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PAVLOVIAN DIFFERENTIATION OF HEART RATE IN THE RHESUS MONKEY

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Stimulus discrimination in classical conditioning is usually achieved by the method of "contrasts" (Pavlov 1927) in which the two stimuli to be differentiated are randomly alternated and one (CS+) is followed by reinforcement while the other (CS−) is not. Since responses generalize in conditioning, not only to stimuli on the same physical continuum as the training stimuli, but to stimuli from other modalities as well, differentiation typically takes some time to become established. Whether it is extinction of the response to the contrast stimulus, or the development of inhibition is a theoretical issue; the empirical evidence merely indicates that differentiation appears to have a time course.

Pavlov noted that the differentiation of closely allied stimuli often proved difficult to establish but, if the contrast stimulus were made "remoter" and then slowly brought closer to the conditional stimulus, stable differentiation could be obtained. This same procedure has been used in operant or instrumental research in developing, for example, "errorless" learning (Terrace 1963ab).

In the course of a study involving classical conditioning of heart rate (HR) in Rhesus monkeys, clear differentiation of stimuli on a line-tilt continuum was not obtained in two out of three subjects by the end of 15 sessions of contrast training. The present paper describes the results of using several training techniques commonly used in the development of stimulus control of operant behavior (Terrace 1966).

METHOD

Subjects. The subjects were three male Rhesus monkeys obtained from a commercial importer and judged to be between two and four

years old. They were maintained on standard laboratory chow with supplemental feedings of fresh fruit given daily.

Apparatus. The monkeys were restrained in primate chairs mounted on slides in wooden chambers, the inner sides of which had been covered with acoustic tile to improve sound attenuation. Line-tilt stimuli were presented by an in-line projector positioned approximately 25 cm in front of the monkey's head. The line, 3 mm wide, appeared on a 2.5 cm circular light patch on the face of the projector. The positive stimulus (CS+) was a vertical line (designated 0°) while the contrast stimulus (CS−) was a line tilted 45° to the left (designated −45°). Electric shock was used as the unconditional stimulus (US) and was delivered through foot electrodes (Weiss and Laties 1962) to which the monkey's feet were strapped before each session with strips of cloth fastener (Velcro).

Recording of HR was accomplished by use of a belt and vest system (Ramsay et al. 1968). Briefly, a belt with two surface electrodes was strapped around the monkey's shaved chest and then a sleeveless, leather vest placed on the monkey to prevent him from disturbing the electrodes or the wires attached to them. EKG tracings were recorded on a polygraph and analyzed by hand. Both recording and control equipment were located in a separate room.

Procedure. Prior to differentiation training, the monkeys had been exposed to a variety of procedures including chair adaptation (9 sessions), CS+ adaptation (5 sessions), one sensitization testing session, further CS+ adaptation (4 sessions), 13 sessions of Pavlovian delay conditioning, and a generalization test session (Ramsay 1969). During the conditioning phase, 14 trials were scheduled each session with a CS+ duration of 30.5 sec and US duration of 300 msec, with US onset coincident with the end of the 30th sec of CS+. Shock intensity was adjusted for individual animals and varied from 6.0 to 9.0 ma. The intertrial interval averaged 7 min, onset-to-onset, with a range of 5–9 min. EKG was recorded prior to, during, and after CS+.

The differentiation phase of the main study, which will be reported here, can be more easily followed if it is broken down into three sections. With the beginning of this phase, the contrast stimulus (CS−) was presented on half of the 14 trials. The CS+ and CS− trials were alternated according to a modified Gellerman series. Five separate sequences were constructed and were rotated from session to session. Shock was omitted on CS− trials while CS+ trials continued to terminate with foot shock. Stimulus duration, intertrial interval, and session length remained unchanged from the preceding conditioning phase.

