Temporal Course of Thermal Adaptation

Abstract. *Previous methods for measuring the range and temporal course of adaptation to thermal stimuli are difficult to use. A technique requiring subjects to adjust the temperature of the stimulator to maintain a just-detectable sensation is described. Complete adaptation occurs to temperatures within the range between 28° and 37.5°C in about 25 minutes.*

Study of the temporal course of thermal adaptation has yielded variable results. Thermal sensations may be reported by subjects without any apparent change in skin temperature and vice versa (*1*). Furthermore, during the terminal stages of adaptation to mild warm and especially to cool stimuli, the sensation waxes and wanes; hence judgment of the endpoint of complete thermal adaptation (*2*) is very difficult.

Two techniques have been used to determine the rate at which thermal adaptation occurs and the range of temperatures at which it occurs. In the first method, usually used only to define the limits of temperature to which complete adaptation will occur, an area of skin was exposed to an extreme temperature—for example, the fingers were dipped in a cold water bath, for up to 30 minutes—and then the temperature of a bath at which a warm sensation occurred was determined. With this method Abbott (*3*) reported that complete thermal adaptation would occur to temperatures between 17° and 40°C and Gertz (*4*) found complete adaptation between 12° and 16°C and between 41° and 42°C.

With the second method the temporal course of adaptation and its temperature limits were investigated. The skin was exposed to particular temperatures and the subject was asked to indicate when that temperature no longer felt warm or cool. Under these conditions Holm (*5*) claimed that subjects ceased to feel warm after 152 seconds at 45°C or cool after 210 seconds at 5°C, and Hensel (*6*) found complete adaptation only within the range of 19° to 40°C. Both agree that adaptation to temperatures close to that of the skin proceeds rapidly, with up to 40 minutes being required at the more extreme temperatures.

Apart from the difficulties of transferring hands between water baths, at least two factors make these methods undesirable. First, it is difficult for a subject to attend to a sensation for even 1 minute, let alone 40 minutes. Second, the lack of a clear-cut endpoint for complete adaptation, as measured by the second method, makes the judgment of the instant at which complete adaptation has occurred extremely difficult, if not impossible. Another method which insures the attention of the subject and in which the subject attempts to maintain a constant criterion throughout the observation is desirable. For these reasons we have used a variation of the psychophysical method of average error (*7*) in which the subject controls the temperature of the stimulator to maintain a particular level of sensation.

The stimulator and its control circuits have been described (*8*). The stimulator operates on the Peltier principle. When a direct current is passed through the series-connected junctions of a semiconductor, bismuth telluride, and copper, one set of junctions warms while the other set cools. A copper-constantan thermocouple, located between one surface of the stimulator and the skin, monitors the temperature and acts as a feedback to the control circuits to maintain the stimulator at a predetermined temperature. Control of the stimulator is sufficiently precise so that any temperature within the physiological range can be maintained within ±0.01°C.

The stimulator has a surface area of 14.44 cm^2; its pressure on the skin is 11.8 g/cm^2. The temperature of the stimulator can be changed by changing the electrical bias of the control circuit. In our experiment the variable resistance, which regulates the control-circuit bias voltage, was connected to a reversible electric motor. The subject could increase or decrease the temperature of the stimulator, at the rate of 0.3°C per second, by moving a lever switch. A continuous record was made of the temperature of the stimulator throughout each observation. A similar technique has been developed by Gunkel and Bornschein (*9*) and employed by Rushton (*10*) to trace the temporal course of visual adaptation to darkness.

Four subjects, two males and two females, were used. Each was thoroughly practiced in making observations of threshold thermal stimuli. The time of day at which observations were made on each subject was held constant. All observations were made in an air-conditioned room, the temperature of which varied between 23° and 26°C.

At the start of each observation period the subject was seated for a minimum of 20 minutes. At the end of this period the skin temperature of the dorsal surface of the forearm, 2

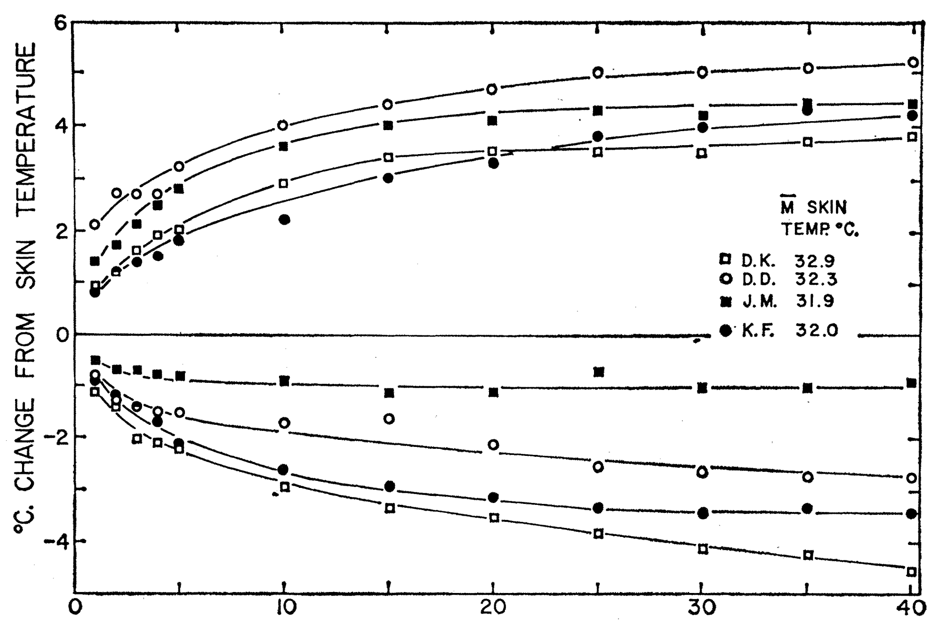

Fig. 1. The temporal course of warm and cool adaptation. Each point on the curves represents the mean of four observations, at the times indicated, of the amount by which the subject had changed the temperature of the stimulator from the initial skin temperature in order to maintain a just-detectable sensation. Also shown are the means of eight measurements of the skin temperature taken just prior to adaptation measurements on each of the four subjects.

