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RESISTANCE TO CHANGE OF OPERANT VARIATION AND REPETITION

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A multiple chained schedule was used to compare the relative resistance to change of variable and fixed four-peck response sequences in pigeons. In one terminal link, a response sequence produced food only if it occurred infrequently relative to 15 other response sequences (vary). In the other terminal link, a single response sequence produced food (repeat). Identical variable-interval schedules operated in the initial links. During baseline, lower response rates generally occurred in the vary initial link, and similar response and reinforcement rates occurred in each terminal link. Resistance of responding to prefeeding and three rates of response-independent food delivered during the intercomponent intervals then was compared between components. During each disruption condition, initial- and terminal-link response rates generally were more resistant in the vary component than in the repeat component. During the response-independent food conditions, terminal-link response rates were more resistant than initial-link response rates in each component, but this did not occur during prefeeding. Variation (in vary) and repetition (in repeat) both decreased during the response-independent food conditions in the respective components, but with relatively greater disruption in repeat. These results extend earlier findings demonstrating that operant variation is more resistant to disruption than is operant repetition and suggest that theories of response strength, such as behavioral momentum theory, must consider factors other than reinforcement rate. The implications of the results for understanding operant response classes are discussed.

Key words: resistance to change, behavioral variability, behavioral repetition, response strength, operant response class, key peck, pigeons

Reinforcement typically decreases response variation, including such dimensions of responding as location, duration, force, and topography (e.g., Antonitis, 1951; Margulies, 1961; Notterman & Mintz, 1965; Vogel & Annau, 1973). Vogel and Annau established repetitive response topographies consisting of combinations of left- and right-key pecks in pigeons under a discrete-trials procedure. At the start of each trial, only the upper left stimulus light of a 4 × 4 matrix of stimulus lights was on. A peck to a left response key moved the stimulus light down (the matrix) and a peck to a right response key moved the stimulus light to the right. Food was delivered following a six-peck response sequence if the six pecks resulted in the stimulus light moving to the lower right position of the matrix. Each pigeon initially emitted a variety of response sequences but with continued reinforcement a single, repetitive response sequence occurred (see also Schwartz, 1980, 1982, 1983).

Page and Neuringer (1985) suggested that decreased response variation of the sort described by Vogel and Annau (1973) occurs only under conditions in which such variation is not specified as a condition for reinforcement. When Page and Neuringer (Experiment 3) reinforced eight-peck response sequences in pigeons only if they differed from the previous 50 response sequences, an average of 67% of the trials ended in reinforcement. This finding of reinforced behavioral variation is consistent with other experiments (e.g., Holman, Goetz, & Baer, 1977; Machado, 1997; Morris, 1987; Neuringer, 1991; Newman, Reinecke, & Meinberg, 2000). In keeping with Page and Neuringer's terminology, the term *operant variation* will be used here to describe such a response class, although it is noted that whether variation itself is the fundamental unit of behavior has been questioned (e.g., Machado, 1997).

Even though reinforcement can engender both of these opposing operant response classes (i.e., variation and repetition), relatively

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little research has directly compared them. For example, because variation reliably occurs only when reinforcement is dependent upon it such that repetition is the *default* response, it has been argued that operant variation is less natural (Schwartz, 1983), or, from a more behavior-analytic viewpoint, weaker than operant repetition. The concept of response strength has received considerable attention in the history of learning (e.g., Skinner, 1938), and a variety of procedures have been employed to investigate this notion (e.g., Nevin, 1979; Nevin & Grace, 2000). Neuringer and his colleagues (L. Cohen, Neuringer, & Rhodes, 1990; Neuringer, 1991) suggested that repetitive response sequences are more susceptible to disruption than variable response sequences, at least under two conditions. Following alcohol administration, response variation in rats increased in each component of a multiple schedule in which variable response sequences were reinforced in one component (vary) and a single, fixed response sequence was reinforced in the other (repeat) (L. Cohen et al., 1990; see also McElroy & Neuringer, 1990). In the repeat component, this increased variation occurred even though it reduced reinforcement rate, whereas reinforcement rate remained approximately the same in the vary component. Neuringer (1991, Experiment 2) systematically varied the time between individual responses (interresponse times or IRTs) within four-response sequences. For rats in one group, variable response sequences were reinforced, and for those in another group, only a single response sequence was reinforced. As the IRT increased from 0.5 to 20 s, response variation increased for each group, and this in turn differentially affected reinforcement probability across the two groups (see also L. Cohen et al., 1990). Neuringer concluded in both instances that variable response sequences are more resistant to disruption than are repetitive ones. Because resistance to disruption was measured primarily by changes in the percentage of reinforced response sequences in each component, the relation of Neuringer's resistance-to-change measures to other response-strength manipulations (e.g., Nevin, 1974) is unknown. A more conventional resistance-to-change analysis applied to varied and repeated response sequences would clarify Neuringer's initial observations about the relative strength of variable and repetitive responding.

Nevin (1992; see also Nevin, Mandell, & Atak, 1983) asserted that reinforcement rate solely determines the resistance of responding to change. His assertion implies that as long as that rate is constant, other factors (i.e., a varied vs. repetitive operant response class) should not affect response strength (see also Nevin, Tota, Torquato, & Shull, 1990). This assertion is at odds with Neuringer's (1991; see also L. Cohen et al., 1990) findings about variable versus repetitive responding, results that also have found some support in the work of Grace, Schwendiman, and Nevin (1998). Grace et al. demonstrated relatively greater resistance of responding maintained by immediate reinforcement than responding maintained by unsignaled delayed reinforcement despite similar reinforcement rates for each (see also Bell, 1999). These authors proposed, among other things, that different response topographies may be differentially susceptible to change, and operant response classes differing along the dimension of variation may be labeled topographically distinct.

The present experiment was conducted to determine the generality of the differential persistence of operant variation and repetition reported by Neuringer (1991) and L. Cohen et al. (1990) by extending its study to the resistance-to-change procedures more commonly used to investigate response strength (e.g., Nevin, 1974). If variation within an operant response class influences resistance to change independently of other factors (e.g., reinforcement rate), then any theory of response strength must take this factor into account. In the present experiment, therefore, operant variation and repetition were maintained at equivalent reinforcement rates in separate components of a multiple schedule before resistance to prefeeding and alternative reinforcement was assessed.

METHOD

Subjects

Three experimentally naive male White Carneau pigeons, 11, 12, and 14, were used. Pigeon 11 was maintained at 80% of its free-feeding weight, Pigeon 12 was maintained at 75% of its free-feeding weight, and Pigeon 14 was maintained at 72% of its free-feeding weight. Pigeons 12 and 14 were maintained at these lower percentages because early in training responding was not maintained throughout the session at their 80% weights. Each pigeon was housed individually, and water and health grit were available continuously in each home cage. Each was fed sufficient mixed grain following its session to maintain its target weight.

Apparatus

A three-key operant conditioning chamber, with a work area 35 cm high by 30 cm wide by 30 cm long, was enclosed in a sound-attenuating box. White noise was presented through a speaker located 4 cm below the right response key. Each response key (2 cm diameter) was located on the front wall and could be transilluminated red or white by 28-VDC bulbs. Each of the two side keys was 6 cm from the side wall and 6 cm from the middle key. A 28-VDC white houselight located in the lower right corner of the front wall, with its lower edge along the chamber floor, provided general illumination. The keylights and houselight were darkened during reinforcement. Reinforcement was access to mixed grain delivered in a food hopper located behind a feeder aperture, 5 cm square, centered on the front wall with its lower edge 5 cm above the floor. The aperture was illuminated white by a 28-VDC bulb during food availability. Programming and data recording were controlled by a computer in an adjacent room using MED-PC® software (MED Associates, Inc. & Tatham, 1991).

Procedure

Following one session of magazine training for each pigeon, key pecking was autoshaped to each of the three keys (red and white) by transilluminating one of the keys red or white following an intertrial interval averaging 120 s. During the intertrial interval, all the keylights were darkened and the houselight was on. If a peck did not occur to the transilluminated key within 6 s, then it and the houselight were darkened and the hopper was raised for 4 s. If a peck occurred to the key within 6 s, then it and the houselight were darkened and the hopper was raised immediately. Each autoshaping session consisted of 60 trials, 10 trials with each key red and 10 trials with each key white. After reliable pecking to each key color was established, two additional autoshaping sessions occurred.

Three other training conditions then occurred for each pigeon in which a single four-peck response sequence (LRLR, where L = left and R = right) was reinforced to red keylights. This training occurred because it had been noted that the training of a single four-peck response sequence often took longer than the training of variable response sequences (L. Cohen et al., 1990; see also Page & Neuringer, 1985). In each of these training conditions, the houselight remained on at all times, except during blackouts (see below) and reinforcement. Each session began with the transillumination of the middle key red. A variable-interval (VI) 20-s schedule operated on the middle key (with the two side keys darkened) such that following an average of 20 s, a single peck to the middle key darkened it and immediately turned on the left keylight. In these training conditions and during the experiment proper, the following intervals comprised each (see below) VI 20-s schedule: 1, 3, 5, 10, 18, 23, 28, 34, 38, and 40 s.

