ALLOCATION OF COMPLEX, SEQUENTIAL OPERANTS ON MULTIPLE AND CONCURRENT SCHEDULES OF REINFORCEMENT

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Pigeons could produce food by pecking exactly four times on each of two keys, in any order. In the first experiment, these response sequences were reinforced on a series of multiple schedules of variable-interval reinforcement. In the second experiment, these response sequences were reinforced on a series of concurrent schedules of reinforcement. In both experiments, highly stereotyped response sequences developed. If these response sequences were treated as individual responses, the resulting data conformed to what is typically reported in studies of multiple and concurrent schedules involving individual responses. For example, behavioral contrast was observed with the multiple schedules, and matching was observed with the concurrent schedules. However, schedule manipulation had no effect on within-sequence characteristics of responses like accuracy, stereotypy, or rate. These data constitute further evidence that response sequences can become functional behavioral units.

Key words: multiple schedules, concurrent schedules, complex operants, stereotyped behavior, pigeons

Schwartz (1980, 1981a, 1981b, 1982a, 1982b; Schwartz & Reilly, 1983, 1985) has reported a series of experiments on the development and maintenance of a complex, sequential operant. These experiments have been based upon procedures adapted from Vogel and Annau (1973). Pigeons could produce food by pecking each of two response keys exactly four times, in any order. At the beginning of a trial, the top, left light in a 5 by 5 matrix of lights was illuminated. Each left-key peck moved the illuminated light across one position, and each right-key peck moved it down one position. When the bottom, right light was illuminated (four pecks on each key), reinforcement was delivered. A fifth peck on either key before a fourth on the other terminated the sequence without reinforcement. Schwartz found, as had Vogel and Annau, that although many different successful sequences were possible, for each pigeon one particular sequence became dominant, sometimes occurring on more than 90% of all trials.

Given that such stereotyped sequences develop, one might ask whether the sequences

become integrated behavioral units. For example, such units might be resistant to disruption by environmental challenges. Schwartz (1981b) explored this possibility by exposing the sequences to extinction. He found that in pigeons with extensive training on the sequence task, extinction had almost no effect on sequence stereotypy. Given that the animals responded at all in extinction, they produced the same dominant sequence as they had during reinforcement, with roughly the same relative frequencies across sequences. In addition, the temporal properties of response sequences were not disrupted by extinction. Extinction certainly resulted in fewer responses per minute. However, when the temporal pattern of responding was analyzed into two components—latency (the time to begin a sequence from trial onset) and response time (the time to complete a sequence once it was begun)—it turned out that although extinction produced marked increases in sequence latency, it had almost no effect on response time. Thus, in well trained animals an extinction procedure did not seem to disrupt stereotypy. If the pigeons responded at all, they produced the same sequences of responses, in the same temporal distribution, as they had produced during periods of reinforcement.

In a second experiment (Schwartz, 1982b), sequences were reinforced on fixed-interval and fixed-ratio reinforcement schedules,

This research was supported by NSF Grant BNS 82-06670, and by a Swarthmore College Faculty Research Grant. Reprint requests should be addressed to the author, Department of Psychology, Swarthmore College, Swarthmore, Pennsylvania 19081.

schedules whose effects on the temporal character of responding are well documented (Ferster & Skinner, 1957). Virtually all characteristics of sequence responding retained their integrity on these schedules; sequence accuracy, stereotypy, and response time were roughly uniform throughout the fixed interval or fixed ratio. The temporal response patterning that is typically observed on these schedules was restricted to the latency to initiate response sequences, a property of sequences that is analogous to interresponse time as a property of individual responses. Thus, as was the case with extinction, schedules of reinforcement affected mainly the probability that the sequence would be initiated at particular times rather than the integrity of the sequence itself. Assuming that schedules of reinforcement of an individual response, such as the key peck, affect the probability of the key peck occurring without affecting the form of the key peck, sequences appear to function equivalently to individual response units.

