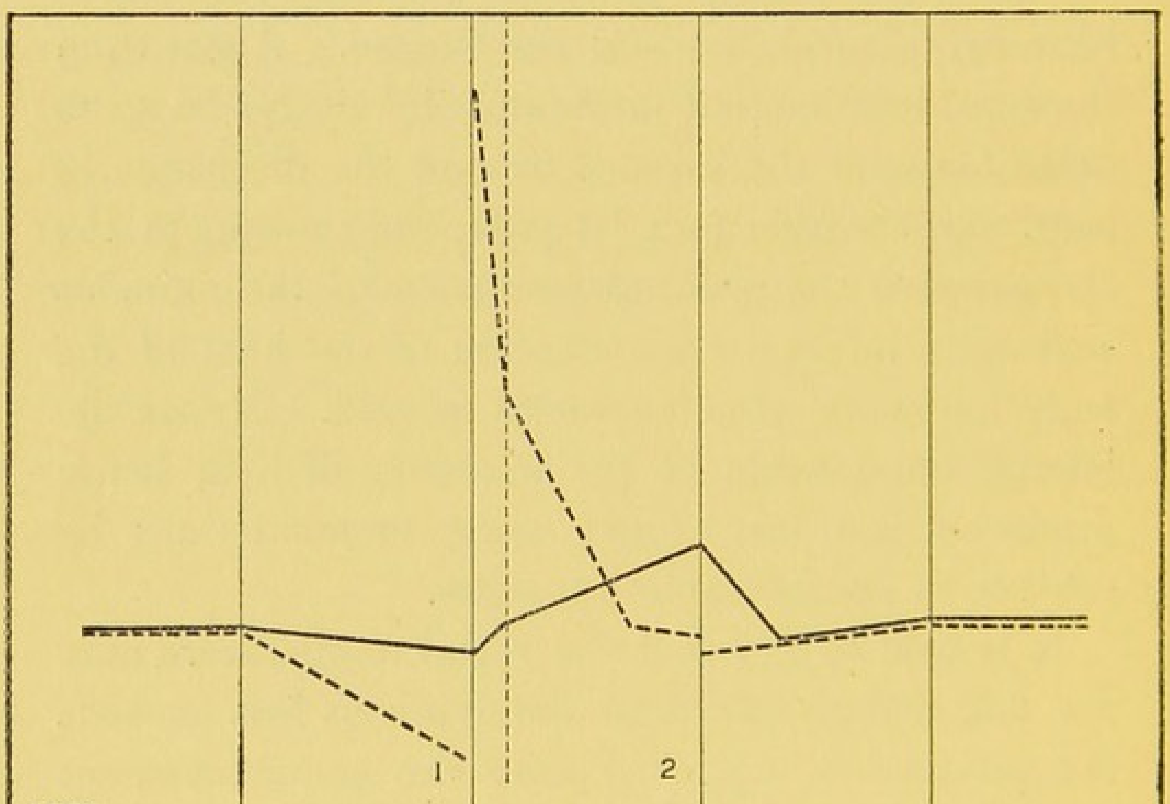
It is safe to say that the rectal temperature may not fall, though the total simultaneous loss exceeds the production, *e.g.*, just after the commencement of exposure to cold when the body is in a Neutral state (*cf.* Chart No. 4 and the early part of Chart No. 14). Again, the rectal temperature may be falling at a time when the total production probably exceeds the loss, *e.g.*, immediately after exposure to cold has ceased (*cf.* Charts Nos. 6 and 8).

The annexed diagram (based upon the observed changes in the state of the circulatory organs) is intended to summarize the probable kinds of variation in the production and in the loss of heat in the conditions which have been under consideration.

The associated changes of temperature are indicated in the table.

SUGGESTED CURVES OF THE PRODUCTION AND THE LOSS OF HEAT.

	In the Neutral state	During accumulation of heat under excess covering	During exposure to moderately cold still air	After re-covering, but not to excess	In the Neutral state



LOSS Equals	reduced	enormous at first, falls quickly and sinks slightly below neutral level	reduced at first, rises gradually to neutral level	
PRODUCTION	reduced proportionately less than loss	soon rises and ascends to a maximum	soon sinks, falls slightly below neutral level, then rises to neutral level	
CUTANEOUS TEMP. Steady	rises	falls rapidly, then slowly	rises gradually to neutral level	
RECTAL TEMP. Steady	rises slowly after cutaneous temperature	falls at first by direct loss from blood in skin; stands, then ascends. Falls if the exposure is severe	falls with warming of the skin	stands at lower level than originally. Total loss probably having exceeded total production

------- = LOSS ——— = PRODUCTION

(1) Marks the Hot condition.

The skin full of blood and perspiring is now adapted to discharge heat in a hotter environment, but as sufficient heat cannot escape accumulation results. The total volume of heat is distributed, as nearly as may be, equably throughout the body.

(2) The Cold condition.

The bloodless skin conserves the internal heat by preventing escape as much as possible. The total volume of heat consists of a warm inner kernel jacketed by a colder shell of skin lined with fat. The deep fascia through which the cutaneous blood-vessels gain access to the surface may be said to form the dividing layer.

The dotted vertical line marks the point when the heat accumulated previously has been discharged, and when the heat-production may be supposed to have risen to its previous neutral level. Right of this line the diagram therefore corresponds with the changes presumed to be associated with exposure of the body when in the Neutral state and to follow the re-covering.

FURTHER OBSERVATIONS ON THE PULSE-RATE.

The investigations which have been described gave suggestive but not pronounced indications of the influence of a cold environment in quickening the heart-rate ; it may be of interest to recount the steps by which this influence, which may be very powerful, was further traced out.

Two series of observations on the pulse-rate and on the temperature of the body, taken on one occasion in the month of August, when the temperature of the room in which the investigation was made ranged between 68° and 71°, and on the other, in January, when this temperature varied between 46° and 50°, exhibited a striking difference in regard to the pulse-rate. The figures were as follows :—

Pulse-rate : Averages of Twelve Counts in an Hour. Sitting throughout.

August		January	
P.M.		P.M.	
2.5	Dinner finished	2.45	
4—5	54·6	5—6	73·8
5—6	53·1	6—7	74·5
6—7	52·4	7—8	69·0
7—8	50·6	8—9	68·9
8—9	50·3	9—10	68·0
9—10	49·0	10—11	66·7

During the periods covered by these observations the rectal temperature and the temperature of the surface of the abdomen ranged between the succeeding levels :—

	August		January
Rectal temperature ...	98·5°—97·7°	...	99° —98·0°
Surface „ ...	97 —96·5	...	97·4—96·4

and exhibited respectively a broadly similar course on both occasions. I inferred that the quicker pulse-rate observed in January was due to the stimulus of cold.

This conclusion was shortly afterwards tested by observations taken at the Kew Gardens, inside and outside the Palm House, the temperature of the air on the occasion being 69° within the house and 44° in the open, where a cold northerly wind was blowing. A slight initial fall of the pulse-rate was detected immediately after entering the Palm House, but the rate so speedily mounted owing to the warmer environment as to preclude the test of a general average. A number of counts were then made in the open during some twenty minutes, and it was found that when a keen whiff of wind sprang up the rate was suddenly raised from 70 per minute to 100, and that as the wind waned the rate fell to near its previous level, and the accelerating influence of the wind was plainly demonstrated by testing the pulse-rate when the body was exposed to the wind and when it was sheltered therefrom by the trunk of a tree. The rate responded at once with stepping aside from the wind into shelter and *vice versa*, and individual half-minute counts were raised by a fresh whiff of wind or lowered during a lull.

A summary of observations taken on different occasions in winter and in summer is given in the table following :—

	Air temperature	Number of counts	Average Pulse-rate	
			In wind	In shelter
Standing—				
North wind ...	44°	5	87·2	77·6
		8	84·5	73·5
Fresh breeze ...	65	5	72·8	68·2
		5	82·4	66·8
Sitting—				
High N.E. wind...	37	4	...	66·5
		4	95	
		4	...	76
Cool sea breeze ...	70	10	76·2	61
		10	80·6	61·6

The rapidity with which the heart may respond to the influence of a cold wind is illustrated by the following counts :—

Standing. Air Temperature 42°. N.E. Wind in Gusts.

1st 15 seconds.			2nd 15 seconds.	
22	...	...	22	Lull.
22	...	...	23	„
22	...	...	30	Wind in 2nd 15 secs.
32	...	...	31	Wind.

Here a rise of 8 beats (36 per cent.) took place in the space of a quarter of a minute.

The pulse-rate was also tested inside and outside a moving vehicle, and some of the results are appended :—

Sitting	Air temperature	Number of counts	Average Pulse-rate	
			Inside	Outside
Travelling on electric car	42°	9	75·5	100
	61	11	76·7	
		12	...	81·3
Riding on horse 'bus	39	7	79·4	96·0

It is interesting to note the rapid fall in the pulse-rate which may occur as the vehicle comes to a standstill when one is sitting in the open.

