Reports

Secondary Reinforcement Established with Subcortical Stimulation

Olds and Milner have demonstrated that direct electrical stimulation of certain structures of the brain has a rewarding effect (*1*). Rats with chronic electrode implants in the limbic system were observed to maintain high rates of self-stimulation if given the opportunity to do so by pressing a lever. Subsequent research has confirmed and extended this finding. For example, Olds has shown that rats will learn to thread a maze for a brain stimulation reward (*2*) and will even accept a painful shock to the feet by crossing an electrified grid to obtain direct brain stimulation (*3*). Using operant conditioning techniques, Sidman *et al.* studied the effects of presenting the electrical brain stimulus under different reward schedules (*4*). The characteristic rates of responding that are known to result when conventional reinforcing agents (like food or water) are presented on particular reinforcement schedules (*5*) were also obtained with brain stimulation reinforcement schedules. These studies make it clear that direct stimulation of certain brain structures can serve as primary reinforcement for the modification or maintenance of behavior.

The study described in the present report was directed at the investigation of the brain stimulation reward with respect to another important property of primary reinforcing agents—the ability to impart (secondary) reinforcing powers to originally neutral stimuli, if these stimuli closely and regularly precede the occurrence of the primary reinforcer (*6*). The present finding that electrical stimulation of the brain can serve as primary reinforcement in establishing secondary reinforcing powers in neutral stimuli extends the generality of its action as a reinforcer and also provides some information about the process through which neutral stimuli take on secondary reinforcing functions.

A slight modification of the classical paradigm for the establishment of and test for secondary reinforcement was used. Eighteen rats with chronic bipolar electrode implants in or near the septum or anterior hypothalamus were trained in a small chamber containing two levers in one wall. Pressing of one of the levers produced a 1-sec tone of clearly audible, but not uncomfortable, intensity. Pressing of the other had no effect. A series of six daily, 1-hour sessions established the neutrality of the tone, as a very slight preference induced initially for the no-tone lever was maintained generally throughout the 6-day period (*7*).

On the seventh day, both levers were removed from the chamber, and 100 presentations of the tone, followed 0.5 sec after its onset by a 0.5-sec train of brain stimulation, were given. The time interval between pairings was varied; the mean duration was 1 minute. The brain stimulation, which was supplied from a pulse-pair generator recently described by Lilly *et al.* (*8*), had a frequency of 100 cy/sec and a pulse-pair duration of 0.1 msec. The current for all subjects was set at approximately 13 ma (positive peak current)—a value known to produce a good reinforcing effect in most positive locations. This procedure was repeated for three additional days, at the end of which time all animals had received a total of 400 pairings of tone and brain shock.

The levers were then placed again in the chamber, and for the next 3 days, 1-hour test sessions were conducted under conditions that duplicated those of the pre-pairings phase. The same lever that produced the 1-sec tone in the first phase also gave a tone when pressed in the test phase, and no brain shocks were given.

If pairing the tone with the brain shock in the second phase establishes the tone as a secondary reinforcer, then two important effects are expected in the test period: (i) a switch in lever preference: the tone-producing bar will be pressed more frequently than the no-tone bar; and (ii), the absolute rate of responding at the tone lever will increase over the pre-pairings level.

These predictions are based on the premise that the brain stimulation employed in the pairings phase was itself positively reinforcing. To determine the primary reinforcing value of this stimulation for each animal, a fourth phase was included in the procedure. Immediately after the last test day, one of the levers was removed, and a train of brain stimulation of the same intensity and duration as that used in the pairings procedure was given for each response at the remaining lever. No tones were given in this phase. The rate of self-stimulation (lever-pressing) at the end of a 1-hour session was taken as a gross index of the reinforcing value of the brain shock (*9*). On the basis of these self-stimulation rates, an unambiguous division of the animals into two groups could be made. Thirteen animals (brain shock positive group) gave rates of 9 responses per minute or higher, and five animals (brain shock neutral group) had rates of 0.2 response per minute or less. The second group was used as a control.

