JOURNAL OF THE EXPERIMENTAL ANALYSIS OF BEHAVIOR 1972, 17, 451-461 NUMBER 3 (MAY)

AVOIDANCE RESPONDING AS A FUNCTION OF STIMULUS DURATION AND RELATION TO FREE SHOCK[1]

ELIOT SHIMOFF

FDR VETERANS HOSPITAL, MONTROSE, N.Y.

Response-independent pairings of a tone and a brief shock were superimposed on uncued avoidance responding in four groups of rhesus monkeys. For one group, tone presentations were immediately followed by an unavoidable electric shock; for the remaining groups, gaps of 5, 20, and 80 sec intervened between tone termination and shock delivery. These temporal values subsume paradigms usually treated as discrete procedures; the conditioned emotional response procedure (0-sec gap between tone and shock), trace procedure (5-sec gap) and safety-signal training (80-sec gap). Within each group, tone durations of 10, 20, 40, and 80 sec were examined. A response pattern marked by maximum response rate in the initial 5 sec of the tone followed by deceleration before shock was observed when shock immediately followed the tone, but not when gaps were interposed between the tone and shock. Response rates in the first 5 sec of the tone were a function of both tone duration and duration of the gap. When the gap was 0 to 5 sec, initial response rates were highest in longer duration tones; this relationship between tone duration and initial tone response rate was not observed for longer gaps.

The behavioral effects of response-independent pairings of an initially neutral stimulus, S_1, and an aversive stimulus, S_2, are partially determined by the temporal characteristics of the individual stimuli and partially by the joint relationship between the two stimuli, that is, the time period from S_1 termination to S_2 onset (the S_1-S_2 gap). In a commonly studied paradigm, the conditioned emotional response (CER) procedure, the S_1-S_2 gap is set at zero, and S_1 ends with or immediately before S_2. Several alternative procedures, usually treated as discrete paradigms, provide for non-zero gaps, such as the trace CER procedure (Kamin, 1965). In the backward conditioning procedure, S_2 precedes S_1, so that the S_1-S_2 gap is identical to the intertrial interval (Kamin, 1963; Paré, 1967). Finally, in safety-signal training (*e.g.*, Davis and McIntire, 1969) the pairing procedure is usualy described in probabilistic terms, with specification of a minimum S_1-S_2 gap.

Rescorla and Solomon (1967) suggest that when S_1 is immediately followed by shock (that is, a zero or relatively short S_1-S_2 gap) the stimulus serves as a warning signal, while stimuli not followed by shock (*i.e.*, with relatively long S_1-S_2 gaps) serve as safety signals. They further propose that the behavioral effects of safety and warning signals are diametrically opposed, and determined by the nature of the response upon which they are superimposed. Positively reinforced responding is said to be suppressed in the presence of warning signals and facilitated during safety signals, while the opposite is true of avoidance responding.

This proposed dichotomy between the behavioral effects of warning and safety signals must also take into consideration the effects of S_1 duration, at least in the case of the CER procedure. While suppression of positively reinforced responding is typically reported in the presence of relatively short S_1s following CER training, response rates in the initial portions of longer S_1s may be equal to (Stein, Sidman, and Brady, 1958) or greater than (Millenson and Hendry, 1967) pre-S_1 response rates. Similarly, in the case of avoidance responding, Pomerleau (1970) has shown that a complex pattern of responding appears during S_1, which may be characterized as suppressed in the presence of short pre-aversive stimuli and facilitated in longer S_1s.

Thus, the continuum of S_1-S_2 gap duration

[1]Supported in part by Grant MH 13049 from the National Institute of Mental Health, U.S. Public Health Service, and in part by the Veterans Administration. The author wishes to thank Dr. A. G. Snapper and Professor W. N. Schoenfeld for their advice and encouragement. Reprints may be obtained from the author, Dept. of Psychology, UMBC, 5401 Wilkens Ave., Baltimore, Md. 21228.

has been investigated under a variety of discrete paradigms, although methodological differences make comparisons difficult and little is known about behavioral changes across the continuum. Examination of extreme values of the continuum, under the rubrics of safety signals and the CER, suggest that the two procedures have opposite effects, in terms of response rate in the presence of the stimulus. Parametric investigations of S_1 duration in the CER procedure suggest a similar modulation of response rate, from facilitation to suppression. In the present study, the joint interaction of these two variables was investigated for S_1 durations from 10 to 80 sec, over a range of S_1-S_2 gaps from 0 to 80 sec.

METHOD

Subjects and Apparatus

Sixteen young male rhesus monkeys (*Macaca mulatta*) were maintained in the laboratory for 15 months before the start of the experiment. The monkeys were individually housed with free access to water. Daily rations of an apple or banana, and 175 g of commercial primate food, were given in three feedings. All animals appeared healthy, although there were several subclinical cases of intestinal parasite infestation.

The experimental chambers were two Lehigh Valley 1317 standard boxes with the dipper access holes covered. The operandum, a General Electric CR104G29 lever, was mounted on the upper right quadrant of one wall, 2.75 in. (7 cm) from the adjacent wall and 12 in. (30 cm) from the ceiling. Above the lever was a row of four 7-w clear lamps that were illuminated during the session to provide ambient light. A 693-v shock, passed through a 56 k ohms resistor, was swept sequentially across the grid floor, providing equal shock density on all grids. The 500-msec shock served both as S_2 and as the avoidable shock. The lever and two pairs of adjacent walls were insulated and served as separate grids. Masking noise was provided by a Grason-Stadler 901 B white noise generator. The neutral S_1, a nominal 2.8 K Hz tone, was provided by a Mallory Sonalert (SC 628, 24 v) mounted behind a grill directly above the lever. All contingencies and data recording were provided by a PDP-8 computer using a program described by Snapper and Kadden (in press).

