RESPONSES AND PAUSES: DISCRIMINATION AND A CHOICE CATASTROPHE

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Pigeons produced a stimulus change either by responding or by not responding for a specified time period (by pausing). They then had to choose between two responses to obtain food. One choice was correct if the first component had been completed by a response; the other was correct if the component had been completed by a pause. The pigeons usually chose correctly, thereby indicating that they used their own prior behavior as a discriminative stimulus. Fixed pause requirements did not produce equal first component completions by a response and by a pause. To obtain equality, the pause requirement was titrated as a function of current performance. Titration resulted in equal completions and also produced accurate discrimination. In addition to showing that pigeons discriminated whether they had responded or paused, the data displayed the discontinuous functions predicted by catastrophe theory. Another procedure used forced choice rather than titration to produce equal completions by pausing and responding and also showed accurate discrimination of behavior.

Key words: behavior discrimination, DRO schedules, random-interval schedules, schedule titration, point of subjective equality, catastrophe theory, response elimination, key peck, pigeons

In a series of experiments (Zeiler, 1976, 1977, 1979; Zeiler & Fite, 1975) responses as well as the absence of the response for a specified time produced reinforcement (a differential-reinforcement-of-not-responding, or DRO, schedule). The procedure proved effective in eliminating the response, although the response recovered when the DRO schedule was removed. The speed of recovery suggested that the pigeons discriminated the behavior necessary for reinforcement. The present research investigated whether pigeons actually could discriminate the source of reinforcement (responses or pauses) in this situation.

Animals can discriminate their own behavior. Pigeons accurately reported whether a stimulus change had been produced by a pause followed by a peck or by a pause alone when only one of the schedules was in effect on a given trial (Lattal, 1981). They also discriminated whether a stimulus change had occurred dependent on or independent of responses

(Killeen, 1981). The unique aspects of the present experiment were that both schedules always were in effect simultaneously, and both imposed a behavior specification (response or pause) for all stimulus changes.

The schedule was a combined response-maintenance (in this case, a random-interval, or RI, schedule) DRO schedule. The procedure was derived from that originally used to study discrimination of response number (Rilling & McDiarmid, 1965). Completion of either requirement resulted in a choice situation. Which choice was correct depended on whether the first component had ended by meeting the RI response requirement or the DRO pause requirement. Choice accuracy measured the ability to use preceding responses and pauses as discriminative stimuli. Conditions involved fixed DRO values, titrating DRO values, and fixed DRO values with the source of stimulus change preassigned to either the RI or DRO schedule on each trial.

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METHOD

Subjects

Six White Carneaux pigeons were maintained at 80% of their free-feeding weights.

Pigeons 40, 111, 137, and 158 had prior experience with a variety of reinforcement schedules and discriminative stimuli, and Pigeons 132 and 162 were experimentally naive.

Apparatus

The three response keys (R. Gerbrands Co.) were 2 cm in diameter and were mounted 21 cm above the floor with the center key 8 cm above the 5-cm square food magazine aperture. Key operations required a minimum force of .18N, and each operation was accompanied by activation of a feedback relay mounted behind the panel next to the key. A 1-W white lamp inside the feeder illuminated the aperture during food presentations, and a 1-W houselight provided dim general illumination except during feeder operations. The center key could be transilluminated by white light, the right side key by green light, and the left side key by red light. Continuously present white noise helped mask extraneous sounds. The reinforcer consisted of 3-sec access to Purina Pigeon Checkers, the birds' standard diet. All experimental events were programmed and recorded by a computer operating on-line.

Procedure

The center key was correlated with two schedules simultaneously (conjoint schedule). One was a random interval (RI) with an average interval of 1 min; the other was DRO t -sec, where t varied in different conditions. The center key was transilluminated by white light and the two side keys were dark. Completion of either the RI or the DRO requirement turned off the center keylight and turned on the side (choice) keylights. If the RI requirement had been met (center key turned off by a peck), a response to the right green key produced food. If the DRO requirement had been met (center key turned off by a pause), a response to the left red key produced food. Every food delivery was preceded by illumination of the hopper light for .5 sec. A 10-sec period with all keys dark followed an incorrect choice. The cycle started anew with the white center key and dark choice keys after each food presentation or 10-sec dark period.

Performance was shaped by lighting one of the two side keys according to an irregular sequence and having a response to the lit key produce food. Then, the center key was added

with the conjoint RI-DRO schedule in effect. The center key was darkened whenever an RI or DRO requirement was met, but only the appropriate choice key was lit. After the chain was established, the discrimination procedures began.