The present experiments extended the investigation of the functional integrity of response sequences to another well studied aspect of operant performance—the allocation of behavior on multiple and concurrent schedules of reinforcement. Multiple schedules are procedures in which two or more component schedules are operative successively and are accompanied by discriminable stimuli, whereas concurrent schedules are procedures in which two or more component schedules are operative simultaneously. In Experiment 1, pigeons were exposed to a series of multiple schedules in which food deliveries were contingent upon response sequences rather than upon individual responses. In Experiment 2, response sequences were treated as unitary operants in a series of concurrent schedules. In both experiments, the question was whether the schedules controlled response sequences, treated as unitary responses, in the same way that they are known to control individual responses.

EXPERIMENT 1

On multiple schedules of reinforcement, rate of responding maintained by a given component schedule is often affected both by the rate of reinforcement available during that component and by the rate of reinforcement available in the other component. Thus, for ex-

ample, if a multiple variable-interval 1-min variable-interval 1-min schedule (a multiple schedule containing two components, each of which provides reinforcement for responses on a variable-interval 1-min schedule; a multiple VI 1-min VI 1-min) is changed to a multiple VI 1-min VI 2-min schedule, while response rate during the VI 2-min component decreases, response rate during the unchanged, VI 1-min component typically will increase. This widely reported phenomenon, known as behavioral contrast (e.g., Reynolds, 1961; Schwartz & Gamzu, 1977), characterizes one way in which the components of multiple schedules interact in controlling behavior. In the present experiment, pigeons were exposed to a series of multiple schedules in which food deliveries were contingent upon particular response sequences, rather than on individual responses. The purpose was to assess whether the phenomena that typify multiple-schedule performance could be observed with extended response sequences as operants, and whether response sequences would preserve their integrity under multiple-schedule conditions.

METHOD

Subjects

Subjects were 4 White Carneaux pigeons that previously had served in a variety of experiments involving sequence performance; they were maintained at 80% of their free-feeding weights.

Apparatus

Each of four Gerbrands pigeon chambers (Model G7313) contained a three-key pigeon intelligence panel. The keys were Gerbrands normally closed keys, requiring a force of 0.1 N to operate. They were spaced 7.5 cm apart, center to center, and were located 21 cm above the grid floor. A grain hopper was located directly below the center key, 5.5 cm above the grid floor, and a pair of houselights was located in the ceiling of the chamber. The houselights were illuminated throughout experimental sessions, except during 4-s feeder operations, when a light in the feeder was illuminated.

On the left side wall of each of the chambers was mounted a 5 by 5 matrix of red lights. The lights were 0.84 cm in diameter, and 0.04 A (Dialco No. 507-3917-1471-60D). The

Fig. 1. Percentage of correct sequences in each multiple-schedule component over all multiple-schedule procedures. Data are averaged across pigeons and across blocks of three sessions. Multiple-schedule values are indicated in each panel, with S1 corresponding to the top schedule value.

lights in the matrix were spaced 2 cm apart. The top row of lights was 20 cm from the grid floor, and the right-most column (closest to the intelligence panel) was 4 cm from the panel.

Scheduling of experimental events, data collection, and data analysis were accomplished with a Digital Equipment Corporation PDP® 8/E digital computer using interfacing and software provided by State Systems, Inc., Kalamazoo, Michigan.

Procedure

As noted in the introduction, the pigeons could produce food only by emitting sequences of exactly four pecks on each key, in any order. Each sequence began with the top, left matrix light illuminated. Each left-key peck moved the illuminated light one position across, and each right-key peck moved it one position down. The pigeons had already had substantial experience with the sequence task in discrete-trial procedures, so no pretraining was required. They were initially exposed to a multiple VI 20-s VI 20-s procedure, in which the two components alternated regularly, and lasted for 30 s. During one of the components, both side keys were red; during the other com-

ponent, both side keys were green. Periods of 3 s during which the keys were dark separated the components. When reinforcement became available, it was delivered on completion of the next correct sequence. Thus, if a pigeon were in mid-sequence when reinforcement became available, completion of that sequence would produce the reinforcer. Correct but unreinforced sequences produced no feedback; the matrix light simply moved from bottom right to top left, indicating the beginning of a new sequence. Incorrect sequences (i.e., a fifth peck on one key before a fourth peck on the other) extinguished both keylights for 0.5 s, followed by reillumination of the keylights and of the top, left matrix light. If a component ended while the pigeon was in mid-sequence, that sequence was canceled and was not recorded. If a component ended with a reinforcement available but uncollected, the reinforcement was canceled.

