from many other procedures, machine- or hand-operated. The economy and convenience of the method make it, in our estimation, superior in some cases both to other hand-processing methods and to punched-card operations that rely on central-office machine installations. Speed and flexibility are its major advantages. It has, of course, some limitations: punching by hand is slower than punching by conventional machine methods, and cards can accommodate only a limited number of cases. These drawbacks are in many instances more than outweighed by the advantages. The individual research worker looking for in-almost-any-pocket convenience at in-almost-any-pocketbook price may well wish to consider this method as a means for solving his data-processing problem.

References and Notes

1. Although the illustrative examples in this article are drawn from the behavioral sciences, the general technique is equally applicable to any situation in which an investigator wishes to examine relationships obtaining between two or more variables.
2. Basic descriptions of this procedure may be found in *The Uniterm System of Indexing: Operating Manual* (Documentation Incorporated, Washington, D.C., 1955). The most detailed exposition of the use of punched cards in applying this principle to indexing is a paper by W. A. Wildhack and Joshua Stern, "The peek-a-boo system—optical coincidence subject cards in information searching," in *Punched Cards: Their Application to Science and Industry,* R. S. Casey, J. W. Perry, M. M. Berry, A. Kent, Eds. (Reinhold, New York, ed. 2, 1958).
3. Those who are convinced that there is almost nothing new under the sun will find their opinion supported by evidence which suggests that the basic principle here described is a very old one. On the site of ancient Sumer, clay tablets have been discovered that may have been used in a similar fashion for medical diagnosis. Each tablet referred to a single symptom and listed the diseases in which it was present. A comparison of symptom tablets would presumably have enabled the ancient medic to reach an appropriate diagnosis. [Reported in *Proceedings of the International Study Conference on Classification for Information Retrieval* (Aslib, London; Pergamon, New York, 1957), p. 106.]
4. That there is an upper limit to the number of positions on a card restricts the utility of this method for very large samples, but anyone working with a sample of 400 or less would encounter no difficulties on this score. For studies in which the size of the sample exceeds the number of cases that can be accommodated on a card, the investigator may set up additional sets of cards. For example, if two sets of cards were needed, entries for every table would in effect be obtained by adding corresponding cell entries of two separate tables. There are, of course, limitations to this method of expanding the system's capacity.
5. Although the punching operation in this method of data processing is slower than conventional procedures in which equipment such as an IBM key punch is used, input is probably at least as rapid as that of any method that does *not* require a major piece of hardware for punching purposes.
6. When the categories are not mutually exclusive —that is, when a punch for an individual may be made in more than one category—reliability checks are more problematic (this is also the case with conventional data-storage methods). The total-check-card method is, however, still applicable.

Behavioral Thermoregulation

Behavior is a remarkably sensitive mechanism in the regulation of body temperature.

Bernard Weiss and Victor G. Laties

Behavior is one of the fundamental mechanisms by which organisms regulate body temperature. But, although one can point to numerous illustrations of its importance, quantitative data on the role of behavior in thermoregulation are rare. Among these are Kinder's findings on nest building in rats. Employing a technique originally developed by Richter, she showed that as the ambient temperature fell, rats increased the amount of paper that they used for nest building (*1, 2*).

In this article we discuss a recent series of studies (*3*) on how behavior contributes to the regulation of body temperature. The major aim of these studies was to specify the relation between body temperature and a response which provided an exteroceptive source of heat.

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The apparatus employed is illustrated in Fig. 1 (*4*). It consists of a Plexiglas cylinder containing a plastic lever attached to a telegraph key. The red-bulb infrared heat lamp above the chamber goes on for a few seconds on certain occasions when the rat presses the lever.

The duration of the burst of heat from the lamp is varied by a timer, and the intensity is varied by a variable transformer. The chambers are located in a refrigerated room, the temperature of which can be controlled to within 1°C. The apparatus that is used to automatically record and program the relevant events is located in an adjoining room.

The fur of the rats used in these experiments was removed by clipping before a session. This procedure makes it impossible for the rat to maintain a normal body temperature at the environmental temperatures used in the experiments.

Initiation

After a rat with no experience in this situation is put into a chamber, it typically spends the first few minutes exploring its surroundings. During this time it occasionally strikes the lever with enough force to close the contacts on the key. This event turns on the heat lamp for several seconds. After this initial flurry of responses the rat usually spends most of the next few hours merely huddling and shivering. Only occasional responses are made during this time. At some point during the session the rat suddenly begins to press the lever at a steady and substantial rate, which it maintains for many hours.

Why does the rat's behavior change so swiftly? It is known that the temperature of a furless rat put into a cold environment undergoes a progressive fall. Perhaps body temperature has to descend to a certain critical point before the burst of heat from the heat lamp becomes reinforcing.

One can test this hypothesis by exposing the rat to cold before putting it into the chamber. Such an experiment was performed with 14 pairs of rats. One member of the pair, randomly selected, was put into a wire-mesh cage in the cold room after being clipped. Its partner was kept at room temperature. Five hours later, both rats were put into test chambers and exposed for 16 hours to a cold-room temperature of 2°C. The heat lamp was set to 250 watts, and each reinforcement (burst of heat) lasted two seconds. This combination produces a transient temperature rise at the skin surface of about 3°C. Each time the lever was pressed while the lamp was off, the lamp came on. Lever presses made while the lamp was on had no effect.