The data used in the analysis for a secondary reinforcement effect are summarized in Fig. 1. The total number of responses to each lever in the three sessions immediately before and the three sessions after the pairings phase were tallied for each animal and then averaged over the two groups. In the curves for the brain shock positive group, the two indications that secondary reinforcing properties were acquired by the tone are clearly evident. The crossing of these curves reflects the shift in preference to the tone-producing bar; the sharp positive slope of the tone-bar curve reflects the absolute increase, exceeding 200 percent, in response frequency at that bar following the pairings.

Statistical tests affirm these observa-

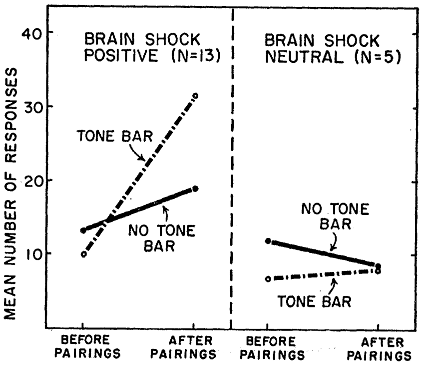

Fig. 1. Mean number of responses at the two bars for the three sessions before, and the three sessions after, the pairings phase for both groups.

All technical papers and comments on them are published in this section. Manuscripts should be typed double-spaced and be submitted in duplicate. In length, they should be limited to the equivalent of 1200 words; this includes the space occupied by illustrative or tabular material, references and notes, and the author(s)' name(s) and affiliation(s). Illustrative material should be limited to one table *or* one figure. All explanatory notes, including acknowledgments and authorization for publication, and literature references are to be numbered consecutively, keyed into the text proper, and placed at the end of the article under the heading "References and Notes." For fuller details see "Suggestions to Contributors" in *Science* 125, 16 (4 Jan. 1957).

tions. A t-test of the difference between the difference scores (responses to the tone bar minus responses to the no-tone bar) before and after the pairings gave $t = 4.07$ ($p \simeq .001$, indicating a significant shift in lever preference. A t-test of the difference in response frequency at the tone bar before and after the pairings gave $t = 4.20$, $p \simeq .001$.

In contrast, neither of these effects was obtained in the brain shock neutral group. The preference for the no-tone bar, although diminished, persisted after the pairings procedure, and the absolute increase in response frequency at the tone bar was negligible.

It is concluded that electrical stimulation of septal and hypothalamic structures can serve as primary reinforcement in establishing secondary reinforcing powers in neutral stimuli. This finding does not seem to be consistent with a theory of secondary reinforcement which assumes that a neutral stimulus must be established as a discriminative stimulus in order to function as a secondary reinforcer (*10*).

It is tempting to speculate that what may be involved here is a kind of neural conditioning, with the tone serving as the conditioned stimulus and the brain shock as the unconditioned stimulus. After the pairings, the tone has reward value because it gives rise to a conditioned neural discharge of a reinforcing nature (in, presumably, the same structure, stimulated electrically). Indeed, it should be possible, through the use of brain-wave recording techniques, to determine directly whether neural activity produced by direct stimulation of subcortical structures can in fact be conditioned to a sensory input.

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References and Notes

→ J. Olds and P. Milner, *J. Comp. and Physiol. Psychol.* 47, 419 (1954).
2. J. Olds, *ibid.* 49, 507 (1956).
3. J. Olds and J. C. Sinclair, *Am. Psychologist* 12, 464 (1957), abstract.
→ M. Sidman *et al., Science* 122, 830 (1955).
5. C. B. Ferster and B. F. Skinner, *Schedules of Reinforcement* (Appleton-Century-Crofts, New York, 1957).
6. C. L. Hull, *Principles of Behavior* (Appleton-Century-Crofts, New York, 1943).
7. Prior to the first day of training, all animals were placed in the chamber for 1 hour, during which time neither lever produced any tone, in order that original lever preference might be determined. The tone was then associated with the nonpreferred lever.
→ J. C. Lilly *et al., Science* 121, 468 (1955).
9. In the case of several animals that had zero or near-zero rates in the first hour, additional test sessions were conducted to make sure that the placements were not positive.
10. W. N. Schoenfeld, J. J. Antonitis, P. J. Bersh, *J. Exptl. Psychol.* 40, 40 (1950). The operations that imparted secondary reinforcing properties to the tone in the study described in this report (that is, the pairings with brain shock) did not provide, at the same time, the conditions favorable to its development as a discriminative stimulus. This is because the effective delivery of the brain shock reward requires no (operant) response on the part of the animal, in contrast to conventional reward situations which involve approaching and consummatory behavior. In a case such as this, it is hard to see how particular responses could have been selectively reinforced with brain shock in the presence of the tone to permit the formation of a discrimination. Furthermore, the brevity of the interval between tone and brain shock (0.5 second) would make the development of superstitious behavior in response to the tone unlikely. No evidence of such behavior was indicated by observation.