Successive Counts taken Sitting Outside :—

Air temperature 42°.

Horse car	½ min. counts	Electric car	½ min. counts
Car in motion ...	47	In motion ...	50
Car standing ...	44	Standing ...	50
" " ...	37	"	46
" " ...	33	"	36

With continued exposure to a cold wind there is a tendency for the pulse-rate to rise progressively. The same phenomenon may appear during a ride in an open motor car. I have thus observed the pulse-rate mount gradually from 90 to 100 to 112 to 120 per minute in the lapse of about an hour and a half. On one occasion, when facing a keen wind in winter, I recorded the astonishing rate of 75 in the half-minute. It is possible that oscillation of the car rendered the observation erroneous; it may be remarked, however, that there had been a progressive rise on this occasion from 47 per half-minute and several counts over 70 were made.[1]

With such figures may be contrasted some observations taken when the body was sheltered in a moving railway carriage. In an express journey I have found the pulse-rate steady at about 72 per minute.

When the vascular system is firmly contracting owing to the agency of external cold, the usual variation of the pulse-rate due to change of posture is reduced and may be almost obliterated.

No. of obs.	Air temperature 36°	Average pulse-rate
10	Standing inside electric car in motion ...	82·6
10	Sitting ,, ,, ,, ,, ...	82·0

The postural difference here was less than one beat per minute, in spite of the fact that a considerable amount of increased effort was required to maintain a steady position in the erect posture owing to oscillation of the moving car.

This contrasts strikingly with the enormous

[1] When standing shortly after leaving the car some involuntary muscular twitching was observed, and the pulse-rate was found at the same time to have fallen to 74 per minute. When exposure to cold is sudden and pronounced the muscular response may be immediate, but if the exposure is gradual and prolonged, although marked changes of the pulse-rate may occur during the exposure, obvious involuntary muscular responses may not show themselves until after the exposure has ceased and when the pulse-rate has fallen.

changes that may occur when the vessels are relaxed by heat: the rate may be more than doubled immediately on standing up after lying in a hot bath.

A cold wind may quite overwhelm postural influences and cause a higher pulse-rate while the body is sitting than when it is standing in shelter, though the external temperature be the same.

No. of obs.	Air temperature 60°	Average pulse-rate per min.
5	Standing partly sheltered	91·6
5	,, in wind	112·4
5	Sitting in wind	111·6

Several of my observations indicate that the per cent. accelerating effect of wind is greater when the body is sitting than when standing. If this should prove to be the case it suggests that the circulatory apparatus is called upon for a proportionately greater effort when the muscles are less active.

Some observations of the associated changes of the blood-pressure and of the pulse-rate during exposure of the body to a cold wind were made upon myself on a very cold day in the month of February when a high north-east wind was blowing. The shelter was an unwarmed conservatory. There was no shivering, but some involuntary spasmodic movements occurred after the final return to shelter.

SITTING. AIR TEMPERATURE, 37°.

Air temp. 37° sitting	Minutes	Blood-pressure				Pulse-rate	
		No. of obs.	Vasc. average	No. of obs.	Syst. impulse average	No. of obs.	Average
Inside ...	10	6	169	6	250	—	—
Outside ...	9	4	187	4	277	—	—
Inside ...	15	4	176	4	260	4	66·5
Outside ...	15	4	190	4	272	4	95
Inside ...	21	4	173	4	242	6	70

The total average results of these observations come out at an increase on exposure of 8 per cent. in the vascular pressure, of 9 per cent. in the systolic impulse pressure, and of 39 per cent. in the pulse-rate. If these figures be compared with those of Tables II and IV, it will appear probable that most of the elevation of the blood-pressure following exposure of the body to cold, takes places before the pulse-rate shows any marked acceleration, and if the observations may be trusted, it appears that the power possessed by the heart of augmenting the pressure of the blood by increased output is comparatively feeble.

In still air at the temperatures which commonly prevail in this country, the effect upon the heart-rate of thermal influences may be very considerable. The investigations which led to the recognition of the distinct power of cold to accelerate the pulse-rate may be adduced in support of this statement. In January, the air temperature being about 48°, the pulse-rate during a period of six hours averaged

35 per cent. higher than in August, when the temperature was 70°. That such differences were not of an exceptional character is shown by the following figures based on observations taken within doors on five days in winter and in summer respectively. The counts were made upon myself in the morning after dressing, fasting, and in the recumbent position.

January			August
	Pulse-rate		
Air temp.	Average of 10 counts	Average of 10 counts	Air temp.
42·5°	61·1	52·8	66°
42·5°	59·9	52·3	64°
42.5°	60·7	52·7	65°
40°	58·7	54·1	65°
42°	59·5	54·2	64·5°
General average	59·9	53·2[1]	

[1] 53·4 was the average result of similar counts on twenty days in summer when the temperature of the air ranged between 60 and 68.

The rate in winter is seen to have averaged 6·7 beats per minute (or 12 per cent.) higher than in summer.

The pulse-rate may thus be raised or lowered both by heat and by cold according to the existing conditions. If the heart-rate is being stimulated to acceleration by cold, warmth will first reduce the rate by removing the stimulus of cold, and subsequently the rate will rise with relaxing vessels: cold will now reverse these processes.

In temperate climates, the influence of the sun and of wind will be in opposite directions. I have made a number of observations on the effect of sunshine and am satisfied as to its power of quickening the pulse-rate, *e.g.*:—

Shade Temperature 85°. Sitting.

Number of observations		In sun		In shade
10	...	77·8	...	74·8
10	...	78·0	...	74·8

The effect even of a passing cloud, by sheltering from the sun's rays, may be discernible, and the reducing influence on the pulse-rate of a whiff of wind in hot weather is also recognizable (vascular contraction). Needless to say such investigations should be made with due care and when the circulation is in a quiet state.

Rain, which cools the air, may be expected to lower the rate in hot weather, but I have not tested the point.

In warm weather, the pulse-rate, when one is sitting inside a closed moving tramcar, may be higher than when riding exposed to the air; but the shade within, on a sunny day, when the doors are open, may render the environment cooler than on the outside, and I have also records showing a lower rate within. On one occasion when I was travelling on an electric car in warm weather, the shade temperature being 76°, the influence of heat upon the pulse-rate was strikingly manifested, for the rate within the car, 75·5 per minute while the door was open at the front, mounted at once to 86·5 when the doors were closed.

When fainting occurs simply from a warm environment, one can hardly doubt that it is due to arteriolar relaxation.

A great-coat curiously exerts an opposite effect upon the pulse-rate in winter and in summer. On a cold day in winter, especially when there is wind, the rate may be reduced by the use of an overcoat, the removal of which may be followed by a rise. In summer, on the contrary, a great-coat may quicken the rate (vascular relaxation), and this may fall when the coat is removed. These effects may be elicited by a few counts in suitable weather, but a number of observations on different days suffice to establish the facts.

OBSERVATIONS MADE WITH THE BODY IMMERSED IN WATER.

WARM AND HOT BATHS.

In a warm or hot bath, if the heat is not too great, the vascular pressure and the systolic impulse pressure both fall, and the pulse-rate in the recumbent position may be more than doubled. The phenomena resemble those found in the Hot condition and described above.

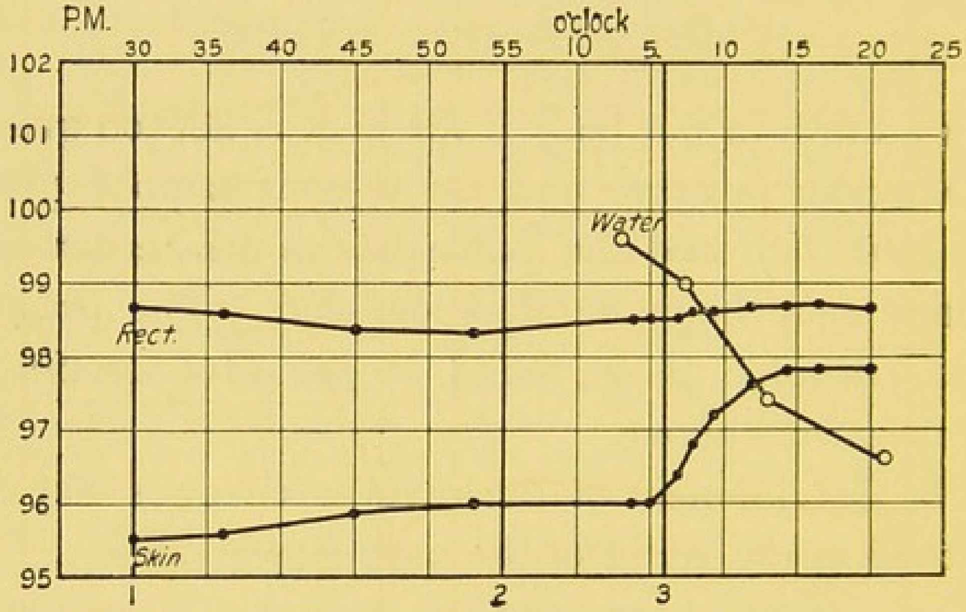
The development of the reverse changes may be watched as the water of the bath slowly cools.