In the first training condition, a peck to the left key darkened it for 0.5 s. Following a 0.5-s interpeck interval (IPI; a key peck during this 0.5-s interval reset it), the right key was turned on and a peck to it darkened it for 0.5 s. The left key then was turned on and a peck to it darkened it for 0.5 s, after which the right key again was turned on. A right key peck then darkened it and was followed by immediate food delivery. Following food delivery, the left key was turned on and the same procedure operated. After five food deliveries, the middle key again was transilluminated and the same procedure as above operated. Each session ended after 60 food deliveries. This condition continued until each pigeon reliably pecked each key within 1 s of its transillumination (two sessions for each pigeon).

In the second training condition, which lasted four (Pigeons 12 and 14) or five (Pigeon 11) sessions, the same procedure as described above operated except that both the left and right keylights were turned on following the offset of the middle key and each of the first three left or right key pecks. Each ''incorrect'' key peck (i.e., a right key peck in the first or third position of the sequence or a left key peck in the second or fourth position of the sequence) darkened both keys for 3 s and reset the trial.

In the third and final training condition, an incorrect key peck did not reset the trial so that response sequences other than LRLR could occur. The only response sequence that resulted in food delivery was LRLR. This condition remained in effect until each pigeon completed the LRLR response sequence on at least 80% of the trials in three consecutive sessions. This third training condition lasted six sessions for Pigeons 12 and 14, but 31 sessions for Pigeon 11 because this pigeon continued to emit an LLRL response sequence relatively frequently.

Following the LRLR training described above, a three-component multiple schedule was effected in which independent two-link chained schedules operated in two of the components and a 30-s intercomponent interval (ICI; the third component) preceded each of these two components. During an ICI, the keylights were darkened and the houselight was on. In each session, the two chain-schedule components each lasted approximately 60 s (see below) and strictly alternated until each occurred 20 times (the first component in each session was chosen randomly). There was a 10-min timeout for Pigeon 14 prior to each session, in which all the lights were darkened, because early in training this pigeon often did not respond early in the session.

In the initial links of either chained schedule, the middle key was either white (hereafter referred to as the vary component) or red (hereafter referred to as the repeat component), and the two side keys were darkened. Following completion of the VI 20-s schedule, the middle keylight was darkened immediately and the two side keylights were turned on. In each component, the terminal link ended after two criteria were met: A four-peck response sequence and its programmed consequence (blackout or reinforcer delivery) occurred and 60 s had elapsed since the onset of the initial link. Thus, each component was 60 s in duration plus the time taken to complete the current response sequence. Each four-peck response sequence that occurred prior to the end of the terminal link resulted in either a blackout or reinforcer delivery.

In the vary terminal link the two side keys were white, and in the repeat terminal link they were red. In each of these terminal links, a discrete-response procedure (Morris, 1987; Page & Neuringer, 1985) operated such that four pecks constituted a response sequence. Because there were two keys available to peck and a sequence consisted of four pecks, there were 16 possible response sequences (e.g., LLLL, RRRR). Following each of the first three pecks, an 0.5-s IPI operated; immediately following the fourth peck, either a 2- or 3-s reinforcer delivery or a 2- or 3-s blackout, in which all the lights were darkened, occurred. For Pigeon 11, the reinforcer deliveries and blackouts were 3 s and for Pigeons 12 and 14 they were 2 s.

In the vary terminal link, a four-peck response sequence was reinforced only if its weighted relative frequency was less than some threshold value (cf. Denney & Neuringer, 1998). That is, a relative frequency following each response sequence was calculated by dividing the number of times that response sequence had occurred by the total number of response sequences emitted. The relative frequencies at the start of each session were taken from the end of the preceding session. If the relative frequency of the response sequence was less than or equal to .05, then it was reinforced, and if that relative frequency was greater than .05, then a blackout occurred. Following a reinforcer delivery, each of the 16 relative frequencies was multiplied by a weighting coefficient (.95) such that recent response sequences were weighted more heavily (Denney & Neuringer, 1998).

In the repeat terminal link, the only reinforced response sequence was LRLR. In addition, this response sequence was reinforced probabilistically. Response sequences that were not reinforced were followed by blackouts. The reinforcement probability for LRLR was calculated separately for each pigeon to maintain similar reinforcement rates across the two components and was changed, if necessary, at the beginning of each session (see the Results for obtained probabilities).

The effects of two disrupters were studied after responding stabilized in the initial and

Table 1

Number of sessions (S) and mean (*M*) and standard deviation (*SD*) of reinforcement rate (reinforcers per minute) in each condition, in order of occurrence, for each pigeon. V and R refer to the vary and repeat components, respectively. Means and standard deviations are for the last six sessions of each baseline condition and all sessions of the four disruption conditions. The baseline condition is a multiple chained schedule (as described in the text).

Condition	Pigeon 11			Pigeon 12			Pigeon 14		
	S	V *M* (*SD*)	R *M* (*SD*)	S	V *M* (*SD*)	R *M* (*SD*)	S	V *M* (*SD*)	R *M* (*SD*)
Baseline	73	3.52 (0.44)	3.92 (0.59)	88	3.06 (0.46)	3.44 (0.40)	86	3.26 (0.55)	2.90 (0.27)
Prefeeding	9	3.15 (1.08)	2.12 (1.22)	10	2.34 (0.54)	2.67 (0.73)	7	2.11 (0.42)	2.62 (0.37)
Baseline	30	3.58 (0.93)	3.50 (0.90)	38	2.16 (0.15)	2.23 (0.25)	39	2.65 (0.31)	2.82 (0.87)
VT 15 s	5	2.29 (1.07)	3.18 (0.57)	5	2.52 (0.23)	1.86 (0.79)	5	1.88 (0.53)	2.13 (1.05)
Baseline	15	3.70 (0.77)	3.80 (0.92)	18	2.50 (0.38)	2.77 (0.31)	25	2.55 (0.23)	2.64 (0.63)
VT 5 s	5	3.03 (1.34)	2.88 (0.82)	5	2.32 (0.62)	2.12 (0.70)	5	3.63 (0.77)	2.75 (0.66)
Baseline	16	4.01 (0.46)	4.09 (0.51)	16	2.36 (0.38)	2.41 (0.44)	15	3.15 (0.62)	3.26 (0.69)
VT 2.5 s	5	2.37 (0.40)	2.53 (1.66)	5	2.03 (0.68)	1.77 (0.75)	5	2.53 (0.80)	2.35 (1.62)