Over a period of 2 weeks, the duration of multiple-schedule components was gradually lengthened to 2 min, and the value of the VI schedules was gradually increased to 1 min. From this point on, the pigeons were exposed to daily sessions consisting of 30 components. Over the course of the experiment, they were

Fig. 2. Percentage of all sequences that were the dominant sequence in each multiple-schedule component over all multiple-schedule procedures. Data are averaged across pigeons and across blocks of three sessions.

exposed to a series of six multiple-schedule procedures, with each set of schedule values in effect for 21 sessions. The particular schedule values used are indicated in the figures presented in the next section.

RESULTS AND DISCUSSION

These procedures produced very little intersubject variability, so all graphic results will be presented as means across the 4 subjects. Data for individual subjects are presented in Table 1. Figure 1 presents the percentage of sequences that were correct, averaged across blocks of three sessions, over all six multiple-schedule procedures. Each panel is labeled with the value of the reinforcement schedules that were operative in the two components. In each case, the top value is the one that was in effect during what is designated Schedule 1 (S1). What is apparent from Figure 1 is that sequence accuracy was unaffected by variations in the reinforcement schedule. With the exception of the first exposure to extinction (second panel), in which sequence accuracy dropped about 2%, about 85% of the sequences produced were correct. There was no difference in accuracy between components, nor was there a difference across procedures.

The degree of sequence stereotypy was sim-

ilarly unaffected by manipulations of multiple-schedule value, as is clear from Figure 2, which presents the percentage of all sequences that were each pigeon's dominant sequence. Stereotypy was substantial; dominant sequences accounted for about 75% of all sequences. But there were no differences in sequence stereotypy either between components or across procedures. The dominant sequence for two of the pigeons was four left pecks followed by four right pecks (LLLLRRRR); for a third, it was RRRRLLLL; and for the fourth, it was LLRRRRLL.

Figure 3 presents data on response time, the time between the first and last response in each sequence. With the exception of the first exposure to extinction (second panel), the picture is the same as in the first two figures. Variation in reinforcement schedule had no effect on response rate once a sequence had begun. The increase in response time during S2 in the second panel of Figure 3 is principally the result of large changes in one pigeon's behavior, with only negligible changes in the behavior of the other three. The mean response time of the one discrepant pigeon increased from about 5.0 to about 6.5 s over the course of the procedure depicted in the second panel. Response times for the other pigeons

Fig. 3. Mean sequence response time (time between the first and last response of each sequence) in each multiple-schedule component over all multiple-schedule procedures. Data are averaged across pigeons and across blocks of three sessions.

increased from 4.2 to 4.4 s, from 4.7 to 4.8 s, and from 3.4 to 3.6 s. Note that in the second exposure to an extinction procedure (fourth panel), there was virtually no effect on response time.

Manipulation of component reinforcement schedules did have one pronounced effect on sequence performance. Latencies to initiate sequences, or what might be called "inter-sequence times," were influenced by the operative reinforcement schedules, as is shown in Figure 4. The data are presented on semilogarithmic (base 10) coordinates. When a component schedule was changed from VI 1-min to extinction (second and fourth panels), sequence latencies during extinction increased from about 1.8 s to about 47 s (second panel) and from about 2 s to about 48 s (fourth panel). When a component schedule was changed from VI 1-min to VI 2-min (sixth panel), latencies increased from 2.4 to 3 s. Concurrent with these increases in latency in components in which reinforcement rate was decreased, there were decreases in latency in the unchanged components. In Panel 2 the decrease was from 1.9 to 1.3 s, in Panel 4 the decrease was from 2 to 1.4 s, and in Panel 6 the decrease was from 2.1 to 1.6 s. These changes in latency were shifts in the entire distribu-

tion, and not just changes in occasional extreme values. Thus, for example, in the change from VI 1-min to extinction (second and fourth panels), modal latency increased from 1.5 to 19.5 s (second panel) and 22.0 s (fourth panel) in extinction, and from 1.5 s to 1.0 s (both panels) in VI. The increases in latency correspond, of course, to the decreases in response rate one expects to observe when reinforcement rate decreases. The decreases in latency correspond to behavioral contrast.

