viduals (Fig. 2, bottom row). The number of dorsal spots among the progeny classified as wild-type ranged from 5 to 14. The gap between a burnsi and a wild-type individual is almost closed, leading to the perplexing query: How many dorsal spots must an individual contain before it is classified as a burnsi or a wild-type?

The situation is further complicated by the finding that the frequency of burnsi frogs may be as high as 10 percent in populations of leopard frogs in Minnesota (*7*). This supposedly rare mutant occurs too frequently in natural populations to be maintained solely by mutation pressure. The burnsi gene is probably being fostered by some selective advantage conferred upon the heterozygote. It is tempting to suggest that selection is promoting the accumulation of minor *nonspotting* genes ("−" modifiers) that enhance the activity of the burnsi gene (or counteract the effects of the "+" modifiers). Thus, it may be that there are two optimal phenotypes—the completely unspotted heterozygous burnsi frog (type "A") and the wild-type frog. The intermediate burnsi phenotypes (types "B" to "F") may be less advantageous or disadvantageous, and a sharp dimorphism may ultimately result. In essence, the burnsi gene, presently behaving as a semidominant, may eventually become completely dominant as a result of persistent selection for nonspotting modifiers.

The investigations thus far have raised more questions than have been answered, but it is apparent that an extended analysis is required to unravel the intricacies of a seemingly simple anuran trait.

E. PETER VOLPE

Department of Zoology, Newcomb College, Tulane University, New Orleans, Louisiana

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6. The type "F" is genetically a burnsi frog, albeit a highly modified burnsi. For details, see E. P. Volpe, *J. Heredity* **51**, 151 (1960).
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13 March 1961

Variations in Thermal Sensitivity

Abstract. In the past, confusion has resulted from the use of relative expressions indicative of the direction of temperature change, rather than positive identification of warm and cool sensations. Data are presented which show that at more extreme skin temperatures sudden changes in temperature may result in two readily discernible sensations. The occurrence of each sensation depends upon the magnitude of the change.

Investigations of thermal sensitivity (*1*), which have related changes in the thermal threshold to skin temperature, have been concerned with the quantitative aspects of the thermal sensation—for example, the occurrence of a detectable change in sensation accompanying a rapid change in skin temperature. The qualitative aspects of sensation—for example, whether the sensation is warm or cool—have not been investigated. It has been assumed that when the skin temperature is raised, warmth will be experienced, whereas reducing the skin temperature will result in a cool sensation. While this is generally true, it is not always the case, as may be seen in the data presented here (*2*).

The stimulator was constructed of a hollow Lucite block 25 by 35 by 25 mm. The top was open and the bottom was a 20- by 30-mm silver plate, 0.025 mm thick. Water from constant-temperature baths was directed into the stimulator through either of two jets. Switching from one jet to the other produced a change in the temperature of the silver plate with a time constant of 0.4 sec. A thermistor inside the chamber, in contact with the middle of the silver plate, monitored the temperature of the water. Temperature changes of as little as 0.025°C could be produced with ease.

The subject was seated in an adjustable chair with the stimulator placed on the dorsal surface of the forearm 1 in. from the bend of the elbow. Water was circulated through the stimulator at the adapting temperature. After a minimum of 20 min, which allowed the subject to adapt to the room temperature and the skin beneath the stimulator to reach a reasonably stable temperature, threshold measurements were be-

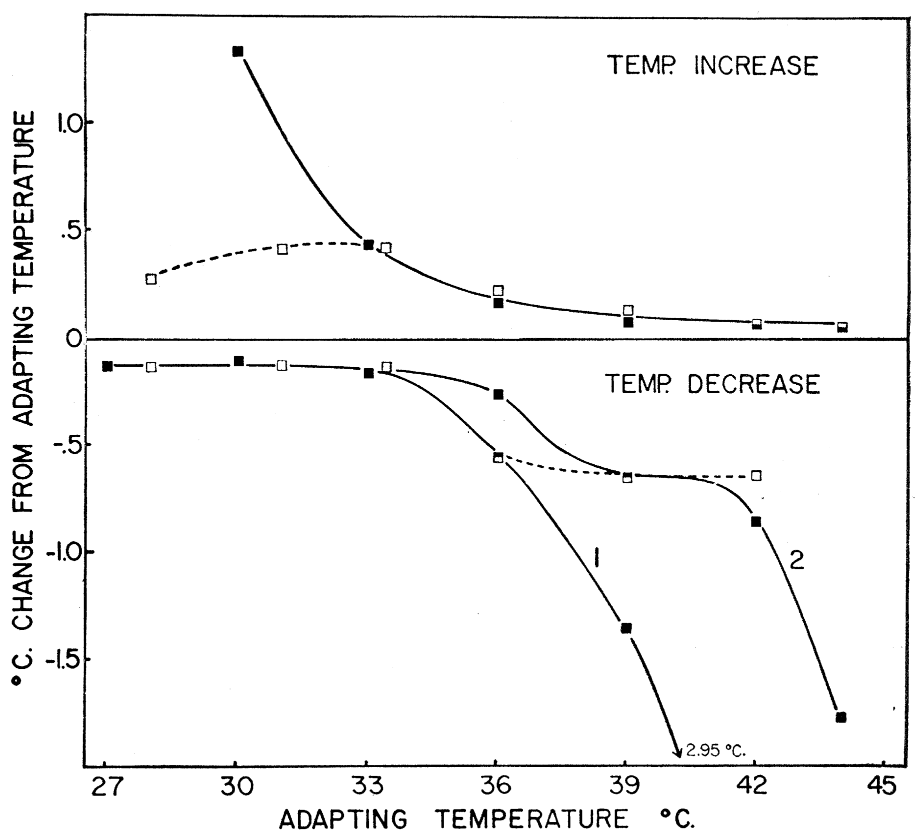

Fig. 1. Changes in the absolute threshold (solid squares, solid curves) and in the just noticeable difference threshold (open squares, broken curves) resulting from the temperature to which the skin was adapted. Male and female subjects showed the same thresholds to both increments and decrements in the adapting temperature except as shown by curve 1 (males) and 2 (females). The vertical dimension of the squares used to plot the mean thresholds represents about 0.07°C on the ordinate. The standard error of each mean threshold did not exceed the size of the square, except on curve 1 at an adapting temperature of 42°C, where it was 0.103°C.

gun. These followed the psychophysical method of limits. The threshold was the mean of ten ascending and ten descending series for each subject. These were obtained in two sessions, one in the morning and the other in the afternoon.