Procedure

Responding was maintained throughout the experiment by an adjusting avoidance schedule similar to that described by Field and Boren (1963). The adjusting avoidance sched ule was chosen because behavior under its con trol is characterized by rapid acquisition, high response rates, and low shock density. Shocks were delivered every 2 sec in the absence of a response. Any response made either during a shock or within 2 sec before a due shock postponed the next shock for 4 sec. Each further response made in the shock delay period postponed the next shock by two additional seconds, up to a maximum of 20 sec. In terms of timeout from the shock pulse train, the first response after a shock, or any response within 2 sec before a shock, earned a 4-sec timeout, while following responses added a 2-sec timeout to that already accrued, up to a maximum of 20 sec. Once the maximum 20-sec timeout had been reached, further responses maintained the interval, that is, they reset the 2-sec timer so as to keep the 20-sec timeout in effect.

The monkeys were randomly divided into four groups and trained on the avoidance baseline for 22 sessions. Sessions were 115.7 min long and were conducted on alternate days. In order to test the unconditioned effects of S_1 (*i.e.*, the neutral stimulus), twenty five 10-sec tone presentations, not followed by shock, were presented with a 4.5-min mean intertrial interval during each of the last four baseline training sessions. With the exception of these 100 trials, all S_1 presentations were followed by shock.

Baseline training was followed by two sessions of Pavlovian conditioning with the lever removed from the experimental chamber. During Pavlovian conditioning, twenty five 10-sec S_1s with a 4.5-min mean intertrial interval were presented. For four of the subjects (A06, A12, A32, and A08), S_2 (shock) immediately followed S_1 termination, and thus corresponded to the standard CER paradigm. For a second group of subjects (A04, A10, A36, and A14), shock presentation followed S_1 termination by 5 sec. A 20-sec period intervened between tone and shock for four subjects (A22, A16, A20, and A40), while for the fourth group (A18, A26, A24, and A38), 80 sec were interposed between S_1 and S_2. Since the temporal interval between S_1 termination and S_2 was held constant throughout the experiment for each group, these may be referred to as the 0-, 5-, 20-, and 80-sec groups respectively.

The remaining phases each consisted of three sessions of baseline training, with neither S_1 nor S_2 presentations, and 10 sessions with S_1-S_2 pairings superimposed on the avoidance baseline. The initial phase following Pavlovian conditioning consisted of pairings of a 10-sec S_1, followed by S_2 after 0, 5, 20, or 80 sec, depending on the group. For the 0-sec group, this may be referred to as 10/0, that is, a 10-sec S_1 followed by shock after 0 sec. For the other groups, this may be called the 10/5, 10/20, and 10/80 phases, respectively. S_1 durations of 20, 40, and 80 sec followed consecutively in the second, third, and fourth phases. Thus, each group was exposed to S_1 durations from 10 to 80 sec, with a constant interval between S_1 termination and S_2 delivery. Following the 80-sec S_1 duration phase, all subjects were reexposed to the initial 10-sec S_1 duration phase. The experimental design is summarized in Table 1.

Table 1

The sequence of experimental conditions. Within the body of the table, the number preceding the slash specifies S_1 duration; the number following the slash refers to the duration of the S_1-S_2 gap.

	Group				
Sessions	*0 Sec*	*5 Sec*	*20 Sec*	*80 Sec*	
1-22	— — — Baseline training — — — —				
23-24	10/0	10/5	10/20	10/80	(Pavlovian pairings)
25-27	— — — Baseline training — — — —				
28-37	10/0	10/5	10/20	10/80	
38-40	— — — Baseline training — — — —				
41-50	20/0	20/5	20/20	20/80	
51-53	— — — Baseline training — — — —				
54-63	40/0	40/5	40/20	40/80	
64-66	— — — Baseline training — — — —				
67-76	80/0	80/5	80/20	80/80	
77-79	— — — Baseline training — — — —				
80-89	10/0	10/5	10/20	10/80	

Twenty five trials, each consisting of an S_1-S_2 pairing, were scheduled for each session. The mean time between shocks was 4.5 min with a range of 3.5 to 5.5 min. It should be noted that the constant session length, coupled with variations in both S_1 duration within groups and the S_1-S_2 gap across groups dictates that the mean time from any S_2 to the following S_1 (*i.e.*, the intertrial interval), will differ both among groups and, from phase to phase, within groups.

RESULTS

In general, avoidance responding stabilized after the first 10 to 15 sessions of baseline training, and S_1 presentations not followed by shock had no consistent behavioral effects. In the three baseline training sessions following Pavlovian conditioning, response rates increased for 13 subjects while three monkeys with relatively high baseline rates showed transient response suppression in these three sessions. Throughout the remainder of the experiment, response rates in the absence of S_1 showed no systematic variation.