To clarify the relation between the temporal pattern of sequence responding shown in Figures 3 and 4 and the effects of multiple schedules like these on standard, single-response operants, sequence response times and latencies were converted into response rates, with each peck counted as a response. Pecks from incorrect sequences were excluded from the analysis. However, because sequence accuracy was uniform throughout the experiment (Figure 1), including them would have changed absolute response rates, but not relative rates. The data are presented in Figure 5. The second and fourth panels reveal both the decreases in response rate one expects from extinction procedures, and the elevation in response rate that constitutes positive behavioral contrast. The sixth panel shows a smaller rate

Fig. 4. Mean latency (log scale, base 10) to initiate sequences (time between the end of one sequence and the beginning of the next) in each multiple-schedule component over all multiple-schedule procedures. Data are averaged across pigeons and across blocks of three sessions.

decrease with a shift from VI 1-min to VI 2-min reinforcement, and a smaller positive contrast effect. So these procedures had precisely the effects on response rate that one

would expect multiple-schedule manipulations to produce. However, as Figures 3 and 4 make clear, the rate effects were almost entirely confined to changes in sequence latency.

Fig. 5. Mean response rate, with each peck counted as a response, in each multiple-schedule component over all multiple-schedule procedures. The data include only correct response sequences and are averaged across pigeons and across blocks of three sessions.

Table 1

Individual subject data from the multiple-schedule procedures. Data are averaged across the last three sessions of exposure to each set of multiple-schedule values. Procedures 1-6 correspond to VI 1-VI 1, VI 1-Ext, VI 1-VI 1, Ext-VI 1, VI 1-VI 1, and VI 1-VI 2, with the first schedule in each pair designated S1.

Sub- ject	Proce- dure	Correct seq (%)		Dominant seq (%)		Response time (s)		Latency (s)		Resp/s	
		S1	S2	S1	S2	S1	S2	S1	S2	S1	S2
Bird 1	1	92.4	92.4	86.2	87.3	4.3	4.2	1.9	1.9	1.3	1.4
	2	90.7	88.4	85.8	82.2	4.2	4.4	1.4	44.5	1.5	0.1
	3	90.4	91.2	87.0	84.7	4.2	4.2	1.8	1.9	1.3	1.2
	4	89.6	91.2	83.9	86.9	4.7	4.2	47.6	1.5	0.1	1.3
	5	91.3	90.3	86.2	85.2	4.3	4.4	1.9	1.9	1.3	1.1
	6	91.7	91.1	85.6	88.7	4.5	4.5	1.5	2.1	1.3	1.2
Bird 2	1	87.8	90.2	74.5	76.0	4.6	4.7	2.3	2.4	1.1	1.1
	2	84.4	83.8	71.4	71.8	4.5	4.8	1.7	45.9	1.3	0.1
	3	85.0	83.9	74.6	72.1	4.9	4.8	2.7	2.7	1.0	1.0
	4	81.2	81.9	71.3	72.3	5.0	4.7	50.4	1.7	0.1	1.4
	5	84.6	82.9	72.6	71.9	5.1	5.0	2.7	2.8	1.2	1.0
	6	85.2	84.1	71.6	71.0	5.1	5.2	1.9	2.9	1.4	1.0
Bird 3	1	90.0	87.4	84.0	82.6	5.2	5.0	2.1	2.0	1.1	1.0
	2	91.4	88.7	83.7	80.6	4.8	6.5	1.2	53.4	1.4	0.1
	3	90.7	91.3	82.4	81.4	5.1	5.2	2.5	2.5	1.1	1.1
	4	90.2	91.0	80.7	81.3	5.3	5.0	41.9	1.8	0.1	1.2
	5	90.7	90.2	84.6	83.1	5.1	5.1	2.4	2.5	1.0	1.2
	6	89.7	91.3	82.2	81.4	5.2	5.1	2.0	3.0	1.3	1.0
Bird 4	1	83.2	81.6	74.7	75.1	3.3	3.4	1.3	1.4	1.7	1.7
	2	78.9	76.0	72.6	70.9	3.2	3.6	0.8	44.3	2.0	0.2
	3	81.8	81.0	71.9	71.4	3.4	3.5	1.5	1.4	1.5	1.5
	4	80.5	81.2	68.9	71.0	3.4	3.4	43.2	1.0	0.2	2.0
	5	83.2	82.3	71.7	72.6	3.5	3.2	1.7	1.7	1.3	1.4
	6	83.3	82.7	72.9	70.5	3.3	3.2	1.0	4.0	1.6	0.9