The cutaneous temperature rises in a warm bath, and the rectal, which may show a slight preliminary fall (if the skin previously has been cold and the water is not too hot), ascends later. After a hot bath the rectal temperature falls and the surface temperature may for a time sink below the usual norm. These changes are illustrated in the charts Nos. 7, 8, 9, and 10.

In these investigations with the body in an aqueous environment the bulb of the surface thermometer was submerged (except chart No. 11) and the readings must be regarded as a compound result due in part to the heat of the water.

CHART 7.

Warm Bath. With Warm Skin. Self.



1. Sitting in rugs.
2. Came into bathroom.
3. Into bath.

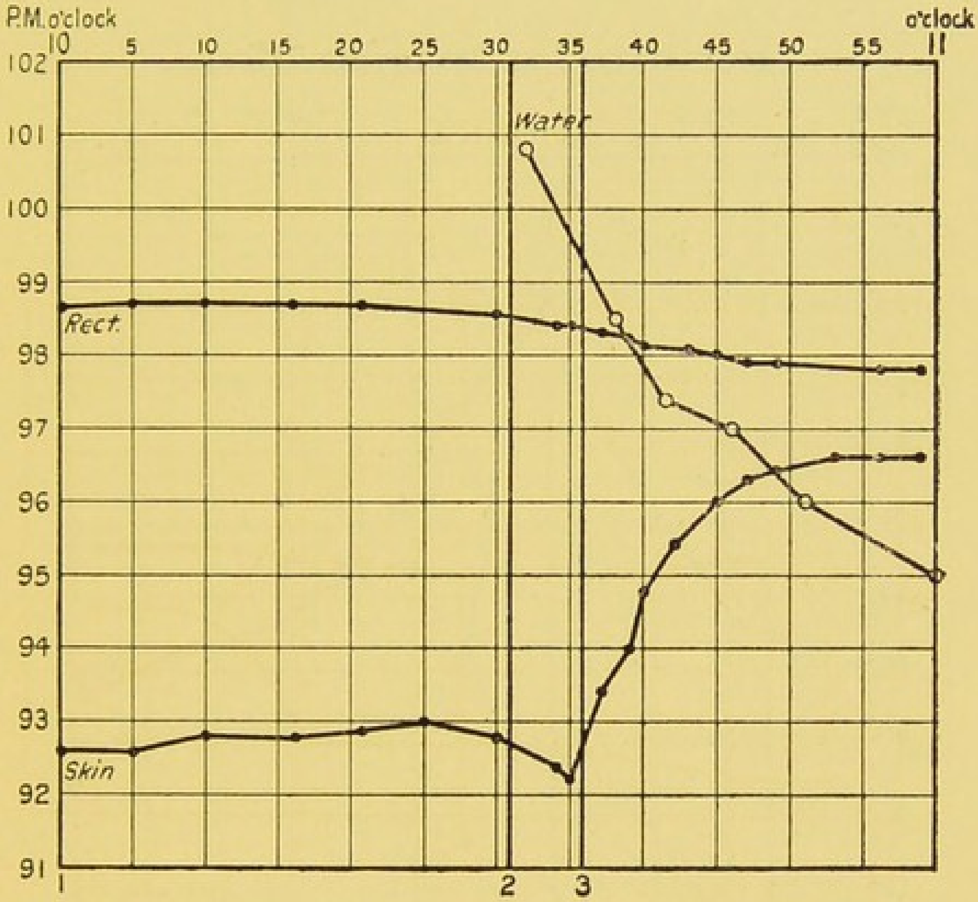
The rectal temperature fell 0·35 with rest (sitting), gained 0·15 from movement, and ascended gradually in the bath 0·15; was just beginning to fall at the end.

The surface temperature rose 1·8° in the bath and then stood.

The rectal exhibited no preliminary fall, the skin having been warm before the bath.

CHART 8.

WARM BATH. WITH COLD SKIN. SELF.



1. Sitting nude.
2. Stood.
3. Into bath.

The rectal temperature fell 0·1 with rest[1] (sitting); dropped 0·15 with standing,[2] and in the bath exhibited a fall of 0·5 in the first eleven minutes (while the cutaneous temperature was rising some 4°); it then sank 0·1 in the next twelve minutes (while the surface temperature became stationary).

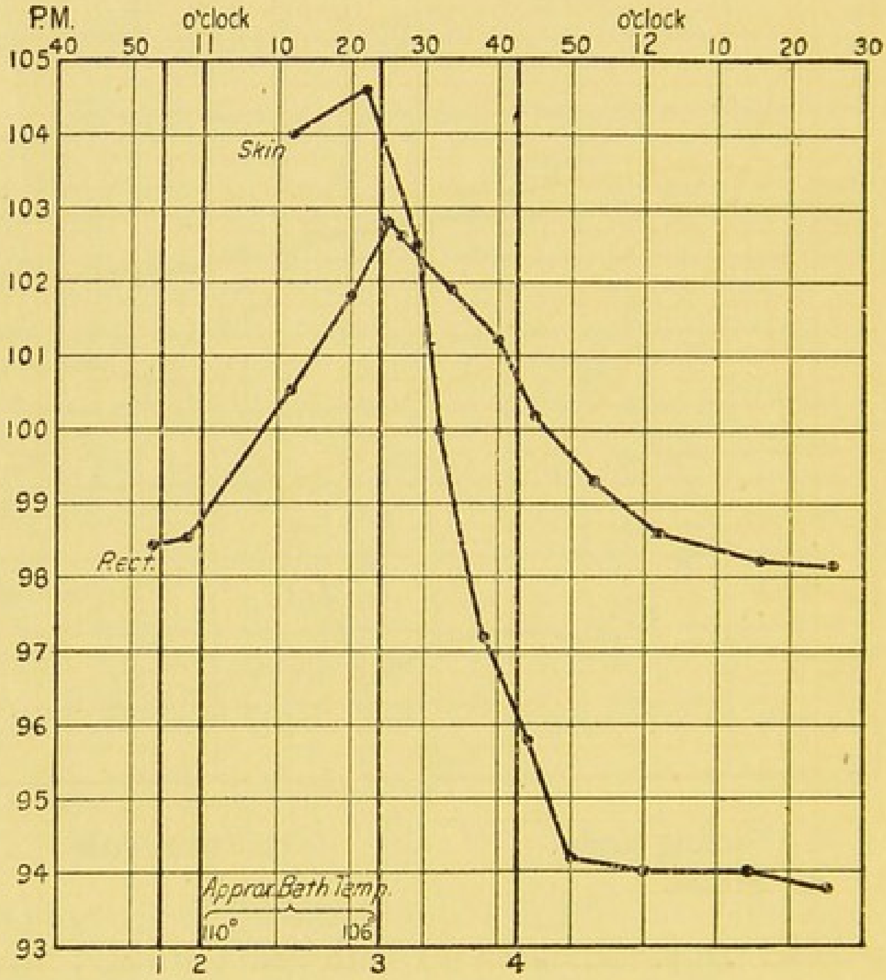
---

[1] Contrast this slight fall with that shown in the preceding chart. While the skin remains cold, the rectal temperature falls with difficulty.

[2] This fall was due, in my opinion, chiefly to a cooling of the blood, as it was driven into the colder superficial and extreme parts.

CHART 9.

Hot Bath; 24 Minutes. Self.



