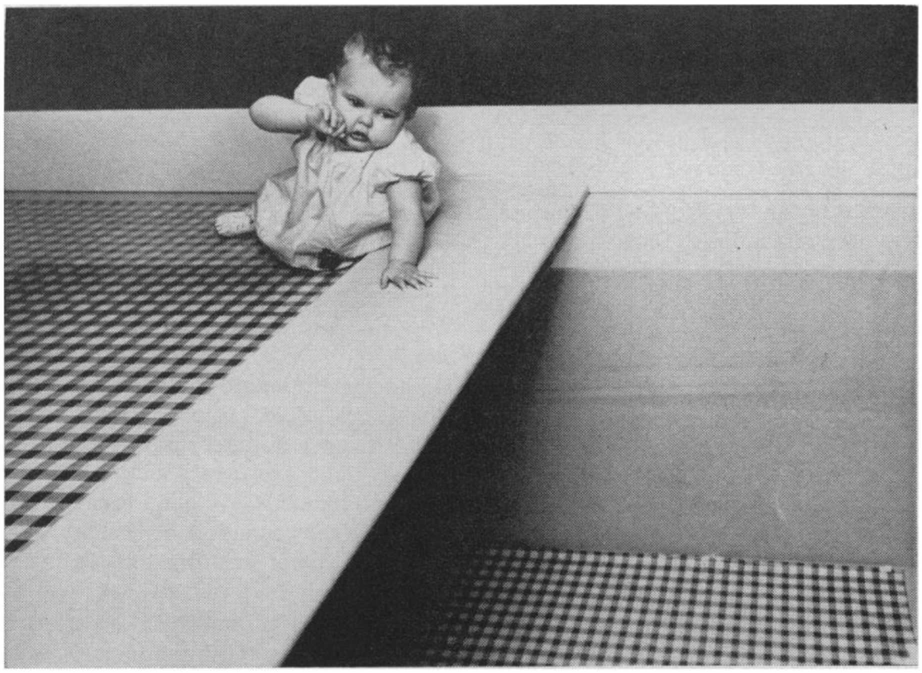

Fig. 1. The infant (the right eye is glass) refuses to cross over the "deep" side to the mother. The photograph was taken 1 week after the experiment. Most of the photography time (30–40 minutes) was spent in calling the infant from the deep side. However, she never crossed the "void" and crawled to the mother at the "shallow" side only.

reaching toward the mother at the deep side, and crawling around on the shallow side. The trial terminated at 3 minutes.

Before the start of trial 5, the mother decided that a nursing bottle, filled with orange juice, would be a better lure. The infant was given a sip and then was placed back on the center board from the west.

Trial 5. (Mother with nursing bottle called from shallow side.) The infant crawled to the mother within 5 seconds.

Trial 6. (Infant placed on board from west. Mother with nursing bottle at deep side.) The infant crawled immediately to the shallow side. When urged by the mother, she crawled back to the center board and looked down. Then she crawled to the experimenter standing near the shallow side and put her arms around his neck. He replaced her on the center board and the mother continued calling. The infant became very upset as the mother urged her to cross the deep side. She began to whimper and then to cry. The trial terminated at 2 minutes.

This monocular infant thus behaved similarly to the average binocular infant. She crawled to her mother over the shallow side, but would not cross the deep side. She looked down into the "void" many times and, in doing so, did not move her head excessively (Fig. 1).

The behavior of this infant is also congruent with the behavioral pattern of animals. The monocular 1-day-old chick and the 60-day-old hooded rat can discriminate depth in a manner comparable to their binocular controls, even when a larger pattern (larger projected texture) is used on the deep side. This feature permits monocular motion parallax to be the main cue (*4*).

Our experiment, therefore, demonstrates that monocular cues suffice for efficient depth perception and may help explode a "common sense" myth about the primacy and necessity of binocular vision for depth perception (*5*).

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References and Notes

1. K. N. Ogle, *Science* **135**, 763 (1962); E. F. Tait, *Textbook of Refraction* (Saunders, Philadelphia, 1951).
2. J. J. Gibson, *The Perception of the Visual World* (Houghton Mifflin, Boston, 1950).
3. E. J. Gibson and R. D. Walk, *Sci. Am.* **202**, 64 (1960); R. D. Walk and E. J. Gibson, *Psychol. Monogr.* **75**, No. 15 (1961).
4. H. R. Schiffman, "Monocular visual depth perception in the new-born chick," unpublished thesis, George Washington Univ. (1961); S. Trychin, Jr., "A comparison of visual depth perception in monocular and binocular hooded rats," unpublished thesis, George Washington Univ. (1962).
5. Our research was supported in part by a grant from the National Science Foundation (G-19411). We thank Nancy Crocker and her parents for their generous help.