Schwartz (1981b, 1982b) found that stereotyped response sequences remain intact when subjected to manipulation by extinction or by schedules of reinforcement. The present experiment confirms those previous findings by extending them to a situation involving multiple schedules of reinforcement. It does appear that complex, sequential operants can become integrated behavioral units that are functionally indistinguishable from simple, single-response operants.

EXPERIMENT 2

Another well studied type of operant procedure is a choice procedure involving concurrent schedules of reinforcement—two or more schedules that are simultaneously operative and available. In most procedures of this type, the resulting choices between schedules can be well described by the matching law (Herrnstein, 1970). The matching law

states that an animal's allocation of responses among alternatives will match the relative frequency of reinforcement provided by those alternatives. In the present experiment, pigeons were exposed to concurrent schedules of reinforcement contingent upon response sequences, to determine whether the matching law describes the allocation of a complex operant as well as it does a simple one.

METHOD

Subjects

Subjects were 4 White Carneaux pigeons with extensive experience in other sequence procedures; they were maintained at 80% of their free-feeding weights.

Apparatus

The apparatus was the same as that described in Experiment 1.

Fig. 6. Percentage of correct sequences in each concurrent-schedule component over all concurrent-schedule procedures. Data are averaged across pigeons for the last five sessions of each procedure. Concurrent-schedule components are identified on the x axis.

Procedure

The concurrent schedules were arranged using a changeover-key procedure (Findley, 1958). Pecks on the two side keys were required to complete sequences, as in Experiment 1. The keys were illuminated with either red or green light, depending on which of the component schedules was operative. In addition, the center key was always illuminated with white light. Pecks on this key, the changeover key, never produced food; they functioned to change the color of the side keys, as well as the operative reinforcement schedule. Thus, a session might begin with the two side keys red, the center key white, and a VI 1-min schedule contingent upon correct sequences on the side keys. This schedule would stay in force until the pigeon pecked once at the center key. Then the side keys would turn green, and (for example) a VI 2-min schedule contingent upon green-key sequence responses would replace the VI 1-min schedule. The timers controlling the two component schedules were both operative at all times, irrespective of which schedule was in force at a given moment. It is well known that proce-

dures of this type produce a great deal of switching between components, perhaps because while time is spent responding on one component schedule, the likelihood increases that reinforcement has become available on the other component schedule. To reduce somewhat the amount of switching, the procedure was arranged so that the first correct sequence after entering a component was never reinforced. This is analogous to the changeover delay constraint that is frequently employed in standard concurrent schedules.

With regard to sequences themselves, the procedure was the same as in Experiment 1. The light matrix functioned as it did in that experiment: Correct sequences (exactly four pecks on each key) were followed by no distinctive feedback, and incorrect sequences (terminated by a fifth peck on one key before a fourth on the other) were followed by a 0.5-s period in which all keylights were extinguished. If a changeover occurred in mid-sequence, the sequence was canceled, and the matrix light returned to the top left corner as the key colors changed. Responses in interrupted sequences like these were not counted;

Table 2

Individual subject data from the concurrent-schedule procedures. Data are averaged across the last five sessions of exposure to each set of concurrent-schedule values. Procedures 1-6 correspond to VI 1-VI 1, VI 1-Ext, VI 1-VI 1, VI 2-VI 1, VI 4-VI 1, and VI 1-VI 3, with the first schedule in each pair designated C1. Responses per second are local response rates (i.e., total pecks in correct sequences divided by seconds of time in a particular schedule component [color] less reinforcement time).