The RI schedule was controlled by a probability gate in conjunction with pulses emitted at 1-sec intervals. Each pulse had a probability of .017 of producing offset of the center keylight and onset of the choice keys for the next center key response. At the same time, whenever a response had not occurred for the t specified by the DRO schedule, the center key went off and the choice keys came on. Each center key response reset the DRO timer. The RI and DRO schedules began anew with each onset of the center key.

Sessions terminated either after 1500 center key responses or after 30 food deliveries, whichever came first. In Procedures I, II, and III, sessions were conducted seven days per week; in Procedure IV, they were conducted five days per week.

Table 1 shows the sequence of conditions. In Procedures I and III, each condition was maintained until performance reached a stability criterion. Starting with Session 10, the percentage of choices of the DRO was calculated for each session. The median percentage was calculated for successive blocks of three sessions. Stability occurred when three consecutive medians (based on nine successive sessions) were within 5% of each other and did not change monotonically. The only exception was that Condition 2 for Bird 132 was changed after 11 sessions, because performance was identical to that of the previous condition. Conditions were changed when the last bird met the criterion. Procedure II was maintained for 32 sessions, and each condition of Procedure IV for 10 sessions.

I. Fixed DRO values: first series. In the first three conditions, the DRO values were fixed within a session. They were changed to alter the likelihood that the first component would be completed via the RI or the DRO. Values were found that produced a high degree of preference for the RI, and other values were determined that produced substantial preference for the DRO. The final values were maintained for the number of sessions shown in Table 1. The intent also was to find an in-

Table 1
Sequence of Conditions

Procedure	Condition	Pigeon 40		Pigeon 111		Pigeon 132	
		DRO	Sessions	DRO	Sessions	DRO	Sessions
I	1	10	28	3	28	30	28
	2	20	20	15	20	60	11
	3	15	29	10	29	85	29
II	4	Titration	32	Titration	32	Titration	32
III	5	8	26	24	20	11	20
	6	20	28	15	18	17	18
	7	13	17	19	28	20	28
	8					30	16
IV	9	10	10	10	10	10	10
	10			1	10	1	10
	11			5	10	5	10

Procedure	Condition	Pigeon 137		Pigeon 158		Pigeon 162	
		DRO	Sessions	DRO	Sessions	DRO	Sessions
I	1	3	28	10	28	15	27
	2	15	20	3	20	10	20
	3	10	29	5	29	5	29
II	4	Titration	32	Titration	32	Titration	32
III	5	15	20	9	20	11	20
	6	8	18	16	18	7	18
	7	5	18	13	27	17	28
	8					20	16
IV	9	5	10	5	10	5	10
	10	10	10	10	10	10	10
	11	1	10	1	10	1	10

intermediate DRO value that would yield approximately equal completions via the two components; however, no value did so for more than the first few sessions.

II. DRO titration. The DRO value was decremented or incremented depending on how the preceding first component was ended. If the component had ended on RI, the DRO was decreased by 1 sec; if it had ended on DRO, the DRO was increased by 1 sec. The first session began with DRO 5-sec. For the next 10 sessions, the starting DRO was the terminal value of the preceding session. In the remaining sessions, the beginning DRO was the mean DRO of the preceding session.

III. Fixed DRO values: second series. Fixed DRO values were reimposed following the titration condition. The DRO values depended on the performance in the last nine sessions of titration. The lowest (highest) values were the means of the lowest (highest) values achieved in each of the nine sessions, and the intermediate values were the average DRO for these same sessions. If performance was not

as expected (lowest DRO producing predominantly DRO completions, highest producing predominantly RI completions), the DRO was adjusted accordingly. The stability criterion was as in Procedure I, except that Condition 8 was maintained for 16 sessions.

IV. Fixed DRO values: forced choice. Now the pigeons were not free to complete the first component of the chain via either DRO or RI on each trial. At the onset of every first component, completion was assigned to just one of the schedules (p of assignment to DRO = .50). When assigned to the RI schedule, the first center key response that met the RI requirement turned off the center key and turned on the two side keys. Pauses meeting the DRO requirement had no effect, because the DRO timer did not operate. When assigned to the DRO schedule, the first pause meeting the DRO requirement turned off the center key and turned on the two side keys. Responses could not end the first component, because now the RI timer did not operate. Pigeon 40 died after the first condition of this phase.

RESULTS

All data analyses were based on the last five sessions of each condition.