4 June 1962

Operant Conditioning of Heart Rate

Abstract. Delay of shock was made contingent upon acceleration of heart rate in human subjects. The number of accelerations rose across sessions for these subjects and fell for their yoked-controls who received equal amounts of noncontingent shock. A shorter delay produced more accelerations but faster adaptation. Interpretation of changes in heart rate is confounded by related respiratory changes.

While feedback would seem to characterize autonomic behavior in the biological system (*1*) little research has been directed toward the use of feedback of external origin. Practically all exteroceptive control of the heart in the laboratory has involved classical conditioning (*2*) despite the striking efficiency of operant conditioning in differentiating skeletal response rate, magnitude, and form.

In the work I am describing, I used operant conditioning techniques as a first step toward differentiation of human heart rate in which the selected response was a temporary acceleration (*3*). Because the research was an initial attempt to manipulate heart rate through response-contingent techniques, the strategy was one of an unhampered attack on heart rate alone. Therefore, while respiration was recorded, no attempt was made to control it.

The procedure employed a modified Sidman-avoidance schedule similar to that used by Verhave (*4*). In the Sidman procedure, shock pulses are delivered at regular intervals (designated SS intervals) unless a lever is depressed by the animal. Depressing the lever delays shock for a specified time. No external warning signal is used. In my research five responses (heart beats) had to occur within a criterion interval in order to postpone shock. Shock was delayed for a time equal to the SS interval. Because of the drifts in heart rate during sessions, average heart rate over the preceding few minutes was used to establish a criterion interval in which five beats had to occur to postpone shock. The criterion time was arbitrarily selected as 5 percent below the average time required for five beats during the preceding period.

Subjects were allowed to watch an illuminated reset timer which timed the SS interval, resetting and delaying shock whenever criterion accelerations in heart rate occurred. A 0.34-second, 18-volt alternating current was delivered to the ankle through an initial skin re-

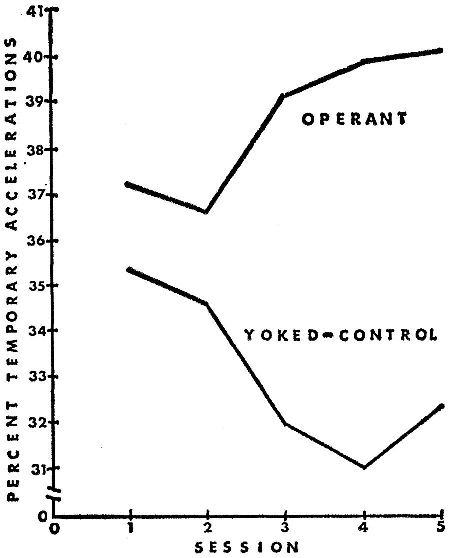

Fig. 1. Percentage of temporary heart rate accelerations of criterion magnitude for operant and control groups across sessions.

sistance of 10 kohm if the timer reached zero. Chest electrodes passed heart signals to a preamplifier, cardiotachometer, and switching circuitry. Heart beats were made audible to the subject by means of a loud speaker.

Since the shock and associated stimuli would produce by themselves rather large increases in heart rate, it was necessary to separate their effects from the effects due to operant conditioning contingencies. A yoked-control procedure was used whereby each of six male subjects receiving the operant treatment had paired with him a control subject who received the same number of shocks with the same temporal distribution, regardless of changes in his heart rate. In short, the yoked-control was placed in a classical conditioning paradigm with irregular pairings of conditioned and unconditioned stimuli. The only difference between operant and classical treatments was that interruptions in the shock sequence were contingent upon criterion heart-rate increases for operant subjects, but not for control subjects.

