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MODIFICATION OF A VISCERAL RESPONSE, SALIVATION IN THIRSTY DOGS, BY INSTRUMENTAL TRAINING WITH WATER REWARD[1]

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Thirsty dogs rewarded by water for bursts of spontaneous salivation showed progressive increases in salivation, while other dogs, rewarded for brief periods without salivation, showed progressive decreases. No obvious motor responses were involved, but dogs rewarded for decreasing salivation appeared more drowsy than those rewarded for increasing it. Implications for learning theory and psychosomatic medicine are mentioned.

The traditional view of most learning theorists who have written specifically on the problem is that, while skeletal responses mediated by the somatic nervous system can be learned as instrumental responses rewarded by the law of effect, visceral responses mediated by the autonomic nervous system can be learned only by classical conditioning (Keller & Schoenfeld, 1950; Kimble, 1961; Konorski & Miller, 1937; Mowrer, 1947, 1950; Skinner, 1938; Solomon & Wynne, 1954).

In sharply challenging this position, Miller (1961, 1963a, 1963b, 1964) has emphasized that this issue has fundamental implications not only for theories of learning and its neurophysiological basis, but also for practical problems of psychosomatic symptoms and of individual differences in patterns of autonomic responses. While the reinforcement for classical conditioning must be a stimulus eliciting a UR similar to the one to be learned by conditioning, any reward can reinforce any response in instrumental learning. Thus if visceral responses can be modified only by classical conditioning, they can be learned and maintained only in situations involving reinforcing stimuli with the unconditioned ability to elicit that particular visceral symptom; whereas if they can be learned as instrumental responses, rewarded by the law of effect, their initial learning and subsequent performance can be reinforced by any one of a wide variety of rewards (Dollard & Miller, 1950).

There is an extensive literature on the modification of many visceral responses by classical conditioning (Bykov, 1957; Kimble, 1961; Pavlov, 1927). For a long time the experimental evidence on the possibility of instrumental learning of visceral responses has been limited to incidental mention of the negative results of two unpublished studies (see Mowrer, 1938, and Skinner, 1938). Very recently, however, there have been a number of reports of the successful modification of the galvanic skin potentials in humans by instrumental techniques (Crider, Shapiro, & Tursky, 1966; Fowler & Kimmel, 1962; Johnson, 1963; Kimmel & Kimmel, 1963; Snyder & Noble, 1965). Furthermore, Shearn (1962) and Shearn and Clifford (1964) have reported modifying the heart rate in humans and in rabbits by instrumental techniques. But there are a large number of ways in which the GSR and heart rate can be affected via skeletal responses, such as breathing; the possibility of such mediational responses probably is much greater with human than with animal *S*s. For this reason we thought it desirable to work with dogs and to use a visceral response, salivation, which has been extensively employed in classical conditioning. It seemed worthwhile to determine whether this response could be modified in any way by instrumental training procedures before going on to the difficult attempt to eliminate all possibilities of mediation via skeletal responses.

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The purpose of the present study was to see whether it is possible to change the rate of spontaneous salivation of mildly thirsty dogs by using water to reward some of them when they increase their rate and others when they decrease their rate. Preliminary tests showed that the water did not elicit any appreciable change in salivation; furthermore, the effects of any classical conditioning produced by any unconditioned effect of water were controlled by the procedure of rewarding different groups for changes in opposite directions.

Experiment 1

Method

Subjects. The *S*s in this experiment were 10 naive mongrel dogs of both sexes purchased through the Yale animal care facilities. Their weights were 18–30 lb.

Apparatus. We used the method of recording salivation from the parotid duct developed by Sheffield (1957).[3] Under Nembutal anesthesia, the parotid duct was cannulated with polyethylene PE50 tubing which was brought outside through a hole in the cheek and fastened to a parallel stainless steel plate on the inside of *S*'s cheek. A stainless steel tube, which made an airtight and watertight seal with the flanged terminal of the cannula, was threaded into the outer Plexiglas plate and served as the exit for the salivary flow and the spigot to which the recording device was attached.