Fixed DRO Values: Procedures I and III

Figure 1 shows the percentage of first components completed by meeting the DRO requirement. The total number of completed first components per bird per condition ranged

from 125 to 169 (mean = 150, standard deviation = 8.3). The frequency of DRO completions decreased as the DRO value increased in both the first and second series with fixed DRO. The precise DRO that yielded a high number of RI or DRO completions varied between birds. For example, with DRO 10-sec, Pigeon 40 always completed the first component via DRO, but Pigeon 137 only completed the DRO in 3 of 145 instances.

Some DRO values did not yield the same behavior before and after titration. Pigeon 111 had DRO 15-sec in Conditions 2 and 6. In Condition 2, 149 of the 150 first component completions were via RI; in Condition 6, this bird had no RI completions. Pigeon 132 had DRO 30-sec in Conditions 1 and 8. All 150 completions were via DRO in Condition 1, but only 17 of the 150 were via DRO in Condition 8. A DRO 15-sec generated 44 of 150 completions via RI in Condition 3 for Pigeon 40, but DRO 13-sec resulted in 107 RI completions in Condition 7. Pigeon 132 never had an RI completion in Condition I (DRO 30-sec), but RI completions occurred with smaller values after titration. Frequency of component completion via RI showed a monotonic relation to DRO value when successive conditions were separated in terms of whether they preceded or followed titration.

Figure 2 shows the percent correct choices in the discrimination (choice) component. Overall, both DRO and RI choices were made correctly 98% of the time. In short, discrimination was accurate whether first component completions were predominantly RI, predominantly DRO, or a mixture of the two.

Titration: Procedure II

The upper section of Figure 3 shows the mean, standard deviation, and range of DRO values during the titration phase when the DRO was increased by 1 sec with each first component DRO completion and decreased by 1 sec with each RI completion. The mean DRO was between 10 and 19 sec. Substantial fluctuations in momentary values were evident: across birds, DRO ranged from 3 to 27 sec.

The middle section of Figure 3 indicates that DRO titration accomplished its goal of producing approximately equal first-component completions via the two sources. The typical sequence was a run of DRO completions

Fig. 1. Percentage of first components completed by meeting the DRO pause requirement with fixed DRO schedules before (1st) and after (2nd) exposure to the titration condition.

Fig. 2. Percentage of correct discriminations with fixed DRO schedules before (1st) and after (2nd) exposure to the titration condition.

followed by a run of RI completions. Only the lowest and highest DRO values produced the same type of completion consistently. Other values yielded either RI or DRO completions. Which occurred depended on the immediately preceding performance. Performance was of one type until the DRO reached a value that shifted first component behavior to the other source. The alternating runs of type of com-

Fig. 3. Summary data for the titration condition. The upper section shows the mean, standard deviation, and range of DRO values. The middle section shows the number of first components completed by meeting the DRO and the RI requirements. The lower section shows the percentage of correct discriminations following DRO and RI first component completion.

pletion resulted in approximately equal DRO and RI completions in each session.

The bottom section of Figure 3 shows discrimination accuracy. Pigeon 40, who made 66% correct RI choices, was least accurate. In all of the other cases, discrimination was 90% or better following either RI or DRO first-component completions. Once again, the birds generally discriminated whether they had completed the first component with a response (RI) or with a pause (DRO).

Forced Choice: Procedure IV

The left column of Figure 4 shows the number of first components completed from each source. Because the probability gate assigning reinforcement operated independently on each trial, 50% assignment to each source was not guaranteed. The actual assignment probability to DRO ranged from .45 to .55.

The right column of Figure 4 shows the percent correct discriminations following each type of completion. Accuracy was a function

Fig. 4. Number of first component completions via the DRO and RI schedules (left column), and percent correct discriminations following each type of completion (right column).

of neither DRO value, order of conditions, nor source of stimulus change. Discrimination was 80% accurate or better following either RI or DRO completions, and exceeded 90% in 26 of the 32 measures.

DISCUSSION

Pigeons usually chose the correct alternative following either a pause or a response. Accurate discrimination of preceding behavior occurred whether most requirements were met with a pause (via DRO), with a response (via RI), or by a mixture of pauses and responses. Responses and pauses served as discriminative stimuli for the availability of reinforcement in a subsequent choice phase; they indicated the prevailing condition of reinforcement.