cm below the bend of the right elbow, was measured by a thermocouple which had been soldered to a piece of silver (10 by 10 by 0.2 mm). The temperature of the stimulator was adjusted to equal that of the skin, and the stimulator was placed on the arm. The subject was instructed to adjust the temperature of the stimulator, by means of the lever switch, so that a just-detectable sensation of warm or cool was maintained throughout a 40-minute observation period. The experimenter changed the temperature of the stimulator toward neutral at 5-minute intervals and instructed the subject to readjust the temperature of the stimulator to produce the just-detectable sensation. This procedure insured the continued attention of the subject. Four measurements, on each of four subjects, were made of the temporal course adaptation to warmth and coolness. In every instance the temperature of the stimulator at which the measurement started was that of the skin of the forearm. The results are shown in Fig. 1.

Under the conditions of measurement, the range of temperatures to which complete adaptation could occur was much smaller than those found by previous investigators. The largest temperature range over which complete adaptation occurred in our study was 8.2°C (subject D.K.) and the smallest was 4.5°C (subject J.M.). Others have found the range to be 23°C (*3*), 27°C (*4*), 21°C (*6*), and even 40°C (*5*). Several factors may account for the smaller temperature range we found: better control of the stimulus and subject conditions, more stringent criterion for complete adaptation, and size and location of the area stimulated.

The rate at which adaptation occurs was very rapid for temperatures close to that of the skin and is markedly reduced for the more extreme temperatures. In practically all instances adaptation was substantially complete after 20 minutes and, in some instances, within 10 minutes. Also, it appears that adaptation to temperatures above skin temperature proceeds more rapidly than it does to temperatures below.

The final temperature to which each of the subjects could adapt was independent of the initial skin temperature. This is not as apparent from Fig. 1 as it was when the results of successive measurements on the same subject were plotted individually.

There are differences between individuals in the extent of the temperature range in which complete adaptation can occur. These differences appear to be characteristic of the individual rather than due to an error of measurement. When the data were plotted with temperature on the ordinate, rather than change in temperature, the individual differences were still apparent.

Kenshalo, Nafe, and Brooks (*11*) have reported measurements of the warm and cool thresholds as a function of the temperature to which the skin had been adapted. The adapting temperatures used by them ranged from 27° to 42°C. Within the range of adapting temperatures from about 30° to 36°C, measurements of the thresholds were fairly straightforward. The direction of the temperature change seemed to determine the quality of the thermal sensation. That is, a rise in temperature felt warm while a decrease in temperature felt cool. Outside this range, however, complications arose. The subjects reported a complex array of thermal sensations when measurements of the warm threshold were made at low adapting temperatures (below 30°C). An increase in the temperature of the stimulator first produced a sensation of "less cool" followed by "neutral" and, finally, "warm." In the measurement of the cool threshold at high adapting temperature (above 37°C) similar observations were encountered. A reduction in the temperature of the stimulator was reported as producing a "less warm" sensation followed by "neutral" and was finally reported as "cool." The extreme adapting temperatures used by Kenshalo, Nafe, and Brooks exceeded the temperature limits to which our subjects could adapt completely. At these extreme temperatures a residual sensation remained, and for experienced observers small increments or decrements in the extreme temperature altered the intensity of the residual sensation without altering its quality.

A statement concerning the nature of the stimulus events responsible for the qualities of warm and cool may be derived from the results of these two experiments. Only within the temperature limits to which complete adaptation has occurred does the direction of the temperature change determine the quality of the sensation. Outside of these limits or before complete adaptation has occurred the direction of small temperature changes only serves to increase or decrease the intensity of the persisting sensation.

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References and Notes

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12. Supported by NSF grant GB 2473. One of us (H.A.S.) was a participant in the 1964 summer program in psychology at Florida State University, sponsored by the Research Participation Program for College Teachers of the NSF.

13 December 1965

Primary-Type Antibody Response in vitro

Abstract. *Organ cultures of lymph nodes obtained from nonimmunized rabbits were incubated with bacteriophage ϕX174; as a result, 19*S *antibody was produced first, and then 7*S *antibody. Differences between this response and the secondary response to ϕX174 induced in vitro suggest that the former is a primary response.*

Secondary antibody formation can be induced and maintained in vitro (*1*), whereas primary antibody formation has not been detected under similar conditions of tissue cultivation (*1*). We now describe an apparent primary antibody response to bacteriophage ϕX174 induced and maintained in cultures of lymph nodes from nonimmunized adult rabbits.

Cervical and popliteal lymph nodes from nonimmunized albino rabbits (1.5 to 2 kg) were removed, cut into fragments, and cultivated in vitro in organ culture (*2*). Each culture initially contained 25 to 50 mg (wet weight) of tissues and 1.7 ml of medium which consisted of 20 percent normal rabbit