Rats that had been exposed to normal room temperature before being placed in the test chambers waited a mean of 5.16 hours before starting to work for heat at a steady rate. But rats that had spent the immediately preceding five hours in the cold waited only a mean of 2.04 hours ($t = 2.40$, $df = 13$, $p < .05$). It appears, therefore, that precooled rats start pressing earlier for heat than rats that have not been precooled, presumably because they begin the experiment with a lower body temperature.

Two other studies supported the hypothesis that the critical variable was a drop in body temperature. In one, the relation between thyroid state and thermoregulatory behavior was examined (*5*). It was found that thyroidectomized rats started to work for heat much earlier during a 16-hour session at 2°C than controls that had undergone a sham operation. This was attributed to the fact that hypothyroid animals lose heat more rapidly in the cold than normal animals (*6*).

The other source of support for the hypothesis came from an experiment on cold acclimatization (*7*). Although animals acclimatized to cold show numerous structural and biochemical changes, perhaps the most dramatic difference between acclimatized and normal rats lies in their resistance to cold after their fur has been removed. Rats that have not been acclimatized die at low temperatures; acclimatized rats survive, presumably because their body temperature does not fall to lethal levels (*8*). If the length of the latency (the period before the rats begin to work at a steady rate for heat) is a function of the rate at which body temperature falls in the cold, then acclimatized rats should wait longer than normal rats to begin pressing. They do. There was a considerable difference, with very little overlap, between two groups of eight animals each, one of which had lived about a month at 2°C while the other had been kept at room temperature (25°C).

Despite the evidence favoring the view that a fall in body temperature is the most important factor leading to a steady reinforcement rate, concrete evidence in support of this view was lacking. It was essential to measure body temperature at the same time that the rat was working for heat.

Some preliminary work showed that core temperature changes too slowly, even in an organism as small as the rat, to be sensitive to individual reinforcements. Skin temperature, although quite responsive to individual reinforcements, was rather labile. Subcutaneous temperature also responded to individual reinforcements, but not as transiently as skin temperature. A technique was therefore developed for recording the subcutaneous temperature of a rat moving freely about the experimental chamber. A plastic tube attached to a plastic Luer connector is inserted under the skin on the back and tied to the supraspinous ligament. A purse-string suture is then drawn around a Lucite washer cemented to the tube, and the Luer connector is left projecting from the rat's back. When a rat's temperature is being recorded, a thermocouple (copper-constantan) cemented to a mated Luer connector is inserted in the tube, and the Luer fittings are pressed together. The thermocouple leads to a Minneapolis-Honeywell temperature recorder in another room.

In the next experiment two questions were examined. One was the relation between body temperature and the point at which the rat began to work for heat. The other was the relation between these variables in successive sessions. Each of five rats underwent three

