CONCURRENT PERFORMANCES: INHIBITION OF ONE RESPONSE BY REINFORCEMENT OF ANOTHER¹

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In an analysis of interactions between concurrent performances, variable-interval reinforcement was scheduled, in various sequences, for both keys, for only one key, or for neither key of a two-key pigeon chamber. With changeover delays of 0.5 or 1.0 sec, and with each key's reinforcements discriminated on the basis of key-correlated feeder stimuli, reinforcement of pecks on one key reduced the pecking maintained by reinforcement on the other key. The decrease in pecking early after reinforcement was discontinued on one key was not substantially affected by whether pecks on the other key were reinforced, but after reinforcement was discontinued on both keys, reinstatement of reinforcement for one key sometimes produced transient increases in pecking on the other key. Correlating the availability of right-key reinforcements with a stimulus, which maintained right-key reinforcement while reducing right-key pecking to negligible levels, demonstrated that these interactions depended on concurrent reinforcement, not concurrent responding. Thus, reinforcement of a response, but not necessarily the occurrence of the response, inhibits other reinforced responses. Compared with accounts in terms of excitatory effects of extinction, often invoked in treatments of behavioral contrast, this inhibitory account has the advantage of dealing only with observed dimensions of behavior.

In concurrent schedules, two or more component schedules operate simultaneously but independently, each for a different response. In multiple schedules, two or more component schedules operate successively for a single response, each in the presence of a different stimulus. The two types of schedules are both formally and behaviorally related in that the analysis of either must be concerned with the relative frequencies of the component responses.

Concurrent performances ordinarily consist of the successive emission of the concurrent responses as the organism switches from one to the other. Simultaneous concurrent responses are possible in principle, but attempts

are usually made to eliminate such responses in practice because independence of the concurrent performances cannot be maintained if each response is not separated in time from subsequent consequences of the other response (Catania, 1962). Thus, in typical concurrent performances the organism successively confronts different stimuli as it moves from one response to another.

In multiple schedules, the component responses and stimuli also occur in succession, with the major difference that changes from one to the other are determined by the experimenter rather than by the organism. This formal equivalence of the two types of schedules is clearest within a concurrent procedure that arranges a separate changeover response (Findley, 1958). For example, when such a procedure is scheduled for a pigeon the concurrent responses consist of pecks in the presence of different stimuli on one key, and the pigeon changes over from one stimulus to another by pecking a second key. This changeover-response procedure has been shown to be functionally as well as formally equivalent to a two-response concurrent procedure (e.g., Catania, 1963).

Because concurrent performances involve changeover responses, which cannot occur in

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multiple schedules, the two types of schedules differ in details of data treatment. The interactions that occur within each type of schedule are, however, qualitatively similar. For example, an increase in the reinforcement of one response produces a decrease in the rate of the other response both in concurrent schedules (*e.g.*, Catania, 1963) and in multiple schedules (*e.g.*, Reynolds, 1961*a*). The interactions in concurrent schedules tend to be larger in magnitude than the analogous interactions in multiple schedules, but it has been shown that both types can be dealt with in terms of a single quantitative account (Lander and Irwin, 1968). The two types of schedules are also similar with respect to interactions involving both reinforcement and punishment. For example, when both component responses are punished in either concurrent or multiple schedules, the absolute rates of each response are reduced but their relative rates are not affected (*e.g.*, in concurrent schedules, Holz, 1968; in multiple schedules, Tullis and Walters, 1968), and when the two component responses are each maintained by reinforcement and only one is punished, the decrease in the rate of the punished response is accompanied by an increase in the rate of the unpunished response (*e.g.*, in concurrent schedules, Reynolds, 1963; Catania, 1966, pp. 245-246; in multiple schedules, Brethower and Reynolds, 1962).

Interactions between component responses have been examined in detail in multiple schedules (*e.g.*, Reynolds, 1961*b*, 1964, 1968). Concurrent performances are characterized by interactions analogous to those observed in multiple schedules, and their quantitative properties have been described on the basis of data from two-response concurrent procedures (*e.g.*, Herrnstein, 1961), from changeover-response concurrent procedures (*e.g.*, Catania, 1963), and from concurrent chained schedules (in which the concurrent responses are each reinforced by a stimulus in the presence of which a schedule of primary reinforcement operates; *e.g.*, Herrnstein, 1964). The present study of two-response concurrent performances extends the analysis of schedule interactions by examining exhaustively the possible sequences of concurrent schedules when either reinforcement or extinction is scheduled for pigeons' pecks on each of two keys. In this two-response concurrent procedure,

as in changeover-response and concurrent-chain procedures, reinforcement can be scheduled for both responses, for only one response, or for neither response. Thus, sequences of concurrent schedules can be arranged in which reinforcement of both responses is followed by extinction either of one or of both responses, in which extinction of both responses is followed by reinforcement either of one or of both responses, and in which reinforcement of only one response is followed either by reinforcement of both responses, by extinction of both responses, or by extinction of that response and reinforcement of the other response. Within such sequences, continued reinforcement, continued extinction, and the change from reinforcement to extinction or from extinction to reinforcement of one response can be observed both when accompanied by reinforcement of the other response and when unaccompanied by reinforcement of the other response.