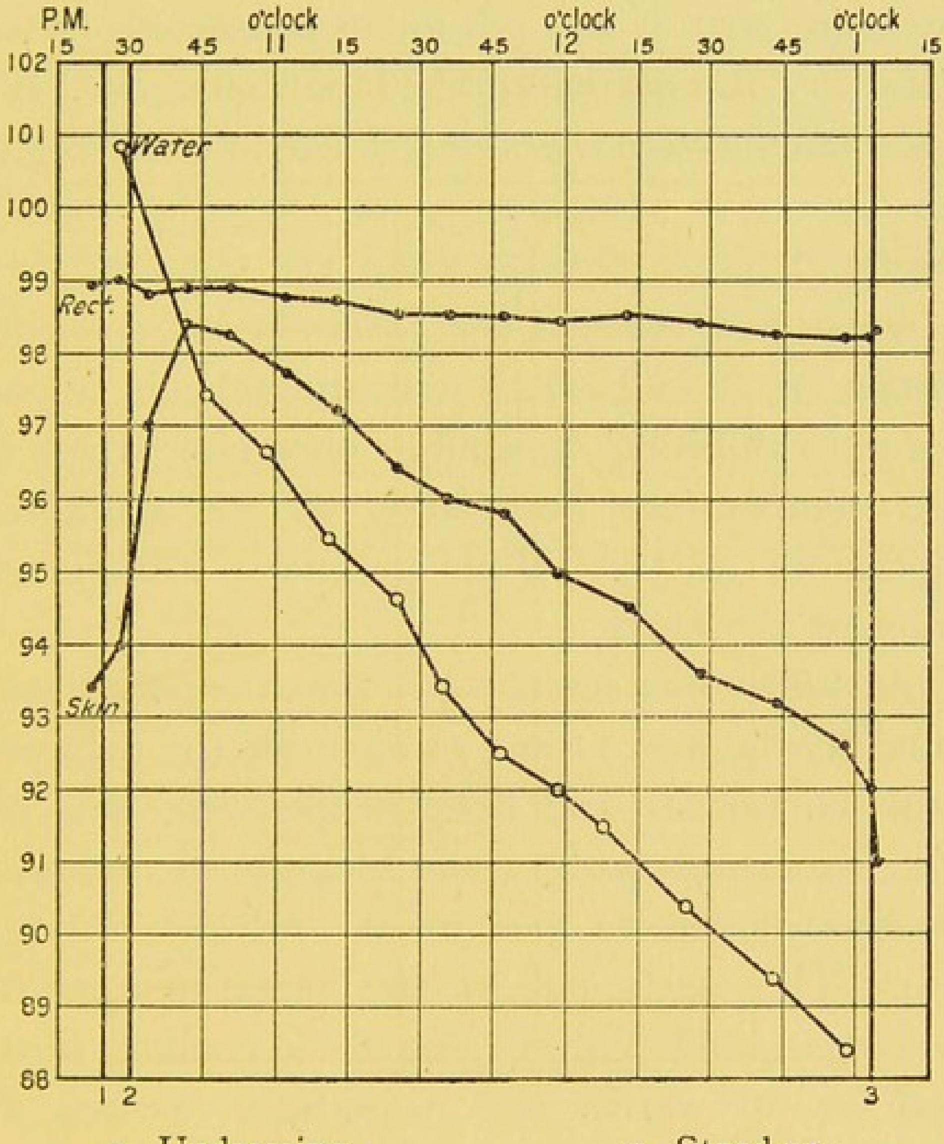
1. Undressing.
2. Into bath.
3. Out; standing.
4. In bed.

The rectal temperature was considerably raised and began to drop at once with standing out of the bath.

The surface temperature sank quickly after the bath and reached 1° below the usual norm before the rectal touched 99°.

CHART 10.

WARM BATH SLOWLY COOLING. SELF.



1. Undressing.
2. Into bath.
3. Stood up.

The rectal temperature showed a preliminary fall of 0·2 (while the cutaneous rose 3°) gained 0·1 (the skin adding 1·4) ~~partly from accession of heat,~~ stood for ten minutes at 98·9° after the water had passed below its level of temperature and then began to sink.

Near the end of the bath the fall of the rectal temperature was beginning to abate (development of heat conservation).

COLD BATHS.

In a cold bath of any intensity the muscular system is so readily stimulated to involuntary contraction that it was not found practicable to take satisfactory observations of the blood-pressure. Both measurements have been seen to rise in water cooling from 97° to a temperature of 89°, the vascular showing definite increase when the temperature of the water had reached 95° (cutaneous temperature between 97·2° and 96·4°) and the systolic impulse pressure exhibiting a similar elevation when the water temperature had fallen to 92° (cutaneous temperature 94·5°). Both pressures subsequently continued to ascend.

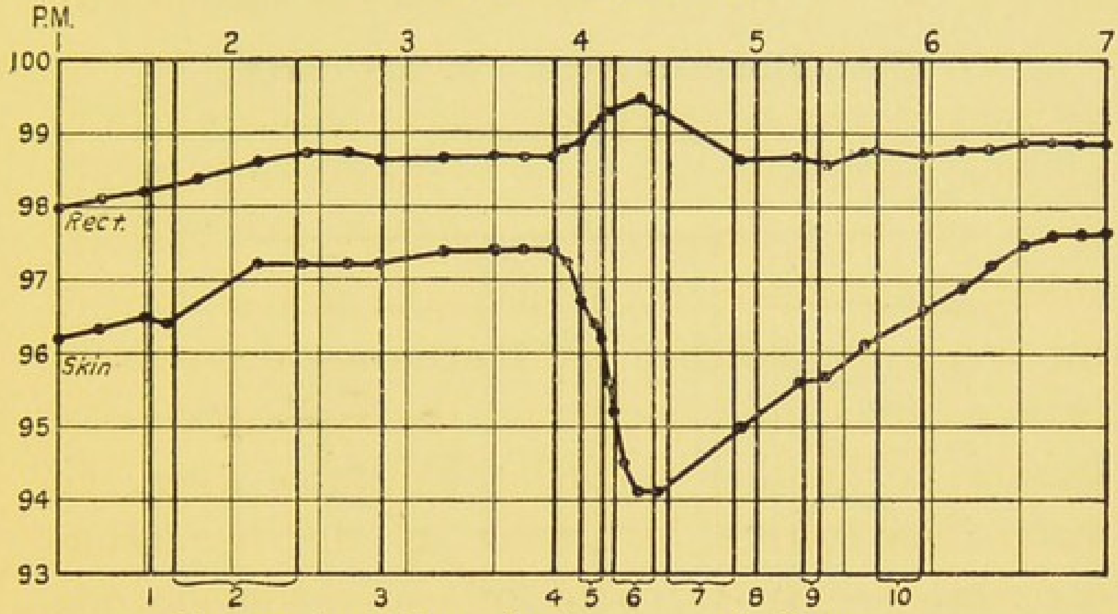
Cold sufficiently intense quickens the pulse-rate.

The charts Nos. 11 and 12 illustrate the behaviour of the superficial and deep temperature in a cold bath associated with some degree of voluntary muscular movement (as in an ordinary morning bath). The early fall of the rectal temperature following a cold bath is due to a cooling of the blood as it warms the superficial tissues, and resembles the occasional preliminary fall seen in a warm bath, and that which has been seen to follow replacement of the coverings after exposure of the body to cold air. A falling off in the production of heat after the bath cannot account for the disappearance of existing heat, but later when the existing heat has been suitably redistributed and the total discharge of heat has risen to an amount equal

CHART 11.

Cold Bath. T. 76°. Self.

Air T. 69·5—71·5°.



1. Sat up in bed, no food since previous day.
2. Dinner.
3. Lay down in bed.
4. Out of bed.
5. Bath (bulb of surface therm. not submerged).
6. Dressing.
7. With patient.
8. Sitting.
9. Interruption.
10. Tea.

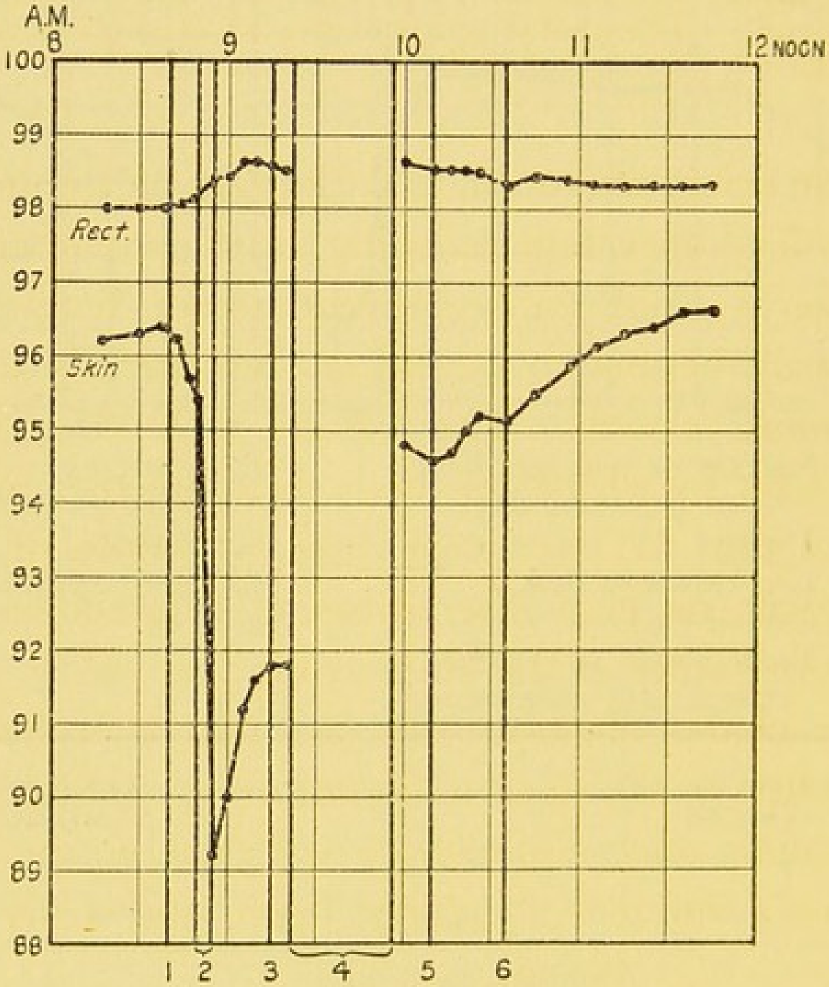
The Rectal Temperature.			The Surface Temperature	
Gained	Lost		Gained	Lost
0·2	...	Sitting up in bed ...	...	0·1
0·3	...	With dinner	0·8	
	0·05	Reclining	0·2	
0·25	...	Out of bed	...	0·7
0·3	...	With bath	...	0·5
0·3	...	Dressing	...	2·1
	0·7	Seeing patient ...	0·9	
0·15	...	Sitting, interruption...	1·1	
	0·05	During tea	0·5	
0·15	...	Sitting after tea ...	1·0	