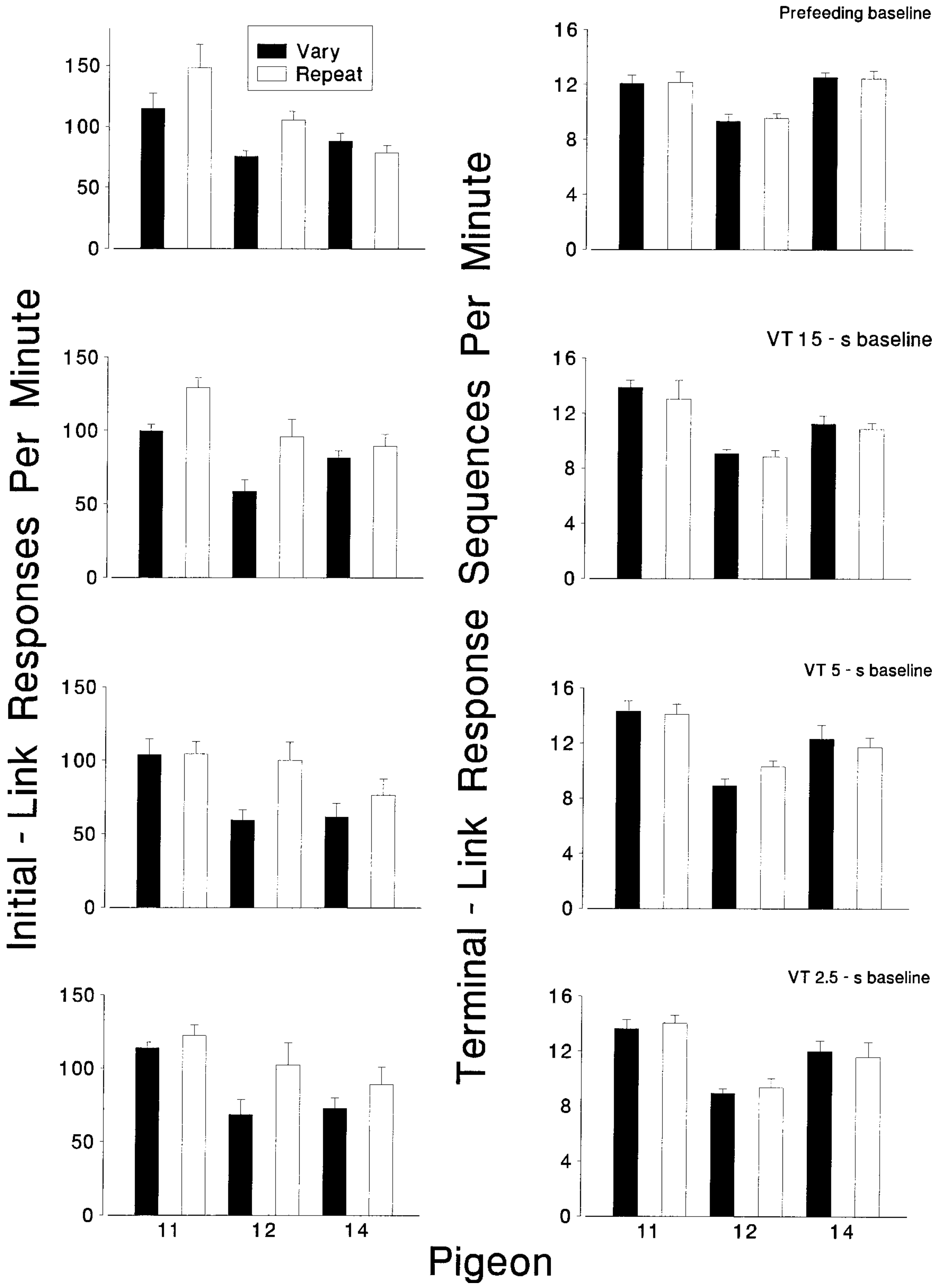
terminal links of each component. Stability was defined as the absence of a trend for at least six consecutive sessions in initial- and terminal-link response rate, reinforcement rate, and degree of variation, as indexed by an uncertainty value (U value; see below) in each component. Table 1 shows the number of sessions in each condition, excluding the training conditions, for each pigeon. The first disrupter was prefeeding (i.e., satiation). Each pigeon was fed increasing amounts of grain 30 min prior to each of a series of consecutive sessions until a session occurred in which a key peck was absent for 10 consecutive minutes. Data from the sessions in which this criterion was satisfied are not presented because this 10-min criterion always was satisfied at the beginning of a session. The amounts of grain given prior to consecutive sessions were 5, 5, 5, 7.5, 7.5, 7.5, 12.5, 12.5, 12.5, and 22.5 g. After each pigeon's weight returned to its target weight, the multiple chained schedule (baseline) operated for at least 15 additional sessions, and until stable responding again was obtained, before the second disrupter was introduced.

The second disrupter was the delivery of food according to a variable-time (VT) schedule during the 30-s ICIs. Variable-time schedules of 15, 5, and 2.5 s were presented, in that order. Five sessions at each of these schedule values occurred, and the baseline, multiple chained schedule operated for at least 15 sessions and until stability was attained prior to introducing each VT schedule. A VT session occurred only if the pigeon's weight was within ±20 g of its target weight. If a pigeon's weight was outside of this range, a session was not conducted and the pigeon was not fed that day.

RESULTS

The mean number of reinforcers obtained per minute (and standard deviations) in the vary and repeat terminal links during the last six sessions preceding each of the four disruption conditions and during the disruption conditions are shown in Table 1. Throughout each condition, the absolute difference in reinforcement rate between the two components was minimal. The mean reinforcement probabilities of LRLR for Pigeon 11 for the six sessions preceding each of the four disruption conditions (in order of occurrence) were .40, .42, .31, and .30. The mean reinforcement probabilitoes of LRLR for Pigeon 12 for the same period were .58, .30, .30, and .37. For Pigeon 14, these probabilities were .24, .25, .23, and .30.

The left graphs of Figure 1 show the mean (and standard deviation) initial-link responses per minute in both the vary and repeat components during the last six sessions preceding each of the four disruption conditions for each pigeon. Initial-link response rates were calculated by dividing the number of responses to the middle key by the amount of time that key was available (transilluminated). For Pigeon 11, initial-link response rates were higher in the repeat component than in the vary component before the prefeeding,


Vary
Repeat
Prefeeding baseline
VT 15 - s baseline
VT 5 - s baseline
VT 2.5 - s baseline
Initial - Link Responses Per Minute
Terminal - Link Response Sequences Per Minute
Pigeon
0
50
100
150
0
4
8
12
16
11
12
14

VT 15-s, and VT 2.5-s conditions. For Pigeon 12, initial-link response rates always were higher in the repeat component. For Pigeon 14, initial-link response rates were somewhat higher in the vary component prior to the prefeeding condition but were higher in the repeat component prior to all the VT conditions. The right graphs of Figure 1 show, for each pigeon, the number of four-peck response sequences per minute across the two components during the same sessions shown in the left graphs. These rates were defined as the total number of four-peck response sequences in a terminal link divided by the total time spent in that terminal link, excluding reinforcement and blackout time. Terminal-link response rates were similar across the two components for each pigeon.

Figure 2 shows the degree of variation for each pigeon during the baseline conditions. Displayed are the obtained relative frequencies of each of the 16 possible response sequences for each pigeon in each terminal link during the final three baseline sessions that preceded each of the four disruption conditions. The 16 response sequences are plotted along the *x* axis such that the leftmost response sequences contain the least number of changeovers (i.e., LLLL and RRRR) and the rightmost response sequences contain the greatest number of changeovers (i.e., LRLR and RLRL). The solid horizontal lines on the left graphs show the predicted relative response-sequence frequencies according to chance (i.e., .0625, or 1 divided by 16). For each pigeon in the vary component (left graphs), a high degree of variation was observed. Despite such a high obtained degree of variation in the vary component, some response stereotypy occurred. For Pigeon 11, six of the eight response sequences that were at or above chance level contained a left key peck in the third position of the sequence (e.g., RRLR). For Pigeon 12, each of the seven response sequences that were at or above chance level began with a left key peck (e.g., LRRR). Seven of the nine response sequences that were at or above chance level for Pigeon 14 ended with a repetition (e.g., LLRR and RLLL). In the repeat component (right graphs) for each pigeon, a high degree of repetition was obtained, with LRLR occurring most frequently. The two most frequent response sequences after LRLR were the same for each pigeon (RLRL and LLRL).

Figure 3 shows the log proportion of baseline responses per minute in the initial and terminal links of each component for each pigeon during each prefeeding session. These data allow comparison between response rates despite absolute response-rate differences during baseline (Nevin, 1974). Proportions were calculated by dividing the response rate from each link during each prefeeding session by the mean response rate from that link during the last six baseline sessions (shown in Figure 1). The solid horizontal lines plotted at zero show baseline response rates in each component for each pigeon, such that, relative to baseline, any points below this line represent a decrease in response rates, any points above this line represent an increase in response rates, and any point on this line represents no change in response rates. Initial- and terminal-link response rates decreased less in the vary component than in the repeat component during the last five sessions for Pigeon 11 and during the last three sessions for Pigeon 12. For Pigeon 14, initial-link response rates in the vary component tended to be closer to baseline, with the exception of the last session, and there was no systematic change in terminal-link response rates between the two components.

Figure 4 shows the log proportion of baseline responses per minute across the initial and terminal links during the vary and repeat components during each prefeeding session for each pigeon. These proportions were obtained and the figure constructed as described above for Figure 3. The response-rate reductions across the initial and terminal links were mixed. In three cases, initial-link response rates decreased more than terminal-link response rates (Pigeon 11 in the vary

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Fig. 1. Mean (and standard deviation) initial-link response rates (left graphs) and terminal-link response-sequence rates (right graphs) in the vary and repeat components during the last six sessions of baseline preceding each of the four disruption conditions for each pigeon.