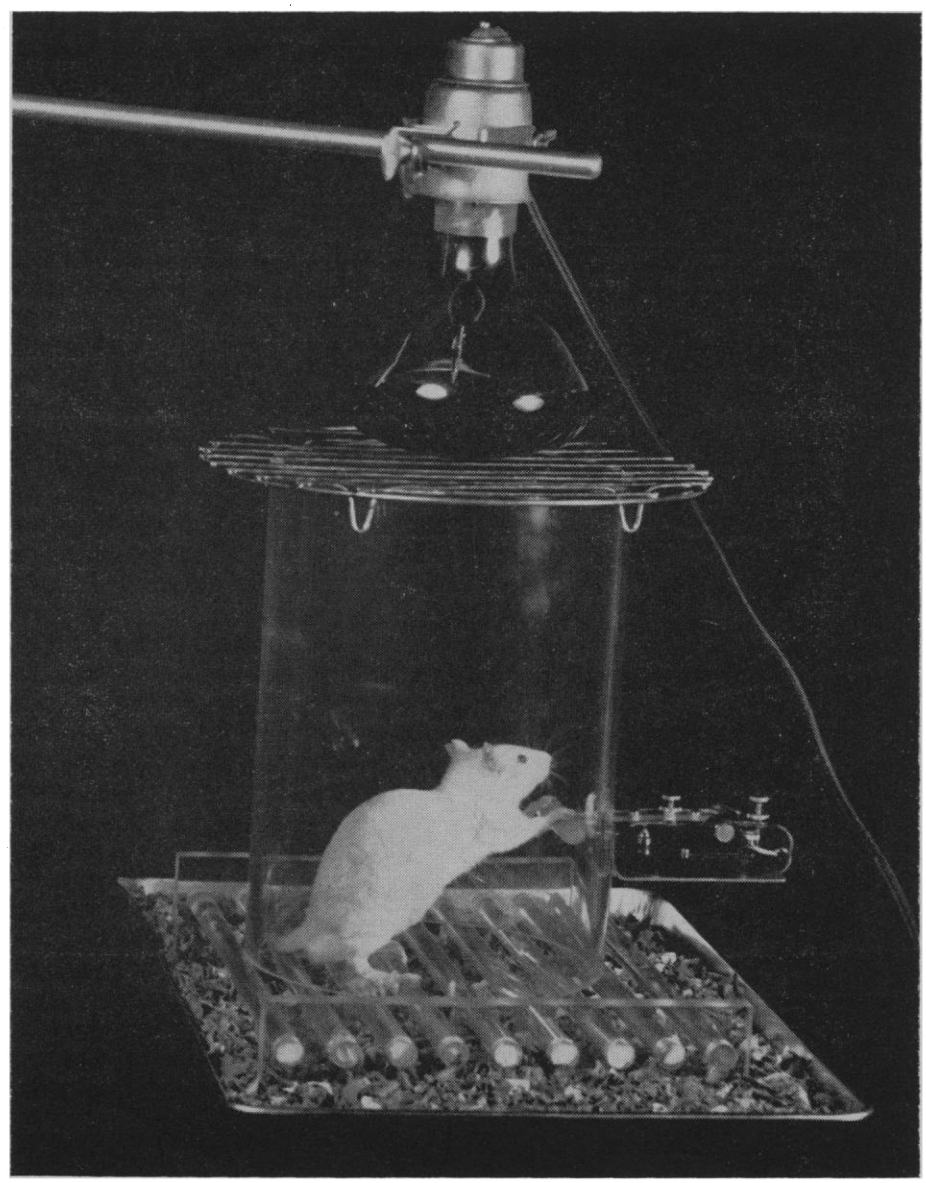

Fig. 1. The heat reinforcement apparatus. Depressing the lever closes a switch that activates the heat lamp.

16-hour sessions spaced a week or two apart. The cold room was set at 2°C, and the heat lamp, at 250 watts. Each reinforcement lasted two seconds, the heat lamp coming on whenever the lever was pressed while the lamp was off.

The mean subcutaneous temperature at the start of the session was about 35°C for all three sessions. Figure 2 shows records from the first session. For each of the rats except rat NN–N, the figure shows the temperature and reinforcement records for the first hour in the chamber and for the hour before and after the start of consistent responding. The upper tracing represents subcutaneous temperature, and the lower represents reinforcements as recorded on a cumulative recorder. Because the latency for rat NN–N is unusually short, all of the first 180 minutes of the session are shown for this rat. Just why rat NN–N started pressing so early is difficult to say. This may be related to the fact that the rat's initial temperature (33.2°C) was the lowest in the group.