RESULTS

Phase I. Method of contrasts

During the first section, the animals were given 15 sessions of differentiation training under the contrast procedure described above. Generalization tests, conducted under extinction conditions in single sessions, were administered periodically but the data will not be reported here. The first four sessions of contrast training were followed by the first generalization test. A second block of four sessions was followed by the second generalization test. During these four sessions, shock intensity had been increased for one monkey (C-3) because of what appeared to be an attenuated cardiac response to CS+. Next, a block of three more sessions of contrast training was run. By this time, there was no clear evidence of stable cardiac differentiation in two of the three animals. The white

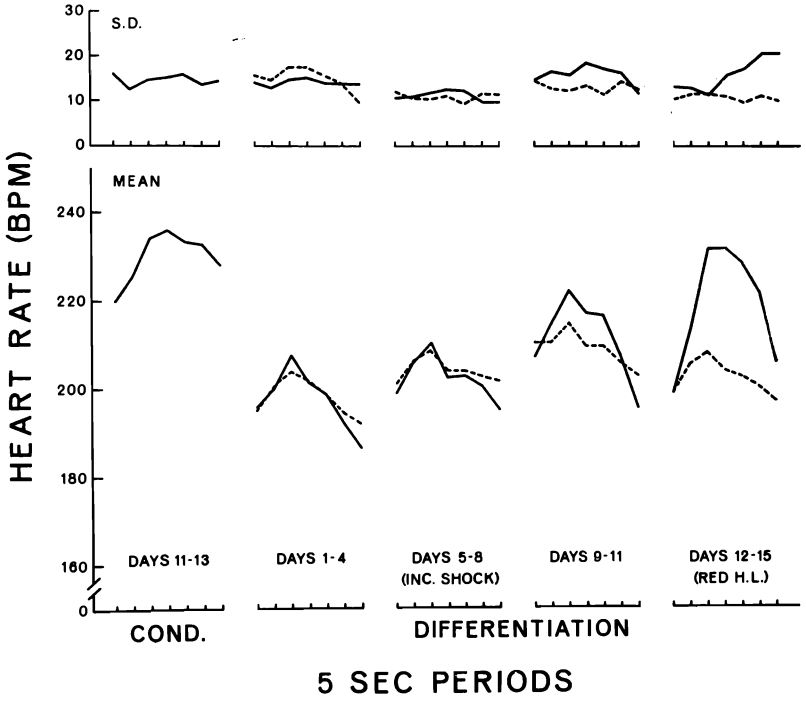

FIG. 1. Effects of differentiation training upon conditioned HR in C-3. The lower panel represents HR response to CS+ (solid line) and CS− (dashed line) averaged over the number of sessions indicated below each function. The average function obtained during the last three days of conditioning is provided for comparison. The upper panel represents pooled standard deviations of the functions presented in the lower panel.

ceiling houselight was replaced by a 7.5 w red bulb, in an attempt to enhance the discriminability of the projected stimuli, and a final block of four sessions were conducted under these conditions.

The results of this section for the three monkeys, C-3, C-4, and C-8 (excluding the data from the generalization tests) are summarized in Fig. 1, 2 and 3, respectively. The HR curves (located in the lower panels) were obtained in the following manner: The stimulus period was divided into six 5-sec intervals (or "bins"), the number of systoles counted in each and converted to beats-per-minute (BPM). The HR in the last 5-sec bin prior to stimulus onset was taken to represent the prestimulus level. Each curve is based upon seven 5-sec intervals beginning with the prestimulus bin and continuing through the stimulus (omitting the final 0.5 sec). Each point represents the mean, for that bin, of all trials for the