The recording was made by connecting a polyethylene tubing (PE240) between the stainless steel tube in the outer Plexiglas plate and a closed water system whose lower end was placed about 18 in. below the level of the floor of the experimental cage. The closed system was filled with a mixture of 50% water and 50% ethyl alcohol. The saliva entering in the upper end of the system allowed fluid to drip out of the lower end. Thus changes in the viscosity of the saliva did not affect the output. The lower end of this system was a No. 27 hypodermic needle, from which each emerging drop touched an upright needle and momentarily closed a circuit to an electronic relay (Grason-Stadler Drinkometer) which activated a counter and an ink-writing recorder.

The experimental chamber was a 3½ × 3½ × 5½ ft. wooden one with glass wool between the walls. A blower unit provided ventilation and white noise. This cage was only relatively soundproof. The clicks of the relays energized by each drop of liquid were always present. A one-way mirror allowed *E* to observe *S* during the experiment.

Procedure. During the first week after operation *S*s were habituated to the experimental situation. On each session, *S* was placed in the experimental chamber and the working condition of the cannula was tested by giving *S* a pellet of food, after which the door was closed. Twenty-four hours after cannulation, only salivation in response to one pellet of food was recorded. For the rest of the experiment, *S*s were tested after 16 hr. of water deprivation. Each session lasted 30 min. after the initial test for the condition of the cannula. For the next 5 days, *S*s were run twice a day in habituation sessions involving only the recording of spontaneous salivation. The *S*s salivating between 20 and 40 drops/min (a middle range from which either increases or decreases were possible) were kept and randomly assigned to one of two groups of 5 dogs each; 9 dogs had to be discarded in the process of securing 10 *S*s.

After habituation, the sessions were reduced to one a day and the instrumental training procedure began. Group 1 was first given 10 sessions during which nonsalivating was rewarded. After this the cannulas were removed and *S*s allowed to rest for 15 days before cannulas were implanted again in the opposite cheeks. Then *S*s were given 10 sessions of reward for the opposite response of salivating. For Group 2 the procedures were exactly the same, except that salivating was rewarded first and nonsalivating second.

In all cases the reward was the delivery of 20 ml. of water when *E* closed a switch. After each reward there was a 30-sec. time-out period (not marked by any cue given to *S*) during which no reward could be earned. The initial criterion for rewarding nonsalivation was a pause of 2 sec. between drops. This criterion was progressively increased to a pause of 30 sec. between drops. The initial criterion for rewarding salivation was 2 drops per 10 sec. This criterion was progressively increased to 10 drops per 10 sec.

In preliminary work on other dogs we had found that, if a CS preceded the delivery of water, the *S*'s orientation response to this CS and the water dish temporarily inhibited all salivation. Therefore, no CS was used. Between rewards *S* sat with its head just above the dish ready to drink as soon as water was delivered.

For each of the 10 days of training, the total number of drops of salivation per day was recorded for each *S*. The slope of the curve for drops per day on successive days of training was calculated for each *S* according to the procedure described by Edwards (1962).

Results

There was a general tendency for the slopes to be negative, indicating decreased

[3] More detailed description available in mimeographed manuscript from F. D. Sheffield, Department of Psychology, Yale University, New Haven, Connecticut.

salivation as training progressed; but during the first period of training, the average negative slope of -2.7 for Group 1 was greater than that of -0.08 for Group 2. Thus the difference was in the expected direction. Furthermore, there was no overlap between the two groups—all five *S*s in Group 1 had negative slopes, and in Group 2 two *S*s had smaller negative slopes, while the other three had positive ones. Such a perfect dichotomy between the two groups would be expected by chance only 1 time out of 512.[4]

During the second period of training, when each group was rewarded for the opposite response, the difference between them reversed, but was small (-0.07 vs. -0.12) and unreliable. Finally, when each *S*'s score during reward for decreasing was subtracted from its score during reward for increasing, the net difference for 8 out of 10 *S*s was in the expected direction, and the mean $+1.3$, also in the expected direction, was reliably different from zero ($p < .05$, $df = 9$).

Although the foregoing overall effects were reasonably reliable, the differences were small and the slopes for individual *S*s were unreliable.

Experiment 2

The purpose of this experiment was to see whether more extensive training would produce more clear-cut instrumental learning of salivation in individual dogs. For those dogs whose salivary ducts remained in good condition, a secondary purpose was to see whether the effect of the initial training could be reversed by rewarding the opposite response.