The earlier arrangements used to study response elimination (Zeiler, 1976, 1977, 1979; Zeiler & Fite, 1975) differed from those used now in that the response or pause was fol-

lowed immediately by reinforcer delivery and no discrimination was necessary. However, in the earlier studies that repeatedly examined the durability of response suppression following suspension of DRO, discriminative properties were likely to develop even if absent at first. The only source of information about whether response absence could be reinforced was the occurrence or nonoccurrence of the reinforcer after a pause long enough to meet the DRO requirement. A reinforced pause indicated that pauses now were reinforced; a nonreinforced pause indicated that only responses could be reinforced. Given the frequent changes of condition, the situation can be viewed as entailing a series of discrimination reversals, and the rapid loss and recovery is not surprising (at it would be if the underlying process was assumed to be the loss and development of the strength of the tendency to pause through reinforcement and extinction). Similar rapid reversals often occur with punishment (cf. Azrin & Holz, 1966).

The conjoint occurrence of response maintenance and response elimination procedures models the nonlaboratory setting on the assumption that unwanted behavior is being maintained in some way, be it by reinforcement, elicitation, or something else, so that attempts to eliminate the behavior necessarily are superimposed on an operation that is maintaining the response. As superimposition also is the arrangement in which punishment has been studied extensively (Azrin & Holz, 1966), the various data permitted comparisons of DRO with punishment. In most respects the effects of DRO paralleled those of punishment (Zeiler, 1979). The main shortcoming of DRO was that response suppression never long survived its removal, whereas durable suppression sometimes had appeared following suspension of punishment.

The reason for the greater durability of punishment may stem from the role of time as a discriminative stimulus in the two procedures. The suspension of DRO is signalled by the absence of reinforcement after the previously relevant time period has elapsed; the subject need not do anything to learn that DRO no longer is in effect. In contrast, detection of the suspension of punishment requires that responding first be resumed. Suppression first must dissipate, and that may occur slowly after

extreme punishment. This explanation is based on the hypothesis that the reinforced responses and pauses in combined response-maintenance DRO schedules serve as behavior-correlated discriminative stimuli. When both the response-maintenance and the DRO schedules are in force, reinforced responses and pauses indicate the further availability of reinforcement for responding and pausing. The present data showed that responses and pauses indeed can have discriminative properties. Given this information, it seems plausible that when pauses no longer are reinforced, the non-reinforced pauses now signal that responding is the only source of reinforcement. Any operation that obscures suspension of DRO presumably would make its response elimination effects more durable.

When reinforcement was available following satisfaction of either the RI or DRO requirement, small fixed DRO values generated predominantly DRO completions, and large values produced mainly RI completions. No intermediate DRO could be found that would generate reliably equal completions from both sources. Instead, when the pigeon completed in one way, it usually continued to do so, sometimes to the total exclusion of the other. The titration procedure, which adjusted the DRO dependent on performance, did result in more equal division of completions (as did having only one source of reinforcement on each trial). Fixed DRO values imposed after titration sometimes yielded a different distribution of completions from those occurring initially. These instances of metastability showed that behavior under a given condition was stable, but interpolation of a different condition again resulted in stable behavior, albeit not of the same form.

Arrangements going under the name of adjusting, tracking, titration, or up-down schedules have proven useful in determining such psychophysical properties as absolute thresholds (Rosenberger, 1970; Stebbins, 1970; Békešy, 1947) and points of subjective equality (Church, Getty, & Lerner, 1976). A psychophysical orientation leads to the view that the present titration procedure provided information about the DRO value serving as the indifference point between the DRO and RI schedules, where the indifference point is the mean DRO.

The indifference point was a DRO that provided reinforcement at considerably shorter intervals than the average yielded by the RI. The mean DRO was between 10 and 19 sec (1.6 to 6 reinforcers per min) as opposed to an RI of 1 min (one reinforcer per min). The imbalance fits with other data in showing that the DRO must be considerably shorter than the response maintenance schedule for the DRO to exert an effect. For example, when combined with a VI 100-sec schedule, DRO 30-sec had no effect, but DRO 10-sec did reduce responding (Zeiler, 1977). Deviations from equality cannot be attributed to preference for variable over fixed interreinforcer intervals. With an FI 3-min schedule, DRO 1-min did not alter responding (Zeiler, 1976). A DRO of 30 sec or less was needed to produce DRO completions in a conjoint schedule.

A pilot experiment using concurrent schedules suggests that the mean value of a titrating schedule provides a statistical determination of when two schedules are equivalent. One key was correlated with an RI 1-min schedule, and the other key with a titrating RI schedule. The steady-state mean of the titrating RI was identical to that of the fixed schedule. Titration, then, yielded precise matching of schedules with choices. The general procedure would seem promising as a tool for determining schedule equivalence in a variety of situations (e.g., equivalence between fixed and variable schedules, between ratio and interval schedules, etc.).