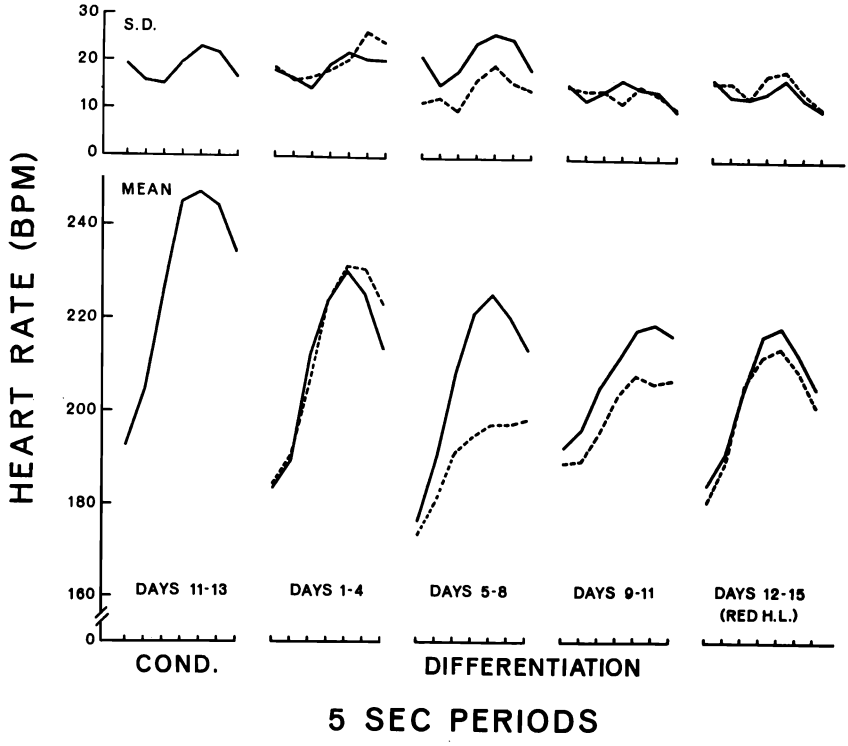

FIG. 2. Effects of differentiation training upon conditioned HR in C-4. The lower panel represents HR response to CS+ (solid line) and CS− (dashed line) averaged over the number of sessions indicated below each function. The average function obtained during the last three days of conditioning is provided for comparison. The upper panel represents pooled standard deviations of the functions presented in the lower panel.

number of sessions indicated on the graph. Included, for comparison, are curves representing the HR response during the last three days of conditioning. The upper panels contain the pooled standard deviations of the means plotted in the lower panels. The data for C-8 differ from the other two in that the first two days of contrast training have been omitted because an apparatus failure resulted in shock omission on CS+ trials.

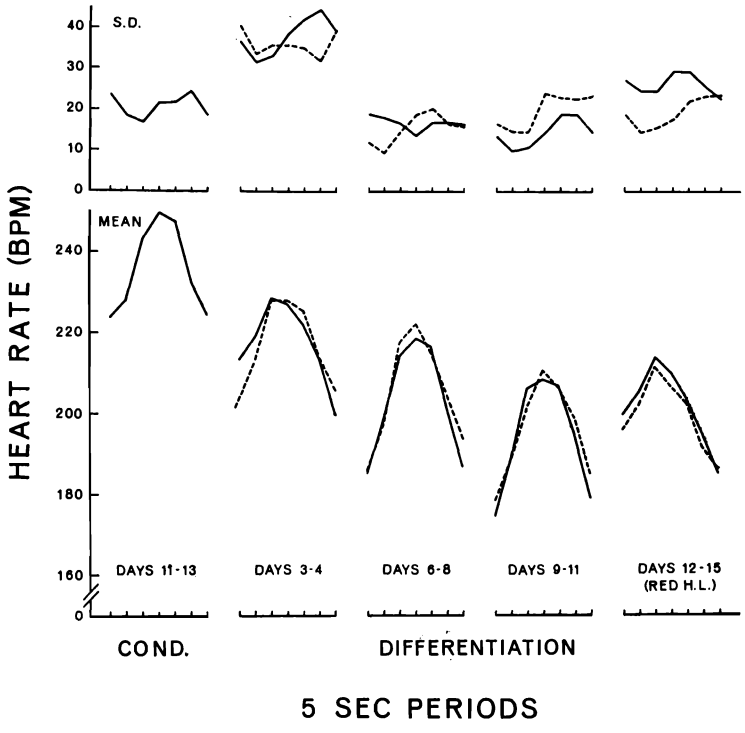

FIG. 3. Effects of differentiation training upon conditioned HR in C-8. The lower panel represents HR response to CS+ (solid line) and CS− (dashed line) averaged over the number of sessions indicated below each function. The average function obtained during the last three days of conditioning is provided for comparison. Data from differentiation days 1, 2, and 5 have been omitted for reasons given in the text. The upper panel represents pooled standard deviations of the functions presented in the lower panel.