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Effects of Brief Exposures to Cold on Performance and Food Intake

The relationship between food intake and temperature is usually studied, as is acclimatization in general, during prolonged exposure to one temperature. Under these conditions, rats typically show a configuration of changes that comprise the state called acclimatization. These include changes in heat production and food intake, endocrine structure and function, peripheral vascularization, and so on (*1*). In this paper, I report data (*2*) based on brief exposures to varied temperatures which appear to demonstrate acclimatization phenomena of very short latency.

Rats were exposed to a temperature of either 0°, 10°, or 20°C (±2°C) for 20 minutes per day. The apparatus used was a box 10 by 10 by 11 in. that contained a lever and a device for delivering a small pellet of food weighing about 0.04 g. The box was kept in an insulated enclosure connected to a refrigeration unit so that its internal temperature could be varied. The lever was connected in such a way that a food pellet was delivered once per minute, provided that the lever was pressed at the end of the period. This periodic reinforcement schedule was used in order to avert differences in food intake among the animals while they were in the apparatus. The animals were given access to food for only 1 hour following their exposure to the various temperatures.

Thirty male Sprague-Dawley rats, about 6 months old, were used as subjects. They were started on the study after 3 weeks of experience on the 1-minute periodic reinforcement schedule. Each animal was exposed to each temperature during each 3-day experimental period. There were eight of these periods, or 24 experimental days in all, for each rat. Three different sequences of exposure were used, with ten animals assigned to each sequence, and each group repeated its assigned sequence four times. These sequences were as follows: Group 1: 0°, 20°, 10°, 20°, 0°, 10°C; group 2: 10°, 0°, 20°, 10°, 20°, 0°C; group 3: 20°, 10°, 0° 0°, 10°, 20°C.

The performance criterion was the number of lever-presses made during each experimental session. The data on food intake are based on the amount of food eaten in the 1-hour period following the 20-minute exposure. This food was a commercial dog food (Red Chain) that had been crushed to powder form. Feeding cups with perforated inserts were used to prevent spilling.

Figure 1 shows the performance data for the first four periods (*3*). Each point in this figure is based on the performance of all 30 animals. During the first period, response frequency was greatest for the highest temperature and least for the lowest temperature. Then, because of increases in responses at the two lower temperatures, the frequency for all three temperatures became about the same. Since rats exposed to cold eat more food, one would expect them to respond more frequently at lower temperatures because of the correlation between length of food deprivation and rate of lever pressing (*4*).

Figure 2 reveals the amount eaten in

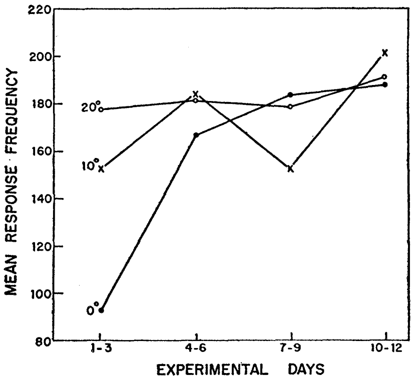

Fig. 1. Performance (lever-pressing) data at the three different temperature levels during the first four of the eight 3-day periods.

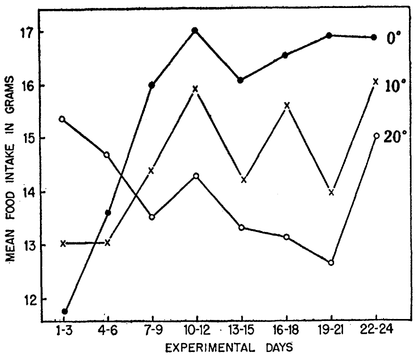

Fig. 2. Food intake during the hour that directly followed exposure to the three different temperatures to which the rats were subjected during the eight 3-day periods of the experiment.