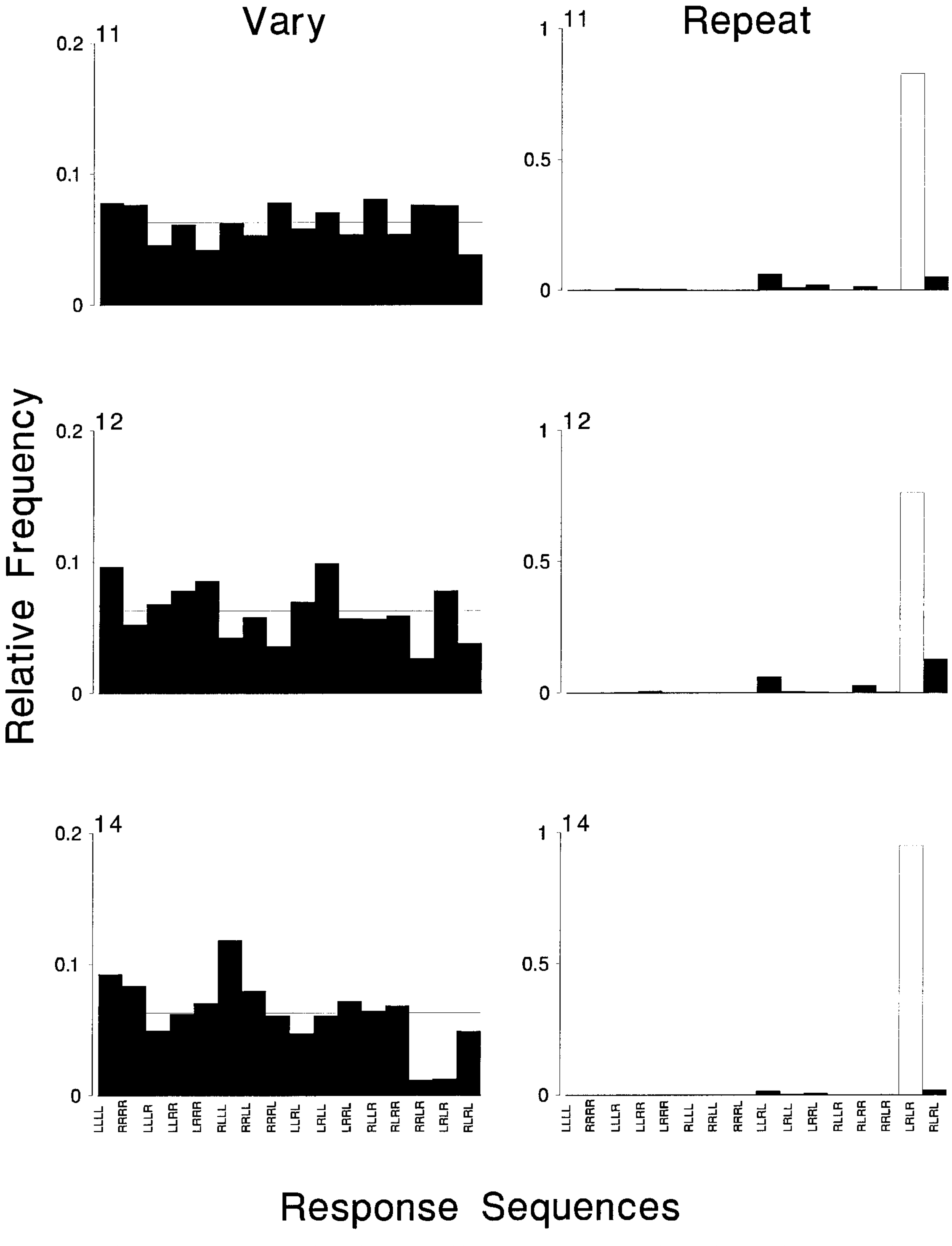

Fig. 2. Relative frequencies of each of the 16 possible response sequences obtained for each pigeon in the vary (left graphs) and repeat (right graphs) components from the three baseline sessions preceding each of the four disruption conditions, for a total of 12 sessions for each pigeon. The solid horizontal lines on the left graphs show the predicted values of the relative response-sequence frequencies according to chance (.0625).

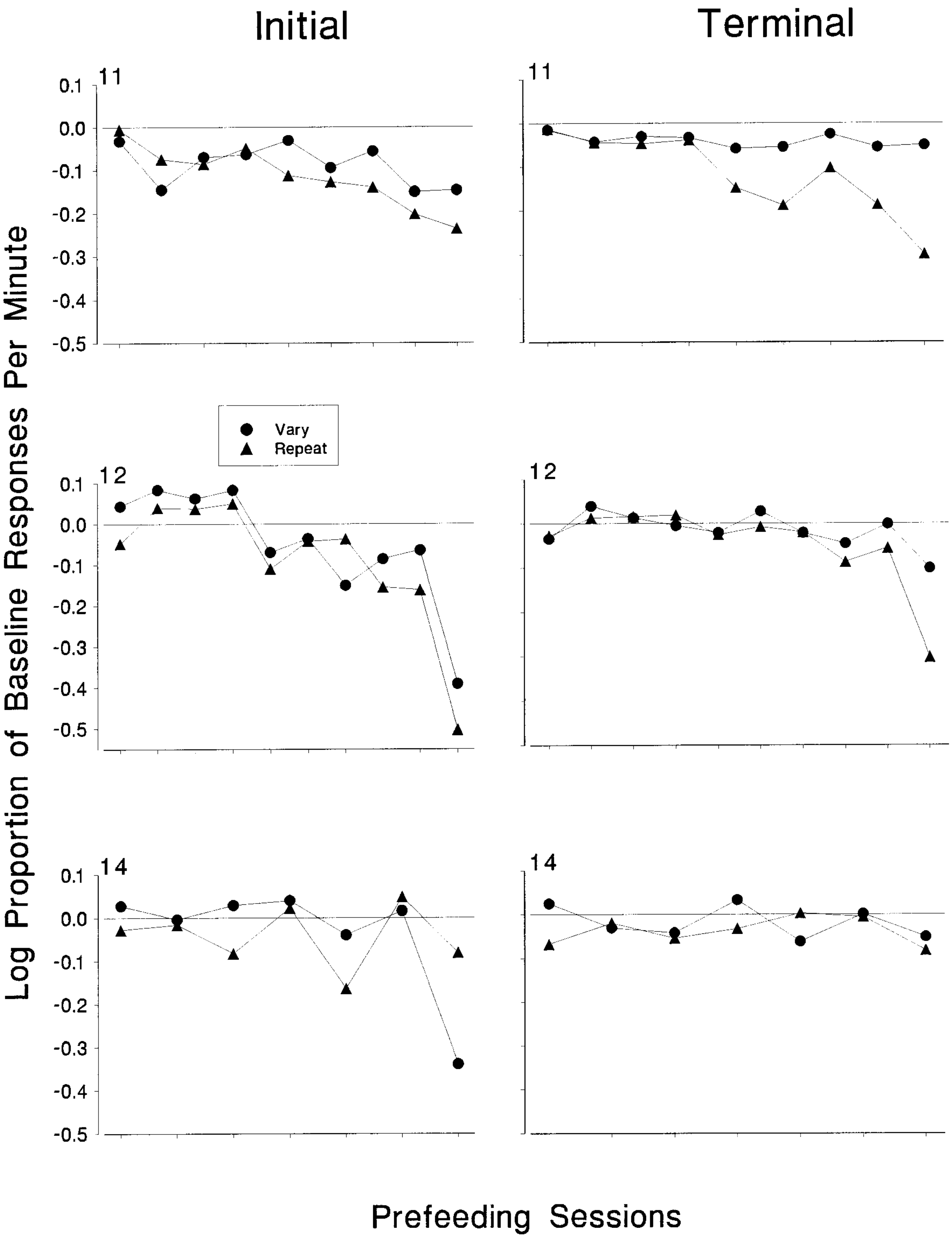

Fig. 3. Log proportion of baseline response rate in the initial links (left graphs) and response-sequence rate in the terminal links (right graphs) of each component for each pigeon during each prefeeding session.