Figures 1 to 4 represent response patterns during stimulus pairings for the groups with 0-, 5-, 20-, and 80-sec S_1-S_2 gaps respectively. In Sessions 80 to 89, the subjects were again exposed to the 10-sec S_1 followed by the appropriate S_1-S_2 gap, duplicating conditions of Sessions 28 to 37, the first exposure to the 10-sec pre-aversive stimulus; these data are presented in Figure 5. In general, the response patterns were consistent both within sessions and across the last three sessions in each condition.

For three of the four subjects in the 0-sec gap group (Figure 1), maximum response rates in S_1 occurred in the first 5 sec of the pre-aversive stimulus; for the fourth monkey, this pattern of initially high rates (relative to rate in the remainder of the pre-aversive stimulus) appeared only in the longest S_1 duration. A second characteristic of response patterns for these subjects, evident in the 10-, 20-, and 40-sec S_1s, was terminal deceleration, *i.e.*, a decrease in rates towards the end of S_1. At the shorter S_1 durations, both initial facilitation and terminal deceleration seem associated, in that the two phenomena appear in the same three subjects. At the 80-sec S_1 duration, the initial high rate remains, although the terminal suppression component is no longer evident. Response patterns on second exposure to the 10-sec S_1 (Figure 5) were similar to those obtained when the subjects were first exposed to that S_1 duration.

Examination of Figures 2 to 4 indicates that the interposition of a gap between termination of the tone and shock delivery engendered considerable differences in response patterns. For subjects in the 5-sec gap group (Figure 2),

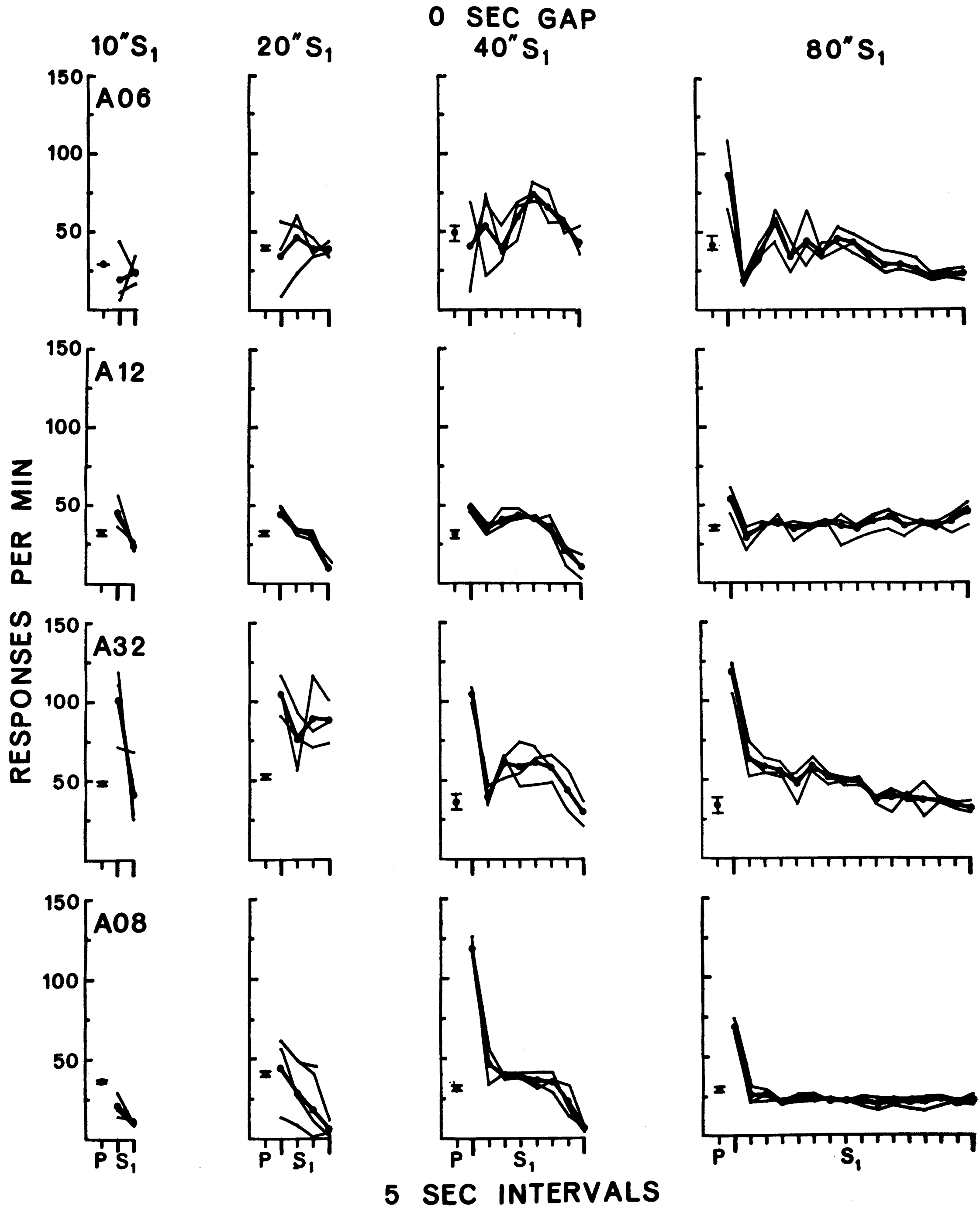

Fig. 1. Response patterns for monkeys with the 0-sec S_1-S_2 gap. The dark curve is the mean of the last three sessions, each of which is represented by a lighter curve. Within each panel, the first point, marked "P" represents the mean pre-S_1 response rate (brackets indicating range) for 15 sec before onset of the tone. The remaining points represent response rates in successive 5-sec subintervals during S_1. Each point is the mean of the last 75 trials (three sessions) for a given S_1 duration. The data for a single animal are presented in a row of four panels, corresponding to 10-, 20-, 40-, and 80-sec S_1 durations.