METHOD

Subjects

Six adult male White Carneaux pigeons, with varied histories in earlier concurrent procedures, were maintained at about 80% of free-feeding body weight. Of the four experimental series described below, Series 1 and 2 included Pigeons 150, 43, 44, and 45, Series 3 included Pigeons 150, 43, 50, and 45, and Series 4 included Pigeons 150, 43, 50, and 72. During Series 1 and 2, Pigeons 44 and 45 showed both physical and behavioral symptoms of illness (loss of feathers, vomiting, difficulty in standing erect, and occasional instances of extreme variability in performance from day to day). Pigeon 44 died and Pigeon 50 was substituted near the end of Series 2 and Pigeon 45 was dropped from the experiment and Pigeon 72 was substituted during Series 3; the data from these pigeons in these series were not incorporated into the data presentation.

Apparatus

The two-key experimental chamber included the following standard devices: a houselight that provided general illumination; a speaker that produced white masking noise; a relay, mounted behind the panel, that could produce feedback clicks when either key was

pecked; a Gerbrands feeder; and a ventilating fan. The two Gerbrands pigeon keys, adjusted for approximately equal 15-g (0.14 N) forces of operation, were mounted above the feeder at a height of 9 in. (230 mm) from the floor and were spaced 2.5 in. (64 mm) apart, center-to-center. The left key was ordinarily illuminated green and the right amber. Pecks on a given key produced feedback clicks only when the key was illuminated. During Series 1, 2, and 3, two white 6-w lamps in the feeder were lit during reinforcement, when all other lights in the chamber were turned off and key pecks were ineffective. During Series 4, the feeder was modified (Fig. 1), and a green and an amber lamp were substituted for the two white lamps.

Procedure

Throughout the experiment, reinforcement duration was 3 sec, daily sessions were 100 min (excluding the duration of reinforcement), and variable-interval reinforcement, arranged according to the specifications of Catania and Reynolds (1968, Appendix II), was scheduled with an average interval of 180 sec. Each key's intervals were timed from the end of reinforcement, the order of the intervals in the schedule for one key was the reverse of that for the other key, and each key's schedule

stopped operating during reinforcement produced by pecks on the other key.

Each session consisted of one of four possible combinations of variable-interval (VI) and extinction (EXT) schedules for the two keys (VI VI, VI EXT, EXT VI, and EXT EXT, where the terms of each pair represent the left-key and the right-key schedules, respectively). Various sequences of changes from one to another of the schedule combinations were arranged in the four experimental series outlined in Table 1: Series 1 and 2 examined the effects of schedule changes with two different changeover delays; Series 3 separated effects of concurrent reinforcement from effects of concurrent responding; and Series 4 examined the effects of schedule changes when discriminated reinforcers were arranged for the two responses.

In sessions of Series 1 and 2, the left key was lit green and the right key amber at all times except during reinforcement. The two series differed in the changeover delay (COD: Herrnstein, 1961) that was scheduled: COD 0.5-sec in Series 1 and COD 1.0-sec in Series 2. The changeover delay arranged that no peck could be reinforced until at least the delay interval had elapsed after changeovers from one key to the other; the delay was timed from the first peck on one key after a peck on the

Table 1

Sequence of concurrent schedules for the left key (green) and the right key (amber), in that order, within the successive series. Numbers indicate sessions. Changeover delays (CODs) were timed from the first peck on one key after a peck on the other. The mean interval of each variable-interval (VI) schedule was 180 sec. In Series 3, the right key lit only when reinforcement became available for pecks on that key (SCVI: stimulus-correlated VI schedule); the key was dark when extinction (EXT) was scheduled.

Series 1			Series 2			Series 3			Series 4					
COD 0.5-sec			COD 1.0-sec			COD 1.0-sec Right key: SCVI			COD 0.5-sec Key-correlated feeder stimuli					
VI	VI	14	VI	EXT	5	VI	SCVI	12	VI	VI	28	EXT	VI	12
VI	EXT	12	EXT	EXT	7	VI	EXT	7	EXT	VI	7	VI	VI	14
EXT	VI	10	VI	VI	10	VI	SCVI	14	EXT	EXT	8	VI	EXT	7
VI	VI	11	VI	EXT	6	VI	EXT	11	EXT	VI	5	EXT	VI	14
EXT	EXT	6	EXT	VI	6	EXT	EXT	10	EXT	EXT	5	VI	VI	10
VI	EXT	8	EXT	EXT	6	EXT	SCVI	7	VI	EXT	7	VI	EXT	7
VI	VI	9	VI	EXT	6	VI	SCVI	9	VI	VI	10	EXT	VI	10
EXT	VI	20	VI	VI	5	EXT	SCVI	16	EXT	EXT	5	VI	VI	14
EXT	EXT	6	EXT	EXT	4	EXT	EXT	7	VI	VI	6			
VI	EXT	16	EXT	VI	8	VI	EXT	6	EXT	VI	9			
EXT	EXT	6	VI	VI	9	EXT	SCVI	9	VI	EXT	7			
VI	VI	8				VI	EXT	9	EXT	EXT	5			
VI	EXT	8							VI	EXT	9			