Faulty belt placement on day fifth made accurate retrieval of EKG data impossible. Data from these sessions, therefore, have been omitted. The curves have been averaged over blocks of sessions separated either by a generalization test or a change of experimental conditions (i.e., introduction of the red houselight).

The first function, on the left, in each of these figures represents the cardiac response to CS+ during the last three days of conditioning. Although individual differences are manifest, all three animals evince a biphasic cardiac response to the delay CS+, with initial acceleration followed by deceleration (Smith and Stebbins 1965), and this waveform is maintained during differentiation. The data from the first block of sessions of contrast training failed to reveal any evidence of discrimination between the two stimuli. During the second block, monkey C-4 appeared to discriminate well, whereas the other two did not. In the next block, the HR differentiation of C-4 began to disappear, C-8 continued to generalize between the two stimuli, and there is some evidence of discrimination in the data of C-3. Because of this separation of CS+ and CS− curves on days 9–11 for C-3, it is unclear whether the distinct differentiation during the last four sessions (with the red houselight) was due to the simple emergence of a discrimination with continued training, or to the altered experimental conditions. Certainly, changing ambient illumination had no beneficial effect on differentiation in the other two animals. C-4 continued to lose the earlier discrimination and C-8 continued to respond similarly to both stimuli.

The variability measures, in the upper panels, partially confirm the findings of Lynch (1968) who showed, in dogs, a decrease in HR variability during CS+ compared to pre-CS+ levels. He, however, averaged HR over the entire CS+ duration (11 sec). Figures 1, 2 and 3 show an initial drop in variability followed by a subsequent rise later in CS+.

Phase II. CS-manipulation

The failure to obtain consistent cardiac differentiation in two animals prompted the use of a procedure originally suggested by Pavlov. He pointed out that a differentiation of closely allied stimuli may be difficult to establish unless one were to begin with a larger difference between the two and slowly narrowed the gap (Pavlov 1927, pp. 121–122). The CS−, therefore, was changed to −90° (a horizontal line) for C-4 and C-8 and nine sessions devoted to testing under these conditions. The CS− was maintained at −45° for C-3 who continued to show sharp differentiation. Changing CS− for C-4 and C-8, however, had little effect upon cardiac differentiation. Samples of HR data from this period will be presented later.

Since simply increasing the difference between CS+ and CS− failed to produce differentiation, another strategem was tried. The addition of another stimulus dimension and its gradual elimination has been used to produce "errorless" learning of operant discriminations (Terrace 1963b)

or to train initially difficult discriminations (Ray 1967). Several such "fading" procedures were adopted subsequently for monkeys C-4 and C-8, while daily sessions for C-3 were discontinued.

The technique introduced at this stage was to interrupt the light source during CS−, creating a flickering light, while retaining a steady CS+. Light interruption was selected because it allowed for a "fading" procedure by gradually reducing the interruption interval until it was no longer discriminable by the animal. Initially, the light during CS− was interrupted once a second for 43 msec, the first interruption occurring 1 sec after CS− onset. At this point, CS− was still −90° and two sessions were conducted under these conditions. For the next two sessions, interruption time was reduced to 20 msec. This was followed by two sessions at 5 msec and finally, three sessions with an uninterrupted CS− (0 msec).