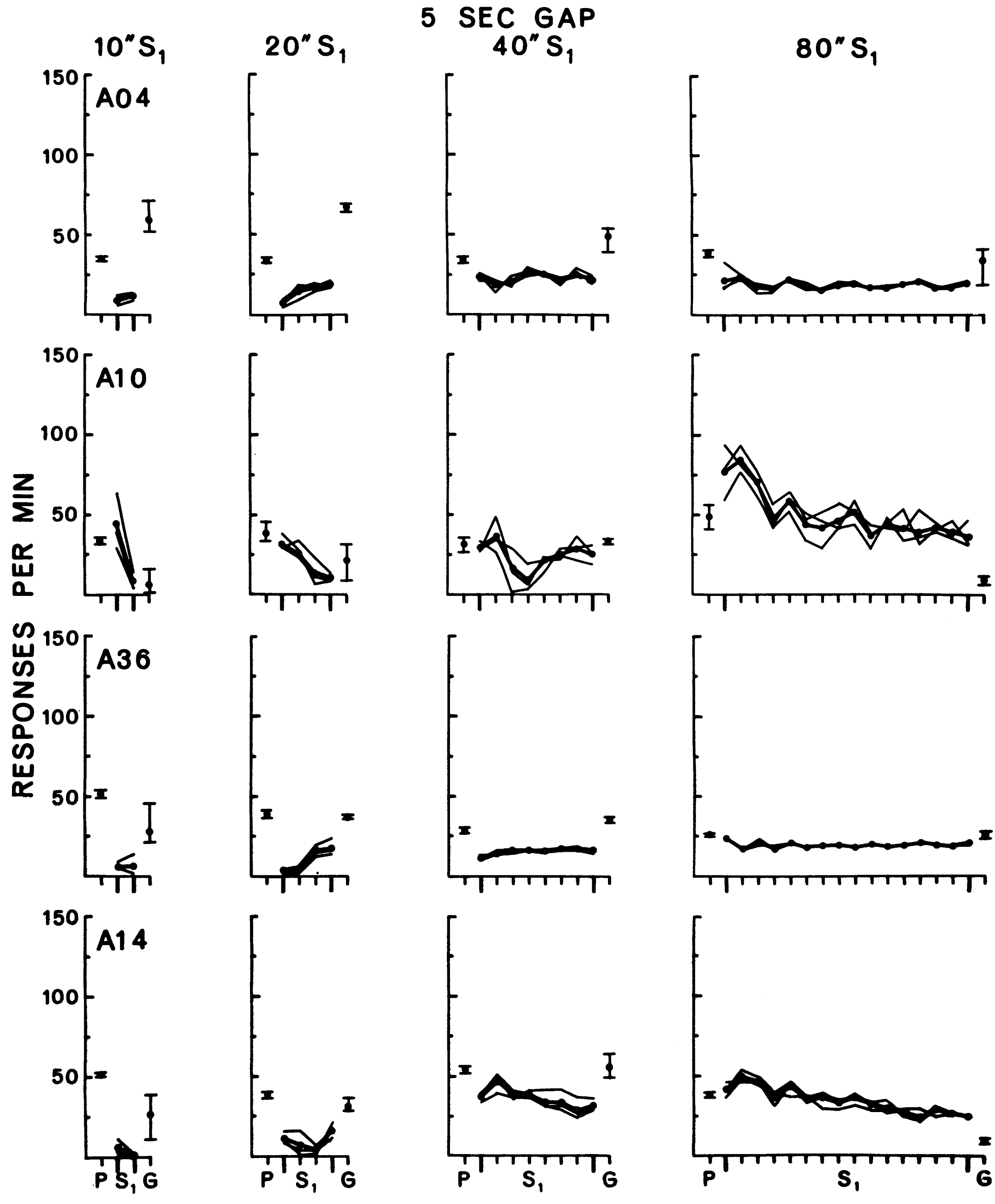

Fig. 2. Response patterns for monkeys with the 5-sec S_1-S_2 gap. The format is the same as in Figure 1. The single point following S_1 represents response rate in the 5-sec gap.

overall response rates during S_1 were lower (relative to pre-S_1 rates) than those observed in the 0-sec group; furthermore, maximum response rates typically occurred in the 5-sec gap, except for two monkeys in the 80-sec S_1 condition for which rates in the gap were markedly suppressed below both pre-S_1 and S_1 levels. When re-exposed to the 10-sec S_1 duration