Sub- ject	Proce- dure	Correct seq (%)		Dominant seq (%)		Response time (s)		Latency (s)		Resp/s		Time in C1 (%)
		C1	C2	C1	C2	C1	C2	C1	C2	C1	C2	
Bird 5	1	92.4	92.8	86.3	81.7	3.7	3.7	1.4	1.6	1.6	1.5	52
	2	91.8	89.7	86.9	79.3	3.6	3.7	1.5	17.6	1.6	0.4	96
	3	92.3	91.8	86.7	83.6	3.6	3.6	1.4	1.5	1.6	1.6	54
	4	91.7	91.8	87.0	85.2	3.7	3.5	1.9	1.4	1.4	1.6	38
	5	90.4	92.0	85.5	85.2	3.9	3.5	2.5	1.5	1.3	1.6	14
	6	91.8	90.7	86.2	85.0	3.6	3.6	1.5	2.1	1.6	1.4	70
Bird 6	1	85.7	87.2	68.4	70.2	4.6	4.9	2.3	2.1	1.2	1.1	51
	2	86.4	85.2	67.2	63.4	4.6	5.3	2.2	9.7	1.2	0.5	98
	3	87.2	86.9	65.8	67.3	4.8	4.5	2.4	2.3	1.1	1.2	52
	4	85.8	86.2	66.4	67.1	4.6	4.6	2.6	2.2	1.3	1.2	36
	5	83.6	86.1	65.0	66.8	4.8	4.4	3.1	2.4	1.0	1.2	11
	6	86.3	85.8	67.1	67.1	4.6	4.7	2.3	2.9	1.2	1.0	67
Bird 7	1	96.4	95.0	91.4	91.5	3.3	3.5	1.0	1.1	1.8	1.7	53
	2	97.2	93.4	92.6	90.8	3.5	3.5	1.2	4.5	1.9	1.0	97
	3	98.6	98.0	93.0	93.4	3.3	3.6	1.3	1.3	1.7	1.6	52
	4	97.6	97.0	92.2	92.8	3.2	3.3	1.1	1.2	1.9	1.8	41
	5	95.4	96.6	90.9	92.3	3.2	3.3	1.8	1.2	1.6	1.8	32
	6	97.8	97.2	92.3	91.8	3.2	3.4	1.2	1.7	1.8	1.6	81
Bird 8	1	90.1	89.7	83.2	84.6	4.2	4.4	1.7	1.8	1.4	1.3	48
	2	92.1	86.3	84.3	81.0	4.4	4.5	1.9	9.7	1.3	0.6	93
	3	91.8	92.0	83.7	82.4	4.1	4.3	1.8	2.0	1.4	1.3	49
	4	90.9	91.2	83.0	83.4	4.3	4.1	2.4	1.9	1.2	1.3	29
	5	89.8	90.0	84.1	81.7	4.6	4.1	2.9	2.0	1.1	1.3	09
	6	90.7	90.2	83.8	81.9	4.1	4.3	1.9	2.5	1.3	1.1	64

changeovers that occurred between sequences and changeovers that occurred within sequences were recorded separately.

Because the pigeons had had extensive training on sequence tasks, they were exposed immediately to the concurrent-schedule procedure. Initially, the component schedules were both VI 30-s, and sessions lasted for 30 min. The pigeons were slow to begin pecking the changeover key, but all did so within the first two sessions without special training. Over a period of 2 weeks, the component schedules were gradually lengthened to VI 1-min, and the session duration was gradually lengthened to 60 min. Thereafter, the pigeons were exposed to six pairs of concurrent schedules. Each pair was in force for 30, daily, 60-min sessions.