other. By interposing a minimum interval of time between a peck on one key and a subsequent reinforced peck on the other, the COD contributes to the independence of the concurrent responses (Catania, 1962).

In Series 3, the left key was lit green as in the preceding series, but the right key was lit amber only when the schedule for that key had arranged reinforcement for a subsequent peck. A 1-sec COD remained in effect for changeovers in either direction, and each key was operative only when lit. The correlation of a stimulus with the right-key VI schedule (Catania, 1963) reduced responding on the right key to a few pecks (satisfying the COD) on the average of once every 3 min, when reinforcement was scheduled; the key was rarely pecked when dark. Reinforcement of right-key pecks, however, occurred at essentially the same rate as in the equivalent VI schedules for the right key in Series 1 and 2. To reduce the likelihood that the pigeon's looking toward the right key would affect the rate of left-key pecking (*cf.* Rachlin and Baum, 1969), the left key was darkened whenever the right key lit. The right key remained dark at all times when EXT was scheduled for that key.

In sessions of Series 4, a COD of 0.5 sec was in effect and both keys were again lit at all times except during reinforcement, but the feeder was modified so that discriminated reinforcers could be scheduled for each key. According to the VI schedule for the left key (green), the reinforced peck turned off the lights in the chamber, made the keys inactive, and lit a green lamp in the feeder; a peck on a switch within the left side of the feeder then raised the food hopper for 3 sec. According to the VI schedule for the right key (amber), the reinforced peck turned off the lights in the chamber, made the keys inactive, and lit an amber lamp in the feeder; a peck on a switch within the right side of the feeder then raised the food hopper for 3 sec. (The procedure is equivalent to concurrent chained schedules, as in Herrnstein, 1964, with the modification that the terminal responses of each chain occur inside the feeder instead of on the keys.)

The arrangement of the switches inside the feeder is illustrated schematically in Fig. 1. Establishment of feeder-switch pecking was facilitated by placing several small black spots above the bottom edge of each switch

plate at the start of training. Two of the pigeons began to operate the switches within a single session during which the concurrent schedules of Series 4 were fully in operation. The responses of the other two pigeons were shaped within a single subsequent session by selectively reinforcing head movements inside the feeder when the feeder was lit. Once the feeder was lit, the time preceding a peck on the appropriate switch was not restricted (no limited hold), nor did pecks on the inappropriate switch have any effect. Before the first schedule change of Series 4, each pigeon was responding accurately and with short latencies with respect to the key-correlated feeder stimuli and their respective switches.

RESULTS

The data obtained in each experimental series are summarized in Fig. 2. The rows show the four series, with the order of Series 3 and 4 reversed because the data of Series 3 differ in labelling and treatment from those of

Fig. 1. Arrangement of feeder switches in sessions of Series 4. Centered in the side walls of a standard Gerbrands feeder, two square 0.75-in. (19 mm) holes each accommodated the roller of a light-force extended-roller miniature switch (Cherry E23-70K). Two 4-in. by 1.125-in. (100-mm by 28-mm) plates of 1/64 in. (0.4-mm) aluminum were bent to fit over the top edges of the side walls. The lower surface of each plate rested against the corresponding miniature switch roller, so that pecks on the plates operated the respective switches. A peck on the left plate when the feeder was lit green (left-key color) or a peck on the right plate when the feeder was lit amber (right-key color) raised the food hopper for 3 sec.

the other series. The columns show the various sequences of concurrent schedules. For convenience of presentation, the data for Series 1, 2, and 4 have been treated so that a given schedule within a concurrent pair is represented by a single set of data points rather than by two sets that distinguish whether the schedule operated for the left key or for the right key. For example, in the change from EXT EXT to VI VI (column 1), the data from the two keys were averaged together because the schedules were the same for each key; in the changes from VI EXT to VI VI and from EXT VI to VI VI (column 2), the data from the left key in the first sequence were averaged together with the data from the right key in the second sequence because in their respective sequences the schedules for these two keys were the same. Symmetrical concurrent sequences (identical except for the reversal of keys, as in the preceding example) could not occur in Series 3 because different types of schedules were arranged for the two keys; the stimulus-correlated schedules for the right key reduced responding on that key to negligible levels, and therefore all the data shown for Series 3 are from the left key only.