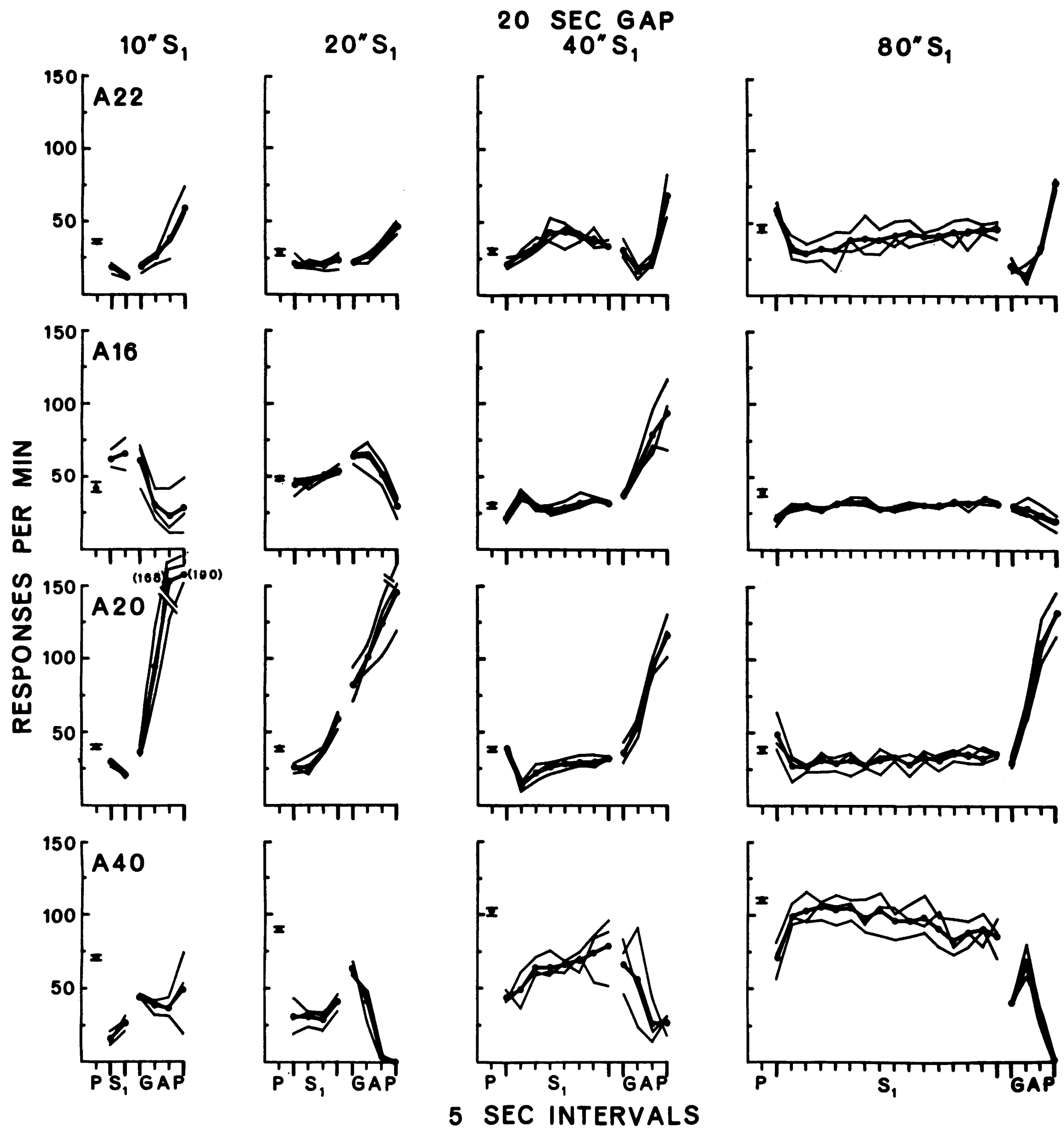

Fig. 3. Response patterns for monkeys with the 20-sec S_1-S_2 gap. The format is the same as in Figure 1. The four connected points following S_1 represent rate in the 20-sec gap.

(Figure 5, column 2), response rates reflected the effects of prior exposure to longer S_1 durations; neither suppression during S_1 nor facilitation during the gap were as marked as in the first exposure to that stimulus duration.

Response patterns during S_1 for subjects with the 20-sec S_1-S_2 gap (Figure 3) were marked by considerable variability, both across and within subjects, from one condition to the next. During the S_1-S_2 gap, both A20 and A22 showed consistent acceleration while response rates decelerated for A40 in all conditions except the first exposure to the 10-sec S_1; response patterns during the gap for A16 were marked by a variety of patterns.

While response patterns in the groups with 0-, 5,- and 20-sec S_1-S_2 gaps generally included segments during which response rates showed considerable changes from pre-S_1 rates, such peak local rates were not evident for subjects with the 80-sec S_1-S_2 gap. During the S_1-S_2 gap, response rates showed terminal increases for