The surface temperature on this occasion continued to fall for some time after the bath.

CHART 12.

Cold Morning Bath. T. 80°. Self.

Air T. 65—70°.



1. Out of bed.
2. Bath.
3. Dressing finished.
4. Breakfast.
5. Sitting after seeing patient.
6. Sitting after movement for a few minutes.

The rectal temperature gained—

0·15	Out of bed.
0·25	With bath.
0·2	Dressing.

and then began to fall; breakfast raised it 0·1. After this it sank gradually 0·3.

The surface temperature—

Lost	1·2	... ...	Out of bed.
,,	6·0	... ...	From bath.
Gained	2·6	... ...	Dressing.
,,	3·0	... ...	With breakfast.
,,	1·8	... ...	Gradually, sitting.

The slight exposure associated with movement caused the surface temperature to fall 0·2 on the first occasion and 0·1 on the second. The rectal temperature sank slightly on each occasion.

to that being produced, a slackening of the internal fires will co-operate in reducing the deep temperature.

After a cold bath the cutaneous temperature ordinarily begins to ascend at once, rapidly at first, then more slowly. The results depend upon the conditions to which the body is subjected, but the skin of the abdomen may take a couple of hours to recover its heat after dressing in summer when the temperature of the air is as high as 70°.

The charts illustrate the fact that a pronounced undulation of the deep temperature as well as of the superficial, may diminish or overwhelm the effect of minor influences acting upon the body heat (*cf.* also chart No. 6).

These charts also illustrate the close association that frequently exists between the changes of the deep and the superficial temperature; the rectal fall occurring while the cutaneous temperature was rising. In the chart No. 12 breakfast intervened and caused the rectal temperature to ascend slightly and delayed the impending fall. The temperature was just beginning to drop before the breakfast, and its subsequent fall was concurrent with the later elevation of the cutaneous temperature, which together with the deep temperature was ultimately maintained above the previous level in bed, thus exhibiting the elevating influence of food and posture on the superficial as well as the deep temperature. (A similar final result is shown also in the chart No. 11.)

Such a difference in the temperature of the skin of the abdomen when the body is in an active, and when it is in an inactive state is real, not accidental. My abdominal surface norm of temperature under clothing in the daytime is 95·85° (average of 20 observations) and in bed in the morning before rising 94·71° (similar average).

It is manifest that the elevating influence exerted on the rectal temperature by food or posture will be greatly affected by the existing condition of the skin: if this is cold part of the increased heat will be utilized in raising the cutaneous temperature and the rectal rise will be correspondingly less marked.

REFLEX ACCELERATION OF THE PULSE-RATE BY COLD AND HOT WATER IN MOTION.

On one occasion when I was taking a hot bath, which was rapidly cooled by successive additions of cold water ready prepared in large cans, it was found that the stirring of the water (to equalize the temperature) affected the pulse-rate, and when the point was definitely tested a rate of 64 per minute in still water (temperature 88°) rose to 124 when the water was in motion, and fell back to 64·5 when the stirring had ceased.[1]

An investigation was then undertaken to trace the incipient development of such an effect in a hot bath allowed to cool slowly. The results are set forth in the accompanying chart (No. 13).[2]

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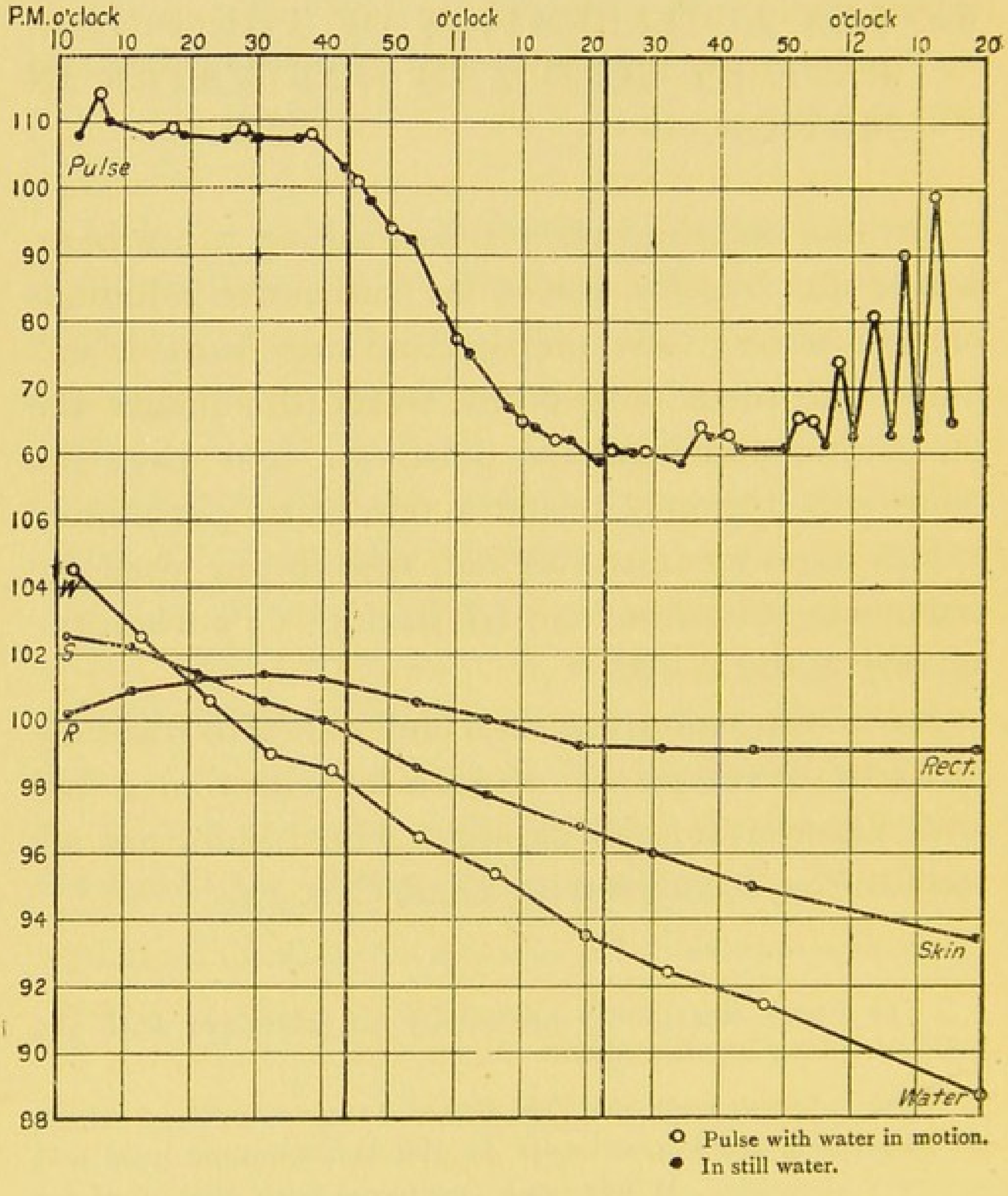
[1] The water was gently stirred by an attendant with the hand or a long wooden spoon.

[2] The observations of the water temperature in these investigations are approximate as the thermometer used was not very accurate. It has been compared with that used for the skin and the readings have been adjusted. Moreover a mass of water will not exhibit a uniform temperature unless kept in constant motion. When the investigations were undertaken I did not know the delicacy of the adaptability of the circulatory organs to outside thermal influences.