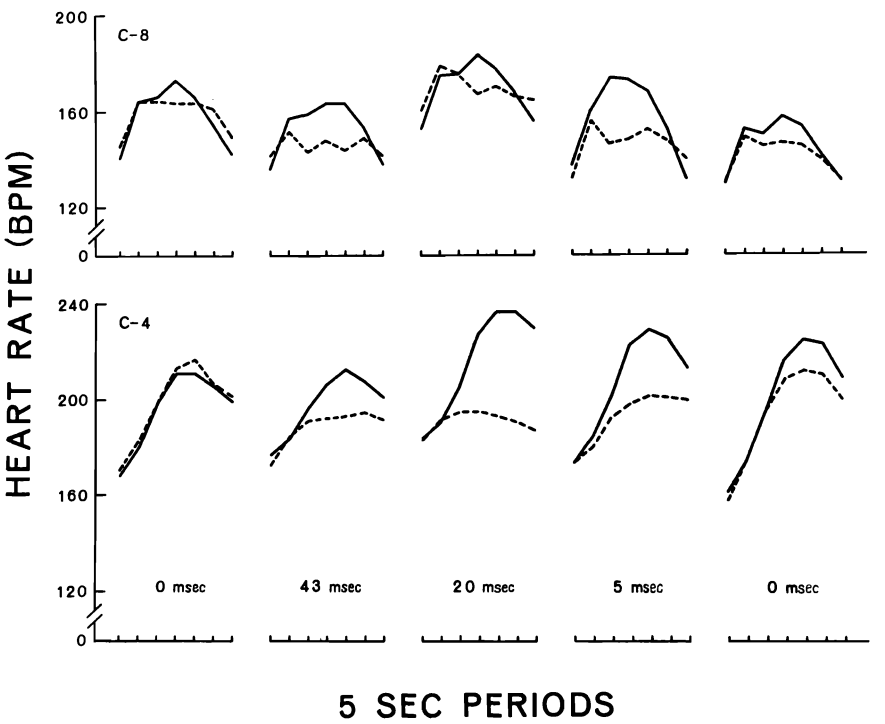

FIG. 4. Effects of introducing and gradually withdrawing light interruption during CS−. The functions on the left were taken from the last two days of exposure to a steady CS− of −90°. The curves for CS+ (solid line) and CS− (dashed line) were averaged over the number of sessions given in the text; the duration of interruption is given under each function.

The results from this part of the study are presented in Fig. 4. Changing CS− from −45° to −90° failed to produce cardiac differentiation. This can be seen in the first curve on the left which is the mean function taken from the last two of the nine sessions under these conditions. There was an immediate effect, however, when CS− was changed to a flickering light. Although CS− onset resulted in initial cardiac acceleration, the peak of the CS− function, for both animals, was clearly lowered. Differentiation continued to be shown as the interruption time was reduced but, with a return to a steady CS−, the discrimination deteriorated and both animals were exhibiting considerable acceleration to the CS−.

Phase III. Final procedure

The preceding phase demonstrated that cardiac differentiation could be rapidly established by adding another stimulus aspect to the CS−. The failure to maintain differentiation may have been the result of fading out the flicker too quickly. In the final attempt to produce clear and stable differentiation, the flicker was re-established and the CS− was progressively changed back to −45°. The first session was conducted with the line tilt at −75° and interruption time at 20 msec. On the following