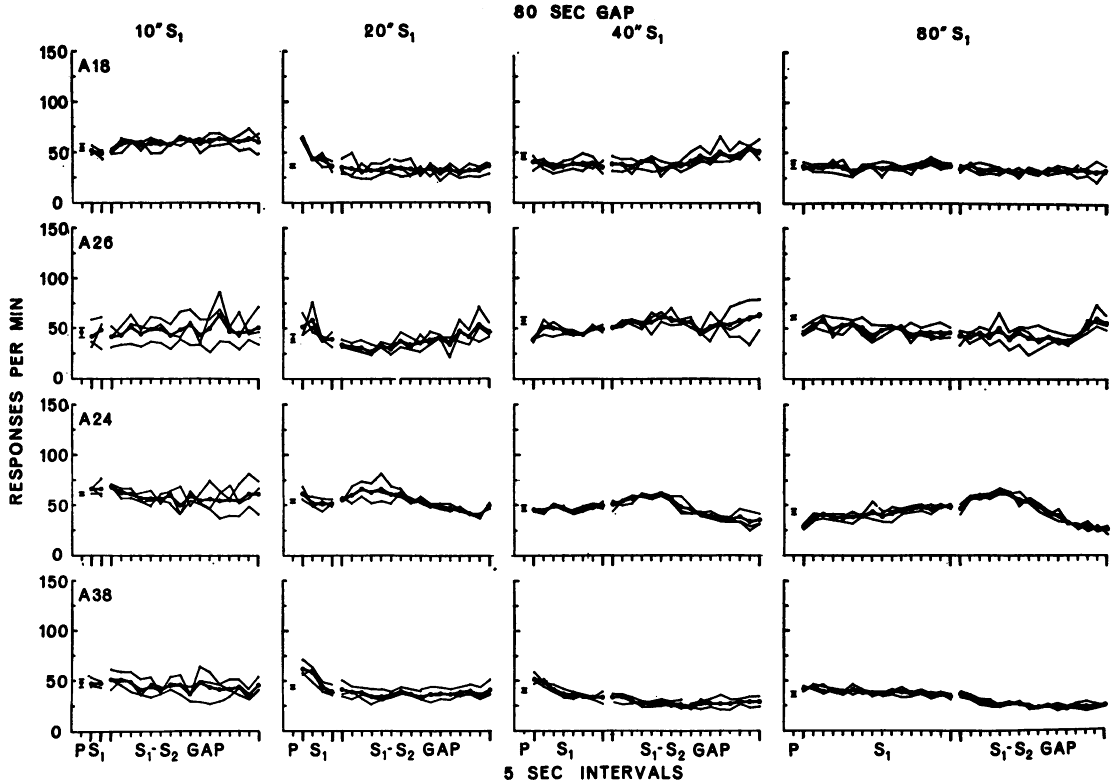

Fig. 4. Response patterns for monkeys with the 80-sec S_1-S_2 gap. The format is the same as in Figure 1. The 16 points following S_1 represents response rate in the 80-sec gap.

A26, were biphasic for A24, and remained stable for two monkeys.

The effects of S_1 duration were primarily reflected in response rates in the first 5 sec of S_1 relative to pre-S_1 rates; these relative initial rates are presented in Figure 6. For all subjects in the 0- and 5-sec S_1-S_2 gap groups, and for three of the four subjects in the 20-sec gap group, response rates tend to increase as S_1 duration increases, while for the fourth subject in the 20-sec group, there is a clear inverse relationship between S_1 duration and initial response rates. For subjects in the 80-sec gap group, the relationship between S_1 duration and initial relative response rate is non-monotonic, with maximum initial relative rate in the 20-sec S_1.

DISCUSSION

The present findings indicate that duration of the S_1-S_2 gap (from termination of the tone to shock delivery) modulates the overall response pattern. Thus, peak rates within a response pattern appear near the start of the tone for 0-sec gap group, during the gap for monkeys with a 5-sec gap, and are variable in location for the 20-sec gap group; for subjects with the 80-sec gap, departures from pre-S_1 rates are less marked, *i.e.*, the response pattern is relatively "flat". The effects of S_1 duration are reflected primarily in relative response rates in the first 5 sec of the tone. For subjects with relatively short gaps, relative response rates in the initial 5 sec of S_1 increase as S_1 duration increases; this relationship is not evident for longer S_1-S_2 gaps.

Investigations of stimulus pairings may be roughly categorized into three classes: (a) CER studies, in which S_1 is terminated by shock, (b) trace conditioning studies, with relatively short S_1-S_2 gaps, in which the proximity of the two stimuli is stressed, and (c) safety-signal studies, with longer S_1-S_2 gaps, which emphasize the temporal distance between the two stimuli. The various groups in the present study permit comparison with these discretely defined paradigms. The data for the group with the 0-sec