CHART 13.

Hot Bath Slowly Cooling. Self.



Sensation faintly cool with water in motion at 10.44 p.m.; became more pronounced later.

The pulse-rate having been raised by previous immersion in the bath for some twenty minutes, fell gradually (from vascular contraction) with each stirring soon after the rectal temperature had begun to sink, and when the water had become about 1·5° cooler than the skin; and the fall continued until the temperature of the abdominal surface had approximated towards its usual norm.[1] Thereafter acceleration of the pulse-rate owing to movement of the water began to show itself when the bath was some 3·5° colder than the skin and rapidly mounted to an increase of 50 per cent. when this difference had reached about 5°.

Towards the end of the investigation the rate in the still water shows a gradual slight ascent from permanent stimulation by cold. It is noteworthy that when the reflex stimulation of the heart-rate appeared, the rectal temperature had ceased to fall although the cutaneous temperature continued to sink. Conservation of the internal heat had become established.

A similar *reflex acceleration of the heart-rate by heat* occurs when the stimulus is sufficiently intense as is shown in the next chart (No. 14) which is based on observations taken in a cold bath made warmer by successive additions of hot water.

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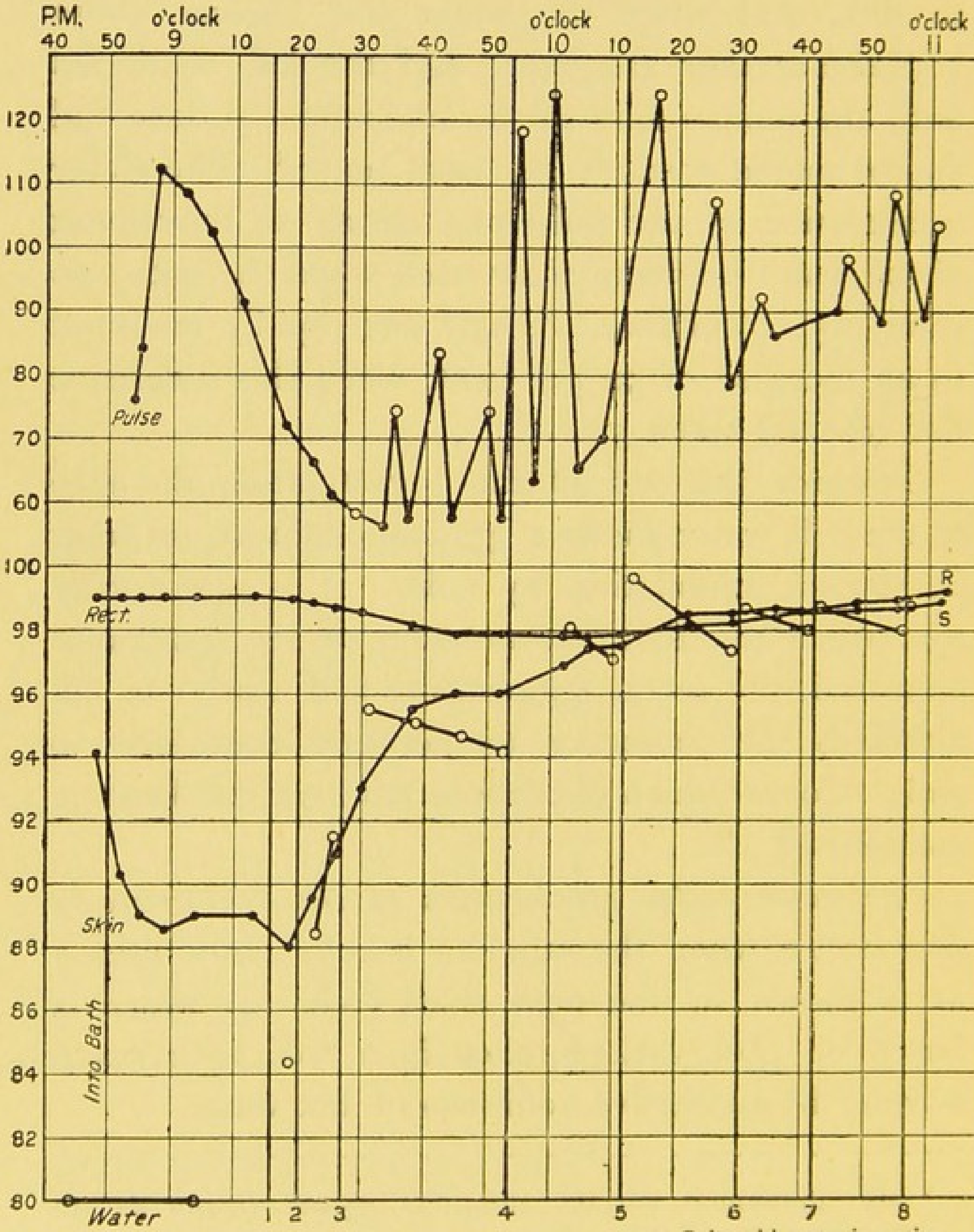
[1] My abdominal surface norm is 95·28° (mean of 40 observations, *cf.* p. 52). From a large number of observations of the surface temperature taken over different parts of the body I estimate that the entire surface has ordinarily in the daytime an equalized heat of about 93·5°.

CHART 14.

Cold Bath Warmed Quickly by Successive Additions of Hot Water (numbered 1 to 8). Self.



o Pulse with water in motion.
• In still water.

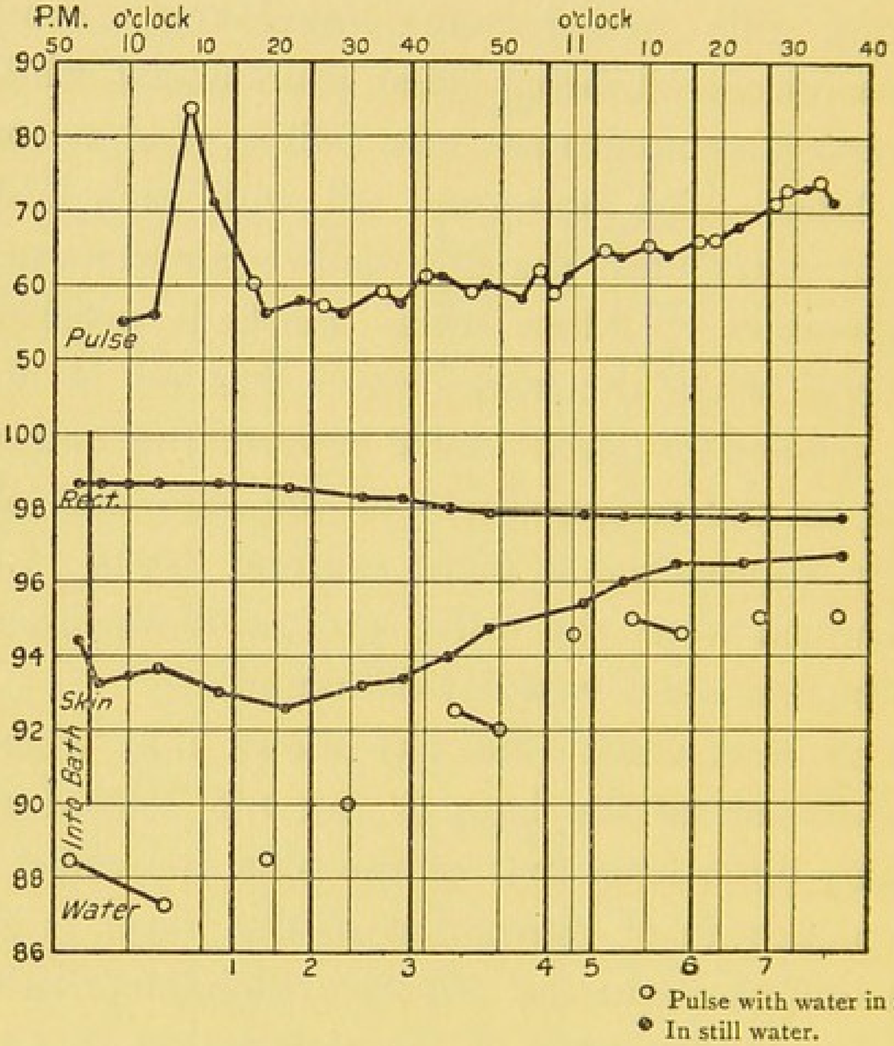
In the cold water the pulse-rate, speedily accelerated at first, dropped considerably after the skin had become accustomed to its new environment. During this period some involuntary muscular spasms occurred, being most pronounced while the cutaneous temperature was falling, and becoming less later. The pulse-rate fell with each addition of hot water until the skin had regained its normal temperature. After this, marked acceleration occurred when the warm water was set in motion and became less pronounced towards the end of the bath, as the temperatures of the skin and of the water approached a more uniform level. In the still warm water the pulse-rate gradually ascended (from permanent vascular dilatation).