The concurrent VI and EXT sequences are treated exhaustively in Fig. 2: reinforcement of pecks on both keys (VI VI) could follow either extinction on both keys (column 1) or reinforcement of pecks on only one key (column 2); reinforcement of pecks on only one key (VI EXT or EXT VI) could follow either reinforcement of pecks on both keys (column 3), reinforcement of pecks on only the other key (column 4), or extinction on both keys (column 5); extinction on both keys (EXT EXT) could follow either reinforcement of pecks on only one key (column 6) or reinforcement of pecks on both keys (column 7).

The subsequent presentation emphasizes the data obtained in Series 4 and in Series 3. The data for Series 1 and 2 were obtained from only two pigeons and were based on fewer repetitions of a given schedule change than the data for Series 4 (*cf.* Table 1). In addition, data from the early exposures to schedule changes in Series 1 probably were affected by the order in which the changes were examined as well as by the properties of the concurrent schedules, especially in those cases in which either schedule changed from VI to EXT.

These considerations may account for the somewhat greater session-to-session variability for a given schedule in Series 1 and 2 than in Series 4.

Nevertheless, the data from the four series are qualitatively similar even if they differ in quantitative detail. The rates of EXT responding were typically higher in Series 1 with COD 0.5-sec than in Series 2 with COD 1-sec, but no other substantial effects were evident. The difference in rates of EXT responding may be attributed both to the order in which the series were scheduled and to the different CODs, which have been shown to affect some properties of concurrent performances (*e.g.*, Catania, 1966, pp. 241-243; Shull and Pliskoff, 1967). The addition of key-correlated feeder stimuli in Series 4, which guaranteed that the reinforcers correlated with each key were discriminated, also did not substantially alter the general characteristics of the interactions. The arrangement of different reinforcers for concurrent responses (*e.g.*, food and shock avoidance: Catania, Deegan, and Cook, 1966) sometimes can reduce concurrent interactions, but the arrangement of reinforcers discriminated only on the basis of the responses that produced them apparently does not have this effect.

The interactions in Series 3 were similar to those in the other series even though there were no symmetrical concurrent sequences in that series. In each graph for Series 3 that shows two sets of data, the two sets were obtained successively in different schedule changes, whereas corresponding data for the other series were obtained simultaneously. For example, the change from VI EXT to VI VI or from EXT VI to VI VI in the other series always provided the data both from the key for which VI reinforcement was maintained and from the key for which the schedule was changed from EXT to VI. These two sets of data were obtained successively in Series 3: one set from the left key in the change from VI EXT to VI SCVI (stimulus-correlated VI), and the other set also from the left key in the change from EXT SCVI to VI SCVI. Because the interactions in Series 3 occurred even though right-key responding was reduced to negligible levels, concurrent reinforcement rather than concurrent responding is implicated as the variable that determined the properties of the concurrent interactions.

These interactions may now be examined by comparing the concurrent performances shown in different columns of Fig. 2. The presentation considers how the following aspects of performance were affected by concurrent reinforcement: the rate of responding maintained by VI reinforcement; the rapidity with which the rate of responding increased after the change from EXT to VI reinforcement; the rate of responding maintained during EXT; and the rapidity with which the rate of responding decreased after the change from VI reinforcement to EXT.

Responding Maintained by VI Reinforcement

The rate of responding maintained by VI reinforcement was consistently lower when concurrent responding was reinforced (columns 1 and 2) than when concurrent respond-

ing was not reinforced (column 3, unfilled circles, and columns 4 and 5, filled circles). For example, with key-correlated feeder stimuli in Series 4, a VI schedule maintained about 40 resp/min during VI VI and about 60 resp/min during VI EXT or EXT VI. The unfilled circles in columns 2 and 3 show the changes in rate that are usually spoken of in terms of behavioral contrast in analogous multiple schedules (*e.g.*, Reynolds, 1961*b*): when reinforcement was introduced for a concurrent response (column 2), the rate of responding maintained by VI reinforcement decreased; when the concurrent response was extinguished (column 3), the rate of responding maintained by VI reinforcement increased. These two changes in rate occurred without exception in each of about 40 observations of each of these schedule changes throughout the

Fig. 2. Summary of data obtained within each experimental series. Each graph shows arithmetic means taken across the schedule changes for each pigeon in a given series and, as labelled above each graph, across corresponding keys of symmetrical schedule changes (*e.g.*, the left key in the change from VI EXT to VI VI and the right key in the change from EXT VI to VI VI). The number of pigeons contributing data to each series is indicated. The order of Series 3 and Series 4 has been reversed for convenience of exposition. VI—variable-interval schedule (180 sec); EXT—extinction; COD—changeover delay. Additional details in text.

four series (including data from Pigeons 44 and 45, which were not incorporated into Fig. 2; see Method).