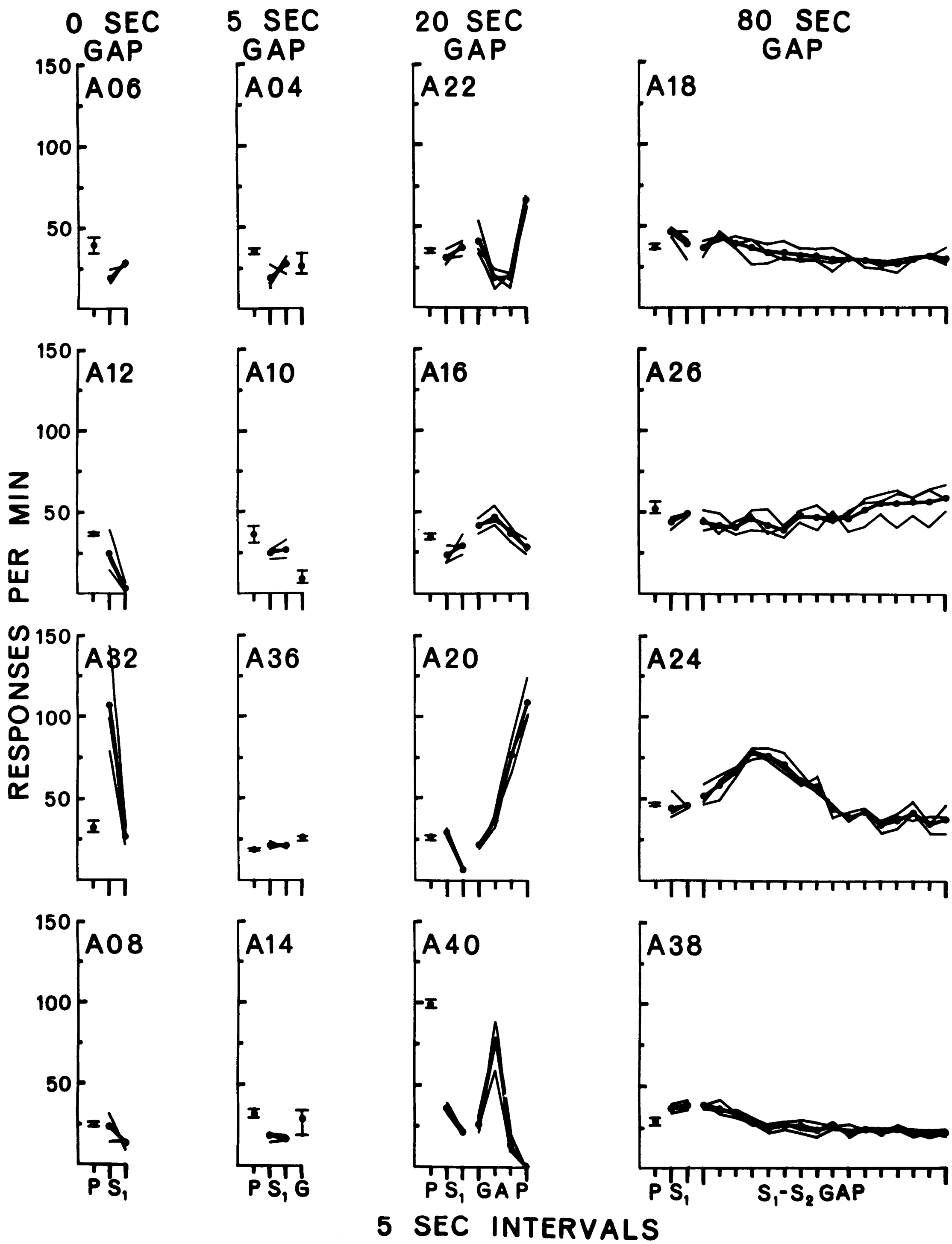

Fig. 5. Response patterns on the second exposure to the 10-sec S_1 duration. All subjects in a single group are presented in a single column of four panels.