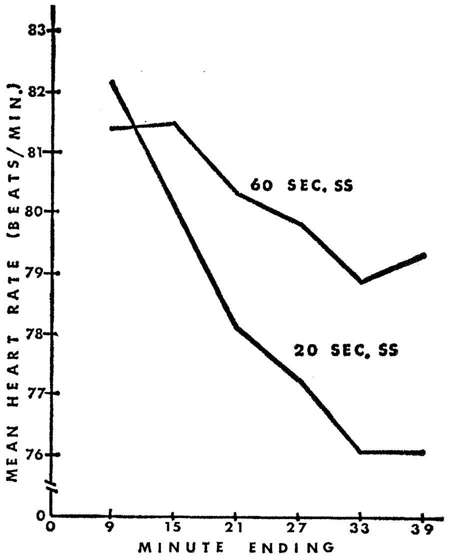

Fig. 2. Mean heart rate during the session for 20- and 60-second shock delay.

Figure 1 summarizes the behavior of the 12 subjects in terms of the percentage of the total number of five-beat samples meeting the criterion for each of the five daily sessions. These curves which begin to diverge sharply after the second session are fairly representative of all subjects. Five of the six subjects exposed to the operant treatment showed an increase in the percentage of accelerations across sessions. All six subjects of the classical control treatment showed a decrease in the percentage of temporary accelerations across sessions. This change across sessions was significantly different for the two treatments ($P < 0.03$, Mann-Whitney U test).

Half of both operant and classical subjects were programmed on a 60-second SS schedule and the other half on a 20-second SS schedule. Total possible shocks were held constant by reducing the length of the session to 40 minutes from 60 minutes and giving shocks 50 percent of the time for subjects on the 20-second SS schedule. Both operant and control subjects on this schedule showed many more criterion accelerations. No subject on the 60-second SS schedule emitted as high a percentage of criterion accelerations during the entire experiment as any SS subject on the shorter schedule.

Overall heart rate was affected markedly by the SS interval but not by the operant or classical control treatments (Fig. 2). The shorter SS interval (both operant and control) produced a significantly greater decrement in heart rate than the longer interval ($P < 0.005$). The more rapid adaptation of the heart rates of the 20-second SS subjects appears as a curious result when coupled with the fact that this treatment produced a greater number of criterion heart-rate accelerations. While there was a steeper downward trend in heart rate, there was also a greater tendency for short-term increases in heart rate of criterion magnitude for the SS subjects on the 20-second SS schedule. The fact that these short-term increases could not be detected as differences in variance between the two interval treatments suggests a rather selective heart rate response.

Unlike the typical results of studies where the Sidman-type schedule is used with skeletal response, my study showed no reduction in the number of shocks. The mean number of shocks (13.3) in the last session was virtually the same (13.9) as in the first session. Whether this reflects a basic difference between skeletal and autonomic operants, the relatively short duration of the experiment, or a phenomenon which is not truly operant conditioning is to be revealed in long-term experimentation where decreases as well as increases in heart rate are studied.

Pneumograph records showed that interpretation of heart rate results is confounded by respiratory changes. Respiration amplitude immediately preceding and during criterion heart-rate accelerations was greater than during periods when criterion heart-rate accelerations did not occur ($P < 0.02$ for combined treatments). No significant distinction could be made between treatments on the basis of respiration amplitude.

Respiration rate, on the other hand, was significantly higher for the operant treatment ($P < 0.05$) immediately preceding the first criterion heart rate increase. Significant differences in respiration between 20-second SS and 60-second SS treatments were lacking despite the important differences which existed between the heart rates of these treatments. An attempt to separate cardiac and respiratory behaviors could be made within the present procedural framework with the use of concurrent schedules (*5*) such that independent reinforcement contingencies would be provided for cardiac and respiratory responses.

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References and Notes

1. R. C. Davis, *Psychol. Rev.* **65**, 1 (1958); E. Gellhorn, *Autonomic Imbalance and the Hypothalamus* (Univ. of Minnesota Press, Minneapolis, 1957).
2. D. W. Shearn, *Psychol. Bull.* **58**, 6 (1961).
3. This research was my doctoral dissertation in the department of psychology, Indiana University, 1960. It was supported by contract Nonr 908–15, Office of Naval Research, R. C. Davis, principal investigator.
4. M. Sidman, *Science* **118**, 157 (1953); T. Verhave, *Science* **129**, 959 (1959).
5. C. B. Ferster and B. F. Skinner, *Schedules of Reinforcement* (Appleton-Century-Crofts, New York, 1957).

1 March 1962