The data from Series 3, obtained with stimulus-correlated VI schedules for the right key, demonstrate that these changes in rate depended directly on concurrent reinforcement rather than on competition between concurrent responses; an increase in the rate of right-key responding in the other series did not reduce the rate of left-key responding by limiting the time available for its emission, because the same reduction in rate occurred when right-key responding was reduced to negligible levels in Series 3.

The Change from EXT to VI Reinforcement

The schedule for a given key could change from EXT to VI reinforcement either accompanied by VI reinforcement of a concurrent response (columns 1 and 2) or unaccompanied by VI reinforcement of a concurrent response (columns 4 and 5). When concurrent responding was reinforced, the change to the rate of responding maintained by VI reinforcement was reached more rapidly after EXT EXT (column 1) than after VI EXT or EXT VI (column 2, filled circles). In Series 4, for example, a rate of about 40 resp/min was reached within the first session after the change from EXT EXT to VI VI, whereas a rate of only about 30 resp/min was reached after the change from VI EXT or EXT VI to VI VI.

When concurrent responding was not reinforced, however, the change to the rate of responding maintained by VI reinforcement was reached more slowly after EXT EXT (column 5, filled circles) than after VI EXT or EXT VI (column 4, filled circles). In Series 4, for example, the rate of responding continued to increase for several sessions after the change from EXT EXT, whereas a relatively stable rate of about 60 resp/min was reached by the second session after VI EXT or EXT VI. This difference may have depended on the sequence of preceding schedules and on effects on the extinguished concurrent response; these factors are considered below.

The Rate of EXT Responding

When EXT was scheduled for a given key, responding was usually maintained at higher rates during VI reinforcement of concurrent

responding (column 3, filled circles, and columns 4 and 5, unfilled circles) than during extinction of concurrent responding (columns 6 and 7), although this difference was small in absolute terms. In Series 4, for example, the rate of EXT responding was 2 or 3 resp/min after at least seven sessions of VI EXT or EXT VI (column 3, filled circles; *cf.* Table 1), whereas the rate of EXT responding was already essentially 0 resp/min after only five sessions of EXT EXT (column 7). This difference indicates that a low rate of EXT responding may be maintained when it can occasionally be followed by reinforcement scheduled for a concurrent response (*cf.* Catania and Cutts, 1963). In Series 1, 2, and 4, the COD imposed a minimum delay between EXT responses and subsequent reinforcements of concurrent responses, but did not eliminate the incidental delayed reinforcement of the EXT responses. In Series 3, the effects of concurrent reinforcement on EXT responding were somewhat greater than in the other series, even though right-key reinforcements were delayed by a COD, presumably because left-key EXT responding could sometimes be followed without any scheduled delay by the stimulus correlated with right-key reinforcements. The available data do not allow speculation on how reinforcement of one response would affect the rate of a concurrent extinguished response if incidental delayed effects on one response of reinforcement of the other could be completely eliminated.

The effect of concurrent reinforcement on responding for which EXT was maintained is shown in columns 5 (unfilled circles) and 6 (filled circles). The introduction of VI reinforcement for one of two extinguished responses, in the change from EXT EXT to either EXT VI or VI EXT, typically produced a transient increase in the rate of the other response. The analogous case in multiple schedules (Reynolds, 1964) has been discussed in terms of an inductive effect on one response of reinforcement of another response. The effect cannot be attributed to a discriminative effect of reinforcement on the responding that follows reinforcement (Reid, 1957), because it occurred in Series 4 with discriminated reinforcers as well as in Series 1 and 2; nor can it be attributed directly to the increase in the rate of the reinforced response, because it occurred when right-key responding was re-

duced to negligible levels by stimulus-correlated schedules in Series 3.

Series 4 assessed the contribution of the schedules in preceding sessions to this inductive effect. In the other series, the effect had been observed in sequences such that the extinguished response had been reinforced in the pair of concurrent schedules that preceded EXT EXT (see bracketed schedules in the labels for column 5). During Series 4, two sequences were arranged so that the extinguished response was not reinforced in the pair of concurrent schedules that preceded EXT EXT (unfilled and filled triangles in column 5 of Series 4; *cf.* Table 1). These sequences of schedule changes did not produce an inductive effect on EXT responding (unfilled triangles), and the rate of responding maintained by VI reinforcement of the other response was reached more rapidly than when the VI reinforcement was accompanied by an inductive effect (filled triangles *versus* filled circles). These differences do not in any sense account for the observed phenomenon of induction, but they do illustrate its dependence either on the preceding sequence of schedules or on the number of sessions for which EXT was maintained for the response in the preceding sequences.