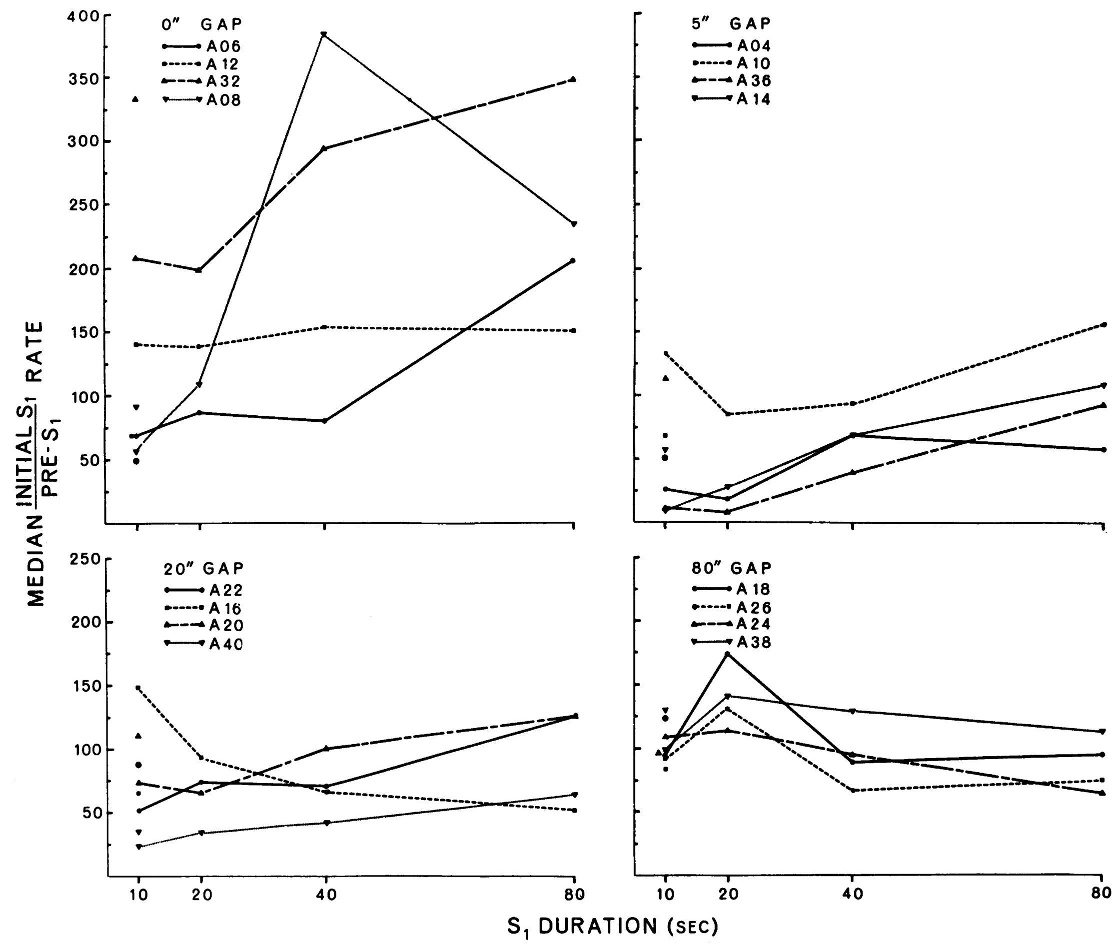

Fig. 6. Relative response rates in the initial 5 sec of S_1 as a function of S_1 duration. Each point represents the median of the final three sessions; the isolated data points are from the final (replication) phase, Sessions 87 to 89.

S_1-S_2 gap corroborate Pomerleau's (1970) report; responding was lower in the presence of short S_1s than during the initial part of longer pre-aversive stimuli. The present results differ from Pomerleau's primarily in regard to the specific waveform of responding; he reported maximum response rates typically 12 to 16 sec after S_1 onset. This difference may have been due to apparatus differences (he used restraint chairs and a visual S_1) or to differences in shock intensity and method of shock delivery.

Results of the two investigations of the effects of trace pairings on avoidance responding are similar to those of the 5-sec and 20-sec S_1-S_2 gap groups in the present study. Kamano (1970), using a 10-sec S_1 and a 2—5-sec gap reported that, in two of three rats, response rates were higher in the gap than in the presence of S_1, while for the third subject there was a slight decrease in response rate on S_1 termination. While the present results substantiate Kamano's findings on response rates in the gap, he found response facilitation in the presence of S_1, although this facilitation was not as great as that observed following CER pairings.

The data for monkeys with the 20-sec S_1-S_2 gap are similar to the averaged response pattern reported by Rescorla (1968) using a 5-sec S_1 and a 20-sec gap, who found positively accelerated responding from S_1 onset until shock delivery. This same pattern was characteristic of both A22 and A20, and also appeared in the group mean pattern (which has not been presented). As Rescorla did not report individual data, it is impossible to determine whether response patterns for all his subjects were similar, or, as in the present findings, some subjects showed different patterns.

The stimulus pairing paradigm for the 80-sec gap group is conceptually similar to safety-signal procedures, in that the S_1 "predicts" an 80-sec period in which response-independent shocks are not delivered. Response patterns in the presence of safety signals have been characterized as opposite in direction from changes in warning signals; in the sense that, for short S_1-S_2 gap durations, initial relative response rate increases as S_1 duration increases, while for the 80-sec gap group maximum initial relative rate occurs in the presence of a relatively short S_1, this characterization is supported by the present study.

Traditional accounts of stimulus pairing procedures (*e.g.*, Rescorla and Solomon, 1967) have stressed the role of "fear" in the control of responding in the presence of S_1. Such an approach suggests that, in the presence of a short S_1 terminated by shock, "fear" would be enhanced, and reflected in increased avoidance responding. In longer S_1s, following the formation of a temporal discrimination, "fear" would be reflected in increased avoidance responding in the terminal segment of the stimulus. Safety signals, associated with the nonoccurrence of shock, are said to inhibit fear, and thus be reflected in reduced avoidance responding. This safety-signal effect should, according to the fear hypothesis, appear in the presence of stimuli separated from shock (*i.e.*, the standard safety procedure), or in the initial portion of longer S_1s terminated by shock. Although the present findings do suggest a distinction between safety signals and warning signals in terms of the functional relationships between S_1 duration and initial response rates in S_1, the observed response patterns do not support such an analysis in its simplest form. For example, response patterns in a discriminable period immediately before shock differ, depending on whether one looks at a short S_1, the terminal segment of a long S_1, or rates in a 5-sec gap. Similarly, response patterns in a 40-sec S_1 are quite different from patterns in a 20-sec S_1 followed by a 20-sec gap. Further, the "fear" analysis does not account for the differences in response patterns caused by the interpolation of a 5-sec gap between S_1 and shock.

An overview of the response patterns in the present study does not suggest any single pattern characteristic of either "fear" or "safety". In the absence of a simple unifying concept to account for the data on stimulus pairing, it may be useful to adopt the "irreducibly primitive" approach to the study of stimulus function suggested by Farmer and Schoenfeld (1966 *a, b*). In their procedure, a neutral, response-independent stimulus intruded into various portions of a fixed-interval schedule of positive reinforcement took on properties similar to those traditionally subsumed under a variety of discrete paradigms. For example, the issue of the interrelationship between the discriminative and reinforcing properties of a stimulus "does not appear to be engendered . . ." when examined in the context of the intruded stimulus paradigm (1966*a*, p. 373). Such an approach is heuristically valuable in that it focuses attention on the procedure itself, rather than on terminological or theoretical descriptions of the procedure, and thus points to parametric investigation as opposed to paradigmatic analysis.

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Received 11 February 1971.
(Final Acceptance 20 December 1971.)