Method

Subjects. We used 6 naive mongrel dogs, 1 female and 5 males, purchased from the Department of Animal Care at Yale University.

Procedure. After being habituated to the experimental situation for 2 wk., *S*s were implanted with cannulas in the parotid gland and 24 hr. later were put on a schedule of 16 hr. of water deprivation preceding each day's preliminary tests. During 7–12 sessions of 1 hr. each, spontaneous salivation was recorded and, if *S*s were salivating less than 10 or more than 35 drops/min, they were discarded. We had to give preliminary tests to 11 dogs in order to get 6 within this range. After this test period, *S*s were assigned to two matched groups which were then assigned by the flip of a coin to the two conditions of treatment.

The *S*s in each group received the same amount of food every day 1–2 hr. before the experimental session. They were run 45 min. a day for 5 days a week. Before the experimental session there was 15 min. of habituation during which the door of the experimental chamber was left open. During weekends *S*s had access to water ad lib, but during the rest of the week received water only during the experimental sessions. An exception occurred with *S*s rewarded for speeding up after being rewarded for slowing down; in those cases, because of the small number of rewards received in the experimental situation, *S*s had to be given water after the experimental sessions.

In order to flush out the cannula with more profuse salivation than food elicits, and also to determine that it was functional, we squirted 5–10 ml. of a mixture of 50% ethyl alcohol and water into *S*'s mouth each day while *S* was standing in the experimental chamber before the experimental session began. Then we followed this mixture with a pellet of food to remove the aversive taste. Whenever *S* salivated less than 100 drops/min in this test, we took the cannula off. We did the same as soon as signs of infections were suspected. After the wound had healed, we implanted the cannula in the same cheek and resumed training. To prevent local infections, we daily applied 2–3 ml. of sulfodiazol around the wound.

The groups were randomly assigned to the following treatments:

Group 1, fast first. Three dogs were rewarded for speeding up during 37, 40, and 39 days, respectively. After a rest period of about 3 mo., we found that one *S* had been infected with distemper and had to be discarded. The other two were run next for 40 days with reward for slow salivation. After a rest period of 2–3 mo., these same *S*s were run for 40 days, with reward now for fast salivation.

Group 2, slow first. Three *S*s were rewarded for slowing down for 40 days. After 3 mo. of rest, one had to be discarded because the salivary gland did not work well. The other two were run for 40 days with reward for fast salivation, and then finally run for 30 days with reward for slowing down. All *S*s were run in the same apparatus, and as a further control *S*s getting opposite training were run on the same day. The criterion for giving the reward was similar to that in Experiment 1, but, with *S*s rewarded for decreases in salivation, the initial criterion of a 2-sec. interval without salivation was progressively increased up to 60 sec. in the final stages. During training for increases in salivation, we initially rewarded every burst of spontaneous salivation of 1 drop or more in a 5-sec. period and progressively increased this

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[4] All probabilities reported in this paper are for two-tailed tests.

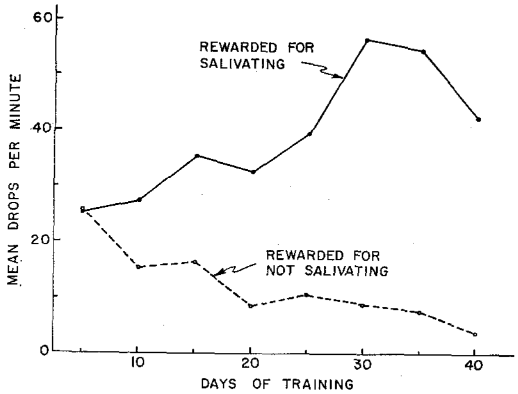

FIG. 1. Mean curves of instrumental learning by three thirsty dogs rewarded with water for increases or decreases in spontaneous salivation.

criterion to 7 drops in 5 sec. in the last stages of the experiment.

The slopes of the curves for amount of salivation on successive days of training were calculated for each *S* in the way described for Experiment 1.