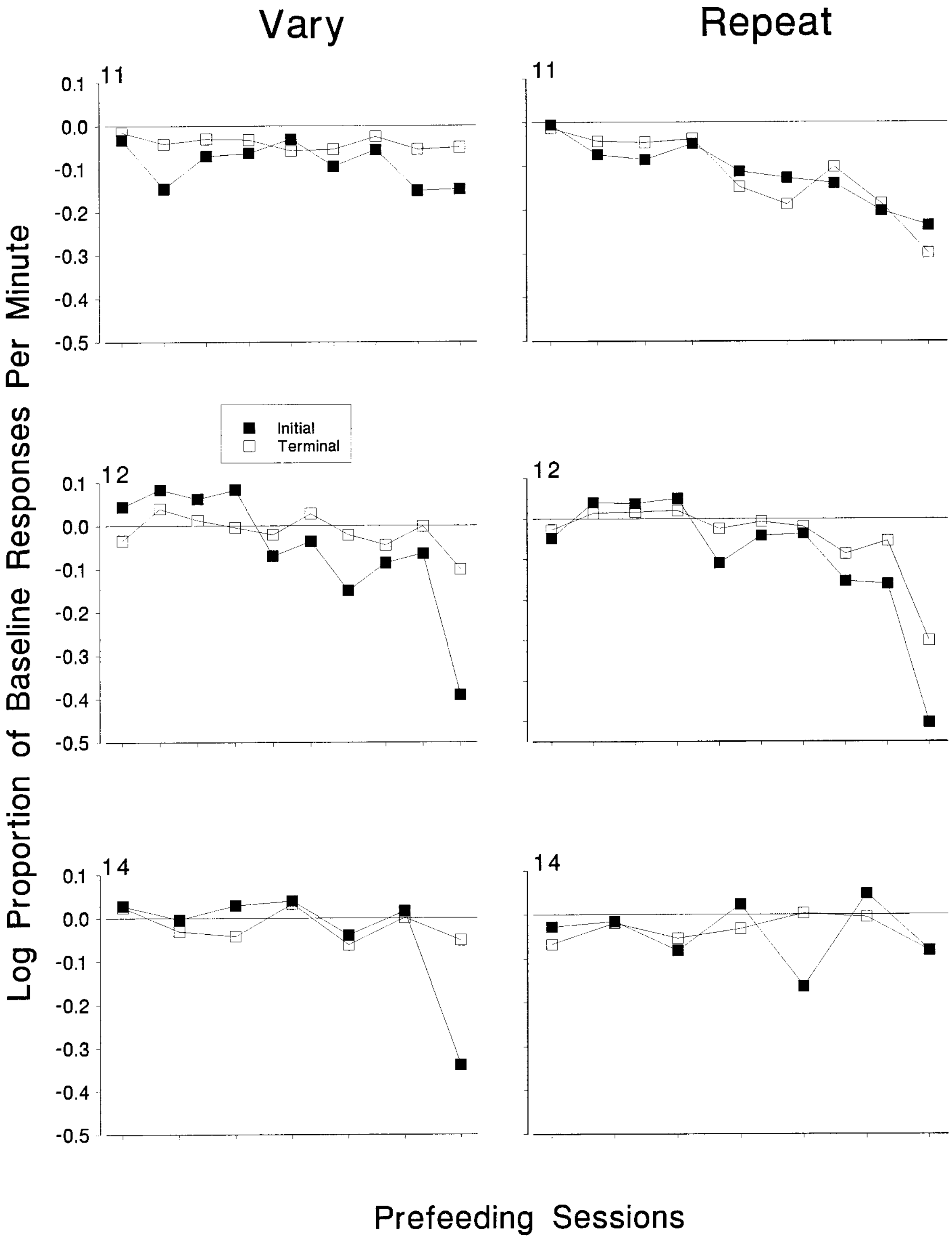

Fig. 4. Log proportion of baseline response rate in the initial and terminal links during the vary (left graphs) and repeat (right graphs) components for each pigeon during each prefeeding session.

component and Pigeon 12 in each component). In the other three cases, there was no differential response-rate decrease between the links.

The left graphs of Figure 5 show the baseline U values (Miller & Frick, 1949; Page & Neuringer, 1985) and the changes in these values across prefeeding sessions in each component. U values were calculated according to the formula: $U = -\Sigma[Rf_i * \log2(Rf_i)]/\log2(16)$, where Rf_i is the unweighted relative frequency of each of the 16 response sequences. A U value of 1 indicates complete uncertainty or variation, and a U value of 0 indicates complete certainty or repetition. In other words, higher U values indicate a higher degree of variation, or, conversely, a lower degree of repetition, and lower U values indicate a lower degree of variation, or, conversely, a higher degree of repetition. For baseline U values, the means (and standard deviations) of the final six sessions preceding prefeeding are shown. In the vary component for each pigeon, U values were above .90 in baseline, and in the repeat component, they were lower, ranging from about .10 to .35. Across prefeeding sessions in the vary component, U values decreased in Pigeons 11 and 14, slightly so in the latter, and changed little for Pigeon 12. In the repeat component, U values increased for Pigeon 11, became more variable (while changing only minimally) for Pigeon 12, and remained similar for Pigeon 14 across prefeeding sessions.

Figure 6 shows the relative frequency distributions of response sequences during each component for the last five prefeeding sessions for each pigeon. This figure was constructed as described above for Figure 2. The U value decreases during the vary component for Pigeons 11 and 14 were due primarily to an increase of response sequences containing zero or one changeover. For Pigeon 11, each of the six response sequences at or above chance level contained either zero or one changeover, as did six of the eight sequences at or above chance level for Pigeon 14. This increase in response sequences containing zero or one changeover was accompanied by a decrease in the response sequences containing two and three changeovers (i.e., the right side of the distribution). In addition, the most frequent response sequence for each pigeon during these prefeeding sessions was LLLL. Only Pigeon 11 displayed a large U-value change (increase) in the repeat component, and this increase was due in part to an increase in the relative frequency of the response sequence LLRL, which was the sequence that prolonged preliminary training because of its relatively high frequency of occurrence.

Figure 7 shows the log proportion of baseline responses per minute in the initial and terminal links of each component during each VT session for each pigeon. These proportions were calculated and the figure constructed as described above for Figures 3 and 4. Greater response-rate decreases generally occurred during the earlier VT sessions than the later ones. Initial- and terminal-link response rates generally decreased more in the repeat component than in the vary component across the VT sessions. Across the 90 comparisons, there were 62 instances in which repeat response rates were reduced more than vary response rates, whereas in only very few instances was the opposite true. In the remaining cases, the response-rate reduction from baseline was similar between components. There was no systematic difference in response-rate decreases as a function of the rate of VT food delivery.

Figure 8 shows the log proportion of baseline responses per minute across the initial and terminal links during the vary and repeat components during each VT session for each pigeon. These proportions were calculated and the figure constructed as described above for Figures 3, 4, and 7. Relative to baseline, terminal-link response rates were more resistant than initial-link response rates during nearly every VT session.

The right graphs of Figure 5 show the obtained U values (means and standard deviations) in each component during the last six baseline sessions preceding each VT condition and each VT session for each pigeon. As in the prefeeding baseline condition, U values were relatively high in the vary component and low in the repeat component prior to the introduction of the VT schedules. Across VT sessions in the vary component, U values tended to decrease for each pigeon, although only slightly so for Pigeon 12. In the repeat component across VT sessions, U values increased for each pigeon, with the ex-

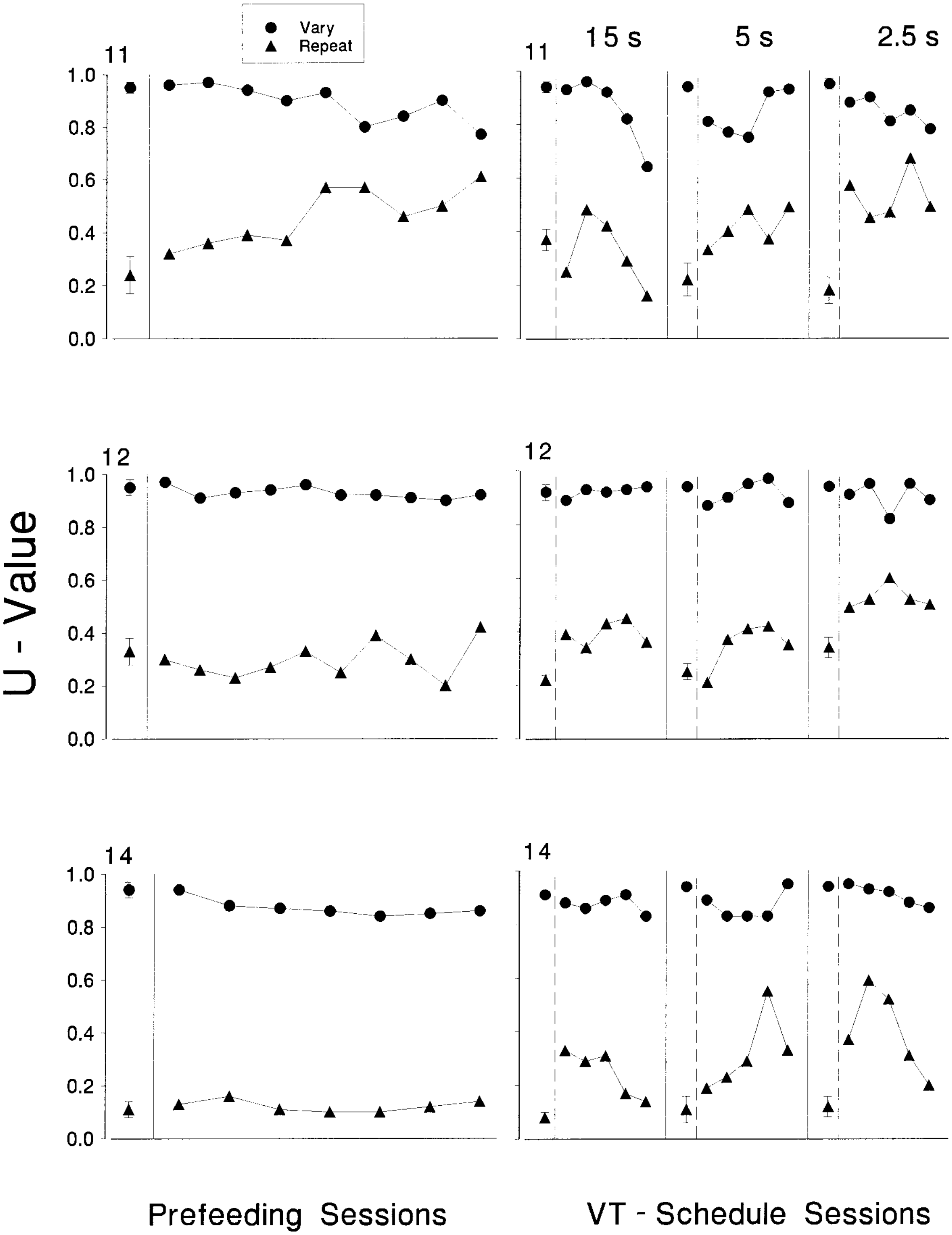

Fig. 5. Obtained U values during baseline (mean and standard deviation from the final six sessions) and each session of prefeeding (left graphs) and from the VT conditions (right graphs). See text for calculation of U values.