The next chart (No. 15) shows that when the temperature of the bath (if not too cold) does not greatly differ from that of the skin the effect upon the pulse-rate of movement of the water is slight. But though slight the effects are characteristic and indicate the intimacy of the association that exists between the state of the circulation and the thermal environment of the body.

On this occasion the water (temperature 88°) while motionless was not cold enough to accelerate the pulse-rate, and the cutaneous temperature, after falling initially, speedily proceeded to ascend somewhat; but the stirring of the water at once caused the rate to rise 50 per cent., and at the same time elicited a response from the muscles. The next count after the stirring had ceased shows a rapid falling off, but is higher than the initial rates, the effect of the movement of the water not having fully passed away, as the reduction of the cutaneous temperature makes evident. The first warm addition

CHART 15.

COLD BATH WARMED SLOWLY BY SUCCESSIVE ADDITIONS OF HOT WATER (numbered 1 to 7). SELF.



diminished the pulse-rate in moving water, although the temperature of the skin now sank 0·4° lower than it had yet been, and some slight muscular reaction soon followed. With the next warm addition, the rate, while the water was in motion, fell still lower. At 10.34 there was a slight rise of the pulse-rate when the water was being stirred, but the water would have cooled somewhat in the lapse of eight minutes. The accelerations associated with the stirring up till now were due, in my opinion, to the diminishing stimulation of cold.

After the third addition the temperature of the water approached near to that of the skin (which was now approximating to its usual norm of heat) and the pulse-rate remained at the same level when the water came to rest that it had shown during the stirring. The now higher rate in the still water indicates, in my judgment, that enlargement of the peripheral channels had commenced. As the water became slightly cooler, stirring reduced the rate by one or two beats, owing to contraction of the lumen of the peripheral arteries which had just begun to enlarge.[1] When the cooling water had further stimulated the vascular contraction (for the rate in still water soon sank yet lower) and the temperature of the bath was about 2·5° below that of the skin, the stimulus of the colder moving water was strong enough to increase the cardiac rhythm by four pulsations a minute. The next (fourth) addition raised the heat of the water nearer to the cutaneous level, and the accelerating effect that had been due to cold disappeared, and as the water came to rest the pulse gained two beats from the returning vascular enlargement.

The fifth warm addition led apparently to the development of a slight reflex stimulating effect of heat when the water was in motion, and the next count in still water rose distinctly higher than the previous similar rates, indicating a further advance in the dilatation of the peripheral vessels. The cutaneous temperature had now approximated to 96° (rather above the usual norm), and the later slight warm additions led to further vascular enlargement. The last count shows a slight fall, doubtless due to returning vascular contraction in association with a cooling of the water.

It thus appears that when the body is immersed in water having a temperature approximate to the abdominal cutaneous norm, the skin also having a similar temperature, the circulatory apparatus is extremely sensitive to minute changes of the thermal environment whether in an upward or a downward direction.[2]

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[1] *cf.* the slight fall in the pulse-rate occurring on exposure of the body in the Neutral state to moderately cold still air as before recorded.

[2] From the charts it appears that the reflex stimulating effect of heat upon the pulse-rate may show itself (if the skin is sufficiently warm) when the temperature of the environment is very slightly *below* the abdominal cutaneous level. A

The temperature curves in the last two charts well illustrate the fall of the rectal temperature associated with a warming of the superficial tissues. It is obvious that the increased heat of the skin was at first derived chiefly from the blood-heat, for during most of the period of the rectal fall while the cutaneous temperature was concurrently rising, the skin on each occasion was warmer than the surrounding water.

The fall of the rectal temperature shown in the charts Nos. 10 and 13, and associated with a cooling skin, the temperature of which was above the usual norm, is of a different nature, and corresponds with the increased discharge of heat occurring when the body in a Hot condition is exposed to cold air and before conservation of the internal heat has become established. With this should be contrasted the steadiness of the rectal temperature, in spite of a cooling skin, when the cutaneous temperature was below normal (*cf.* the early part of charts Nos. 14 and 15, also the later part of charts Nos. 10 and 13).

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single observation, however, of the abdominal cutaneous temperature is but a partial guide to the general heat of the skin, and it may well be that the temperature of the skin of the limbs was at the time below the thermal level of the water.

CRITICAL CHANGES OF THE CIRCULATION IN A VARYING THERMAL ENVIRONMENT.

When the body is subjected to a slowly changing thermal environment, involving in one direction an acceleration of the pulse-rate due to dilatation of the arterioles, and in the opposite direction an acceleration arising from the stimulus of cold, the pulse-rate in the transition will fall to its lowest level and remain steady at this level for a period (lasting according to the rapidity of the external changes). If the change is from warmth to cold, I take it that the first lowest rate signifies that the preceding dilatation of the peripheral arteries has passed away, and that the last lowest rate is associated with a firmer contraction of the vascular muscles, but no further contraction of the lumen, the arterial vessels grasping the mass of the blood with a firmer grip. The first acceleration which succeeds marks a stimulation of the heart-rate.

The following table, based upon these assumptions, has been drawn up to exhibit the co-existent conditions of the superficial and the deep temperature of the body and of its thermal environment, together with the associated state of the pulse-rate, about the times when the critical changes of the heart-rate (in respect of acceleration due to the stimulus of cold or heat), and of the peripheral arteries (in respect of dilatation from heat or of contraction from cold) began to show themselves in five investigations of immersion in water. The cases in which the changes of the temperature of the water were more gradual have been placed first, as giving the more reliable results, and some latitude must be allowed in comparing all the figures, both on account of differences in the regularity and rapidity of alteration of the heat of the baths on the several occasions, and also on account of the fact that the various observations were being taken intermittently.

TABLE OF CRITICAL CHANGES.

Assocd. pulse-rate	Temperature of— Bath	Skin	Rectum	
	Deg. F.	Deg. F.	Deg. F.	STILL WATER SLOWLY COOLING.[1]
54	92	95	98·4	First lowest pulse-rate. Dilatation of peripheral arteries ceased.
60·6	91·5 90·5	94·5 93·6	98·5 98·4	First doubtful transitory appearance of acceleration from cold.
54	88·5	92·6	98·2	Last lowest count. Permanent acceleration from cold not yet begun.
				WATER SOMETIMES IN MOTION. *Slowly cooling.* (Chart No. 13.)
59	93·5	96·8	99·4	First lowest count. Dilatation of peripheral arteries ceased.
60·5	inter	inter	inter	First acceleration from motion of cold water.

[1] The observations of blood-pressure referred to on p. 48 were taken in connection with this investigation. The temperature chart is given on p. 47.

TABLE OF CRITICAL CHANGES.—*Continued.*

Assocd. pulse-rate	Temperature of— Bath	Skin	Rectum	
58·5	92·5−	96−	99·15	Last lowest count. Vessels more tightly contracting.
61	90·5	95	99·1	First acceleration in still cold water.
				Warmed slowly by successive additions. (Chart No. 15.)
56	87	93·6	98·55	Lowest count before first warm addition.
56	88·5	92·6	98·45	First lowest count after first warm addition.
56	90·5	93·2	98·2	Last lowest count. Acceleration from motion of cold water not yet ceased.
61	92·5+	94	98+	First appearance of dilatation of peripheral arteries in warmer water.
62	92−	94·8−	97·9	Last acceleration from water in motion (cold stimulation).
65	95+	95·4 96·0	97·85 97·8	Acceleration from water in motion (? heat stimulation).
				Warmed rapidly by successive additions. (Chart No. 14.)
56	95·5	93+	98·5−	First lowest count. Acceleration from cold ceased.
74	95·5	93 95·4	98·5 98·1	First appearance of acceleration from warmer water in motion.
57	94	96	97·9	Last lowest count. Dilatation of peripheral arteries in still water not yet begun.
63	98·5	96·9	97·85	First appearance of dilatation of peripheral arteries in still water.
				Cooled rapidly by successive additions.
64	90·5 90	93·6 92·8	99·8 99·7	First lowest count. Dilatation of peripheral arteries ceased.
76	88	90·6+	99·5+	First acceleration from cold water in motion.
64·5	87	90·4	99·2	Last lowest count. Acceleration in still cold water not yet begun.

The table indicates that while the critical changes in the circulation began to develop when the abdominal cutaneous temperature was not much above or below its usual norm, acceleration of the heart's rhythm from cold and arteriolar dilatation due to heat, did not begin nor pass off when the temperature of the skin reached definite and rigid levels. It is evident that acceleration from the stimulus of cold may take place when the cutaneous temperature is standing at various levels, and it is almost certain that such acceleration may occur, when the arterial vascular system is in different states of muscular contraction. The latter point, as it appears to me, is put beyond question by the behaviour of the heart-rate, when the body is suddenly exposed to somewhat severe cold, as in the investigation shown in chart No. 14. The heart was stimulated to its greatest activity in the first few minutes after immersion in the cold water, when the temperature of the skin was rapidly falling, but afterwards the pulse-rate fell off considerably, though the effect on the vascular system at its cutaneous and peripheral parts must now have become more pronounced. Should acceleration have been induced by stirring at this time, it must have been associated with more firmly contracting vessels.