In the present titration situation, the individual DRO values ranged widely about the mean. Although values near the mean produced approximately equal overall completions via RI and DRO, at any given time one type of completion occurred until the DRO deviated substantially from the mean. Then the source of completions reversed, driving the DRO to and past the mean, then reversed again to drive the DRO in the other direction. Except at values far from the mean, no given DRO had a fixed effect.

If the conjoint schedule is viewed as a form of concurrent schedule (Catania, 1966), then the frequency of occurrence of each type of completion would correspond to choices among the alternatives. Choice processes imply the relevance of the matching law (de Villiers, 1977; Herrnstein, 1970). According to the

matching principle, either or both the proportion of total choices or the proportion of total time allocated to an alternative should match the proportion of total reinforcers obtained from that alternative. Matching of frequency of component completion by responses or pauses to relative reinforcement frequency describes the present behavior. With fixed DRO, where the pigeons exclusively preferred one alternative, all reinforcers occurred via that alternative. With titration and forced choice, equal preference corresponded with equal reinforcement. However, the law deduces neither relative reinforcement frequency nor choice from schedule parameters. It relates the two dependent variables of reinforcement frequency and choice and thereby does not offer predictions in advance of data collection.

Attempts to deal with performance as a function of the independent variables have assumed that reinforcement frequency is some continuous function (power, hyperbolic, etc.) of the schedule parameter value (Baum, 1973; Rachlin, 1978; Staddon, 1979). The present data imply that in fact at least some forms of choice may be the outcome of a discontinuous rather than a continuous function and also that a given parameter value may result in quite different forms of behavior. A possible answer may be provided by catastrophe theory (Thom, 1975), a discontinuous theory of how variables interact that was derived from the mathematics of topology. The theory has seen limited application in psychology to date, but it has been used to explain acquisition processes in Pavlovian conditioning (Frey & Sears, 1978).

A cusp catastrophe (the catastrophe involving two variables) is described by the polynomial: $X^3 = a + bX$. For some combinations of a and b (these terms are some transformation of the independent variables), the equation has a single real solution, but for others it has two. As long as only one solution exists, behavior will vary continuously. However, further changes in parameters will encounter the two-solution cases (the bifurcation set). Behavior will reflect the solution closest to the previous one. Further parameter changes will reach the far edge of the bifurcation set, at which point behavior will shift immediately to the solution furthest from the previous one and will be continuous beginning from the new level. If the parameters then are changed in the opposite

direction, behavior will shift radically again when the new furthest edge of the bifurcation set is reached (the point at which the bifurcation set was first encountered in the initial series). Therefore, the precise point of the shift differs depending on the direction of approach to the bifurcation set. A detailed narrative and graphic description of a cusp catastrophe is available in Frey and Sears (1978); the mathematical analysis is presented by Thom (1975). This theory of how variables interact predicts discontinuity, hysteresis, bimodal behavior, and an inability to maintain two forms of behavior with equal frequency.

The following describes the correspondence between the present data and a cusp catastrophe. (1) Abrupt transitions occur between two types of behavior. In the present case, when the DRO was changed in the fixed free-choice conditions, preference cleanly and suddenly shifted between the DRO and RI alternatives. (2) Behavior is bimodal. In the current data, a given choice (RI or DRO) occurred at any given time with either a high or a low probability. (3) An intermediate response probability (approximately equal occurrence of different forms of behavior) cannot be maintained. This inaccessibility property was demonstrated with the fixed DRO values in the free choice conditions, although it was weakened somewhat following titration. (4) Behavior displays hysteresis. This was evident from the titration condition where the behavior generated by a DRO value tended to be the same as that produced by the preceding value. Frey and Sears (1978) discussed the limitations in applying either a theory of continuous functions or Markovian models to such data. Whether discontinuous properties in choice situations may be more evident when the schedules are nonindependent as in the present case than when they are independent as in the typical concurrent schedule is not clear at this point. Abrupt transitions between forms of behavior also have been observed when pigeons discriminated between response-dependent and response-independent reinforcement (Killeen, 1981) and in the number of responses emitted in successive fixed intervals (Zeiler & Davis, 1978). Such instances of catastrophe-like behavior with independent schedules suggest that the utility of the theory may extend beyond situations like the present one.

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