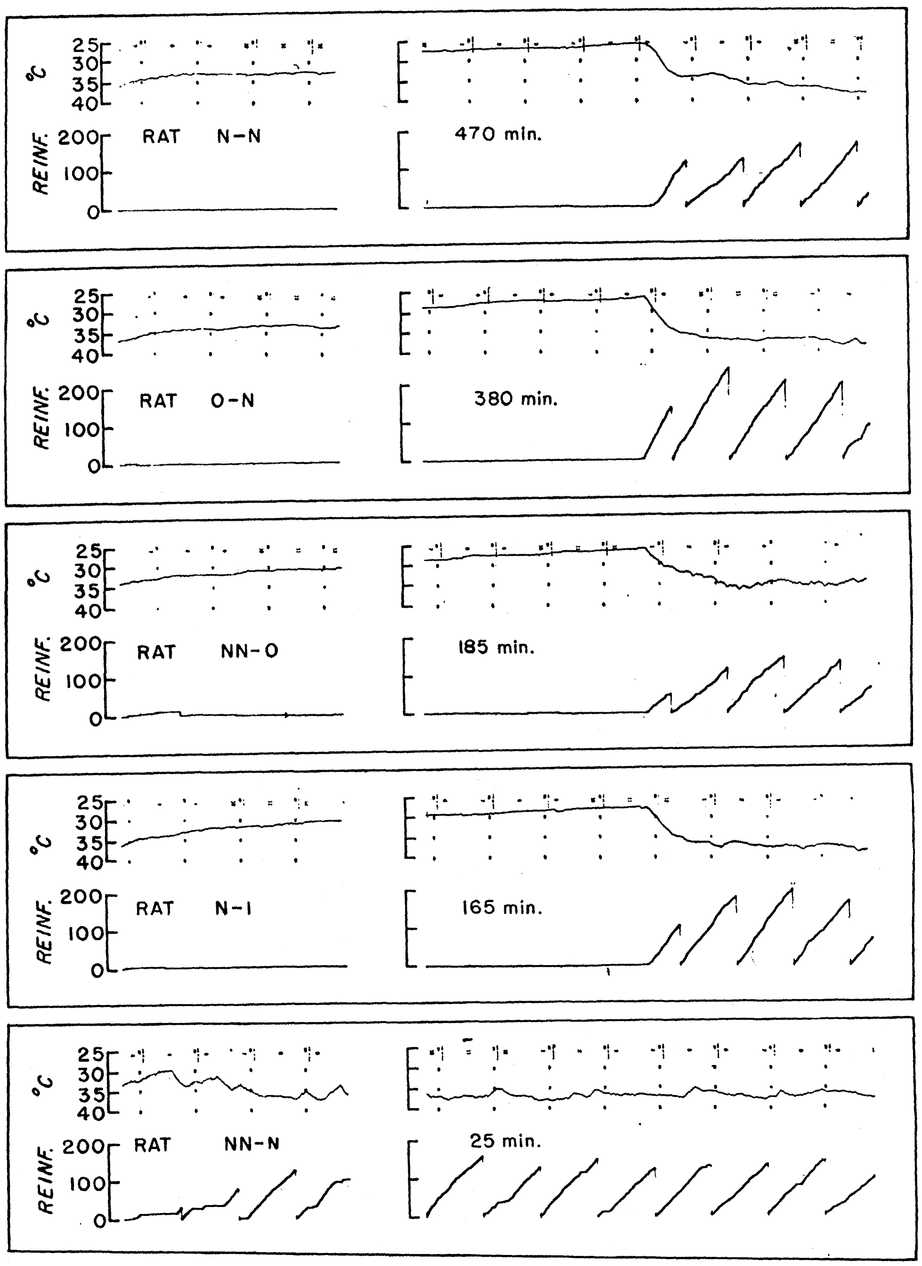

Fig. 2. Parallel records of subcutaneous temperature and reinforcements for all five rats on their first session. Records at left, temperature and reinforcements during the first hour in the cold. Top four records at right, temperature and reinforcements during the hour preceding and the hour following the initiation of steady lever pressing. Record at the bottom (rat NN–N), temperature and reinforcements during the entire first three hours, shown because of the short latency. Also shown for each rat in the records at right is the latency (in minutes) to the initiation of steady lever pressing. Reinforcements were recorded cumulatively, the recording pen resetting to the base line every 15 minutes.

Subcutaneous temperature declines from the time the rat is placed in the chamber until it begins to work steadily for heat. Then, as shown in Fig. 2, subcutaneous temperature rises when the rat begins to respond. The transition from a near-zero reinforcement rate to a steady and substantial one occurs so abruptly that it looks practically instantaneous on the records. Once the rat begins to obtain reinforcements at a steady rate, the temperature climbs rapidly to the level that is maintained for the rest of the 16-hour session.

The data in Fig. 2 are from experimentally naive rats. Does the same sequence of events appear in rats already experienced in the situation? Figure 3 shows, for the same five rats and for three successive sessions, the amount of fall in subcutaneous temperature between the time the rat was placed in the chamber and the time it began to obtain reinforcements at a steady rate. The mean fall in temperature was 8.20°C for the first session, 3.68°C for the second, and 4.64°C for the third. An analysis of variance showed that differences among sessions were significant at the .05 level; the main contribution to this result is the difference between the first session and the two later sessions. It appears, therefore, that once the rat has had experience in this situation, a fall in temperature considerably less than the fall required in the first session initiates responding. What other factors contribute to the change in latency is a still unanswered question.

Maintenance

The peripheral event that seems most closely related to the initiation of a steady rate of working for heat is a drop in peripheral temperature. Another question is, what keeps a rat working for heat? In particular, what governs the rate at which it obtains reinforcements?

Since the rat survives, the reinforcement rate must be governed in part by the body temperature; otherwise, the rat would succumb to the cold or burn its skin. An interesting deduction follows. If the amount of heat per reinforcement increases, the rate should decrease; if the amount of heat per reinforcement decreases, the rate should increase. In a recent series of studies (*9*) the amount of heat per reinforcement was varied in two ways: by varying the intensity of the heat lamp and by varying the length of time that it remained on. We discuss here only the data obtained by intensity variation, since both methods of varying the amount of heat per reinforcement give the same results.

Six different intensity settings were selected for the experiment: 125, 175, 225, 275, 325, and 375 watts. Figure 4 shows the transient rises in skin and subcutaneous temperature produced in an anesthetized rat by 2-second bursts of heat with different settings of the lamp. The cold room was maintained at 2°C. After a rat was put into the chamber, we waited until it had been responding steadily for at least 30 minutes. Then, according to a randomly determined sequence, it was switched from one intensity setting to another every 30 minutes. A dozen rats took part in this study.

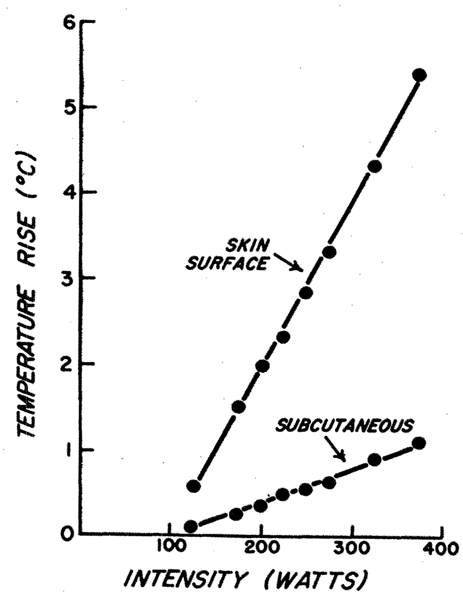

Fig. 4. Transient changes in skin temperature and subcutaneous temperature produced by 2-second bursts of heat with the intensities shown. The subject was an anesthetized rat.

Pooling the data from all 12 of the rats used in the experiment produced a monotonic function between 125 and 375 watts; the greater the intensity, the lower the reinforcement rate. The cumulative records showed that the change in rate following a change in intensity took place at once. But, as Fig. 5 shows, five of the individual curves reverse either at 125 or at 175 watts. Three of the seven rats that did not show a reversal were run at a reinforcement intensity of 75 watts. All three then responded less than they had at higher intensities. One interpretation of this lowered rate of response is that the low intensities are not adequate reinforcers, so that extinction of the lever-pressing response begins to occur. This interpretation is strengthened by the fact that at the lower intensities there were often alternating periods of responding at high rates and of no responding at all. Such behavior is also characteristic of inadequate food reinforcement (*10*).