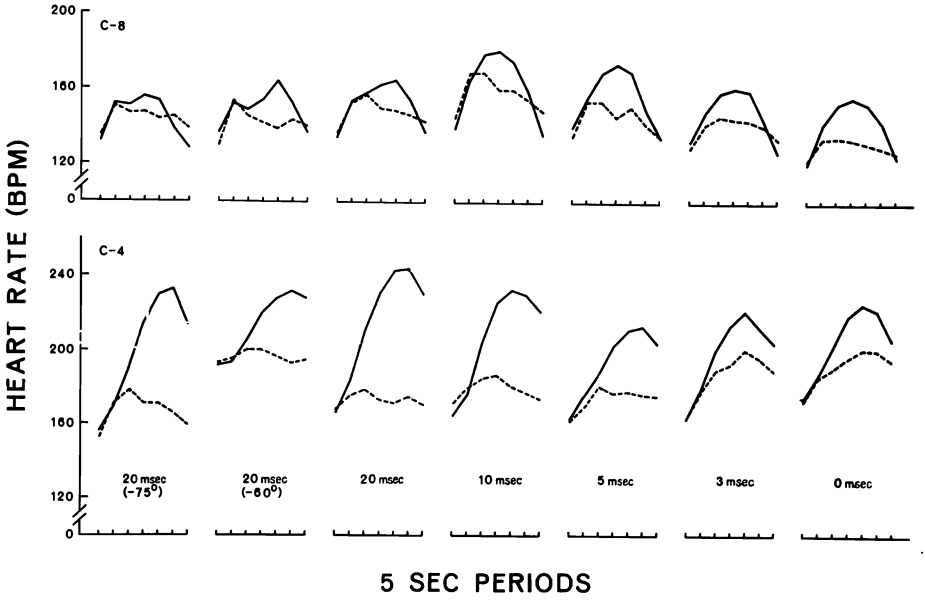

FIG. 5. Results of the final attempt to train differentiation in C-4 and C-8. Line tilt of CS− was −45° except where indicated otherwise. Functions for CS+ (solid line) and CS− (dashed line) were averaged over the number of sessions given in the text. Duration of interruption is given under each function.

session, line tilt was reduced to −60°, and then to −45° on the succeeding two sessions. With a return to the original CS−, the interruption time was gradually reduced. During the next two sessions it was set at 10 msec, followed by two sessions at 5 msec. The next four sessions were conducted with an interruption time of 3 msec and, finally, five sessions were conducted with a steady CS−.

The results of this section are presented in Fig. 5. Each curve is based on the number of sessions specified above. It can be seen that reintroduction of the flicker had an immediate effect on CS− responding for C-4, but that C-8, though still showing evidence of differentiation, retained considerable acceleration to CS−. With a return to a steady CS−, after a more gradual elimination of the flicker, both animals exhibited fairly pronounced cardiac differentiation. During the early stages, CS− curves peaked earlier in the stimulus than the CS+ curves. Although this feature was retained in the case of C-8, CS− curves for C-4 began to peak later in the stimulus until, with a return to the steady CS−, the CS− function paralleled that of CS+ but with reduced magnitude.

DISCUSSION

The initial failure to obtain stable cardiac differentiation in two animals after 15 sessions of training may reflect an inherent problem for Rhesus monkeys with the stimulus continuum employed. Ray (1967), for example, found that without special training procedures, similar to those used here, line-tilt discriminations in an operant study were difficult to establish in Rhesus monkeys. There is the possibility, of course, that discriminations of angularity show up poorly in feral adolescent monkeys because of prior conditioning histories which do not favor the development of similar discriminations and which, therefore, make transfer more unlikely.

It should be noted that one procedural aspect may have contributed to the difficulty in obtaining differentiation. Following common practice, CS+ and CS− trials were scheduled equally often. Bersh et al. (1956), on the other hand, in establishing cardiac differentiation in human subjects, maintained a 5-to-2 ratio of CS− to CS+ trials. Nathan and Smith (1968), who measured HR in monkeys under a differential conditioned suppression procedure, found it necessary to maintain a 7-to-1 ratio of CS− to CS+ trials in order to establish and maintain cardiac differentiation. They state that this ratio was used to prevent stimulus generalization of HR and elevation of cardiac basal levels. The data presented here, however, indicate that a reduction in the number of shocks per session, in the transition from conditioning to differentiation, results in a lower-

ing of pre-CS HR (Fig. 1, 2 and 3). It is still possible that cardiac differentiation might have been obtained earlier if some ratio other than 1-to-1 had been used.

The later differentiation phases demonstrated the effectiveness of the "fading" procedures. The addition of another stimulus dimension exerted an immediate and powerful effect on cardiac differentiation. The reinstatement of the HR response to CS− when light flicker was removed too rapidly argues against the possibility that cardiac differentiation would have developed if training had been merely extended under the contrast procedure.

SUMMARY

Three monkeys were exposed to a classical conditioning procedure with randomly alternated positive and negative stimuli (CS+ and CS−) with electric shock following only CS+ presentations. Two of the three animals failed to achieve heart rate (HR) differentiation after 15 sessions. Changing the separation of the two stimuli along the underlying physical continuum, line tilt, failed to produce differentiation in these two subjects, but when CS− was changed from a steadily illuminated to a flickering light, HR differentiation was quickly achieved. "Fading out" of the flicker resulted in substantial loss of the differentiation. A further attempt, with more gradual removal of the flicker, resulted in retention of a more distinct cardiac differentiation upon final elimination of flicker.

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