RESULTS AND DISCUSSION

Sequence accuracy, sequence stereotypy, and sequence response time were quite stable across all concurrent-schedule procedures and were quite similar to the values obtained in Experiment 1. As an example, group data on the accuracy of sequence performance are presented in Figure 6. The concurrent schedules designated as Components 1 and 2 are identified on the *x* axis, and each pair of bars represents group performance in each component averaged across the last five sessions of exposure to the particular pair of concurrent schedules identified on the *x* axis. It is evident from Figure 6 that sequence accuracy was extremely high throughout the experiment and was uniform both between components and

Fig. 7. Mean latency to initiate sequences in each concurrent-schedule component over all concurrent-schedule procedures. Data are averaged across pigeons for the last five sessions of each procedure.

across procedures. Thus, variation in the values of the concurrent schedules had no effect on sequence accuracy.

The same was true of sequence stereotypy, as can be seen in the data from individual subjects in Table 2. For 3 of the 4 birds, more than 80% of all sequences produced consisted of the dominant sequence of the individual pigeon. For the remaining bird, the dominant sequence consistently occurred more than 65% of the time. For 2 pigeons, the dominant sequence was RRRRLLLL; for 1 it was LRRRLLL; and for 1 it was LLLRRRL. Furthermore, also clear from Table 2, sequence response time was quite stable between components and across procedures. Only for Pigeon 6 did response time in extinction increase by more than 0.1 s.

Figure 7 presents latencies to initiate sequences, or intersequence times. As in Experiment 1, it was on this variable that schedule manipulation had its effects. Latencies were quite stable across all VI 1-min procedures, with means ranging between 1.6 and 1.8 s. Latency on VI 2-min was about 2.0 s; on VI 3-min, it was 2.3 s; and on VI 4-min, it was 2.6 s. As in Experiment 1, changes in latency

were changes in the entire distribution, and not just increases in the number of extreme values.

On concurrent procedures of this type, one would expect the matching relation to be reflected in the way time was allocated between components. Figure 8 presents the relevant data, the percentage of total session time spent in Component 1 of each pair of concurrent schedules. The matching law would predict percentages of 50, 100, 50, 33, 25, and 67 across the six procedures. The obtained percentages were 52, 96, 53, 36, 16, and 71. The fit is rather close.

There is one last result that should be mentioned, concerning changeovers between components. If response sequences become integrated behavioral units, one would expect changeover responses in mid-sequence to be very rare. This is true despite the fact that pigeons must move past the changeover key at least once in the course of completing a sequence. Across all procedures, the pigeons made an average of 145 changeover responses per session. Of these, only 3.1% occurred in mid-sequence. Furthermore, for 3 of the 4 pigeons, fewer than 2% of all changeovers oc-

curred in mid-sequence. Thus, in a typical session, about 3 of 600 sequences were interrupted by changeover responses.

GENERAL DISCUSSION

These experiments confirm and extend the suggestion made in earlier papers (Schwartz, 1981b, 1982b) that a sequence of responses may become a functional behavioral unit, essentially indistinguishable from individual responses in the way it is controlled by reinforcement. Analogs to these phenomena from the more traditional operant literature can be found in studies of second-order reinforcement schedules, in which the component "responses" under schedule control are themselves schedule-controlled response sequences. Indeed, it has been suggested in discussions of second-order schedules that responses controlled by the component schedules become functional behavioral units (e.g., Findley, 1962; Marr, 1979). Also consistent with this general line of work are studies suggesting that stereotyped, functional "units" of behavior can emerge from the relation between responses and the discriminative stimuli that control them (Zeiler, 1968, 1970, 1972).

As discussed in an earlier paper (Schwartz, 1982b), a central theoretical issue on which these results bear is that of determining what the appropriate level of analysis of free-operant behavior should be. There is much dispute about whether analysis is most profitably carried out at the molecular level (the determination of individual responses and inter-response times) or at the molar level (the determination of overall response patterns, choices, and rates). With respect to the present data, a molecular analysis, at the level of individual responses, might miss regularities that are apparent at the more molar level of response sequences. However, this does not argue for the appropriateness of molar analysis in general. The point of these experiments with regard to levels of analysis in general is that the appropriate level of analysis in any particular experiment is likely to be the level at which differential reinforcement contingencies can be shown to operate. In these experiments, they operated at the level of response sequences. Different procedures that imposed contingencies on within-sequence temporal patterns