Once the technique for recording temperature in the freely moving rat had been developed, an obvious application was to perform another experiment on intensity variation. Four intensities were selected: 155, 205, 260, and 310 watts. According to measurements on an anesthetized rat (see Fig. 4), single 2-second bursts of heat at these intensities produced transient rises in

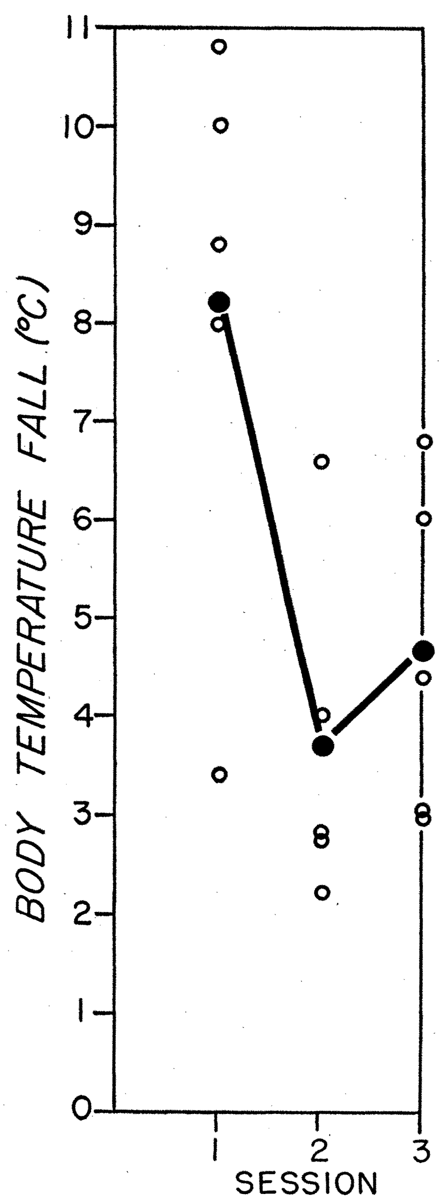

Fig. 3. Amount of fall in subcutaneous temperature before the initiation of a steady rate of working for heat. Data for three successive sessions are shown. Open circles, individual rats; solid circles, the means.

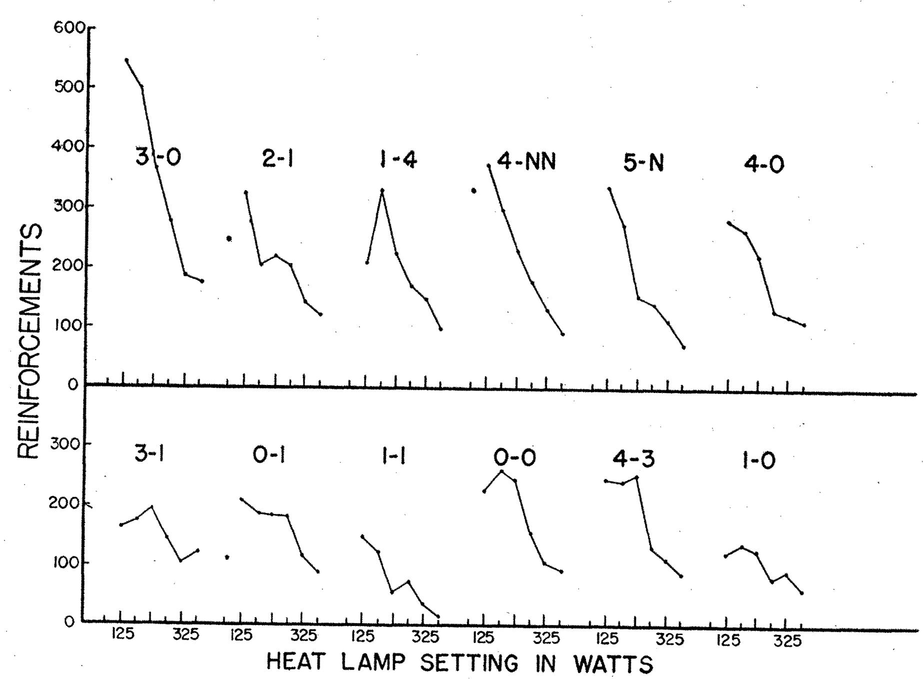

Fig. 5. Number of reinforcements obtained in a 30-minute period at intensity settings of 125, 175, 225, 275, 325, and 375 watts. The data are plotted individually for each rat. The left end of the curve represents 125 watts; the right end, 375 watts. Rats 2–1, 4–NN, 3–1, and 0–1 were also run at an intensity setting of 75 watts. These points are not connected to the remainder of the function.

skin temperature of 1°, 2°, 3°, and 4°C.

The performance of each of eight trained rats was recorded at each intensity for two hours. Figure 6 shows the mean subcutaneous temperature maintained during this two-hour session. The three highest intensity reinforcements led to higher temperatures than the lowest intensity. An analysis of variance indicated that the temperature differences for the four intensities were significant at the .05 level, but only the differences between temperatures at the lowest intensity and temperatures at the other intensities were significant according to *t* tests.