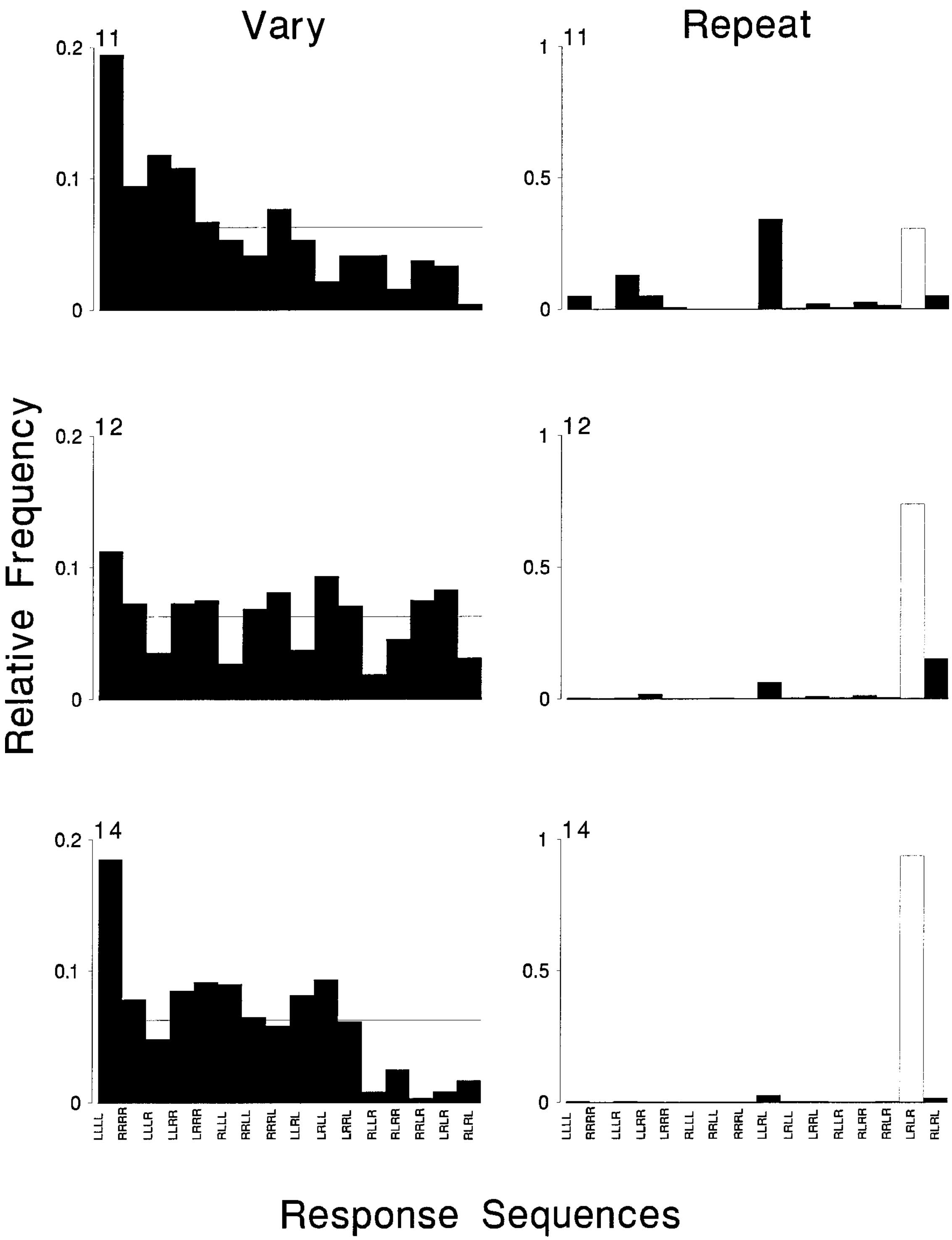

Fig. 6. Relative frequencies of each of the 16 possible response sequences obtained for each pigeon in the vary (left graphs) and repeat (right graphs) components during the last five prefeeding sessions. The solid horizontal lines on the left graphs show the predicted values of the relative response-sequence frequencies according to chance (.0625).

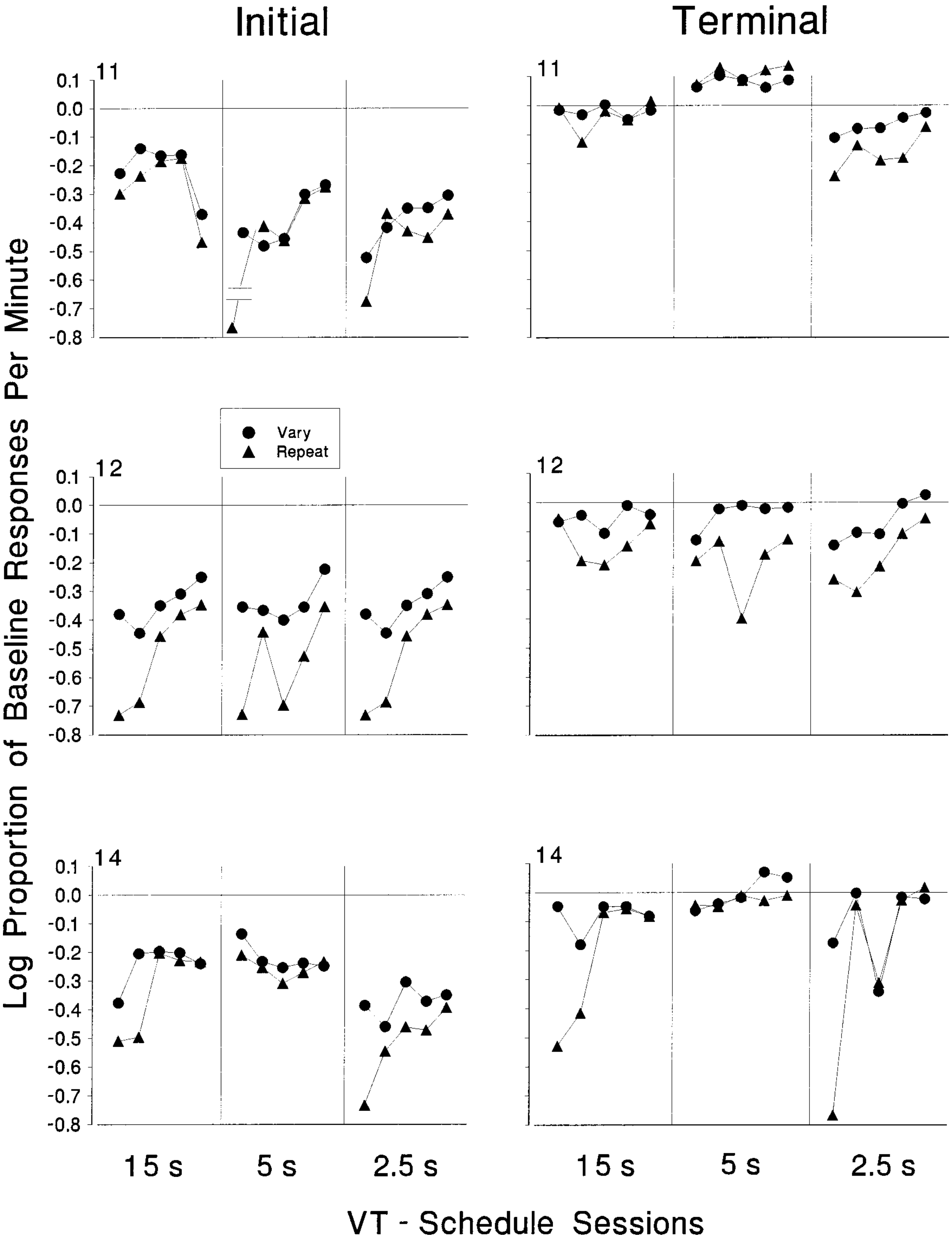

Fig. 7. Log proportion of baseline response rate in the initial links (left graphs) and response-sequence rate in the terminal links (right graphs) in each component during each VT session.