When EXT was maintained for one response while VI reinforcement was discontinued for the other response, the rate of the maintained EXT responding ordinarily decreased (column 6, filled circles). This effect was small in absolute magnitude, and exceptions were sometimes observed during the early sessions after the change in schedules (*e.g.*, in Series 2, a slight increment in responding in Sessions 1 and 2 was followed by a decrease to a final EXT rate lower than that in the session before the schedule change). In Series 4, the rate decreased from 2 or 3 resp/min during VI EXT or EXT VI to essentially 0 resp/min in the last of the sessions of EXT EXT; in Series 3, the rate decreased from 4 or 5 resp/min during EXT SCVI to less than 1 resp/min in the last EXT EXT sessions. These effects of concurrent reinforcement on maintained EXT responding are consistent with the other effects on EXT responding considered above.

The Change from VI Reinforcement to EXT

The change from VI reinforcement to EXT for a given response could occur either ac-

companied by concurrent VI reinforcement (columns 3 and 4) or unaccompanied by concurrent VI reinforcement (columns 6 and 7). When the change followed VI VI (columns 3 and 7), the decrement in responding during EXT began from a lower rate of responding than when the change followed VI EXT or EXT VI (columns 4 and 6).

Responding in EXT after VI VI decreased more slowly when VI reinforcement continued for the concurrent response (column 3, filled circles) than when VI reinforcement did not continue for the concurrent response (column 7). In Series 4, for example, the rate of responding during the first session of EXT dropped only to about 30 resp/min when reinforcement continued for the other response but to about 20 resp/min when reinforcement was discontinued for both responses. This difference was fairly consistent across pigeons and series; the reversal in Series 1 probably depended on the order in which the schedule changes were examined during the initial exposures of each pigeon to EXT in this series (*cf.* Method).

Concurrent reinforcement did not have consistent effects on the decrements in EXT responding after VI EXT or EXT VI (columns 4 and 6). The rate of EXT responding in the first session of EXT VI after VI EXT or in the first session of VI EXT after EXT VI (column 4, open circles) was higher in Series 2 and 4 and lower in Series 1 and 3 than the rate in the first session of EXT EXT after VI EXT or EXT VI (column 6, open circles). Two effects may have operated together in these cases: a direct reduction of EXT responding by concurrent VI reinforcement may have been balanced by an inductive effect of VI reinforcement like that shown in column 5. In the absence of data separating two such effects, however, it is more appropriate to conclude that concurrent reinforcement does not affect the decrease in responding during EXT. This conclusion is consistent with the observation that reinforcement of one response has different effects on concurrent responding also maintained by reinforcement than on concurrent responding that is only maintained at operant level (Catania, 1966, p. 259).

The change from VI reinforcement to EXT in column 4 (unfilled circles) has a unique characteristic: because VI reinforcement was initiated for concurrent responding when

EXT began, it is the only case in which the dependency between responses and reinforcers was terminated while the rate of delivery of reinforcers continued unchanged. Thus, this example of extinction may be uncontaminated by effects of the termination of reinforcers (e.g., emotional behavior) that typically accompany the termination of a dependency between responses and reinforcers. This schedule change may have special relevance for the

analysis of extinction, but its advantages may be offset by the need to evaluate the inductive effects of concurrent reinforcement on the extinguishing response.

Data obtained in successive schedule changes for Pigeon 150 in Series 4 and Series 3 are shown in Fig. 3, to illustrate the extent to which the summary data in Fig. 2 are representative of individual performances. Data from Series 3 show left-key responding only,

PIGEON 150

SERIES 4: COD 0.5-sec; key-correlated feeder stimuli.

SERIES 3: COD 1-sec; stimulus-correlated (SC) schedules on right key

Fig. 3. Data from Pigeon 150, showing successive schedule changes in Series 4 and in Series 3. Details in text.

because right-key responding occurred at near-zero rates throughout that series. For this pigeon, the rate of responding maintained by VI reinforcement in Series 4 tended to be slightly higher on the right key (unfilled symbols) than on the left key (filled symbols), a difference that might be referred to as a response bias in favor of the right key. Nevertheless, the interactions were qualitatively similar to those illustrated in Fig. 2.

DISCUSSION

In summary, the present findings show that the rate of one reinforced response is reduced by the reinforcement of a concurrent response, that this interaction depends on concurrent reinforcement rather than on competition between the concurrent responses, and that reinforcement of one response sometimes has transient inductive effects on concurrent extinguished responses but does not accelerate the reduction in rate when extinction begins for the concurrent response. These findings are consistent with a quantitative account of concurrent performances (Catania, 1963) in which the rate of one of two concurrent responses is described by the following equation:

$$R_1 = \frac{Kr_1}{(r_1 + r_2)^n}.$$

In this equation, R_1 is the rate of Response 1, r_1 and r_2 are the respective rates of reinforcement of the two responses, and K is a constant that depends on the units of measurement. The exponent, n , is slightly less than 1.0 (in a related account by Herrnstein, 1964, $n = 1.0$). According to this equation, the rate of Response 1 decreases as the rate of reinforcement of Response 2 increases; the rate of Response 1 is determined solely by the rates of reinforcement of the two responses, because the rate of Response 2 does not enter into the equation; and the rate of Response 1 is zero when its rate of reinforcement is zero, but the rapidity with which rates may change when reinforcement is discontinued or reinstated for either response is not specified.