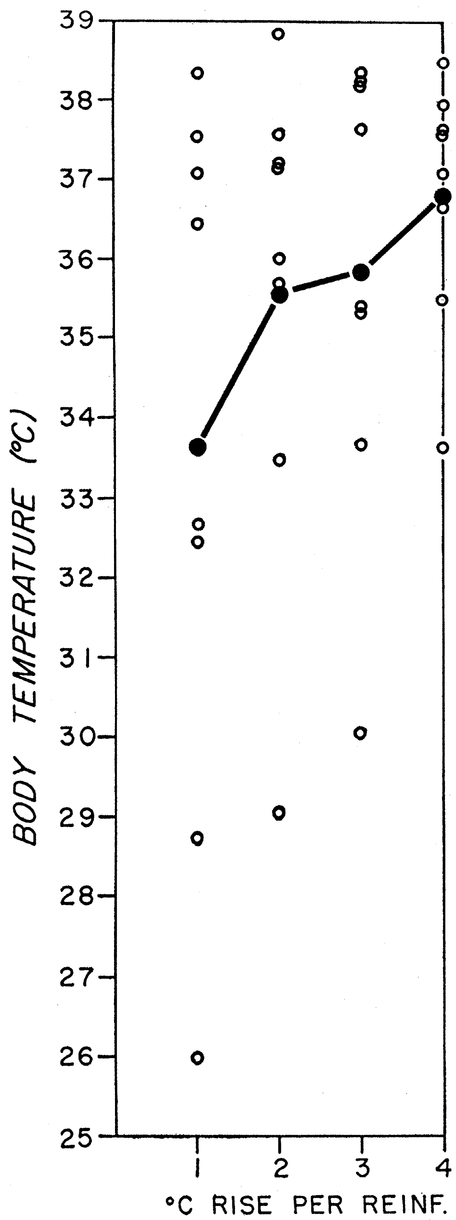

Fig. 6. Mean subcutaneous temperature maintained during a 2-hour period as a function of heat-lamp setting. This setting is given in terms of the rise in skin temperature, in degrees centigrade, produced by an individual reinforcement. Open circles, individual rats; solid circles, the means. These data were obtained by calculating the mean temperature during 24 5-minute segments of the 2-hour experimental period. The temperature represented by the open circles is the grand mean for each rat for the entire 2-hour period.

This finding is similar to that displayed in Fig. 5—namely, a disproportionately low increase in reinforcement rate to compensate for the decline in reinforcement intensity when the latter falls below about 175 watts. The function obtained by connecting the mean values, however, does not reflect the performance of all the subjects. Four rats (half the group) showed no temperature difference as a function of heat-lamp setting. The other four showed a considerable dip at the lowest setting. There was a good deal of consistency in the temperature values for individual rats. The animal with the lowest temperature at the lowest intensity setting also had the lowest temperature at the three higher settings. The four rats that maintained the lowest temperatures at the lowest intensity also maintained the lowest temperatures at the next two highest intensities. At the highest intensity there was more overlap, but the two highest temperatures were maintained by rats from the top half of the group, while the two lowest temperatures were maintained by rats from the bottom half of the group.

The temperature records in Fig. 7 represent the first hour of each 2-hour session at the four different intensity settings of the heat lamp used in this experiment. Rat *A* is the animal designated in Fig. 6 by the second circle from the bottom at a heat-lamp setting of 1°C rise per reinforcement. This rat maintained a relatively low temperature at this reinforcement setting. At the higher reinforcement settings, however, he maintained a peripheral temperature close to the normal value. Rat *B* is designated in Fig. 6 by the topmost circle at a setting of 1°C rise per reinforcement. That is, he maintained the highest subcutaneous temperature of the group at this heat-lamp setting. Note the stability of the temperature tracing, and note how relatively little variation there is as a function of reinforcement intensity. These records illustrate the main finding of this experiment: that rats adjust reinforcement rate in accordance with reinforcement intensity to produce the end result of a constant peripheral temperature.

Metabolic Variables

The tendency of rats to compensate for variations in the intensity parameter by variations in reinforcement rate and the stability with which they maintain peripheral temperature by such behavior suggest that the heat-reinforcement technique might be useful for studying metabolic variables. That is, if we interfere with or enhance the rat's ability to produce heat, would we find compensatory changes in behavior?

In some earlier experiments one of us found that starved and underfed rats responded more often than control rats to obtain heat reinforcement (*11*). Hamilton varied the technique by allowing the rats to determine the duration of the reinforcement (*12*). He found that food-deprived animals kept the lamp on for a greater portion of a session than controls did. Carlton and Marks (*13*) found that cold-exposed rats that had suffered weight loss turned on a hot-air blower in the cold more frequently than control rats did. And, studying a quite different kind of behavior, Kinder (*2*) found that rats deprived of food increased their nest-building activity. There seems little doubt that the disturbance of heat balance produced by starvation and weight loss is reflected in compensatory behavior.

A higher proportion of rats fed a diet deficient in the vitamin pantothenic acid die in the cold than rats fed an adequate diet. The former also press a lever at a higher rate for heat reinforcement than the latter (*11*). It seems likely that this is another example of how the inability to maintain body temperature in the cold is reflected in overt behavioral thermoregulation.

