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The Adequate Stimulus for Shivering.* (20861)

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In man, acute exposure to cold is a stimulus for a heat conservation mechanism (vasoconstriction) and a heat production mechanism (increased metabolism). The response of the vasoconstrictor mechanism to decreasing environmental temperature has been repeatedly demonstrated by both skin temperature(1) and blood flow measurements(2). Although the adequate stimulus can be either local or general body cooling, it is usually local skin cooling, vasoconstriction occurring before deep body temperature changes. Previous exposure to cold, however, modifies this response(3-5). The mechanism inducing increased metabolism upon acute exposure has been the subject of controversy for almost a century. The argument is still much as Cannon *et al.*(6) stated it: whether there is a true chemical regulation as Rubner(7) defined it in addition to the metabolic response to increased muscular activity in the form of involuntary shivering. The work from Cannon's laboratory gave evidence that a cold stimulus causes increased metabolism when there is no muscular activity. This was ascribed to the release of adrenalin. Subsequent work has failed to confirm these results, whether the negative heat load was from the external environment(1) or from internal cooling(8). Cannon had hinted that acute rapid application of the negative heat load gives rise to early shivering which masks the chemical regulation, but the data of Hardy and DuBois(1) and Pinson and Adolph(8) do not bear out this suggestion. A steady state was approached in both series of experiments, in the former with a lowered skin temperature and a maintained rectal temperature, and in the latter with a lowered rectal temperature and less change in skin temperature. However, during long-term exposure of animals to cold, shivering seems to decrease while the increase in metabolism is maintained (9). Initiation of shivering has been attributed to a fall in internal body temperature (rectal)(10,11) or in skin temperature(12). Hensel's(13) recent account of the thermal sense organs gives a basis for predicting that shivering is the result of the rate (depending on steepness of thermal gradient) at which cold sensitive end organs are discharged, the number (depending on area and density of end organs) being stimulated and the thermal state of the temperature regulating center.

The following experiments were conducted to determine if a true chemical regulation could be demonstrated and if shivering is controlled according to Hensel's description.

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Methods. Skin temperature, heat loss, oxygen consumption and blood flow were recorded in four normal subjects. All experiments were conducted 2 to 3 hours after breakfast during June, July and August. The subjects lay supine on a cot with a plastic screen in place of canvas, in a room with controlled temperature and a fixed air flow. After control records were made at 24-25°C, the room was cooled at a rate of 0.6°C per minute. In some experiments, the subject drank a liter of ice water just before the room temperature was reduced. Skin temperatures were measured with copper-constantan thermocouples of 30 gauge B & S wire and recorded on a Brown potentiometer with a −0.5 mV to +2.5 mV range. Thermocouples were located at the points recommended by Hardy and DuBois(1), those from corresponding parts of the body surface being connected in parallel to give an average reading. To record heat loss single Hatfield tellurium discs were used on the hand and foot, and for the chest and on the thigh and legs four elements connected in series were used. Oxygen consumption was determined by measuring minute volume with a linear flowmeter and with a Pauling oxygen analyzer (range 110-160 mm Hg). Blood flow in the first two phalanges of the right middle finger was determined by an air plethysmograph with a condenser pickup. The occlusion cuff, proximal to the finger cot, was inflated to 46-50 mm Hg.

Results. The data obtained are shown in Table I. The sequence of events was roughly skin cooling, reduced blood flow, shivering, and increased oxygen uptake. The first 2 were almost simultaneous and subjects often first reported shivering at the same time as their oxygen uptake increased. The position of reduced deep body temperature in this sequence is not definite. Decreased rectal temperatures sometimes preceded, sometimes followed the onset of shivering. In any event, lowered deep temperature does increase the tendency to shiver. The average time to onset of shivering was six minutes less when shorts-clad subjects drank ice water. At no time did shivering reach a level sufficient to maintain total body temperature.

By covering a region of the body, the rate

TABLE I. Average Data from 4 Subjects Tested for Shivering Response.

Approximate area exposed	Time to shiver, min.	Change in avg temp. (°C) of			Heat debt, kilo-calories	Change in rectal temp., °C	Heat loss during cooling‡				Max mot.	Avg time to inc. in O_2 uptake, min.
		Skin	Thorax	Thigh			Heat loss during control				Control met.	
							Thorax	Leg	Hand	Foot		
Shorts, 100%		(31.8)*	(33.0)	(31.8)			(45)	(56)	(47)	(35)		
		2.9	1.8	3.1	44	0	2.5	2.7	3.4	2.7	1.7	19
	14	(1.2–4.4)	(1.0–2.2)	(2.0–4.4)								
	(12–20)†											
Thorax & arms covered, 51%		(33.5)	(34.6)	(32.3)			(20)	(40)	(60)	(60)		
		4.5	1.0	7.0	59	0.2	3.0	5.0	2.0	2.3	1.8	31
	31	(2.6–6.2)	(.6–1.7)	(3.0–10.0)								
	(17–47)											
Legs & feet covered, 41%		(33.0)	(33.0)	(33.3)			(50)	(20)	(70)	(22)		
		2.4	3.2	.8	31	0	5.8	3.0	2.0	3.1	1.9	25
	18	(1.4–3.5)	(1.7–4.0)	(.2–1.0)								
	(8–28)											
Ice water, shorts, 100%		(32.3)	(33.1)	(31.7)			(57)	(55)	(51)	(50)		
		1.5	1.1	1.3	41	0.9	1.9	2.4	1.6	2.0	—	—
	8	(.7–2.6)	(.7–1.7)	(.8–2.0)								
	(2.5–12.5)											

* Skin temp. during control period in parentheses. † Range in values. ‡ Figures in parentheses give control period heat loss in $Cal/M^2/hr.$

of cooling there was reduced below that given by Hardy and Oppel(14) as the adequate stimulus for cold sensation. As can be seen from the Table, the time to onset of shivering was related to the regions of the body exposed. Covering the thorax delayed the onset of shivering longer than covering the legs. The relative rates were analogous to the relative distribution of cold spots(15). The estimated ratio of the number of cold spots in the trunk versus those in the legs is 6 to 4, as is the reciprocal of the time to shivering in the present experiments.

Discussion. Since the increased oxygen uptake noted was always subsequent to subjective reports of shivering, our data do not indicate the existence of a true chemical control of metabolism under the present conditions of cooling. The data are consistent with the hypothesis based on Hensel's description of thermoregulation, but pose a perplexing question in the long durations of stimulation necessary to occasion shivering. A possible explanation is the fact that cold-sensitive end organs sense absolute temperature as well as respond to rate of change. Alternative explanations are that the temperature regulating center can summate over long periods, or that changes in temperature of the brain occurred not demonstrated by rectal temperatures.

Summary. On the basis of Hensel's account of thermal sense organs, it may be postulated that adequate stimulus for shivering is a combination of the rate at which cold sensitive end-organs are discharged, the number stimulated, and the thermal state of the center. In some experiments, subjects drank cold water to lower deep body temperature before the start of room cooling. Skin and deep body temperatures, oxygen uptake, and finger blood flow were measured. In 4 subjects, the sequence of events with room cooling at 0.6°C/minute from 25°C was: skin cooling, reduced blood flow, shivering, and increased oxygen uptake. Lowered deep body temperature does increase the tendency to shiver. At no time did shivering reach a level to maintain total body temperature. Onset of shivering was related to regions of body exposed. Covering the thorax delayed its onset longer than covering the legs. The geometric areas exposed were comparable, a difference existing in the number of cold spots/cm^2.

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