The relationship described by the above equation can be expressed in the following way: reinforcement of one response inhibits the rate of other reinforced responses. This application of the vocabulary of inhibition is

descriptive, and has the advantage that both the inhibited and the inhibiting processes are precisely and quantifiably specified in terms of concrete experimental operations. Thus, the vocabulary of inhibition can provide a convenient way of speaking about certain properties of behavior. But this vocabulary is inconsistent with the vocabulary applied to interactions in multiple schedules, which often have been attributed to excitatory properties of extinction. The discussion that follows therefore will be concerned with some characteristics of the vocabulary of inhibition and its implications for the analysis of interactions in both concurrent and multiple schedules. What follows, in other words, is not so much about the empirical findings as it is about the ways in which these findings may be spoken of.

The trouble with the concept of inhibition, as it is often applied to behavior, is that it is difficult to say unambiguously what is inhibited by what. If the inhibited and the inhibiting events are not clearly specified, the conditions that actively reduce responding may not be distinguishable from those that simply fail to maintain responding (*cf.* Skinner, 1938, p. 96). In the classical account (Pavlov, 1927), extinguished responding was said to be inhibited, but the process that did the inhibiting was not so concretely identified. The process was inferred not only from the response decrement produced by extinction, but also from accompanying increments in other responses (positive induction).

This inhibitory account is paralleled in current treatments of behavioral contrast in multiple schedules (*e.g.*, Reynolds, 1961*c*; Terrace, 1968). When reinforcement in the presence of two successive stimuli is followed by extinction in the presence of one of them, the rate of responding in the presence of the other typically increases (Reynolds, 1961*a*). This increase, an example of behavioral contrast, is usually treated as an excitatory side-effect of extinction. Such accounts have not always been formulated in the vocabulary of inhibition, but like the inhibitory account they speak of two processes: a direct effect on the extinguished response, and an indirect effect on other responses.

There is an alternative way of talking about what is inhibited by what in behavior: the maintenance of one response may be said to inhibit other responses (*cf.* Hovland, 1936).

Although this account may be expressed solely in terms of observed interactions between responses and therefore need not appeal to an unobserved inhibitory process, the common vocabulary of inhibition has tended to obscure the distinction between the two formulations (*cf.* Wendt, 1936). Figure 4 illustrates the way in which they differ.

An interaction characterized in terms of an excitatory effect of extinction is shown in *A*. Response 1 is maintained by reinforcement. When extinction reduces the rate of Response 2, the rate of Response 1 increases from x to y . When reinforcement is reinstated for Response 2, Response 1 returns to x , its original level. The arrows show the locus of the effect: extinction of Response 2 produces an increment in Response 1.

In *B*, the same interaction is shown in terms of inhibition of one response by reinforcement of another. When Response 2 is extinguished,

Response 1 is maintained by itself, at rate y . When reinforcement is reinstated for Response 2, the rate of Response 1 is reduced from y to x . Again, the arrows show the locus of the effect: reinforcement of Response 2 produces a decrement in Response 1.

The hypothetical data in *A* and *B* are the same. Yet the first characterizes extinction as the effective process and takes the reinforcement of both responses as the baseline level from which effects are measured (solid line at x). The second characterizes reinforcement as the effective process and takes the reinforcement of one response alone as the baseline level from which effects are measured (solid line at y). What is an effect in one formulation is the baseline level in the other. Because both formulations are consistent with the data, there is no simple empirical basis for choosing between them. But the second has a logical advantage, in that it treats reinforcement, an experimental operation, rather than extinction, the discontinuation of that operation, as a causal variable in the control of behavior. This treatment is consistent with the view that the extinction process is fundamentally nothing more than a manifestation of reinforcement (*cf.* Morse, 1966, pp. 53-54): the effects of reinforcement persist in time even after reinforcement is discontinued, and the time course of this persistence is called extinction. In any particular case, the analysis of this time course may be complicated because other effects are superimposed, but such effects need not force us to regard reinforcement and extinction as dichotomized processes. For example, the generalized changes in behavior called emotional probably depend directly on the termination of reinforcers. This termination is not a necessary accompaniment of extinction and its effects can be separated experimentally from the effects of its defining property, the termination of a dependency between responses and reinforcers (*cf.* Fig. 2, column 4).