Our most complete data on metabolic state and thermoregulatory behavior come from a series of studies on thyroid function (*5*). It was stated above that hypothyroid rats begin to respond earlier during a session than euthyroid rats, presumably because their body temperature falls more rapidly. Hypothyroid rats also seek reinforcements at a higher rate than euthyroid rats once they begin to work steadily for heat. Part of the difference, at least, results from the fact that rats with intact thyroids pause more frequently during the session than hypothyroid rats; the hypothyroid rats work at the task with greater constancy.

One can counteract the deficit in heat

production that accompanies hypothyroidism by administering a thyroid hormone. In one experiment we were able to produce a fall in the frequency of heat reinforcements sought by thyroidectomized rats by administering the thyroid hormone 3,5,3′-1-triiodothyronine via their drinking water. The fall was great enough, in fact, to carry the rate below that of their intact controls.

With the present system, then, metabolic variables that influence the heat-production capacity of the rat are reflected in the rate at which it works for heat.

Basis of Thermoregulatory Behavior

The experiments under discussion were directed toward the question of how behavior contributes to the regulation of body temperature. Two aspects of this question were considered: the factors that lead to the initiation of thermoregulatory behavior and the factors that maintain it.

By correlating subcutaneous temperature with the behavior of pressing a lever for brief bursts of heat, we were able to show that the rat's behavior in the situation we have described results in a fairly constant peripheral temperature. The very precision with which the rat regulates this temperature poses a problem. Why does a large drop in body temperature seem necessary to initiate responding, while much smaller fluctuations govern reinforcement rate once a substantial rate of responding is established?

One reasonable possibility is that when the rat is first placed in the cold, lever pressing must compete with other responses elicited by the cold, such as shivering and huddling. When shivering and huddling can no longer avert a further decline in temperature, they may then be replaced by gross motor activity. When such activity accidentally results in depression of the lever, the burst of heat from the heat lamp produces such a profound change that it is quickly followed by other presses. A sudden onset of responding also appears when food, rather than heat, is the reinforcement (*14*).

A more general question may also be asked. What do these data demonstrate about the way in which behavior fits into the pattern of regulatory processes that sustain life?

In most of the experiments set up to answer such questions, factors that control eating and drinking have been studied—to determine, for example, whether an animal can compensate for a diet deficient in a particular substance by the appropriate selection of nutrients. Such studies have demonstrated that under many conditions animals do vary ingestive behavior to compensate for deficiency states. But in numerous instances they do not. Perhaps the reason for the substantial proportion of failures in experiments on eating and drinking is the long chain of processes that intervene between behavior and the ultimate effect. By contrast, the effect of heat is practically instantaneous. This is probably the reason why behavior seems so exquisitely attuned to the regulation of body temperature.