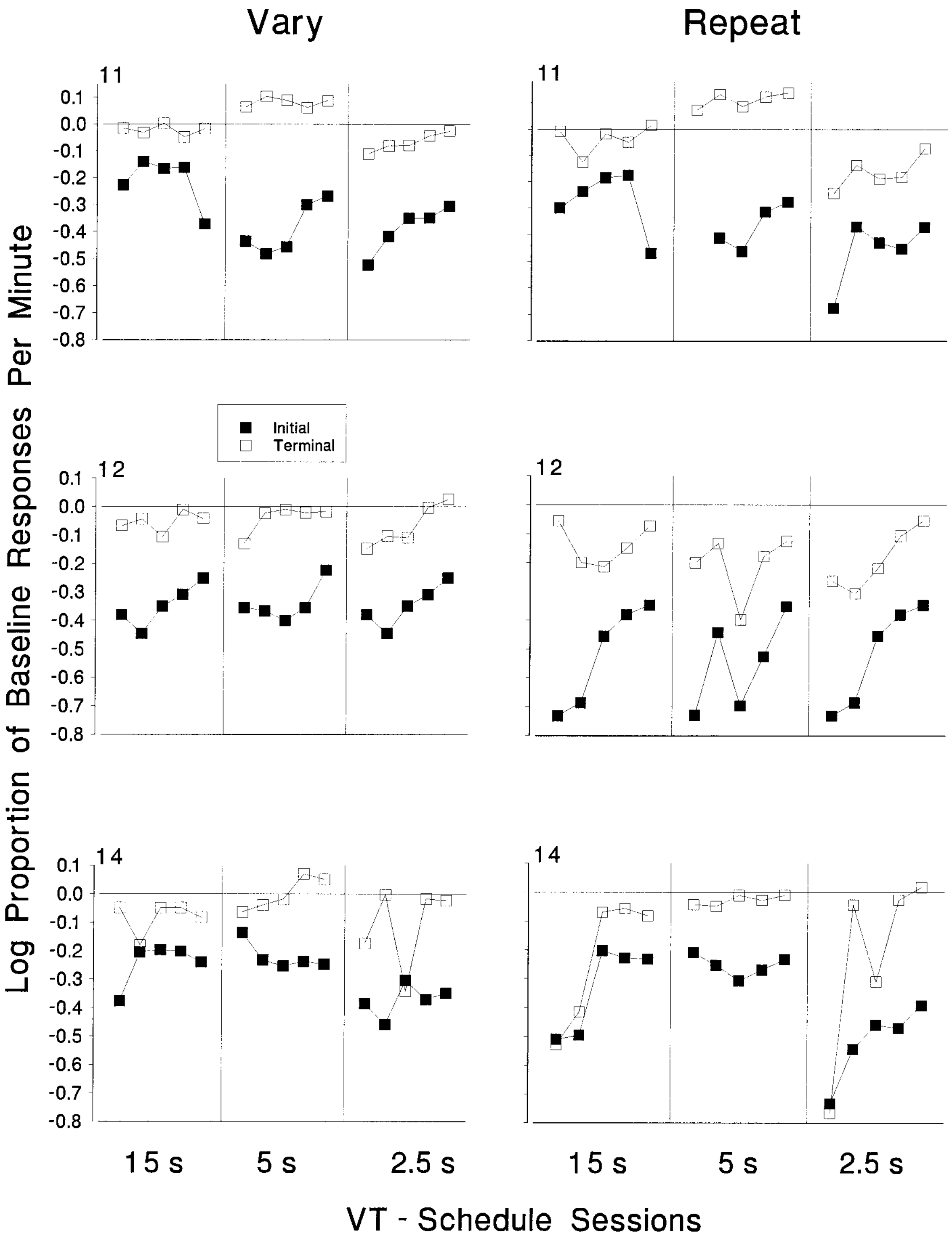

Fig. 8. Log proportion of baseline response rate in the initial and terminal links during the vary (left graphs) and repeat (right graphs) components for each pigeon during each VT session.

ception of an initial decrease, then increase, followed by a decrease below baseline for Pigeon 11 during the VT 15-s condition.

Figure 9 shows the relative frequency distributions of response sequences during each component from all VT sessions for each pigeon. Figure 9 was constructed as described above for Figures 2 and 6. The relative frequencies from the VT sessions were pooled because they were similar in each of these conditions. Several response stereotypies again were observed within and across pigeons during the vary component. For Pigeon 11, seven of the nine response sequences that were at or above chance level began with a left key peck; this also occurred in five of the seven response sequences at or above chance level for Pigeon 12. Also for Pigeon 12, of these seven response sequences at or above chance level, five ended in a repetition, as did seven of the nine response sequences at or above chance level for Pigeon 14. A final commonality among pigeons was the change in the relative frequencies of the response sequences LRLR and RLRL relative to baseline. For Pigeons 11 and 14, LRLR increased relative to baseline, and for each pigeon, RLRL did. In the repeat component for each pigeon, several of the response sequences increased relative to baseline, including LLRL.

DISCUSSION

Generally greater resistance to response-independent food delivery and, for 2 of 3 pigeons, to prefeeding occurred in both the initial and terminal links of a component in which operant variation was reinforced than in a component in which operant repetition was reinforced. This differential resistance was obtained despite similar response and reinforcement rates across the terminal links and different changes in the relative response-sequence frequencies in the vary component as a function of the two disrupters. In addition, several systematic and idiosyncratic effects from both the reinforcement contingencies and the disrupting operations on the development and alteration of the relative response-sequence distributions were encountered. Thus, these findings have implications for comparisons of the operant response classes of variation and repetition, theories of response strength (e.g., behavioral momentum theory), and conceptions of what constitutes an operant response class.

That operant variation was more resistant to change than operant repetition in the present experiment confirms and extends the findings of Neuringer (1991) and L. Cohen et al. (1990). That variation tended to decrease less in the vary component than repetition did in the repeat component (during the VT conditions) is consistent with the greater disruption by alcohol administration (L. Cohen et al., 1990) and increased IRT requirements (Neuringer, 1991) on operant repeating than operant varying. In the present experiment, changes in response rates also were analyzed across the two response classes, and less disruption occurred in a multiple-schedule component maintaining variation rather than repetition. This comparison of response-rate changes extends Neuringer's observations to a more commonly used response-strength measure (e.g., Nevin & Grace, 2000). A second extension of the present experiment was that the effects of altering the efficacy of the reinforcer maintaining operant variation and repetition was investigated instead of alcohol administration (L. Cohen et al., 1990) or changing IRT requirements (Neuringer, 1991). These latter two manipulations decreased reinforcement rate for operant repeating, relative to operant varying, whereas in the present experiment reinforcement rate remained the same for both varying and repeating. That differential resistance was obtained here independently of a differential decrease in reinforcement rate is important because unequal reinforcement rate might have, in and of itself, yielded unequal resistance (Nevin, 1992; Nevin et al., 1983).

That an operant response class consisting of many different response sequences (i.e., vary) was more resistant to disruption than one containing only one (i.e., repeat) is consistent with Schoenfeld's (1968) description of the partial-reinforcement extinction effect (PREE). Schoenfeld suggested that under partial-reinforcement conditions, responses other than the one necessary for reinforcement (e.g., the rat's bar press) gain some level of strength, but under continuous reinforcement, only the one necessary for reinforcement does (see also Hearst, 1997). Thus, in extinction following partial rein-