The essential property of inhibition is not merely the reduction of an activity or process, but rather the dependence of this reduction on an increment in some other activity or process. Such a relationship precisely describes concurrent performances: the rate of a reinforced response is inhibited by the reinforcement of other responses. The inverse relationship, that extinction of a response produces increments

Fig. 4. Interaction between two responses illustrated as an excitatory effect of extinction (*A*) or as an inhibitory effect of reinforcement (*B*). Details in text.

in the rate of other responses, has never seemed a plausible description of concurrent performances because, in a given experimental situation, there are always any number of unreinforced concurrent responses that could be taken into account. For multiple schedules, too, the description of performances in terms of inhibitory effects of reinforcement has been suggested (Catania and Gill, 1964; Staddon, 1967), but the description in terms of excitatory effects of extinction has been predominant (*e.g.*, Reynolds, 1961*c*; Nevin and Shettleworth, 1966; Terrace, 1968).

The alternative ways of speaking are also evident in the description of punishment interactions in concurrent and multiple schedules. For example, when two responses are each maintained by reinforcement and only one is punished, the decrease in the rate of the punished response may be accompanied by an increase in the rate of the unpunished response (*e.g.*, Brethower and Reynolds, 1962). In a description that parallels the description of behavioral contrast as an excitatory effect of extinction, the increment in the unpunished response has been spoken of as a facilitative effect of the punishment of another response. But it is also possible to say that punishment counteracts the effect of reinforcement, and in so doing releases the unpunished response from inhibition by reinforcement. In this vocabulary, the effect of punishment on unpunished responding is disinhibiting rather than facilitating (in order of magnitude, the increments that punishment produces in unpunished responding are consistent with this interpretation).

The formal and functional similarities between concurrent and multiple schedules suggest that if the vocabulary of inhibitory effects of reinforcement is preferable to the vocabulary of excitatory effects of extinction in the concurrent case, it should also be preferable in the multiple case. The alternative is to retain two incompatible accounts of behavioral phenomena that may be fundamentally related but that differ perhaps in only superficial properties of the baseline schedule within which they have been observed.

What stands in the way of extending the present inhibitory vocabulary to multiple as well as to concurrent schedules? One substantial factor is that the phenomenon of behavioral contrast has been studied predominantly

by manipulating conditions during the extinction component of the multiple schedules within which contrast is observed. (This experimental strategy itself arises from the assumption that behavioral contrast is a consequence of excitatory effects of extinction.) Various schedules of reinforcement (*e.g.*, differential-reinforcement-of-long-interresponse-time or DRL schedules: Terrace, 1968; Reynolds and Limpo, 1968) have been substituted in the extinction component to reduce the rate of responding in that component while maintaining presentations of the reinforcer (the rationale is related to that for the stimulus-correlated schedules of Series 3 in the present experiment). Such procedures must deal with the possible induction of the differentially reinforced response properties (*e.g.*, interresponse times) from one component to another (*cf.* Segal, 1961). Other procedures have involved changes in the parameters of reinforcement schedules, without the scheduling of extinction (*e.g.*, transitions among various multiple VI VI schedules, in Terrace, 1968). Such schedules tend to reduce the emphasis on absolute rates of responding, favoring the direction of change of the component rates, and can deal with excitatory effects of extinction only with difficulty in terms of the effects of reductions in reinforcement. The graded effects on one response produced by graded changes in the reinforcement of other responses (*e.g.*, as in Nevin, 1968) are handled more comfortably by the vocabulary of inhibition by reinforcement than by the vocabulary of excitation by extinction. Finally, procedures for establishing stimulus control without extinction responding ("errorless" discrimination: Terrace, 1963*a*, 1963*b*) eliminate behavioral contrast while maintaining alternating periods of VI reinforcement and extinction. This finding supports the argument that the absence of extinction responding during the acquisition of stimulus control prevents extinction from having its usual excitatory effect. But emotional effects or the incidental reinforcement of unspecified classes of responses may also be involved in the outcome, and from the conclusion that an extinction component in a multiple schedule may have aversive properties it does not necessarily follow that extinction is inhibitory.

Each of these cases may involve different empirical problems and different problems of

interpretation, and this is not the place to evaluate all the possibilities. But it is possible to reformulate some of the questions. If it is plausible to state that reinforcement of one response inhibits other reinforced responses in concurrent schedules and that this vocabulary can appropriately be extended to multiple schedules, then it follows that the appropriate baseline condition for studying reinforcement interactions is one response reinforced alone. The present account in terms of inhibitory effects of reinforcement suggests, therefore, that rather than asking why most multiple VI EXT schedules produce the increase in VI responding that is spoken of in terms of behavioral contrast while those in errorless-discrimination procedures do not (Terrace, 1963a, 1963b), it may be profitable to ask instead why errorless-discrimination procedures produce a decrease in VI responding compared to the rates typically maintained in other multiple VI EXT schedules.

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