Results

The results of the first period of training are presented in Figure 1. In Group 1 the dogs rewarded for fast salivation increased with slopes of +.91, +.59, +.29, each reliably different from zero (p < .001, .016, .013; *df* = 35, 38, 37, respectively). In Group 2 the dogs rewarded for not salivating decreased with slopes of −.50, −.90, −.45, each reliably different from zero beyond the .001 level (*df* = 38). During the early part of this training, *S*s in Group 1 received more rewards than those in Group 2; but during the last 10 days of training, the criterion for Group 1 had been increased so that the two groups did *not* differ in amount of water received as a reward.

When the conditions of reward were reversed during the second period of training, the signs of the slopes reversed. The slopes in Group 1 were −.59 and −.92, both reliable at the .001 level; those in Group 2 were +.07 and +.16, reliable at the .007 and .052 levels, respectively.

When the conditions of reward were reversed yet again during the third period of training, one *S* in Group 1 continued to decrease its salivation, showing a slope of −.17, reliable (p = .02) in the wrong direction, while the other dog showed a slope of +.02 in the correct direction, but not statistically significant. In Group 2 both *S*s showed successful reversals with slopes of −.58 and −1.2 in the expected direction which were highly reliable (p < .002, .001).

When the slopes of individual *S*s during different conditions of reward were compared (i.e., *S* 1 fast *minus S* 1 slow for first vs. second training periods, and separately for third vs. second periods), the algebraic differences of all eight possible comparisons are in the direction to be expected on the basis of the rate rewarded, with six significant at the .001 level, one at the .01 level, and one not significant.

DISCUSSION

The results clearly show that the autonomically innervated visceral response of salivation can be modified by an instrumental training procedure. From the point of view of the theory and neurophysiology of learning, it is important to know whether the visceral response was directly modified or whether the change was mediated by the learning of some skeletal response which in turn had an unlearned tendency to affect the visceral response. We did not observe any obvious skeletal responses, such as chewing or panting, regularly associated with the amount of salivation, but more subtle ones may have occurred.

In an attempt to get more accurate data on the skeletal response most likely to affect salivation, we recorded the frequency of respiration by a strain-gauge pneumograph in 5 cases of reward (in different stages of Experiment 2) for increases in salivation and 4 cases of reward for decreases. As supplementary data we also recorded the number of heartbeats by taking EKGs. The records for these responses and for salivation were scored during the 5–10, 20–25, and 35–40 min. periods of each day. The daily averages were used to compute separate correlations between these measures for each type of training on each dog.

Salivation on daily tests was positively correlated with number of breaths on daily tests for all 9 cases, indicating a definite relationship between rate of breathing and amount of salivation. Similarly, the number of heartbeats was correlated with the amount of salivation for 7 out of the 9 cases. There was a general tendency for the number of breaths to decrease as training progressed, but no appreciable difference between the groups in this respect.

In order to determine how much of the effects of training on salivation could be accounted for on the basis of any effects on breathing, partial correlations were calculated. With the effects of breathing partialed out, correlations between days of training and amount of salivation were positive for the 5 cases rewarded for increasing and negative for 3 of the 4 rewarded for decreasing, a difference in the expected direction reliable at a little better than the 10% level. When the effects of both heart rate and breathing were partialed out, the correlations between training and salivation were larger (i.e., more positive) for all of the cases rewarded for increased salivation than for any of them rewarded for decreased salivation, a difference reliable beyond the 1% level by Fisher's exact test. These results indicate that the difference in salivation between the cases rewarded for increasing and for decreasing salivation probably cannot be attributed solely to differences in rate of breathing.

We started to proceed to the next step of more conclusively ruling out the effects of breathing and other skeletal responses by paralyzing them with curare and maintaining the dogs on artificial respiration, but found that this drug elicited continuous copious salivation, without the pauses and bursts necessary for rewarding increases or decreases. Furthermore, the saliva was viscous and likely to clog the cannula.

A second question is whether the learned response is relatively specific to the salivation that was rewarded, or is a part of some more general pattern, such as arousal. We observed that *S*s rewarded for increasing salivation tended to be especially alert; the EEG records taken on two of them were characterized by many movement artifacts and a typical arousal pattern of fast, low-voltage activity. The *S*s rewarded for not salivating tended to be more drowsy, sitting quietly in front of the water dish, sometimes appearing to take short naps. The EEG records on two of them showed much more slow-wave, high-voltage activity. These observations suggest that the salivation may have been part of a larger pattern of general arousal vs. relaxation.

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