Fig. 8. Percentage of total session time that was allocated to Component 1 of each concurrent-schedule procedure. Data are averaged across pigeons for the last five sessions of each procedure. Component 1 is identified on the x axis.

might well yield most impressive regularities at the molecular level. The level at which behavior may be partitioned into functional units may vary from experiment to experiment, in general being precisely that level at which such a partitioning actually has a function. This general flexibility of the operant class is something of which Skinner was well aware in his earliest writings in the analysis of behavior (Skinner, 1935, 1938). One of the virtues of the operant framework, often missed by critics who confuse it with stimulus-response connectionism, has been that within a rather wide range, it allows the animal to tell the experimenter how behavior is to be partitioned, rather than the reverse (see Catania, 1984, for a recent discussion of these issues).

However, if it is true that the appropriate level of analysis of operant behavior will be procedure dependent, a problem emerges for experiments that attempt to determine the appropriate level, in general, for analysis of operant behavior. Frequently, the way in which a case is made for analysis based on a particular molecular characteristic of behavior is by demonstrating that when a contingency that depends upon that characteristic is introduced, it controls the behavior. Once it is shown that this molecular characteristic can be relevant in a particular situation, the argument follows that it is relevant in general.

Thus, in Anger's classic paper (1956) on the reinforcement on interresponse times, the argument that, in general, reinforcement schedules controlled interresponse times was based on the demonstration that they *could* control interresponse times—that is, on the demonstration that interresponse times were reinforceable. Zeiler (1977) has elevated Anger's demonstration to the level of general methodological principle. He suggests that the validation of theoretical units of behavior begins by showing that they are conditionable units of behavior. The present suggestion, however, is that almost any scale of activity may be a conditionable unit of behavior (but see Buchman & Zeiler, 1975, for an exception), and the fact that it is actually conditioned in a situation containing contingencies that are specifically directed at it has no implications for its causal or analytic efficacy in general. Shimp (1975) and Fetterman and Stubbs (1982) have reached similar conclusions. The point here is that there may be sufficient plasticity to potential behavioral organization to undermine the analytic experiment as a tool for determining what that organization is.

The present results have another implication for operant research in general. Despite evidence like that provided by Anger (1956) that response rates are conditionable, rate of responding has remained the principal dependent variable in operant experiments. The present experiments suggest that response rate may be a good measure of behavior only after the functional behavioral units have been identified. In these experiments, rate of individual key pecks conformed to previous results in the literature only because of the effects of schedule parameters on latencies for initiations of sequences. It was latencies, and not response rates, that the independent variables were affecting. An undifferentiated measure of response rate would have provided a misleading assessment of response strength. More dramatic evidence of the problems with response rate as a dependent measure have been reported by Fetterman and Stubbs (1982) and by Zeiler and Blakely (1983). In those experiments, whether or not results conformed to those obtained in previous research depended critically on specifying the behavioral units of which response rates were a measure. This led Zeiler and Blakely to conclude that time

allocation, not response rate, should perhaps be the dependent variable of choice.

But there are problems also with time allocation as a dependent variable, many of them identified by Zeiler and Blakely (1983). One they did not identify is that time allocation may be as conditionable as response rate. Another, perhaps more promising candidate is what Nevin has termed "behavioral momentum," or resistance to change (Nevin, Mandell, & Atak, 1983). According to this view, assessment of the strength of behavior is made by determining how resistant its various properties are to change when the controlling variables are changed. Some properties of behavior may be more resistant to change than others, and resistance to change may be imperfectly correlated or even uncorrelated with response rate. Resistance to change may even be a useful tool for determining what the functional behavioral unit is in any given circumstance. The logic of analysis would be that those properties of behavior that are most resistant to change are the central, or defining, properties of the functional unit. The series of experiments on stereotyped response sequences that preceded the present one has adopted this logic implicitly, by looking at the resistance to change of various characteristics of response sequences when subjected to environmental challenges like extinction. Resistance to change may be a unit-free measure of response strength, and, at least at present, it is difficult to imagine it as a conditionable property of behavior.

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Received May 1, 1985

Final acceptance January 8, 1986