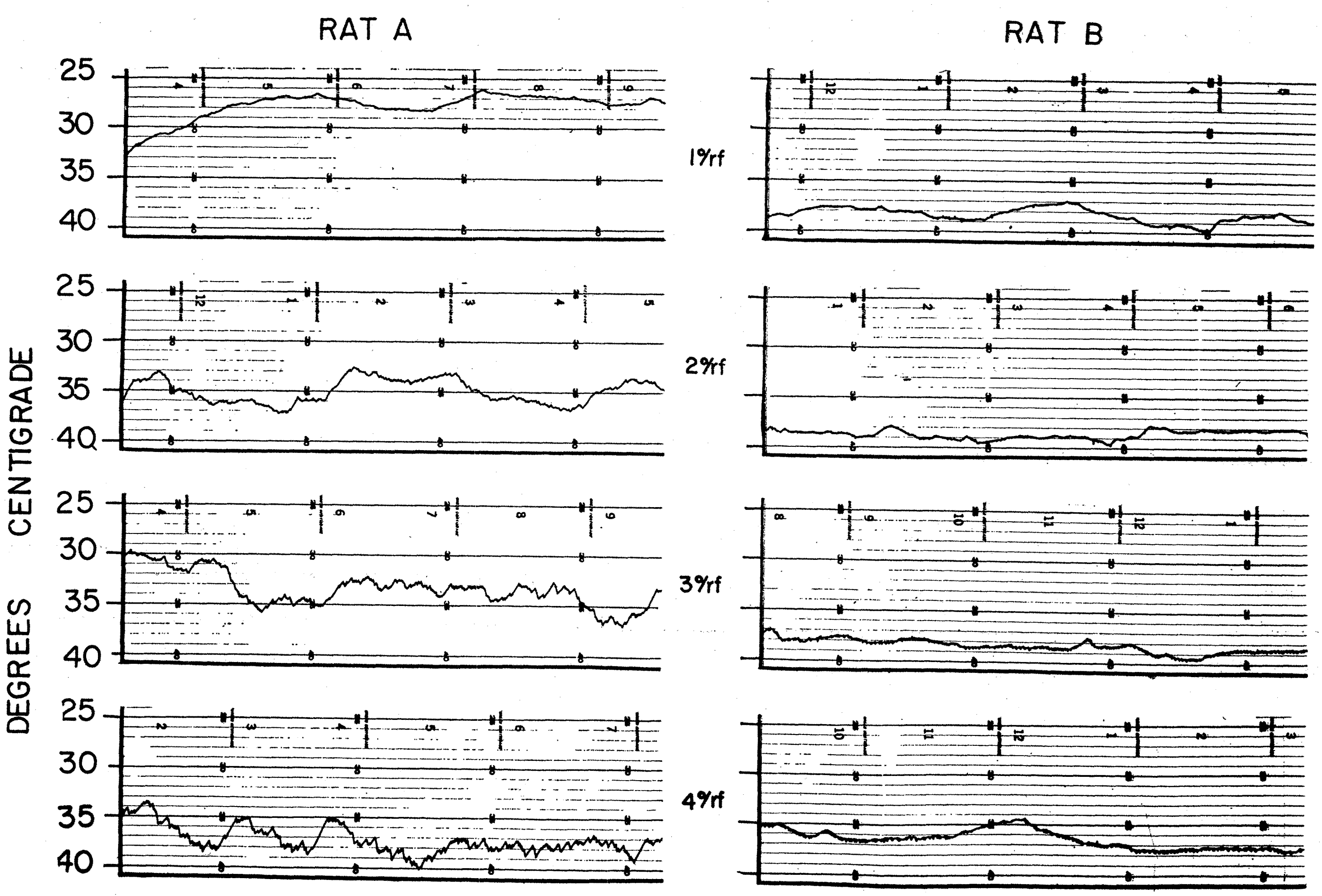

Fig. 7. Records of subcutaneous temperature for two rats at the four different heat-lamp settings noted. Only the record for the first hour of each 2-hour session is shown. These rats belong to the group of Fig. 6 (see text).

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Science in the News

The Test Ban: The Russians Now Say That the Inspection System Is Only "Symbolic"

The negotiations at Geneva have reached a critical point, and the outlook is dim. It is still barely conceivable that the recent Soviet attitude is merely a bluff. But this hope, rather widespread when the first signs of a hardening of the Russian line appeared, has steadily lost ground.

We offered a number of concessions: a reduction of the number of detection sites on Russian soil, a longer extension of the unpoliced moratorium on small tests, a willingness to let the Russians inspect the devices we would use for the testing program, and several others. For a time the argument was made that the apparent lack of Soviet interest in these concessions was merely a little tactical bluffing, and that they would, in due time, come up with counterproposals of their own. But hopes of this sort have all but disappeared in the light of the continued lack of interest of Tsarapkin, the chief Soviet negotiator, and by the recent attitude of Khrushchev as reflected in his interviews with Llewellyn Thompson, our ambassador to Moscow, and with Walter Lippmann.

The Soviet attitude shows most clearly in the demand that the previously agreed to administrative control by a neutral be replaced by a tripartite administration, representing East, West, and neutral views, with unanimous agreement required for any affirmative action. In effect, this means that the Russians would have the right to veto any particular proposed inspection.

Nondetecting Detection

Under such circumstances the value of the inspection system as a deterrent to clandestine testing becomes almost nonexistent, and the Russian delegate, according to reports leaking out of the meetings, has frankly taken the position that the detection system, and the inspections, will not really be intended to deter cheating, but will be only "symbolic" moves reflecting the good intentions of the treaty signers. If this view is accepted, it follows that the detection system should be as unelaborate as possible, since there is obviously no point in wasting a lot of money setting up a detection system which is not intended to detect anything.

There is no chance of a treaty's being signed so long as the Russians insist on the right to veto any inspection. Whatever might be said about the wisdom of continuing the present *de facto* ban on testing, nothing can be said for formalizing this ban, which in effect would abandon the position agreed to until now by everyone, including the Russians, that disarmament agreements should be accompanied by a reasonable inspection system to deter cheating. This is what provoked the President's remark at his press conference that "it is quite obvious that the Senate would not accept such a treaty, nor would I send it to the Senate, because the inspection system [based on the right of each nation to veto any inspection that might prove embarrassing] would not provide any guarantees at all."

The common view is that the Russians have now decided that the advantages of a test ban are not alone sufficient to overcome their distaste for inspection, and that they now feel the treaty is worth considering only as part of a larger scheme of disarmament proposals.

This leaves the Administration with the problem of what to do about the *de facto* ban. The public attitude of the Administration, again as expressed at Kennedy's press conference, is that "if there is any chance at all of getting an agreement on a cessation of nuclear tests, regardless of what appear to be the obstacles, I think we should press on . . . I still believe that Mr. Dean [the chief American negotiator] should continue to work at Geneva."

Administration's Dilemma

It may be that the Administration would consider giving in to the Soviet view, and allow the Geneva talks to drag on another 6 months, and then be merged with the general disarmament talks which are expected to be underway then. But there are strong pressures against this course. Last week, after unfolding the Anglo-American position gradually since the talks resumed on 21 March, the Western negotiators placed before the Russians the full text of a draft treaty we were prepared to sign. We have now laid all our cards on the table, and there is nothing more of an affirmative nature that we can do. The Russians have showed no interest at all in the Western concessions. ("Much ado about nothing," Tsarapkin has told the press.) Their principal response, the demand for a veto, rather than being a counteroffer, is a retreat from a position they had earlier accepted.

The original "gentlemen's agree-