After the first addition of warm water on this occasion, the cutaneous temperature sank to its lowest point and the pulse-rate coincidently fell.[1]

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[1] A similar coincidence has already been pointed out (*cf.* chart No. 15).

It appears, therefore, that the stimulation of the heart by cold is not simply connected with the actual temperature of the skin. This is supported by the observations of the pulse-rate and of the superficial temperature in summer and in winter given previously (pp. 34 and 35).

From the table it further appears that acceleration of the heart-rate from cold may occur when the cutaneous temperature is standing at a level higher than this may exhibit, when at another time distinct signs of some vascular dilatation are present. It is obvious that the critical cardio-vascular changes brought about by thermal influences have a close, if somewhat elastic, relationship with the temperature of the skin. The condition of the blood-vessels appears to be closely connected with the actual temperature of the skin ; thus, as long as the cutis remains cold, *i.e.*, definitely below the norm of temperature, the vascular muscles remain firmly contracting, the intensity of their contraction probably varying according as the thermal environment tends to elevate or depress the cutaneous temperature. On the contrary, the state of the heart (as regards acceleration by cold) appears to be more intimately associated with the passage of heat from the skin, and while such acceleration probably does not occur so long as the cutaneous temperature is distinctly above the normal, it is less immediately dependent upon the actual temperature of the skin than upon the rapidity with which the skin is losing heat—in other words, it depends rather upon the intensity of the irritation which the stimulus of cold is able to excite.

The condition of the skin as regards warmth thus appears to be a rough guide to the co-existent general state of the circulation in health in the resting or quiet state of the body. If the skin is cold the vascular system may be assumed to be contracting firmly ; if warm or about the usual level of temperature, a medium degree of contraction probably exists involving some slight enlargement of the diameter of the peripheral arteries; and if the surface is hot, and perhaps perspiring freely, some relaxation of the peripheral vessels is probably present. Further, the subjective thermal sensations may indicate the direction in which changes of the circulation are in progress should the body have been placed in a new environment, or indeed apart from external change should the sensations themselves exhibit a progressive alteration.

The skin performs two distinct yet intimately related functions in respect to the body heat—a physical and a nervous. Upon the physical condition of the cutis at any moment, in its relation to the external thermal environment, depends the immediate facility of the discharge of heat. The same factors contribute to determine the character of the afferent impulses ascending to the nerve centres, which preside over the thermogenetic and the thermolytic organs. The most important of these latter is the skin itself. Thus the physical state of the cutis at any moment is largely determined by its preceding, and will affect its succeeding, condition. But the nervous impulses are more immediately responsive to the thermal changes taking place in the skin than is its physical state in general, which requires an appreciable period of time for its modification. The skin, moreover, is subject to thermal influences operating from its internal as well as its external surface, and the reflex effects on the generation and the discharge of heat must therefore depend upon the resultant of all the component thermal forces whether acting from within or from without.

The Neutral state, when the cutaneous temperature stands about its normal level, appears to be that which is commonly most favourable to the continuous escape of heat. It is remarkable that the heat of the skin should be so nearly equal in summer and in winter, as indicated by the observations before given (p. 35). So long as the heat of the skin is maintained at the normal or at a higher level by internal causes, the colder the external environment the more rapid and free will be the escape of heat. Otherwise, the cutaneous circulation will become curtailed and the skin will assume a condition unfavourable to the passage of heat.

The table (p. 62) throws little light upon the immediate relationship of the rectal temperature to the state of the cardio-vascular mechanism. It is obvious that the circulatory changes must sooner or later affect the deep temperature because they exert such a powerful influence upon the discharge if not also upon the generation of heat. The reciprocal influence of the blood-heat upon the circulatory organs must be one of great importance, and in addition to the direct effect it is evident from what has gone before that an indirect influence may be exerted through the skin. The rectal temperature may be considerably affected, as has been seen, in consequence of a cooling of the blood as this irrigates and warms a cold skin. The heat of the blood thus powerfully affects the skin whenever the cutaneous vessels permit the fluid to circulate in this region, and then co-operates in originating the ascending nervous impulses. If, *e.g.*, the deep temperature has been elevated by a hot bath or by exercise, the heated blood travelling through the skin will be able, by this reflex action, to keep open the sluices to the surface for a longer period, and so enable the excessive heat to be discharged. At such a time the changes of the pulse-rate may appear to follow those of the rectal temperature.

CONCLUSION.

Summing up the results of a large number of observations, one is drawn to the conclusion that in a given thermal environment a certain corresponding equilibrium of the circulatory apparatus ultimately becomes established, comprising, **as regards the blood-vessels, a suitable degree of muscular contraction of their coats, and as regards the heart a suitable rate and force of its pulsations.** Besides determining the **pressure** and the **speed of the current**, these factors involve a corresponding **distribution, of the blood,** the proportionate amount of which may thus be made to vary in two regions, important from a thermal point of view :—

(1) The skin, the superficial, and the remote parts ;—the amount of blood here enabling the circulation to regulate the facility of the discharge of heat.

In view of the promptness with which the heart responds to thermal calls arising from the stimulation of wind, one cannot doubt that the sluices to the surface are similarly under ready control and that when wind accelerates the cardiac rhythm it simultaneously tends to curtail the supply of blood to the skin by specially stimulating the cutaneous vessels to contract more strongly, and so diminishing the area of irrigation at the surface, and that when the exposure to wind ceases and the heart proceeds to beat more slowly, the sluices to the skin enlarge, and the area of irrigation in this region again becomes more ample.[1]

(2) The arterial vessels;—the quantity of blood here according to its distribution determining the state of distension of the central vessels, and consequently the immediately available higher limit (apart from further increase of the vascular tonus) of the mean aortic pressure which a new acceleration of the heart's rhythm under the stimulus of cold can bring about, thus affecting the facility of the generation of heat by the heart, as well as the supply of blood to the other thermogenetic organs.

The diameter of an artery is not necessarily related to the strength of the muscular contraction of its walls; this being given, that will depend upon the amount of the contained blood—in other words (apart from local vascular changes) upon the amount of the output from the heart. Hence in peripheral arteries the pressure of the blood may (within limits) be independent of the volume which they contain, but in the aorta and more central vessels which possess but little muscular tissue, the pressure of the blood will more depend upon the amount contained. The entire arterial cistern may therefore be divided into a central portion having

[1] *cf.* the warm glow in the skin which is felt after a momentary dip in cold water.

predominantly elastic properties, and a peripheral portion having predominantly muscular properties. Hence, in a warm environment when the arterioles are dilated the aorta and central vessels will be but slightly distended, even though the heart may be beating rapidly, and the increased sectional area of the arterioles can easily transmit the large amount of blood which is being discharged by the heart, so that the mean blood-pressure may be at a low level. When, on the contrary, the arteries and arterioles are tightly contracting owing to the influence of cold, if the heart should be stimulated to accelerate its rhythm, the larger amount of blood ejected will pass through the vessels by forcibly distending their coats, and the mean blood-pressure will be raised coincidently with the development of an enlarged channel, perhaps even in the peripheral arteries. If the arterial cistern as a whole contains approximately equal amounts of blood in the Hot and Cold conditions of the body, when the pulse-rate is at the same level, it is manifest that in the latter state the blood will accumulate in larger proportion in the aorta and the central vessels, while in the former condition the amount contained in the smaller and peripheral vessels will be relatively greater, and there must be some point in the arterial tree where the amount of contained blood remains unaltered, the varying contraction of the muscular tissue exactly neutralizing the yielding of the elastic coats.

As the walls of many of the remaining spaces in the tissues and the venous channels of the deeper structures and of the trunk contain muscular tissue, the amount of blood which can be held in these parts must be variable and will doubtless be accommodated to the requirements of the regions which control the generation and the discharge of heat.

One cannot doubt that the reflex stimulation of the heart-rate by cold involves an increased supply of blood to the heat-generating foci as well as a distributive effect in regard to the body-heat, but in my opinion, in order to fully cover all the facts, it is necessary to regard the heart-beat itself as an important means of increasing the production of heat. The acceleration of the pulse-rate which arises not from relaxed arteries but from a reflex stimulation of the heart by heat appears to have little or no purposive relation to either the generation or the discharge of heat, but points rather to a toning up of the circulatory mechanism so that the body may be ready for activity in a thermal emergency.

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