Two criteria of "threshold" were used. In one, the subjects were required to report when they could perceive a change in the thermal sensation produced by a change in the stimulator temperature. These thresholds appear in Fig. 1 as open squares and are henceforth referred to as the "just noticeable difference" (jnd) thresholds. The other criterion required the subjects to identify the sensation as being either warm or cool. These thresholds are shown by filled squares in Fig. 1 and are referred to as absolute thresholds.

Two males, ages 21 and 38, and two females, ages 20 and 26, were the subjects in these measurements. None of the subjects had any known physical defects which might impair their sensitivity to temperature changes. Each subject had received more than 30 hr of practice in making the discriminations prior to threshold measurements. The thresholds of the subjects were averaged, except the thresholds to temperature reductions at adapting temperatures above 33°C. Here the males (curve 1) and females (curve 2) differed so markedly that they were plotted separately.

Figure 1 shows that the just noticeable difference curves follow those of the absolute thresholds throughout most of the range of adapting temperatures. However, the thresholds to temperature increments diverge at low adapting temperatures, while those obtained from temperature decrements diverge at high adapting temperatures. This suggests a change in the conditions of measurement, which appears to be related to the degree of sensory adaptation experienced by the subjects at the various adapting temperatures. All the subjects failed to adapt completely (complete loss of thermal sensation) to temperatures below 33°C. Additional time did not change the level of adaptation. The subjects invariably reported a persisting cool sensation. Increments in the stimulator temperature of 0.4°C could be detected as a change (just noticeable difference threshold). Considerably greater changes had to be produced for the subjects to identify the change as "warm." Increments in the stimulator temperature of greater than 0.4°C, but less than that required to produce a sensation of warm, were identified as "less cool."

When the subjects were adapted to temperatures greater than 33°C, increments in the stimulator temperature were readily detected and no differences were observed between the just noticeable difference and the absolute thresholds.

The female subjects reported complete sensory adaptation to higher temperatures (41°C) than males did (36°C). The thresholds obtained by decrements in the stimulator temperature started to diverge at these points. At higher adapting temperatures a persisting warm sensation was experienced throughout the threshold measurements. While decrements in temperature of as little as 0.6°C could be detected, they did not result in a cool sensation; much greater changes were required. Changes of more than 0.6°C, but less than that required to produce a cool sensation, resulted in reports of "less warm."

In general, these data show that small rapid changes in skin temperature produce sensations appropriate to the direction of the temperature change. However, when the skin temperature is low, small increments can be detected, but result in sensations of less cool. Larger elevations are required to produce a sensation of warm. When skin temperature is high, sudden small reductions can also be perceived but are sensed as less warm. Larger changes are required before cool is experienced.

The elevations of the absolute warm threshold at low adapting temperatures and the absolute cool threshold at high adapting temperatures are indicative of the manner of operation of the thermal receptors. Two explanations appear possible at this time. First, the variations in thermal thresholds observed here may have resulted from changes in the thermodynamics of the tissue due, perhaps, to the greatly altered cutaneous blood flow in response to the temperature to which the skin is adapted. If tissue thermodynamics were the only consideration, one would expect that the just noticeable difference threshold, as well as the absolute threshold, would be altered equally. It is obvious that this is not the case. It might also be expected that both the warm and cool absolute thresholds would be affected at both extremes of the adapting temperature. A second explanation must be entertained—that of altered receptor sensitivity resulting from the temperature at which they are required to operate. Kenshalo and Nafe (*3*) have reviewed a theory of thermal reception, presented earlier by Nafe (*4*), which is based on the direct action of thermal energy upon the smooth muscle of the cutaneous vascular system. It predicts changes in thermal sensitivity associated with changes in the skin temperature.

D. R. KENSHALO
JOHN P. NAFE
BARBARA BROOKS

Department of Psychology, Florida State University, Tallahassee

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Dating Desert Ground Water

Abstract. Tritium in Arabian rainfall has followed the trend observed in North America with peaks in 1958 and the spring of 1959. These measurements will be useful for future hydrologic studies. Water from wadi gravels averages 10 yr old. Carbon-14 measurements of deep waters indicate ages of several thousand years.

Samples of water collected by the Arabian American Oil Company in the course of field operations in Saudi Arabia during the past 2 yr were made available for analysis in the tritium and carbon-14 laboratories of the U.S. Geological Survey to help evaluate the use of the radioactive isotopes in studies of desert ground water.

Some of the samples of deeper ground water tested for tritium indicated an age (time since exposure to atmospheric supply) older than the limiting time span of about 50 yr measurable by this technique. However, values of 3.7, 3.8, and 5.2 tritium units (T atoms per 10^{18} H atoms) with a possible error of $\pm$ 0.5 came from three samples from "wadi" gravels in the central region of the Arabian peninsula, from which the age of waters in the lower part of a great incised dendritic drainage system seems to be on the order of 10 yr (as of 1958), unless fallout from 1952–54 hydrogen bomb explosions had spread into the system. The location of the wells, the