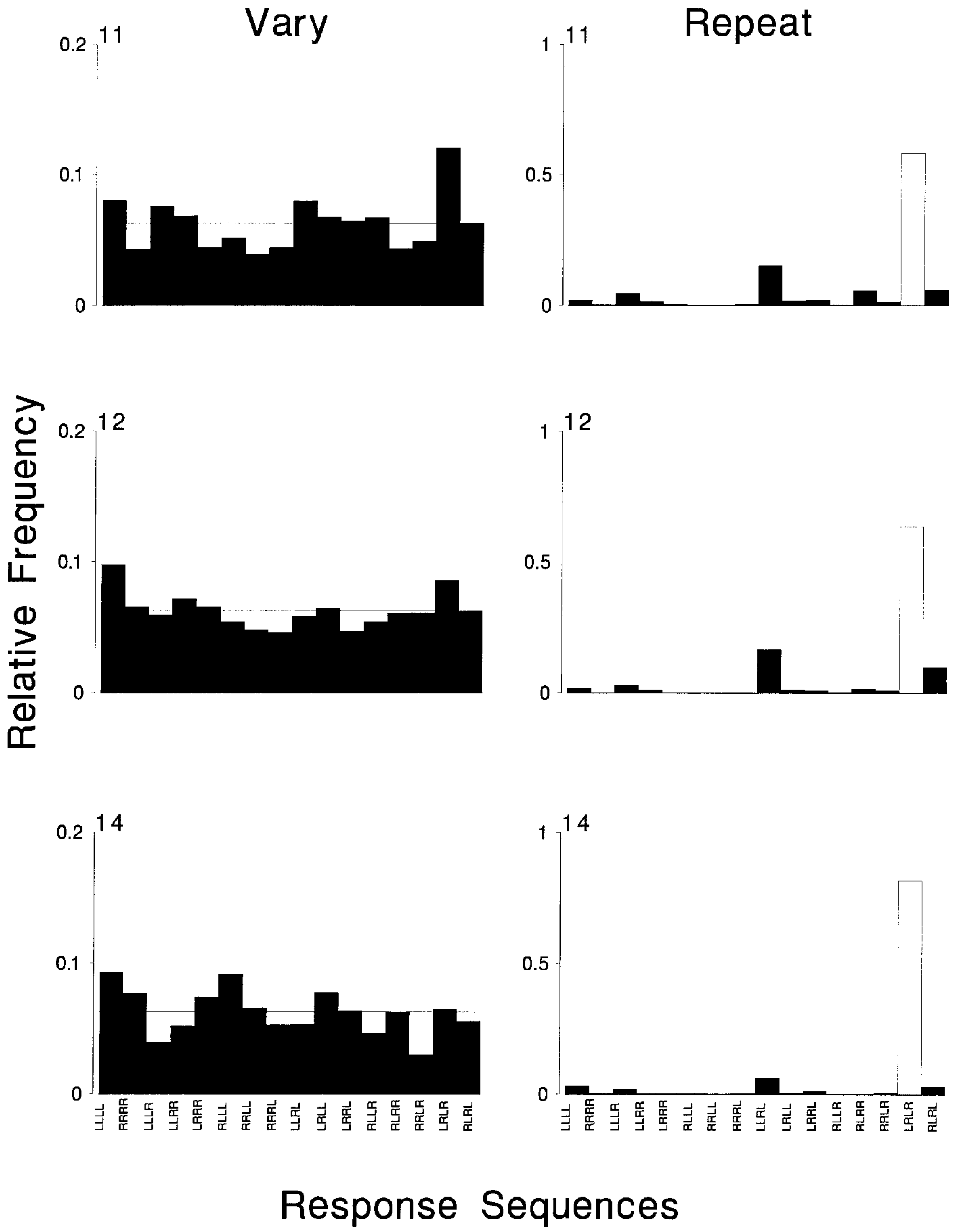

Fig. 9. Relative frequencies of each of the 16 possible response sequences from each VT schedule session for each pigeon in the vary (left graphs) and repeat (right graphs) components. The solid horizontal lines on the left graphs show the predicted values of the relative response-sequence frequencies according to chance (.0625).

forcement, multiple responses must be extinguished rather than only one, resulting in a relatively greater number of responses during extinction. Although extinction was not used as a disrupting operation in this study, an interpretation consistent with Schoenfeld's applies to these results. The only response sequence that was reinforced in the repeat component was LRLR, and it may have reached some asymptotic level of strength sometime during training. In the vary component, however, each of 16 different response sequences was reinforced, and each sequence might have reached its own level of strength that when summed together surpassed that achieved by LRLR (in repeat). An examination of baseline response rates, which were equal, did not reveal such strength differences but the disrupters did, in that response persistence during the vary component, with its several constituent parts, exceeded that during the repeat component, with only its one part. Resistance-to-change tests comparing the persistence of response classes consisting of a different number of responses available for reinforcement could corroborate this type of analysis.

A recent study by Neuringer, Kornell, and Olufs (2001) is related to the present discussion. They compared resistance to extinction of operant variation and repetition between two groups of rats (Experiment 3). During baseline, response rates for the vary group were approximately double those of the repeat group, but the rates of both groups were reduced to similar levels during four sessions of extinction. This result seems at odds both with Schoenfeld's (1968) interpretation of the PREE and with the above-described account of the present results. There are several differences, however, between Neuringer et al.'s study and the typical experiment demonstrating the PREE, as well as between their study and the present one. Although Neuringer et al. reinforced only one response sequence (in their repeat group), this sequence occurred only on approximately 50% of the trials during baseline. When, however, a response is continuously reinforced, as during demonstrations of the PREE, this target response dominates at the expense of others. In the present experiment, the relative frequencies of LRLR (in the repeat component) during baseline for each of the 3 pigeons were .83, .76, and .95, respectively. Because of the presence of these other responses in Neuringer et al.'s repeat group, the extinction of the target response may have been prolonged relative to a situation in which that response occurs almost exclusively. Compared to the present study, Neuringer et al. used a between-subject comparison and a different disrupting operation. These two differences may have produced these apparently conflicting results because of the importance of context in resistance-to-change demonstrations (e.g., S. L. Cohen, 1998; but see Nevin, 1988) or the suitability of extinction as a disrupter relative to prefeeding and alternative reinforcement (e.g., Nevin & Grace, 2000), respectively.

Some of the present results replicate and extend earlier resistance-to-change research. During the VT conditions, response rates decreased more, relative to baseline, in the initial links than in the terminal links (Figure 8), replicating previous findings of Mellon and Shull (1986) and Nevin, Mandell, and Yarensky (1981). This finding, however, was not as evident during prefeeding. This differential resistance across links is consistent with an interpretation that responding maintained by primary reinforcement is stronger or more resistant to disruption than is responding maintained by conditioned reinforcement, delayed primary reinforcement, or both. The finding of somewhat greater resistance to change in the initial link preceding the terminal link that was more resistant (i.e., vary) (Figure 7) also replicates earlier research (Mellon & Shull, 1986; Nevin et al., 1981).

At least two aspects of the present results support the assertion that resistance-to-change manipulations can be utilized to study operant response classes consisting of more than a discrete response (i.e., a single key peck or bar press). First, during the VT conditions, terminal-link response rates were more resistant to change than initial-link response rates (Figure 8) despite the former maintaining an extended (four-peck) response sequence. Second, the decrease in variation during the vary component and the decrease in repetition during the repeat component as a function of the disrupters are consistent with a weakening of the operant response class that developed during baseline. This finding suggests that response classes that differ in other qualitative dimensions may be tested by resistance-to-change manipulations (cf. Galbicka & Kessel, 2000; Nevin & Grace, 2000).

The present finding of differential resistance between the two components, however, is inconsistent with behavioral momentum theory (Nevin, 1992), which predicts equal resistance because reinforcement rate was similar. Nonetheless, the present results are consistent with a number of demonstrations of differential persistence despite equal reinforcement rates (Bell, 1999; Blackman, 1968; Grace et al., 1998; Lattal, 1989; Lattal, Reilly, & Kohn, 1998; Mellon & Shull, 1986; Nevin, Grace, Holland, & McLean, 2001). The above interpretation of the present results, proposing that operant response classes with more members are stronger than classes with fewer members, can account for some of these findings. Low-rate responding generated either by IRT contingencies (Blackman, 1968; Lattal, 1989) or interval schedules (Lattal et al., 1998; Nevin et al., 2001) is more resistant to conditioned suppression (Blackman, 1968), progressively increasing schedule requirements (Lattal et al., 1998), and the more common resistance-to-change disrupters (Lattal, 1989; Nevin et al., 2001) than is high-rate responding. Perhaps under these low-rate contingencies, responses other than the one necessary for reinforcement are strengthened, whereas only the response necessary for reinforcement is strengthened under the high-rate contingencies. In other words, under each of these contingencies the nominal or descriptive response class is similar in number but the functional response class is not (Catania, 1973); consequently, the larger one is more resistant to change.

The lower response rates per se in the above-mentioned studies probably are not responsible for the obtained differential resistance (see Lattal, 1989). Relatively low response rates maintained by unsignaled delayed reinforcement are not more resistant than higher response rates maintained by immediate reinforcement (Bell, 1999; Grace et al., 1998). In addition, although response rate per se may be suggested to account for the differential initial-link resistance in the present experiment, in that lower response rates generally occurred in the vary component, it cannot account for the differential terminal-link resistance because these response rates were similar. How then might the present response-strength description emphasizing the size of an operant response class account for these other findings of unequal resistance in the presence of similar reinforcement rates? Unsignaled delayed reinforcement maintains responses other than the one necessary for reinforcement (Schaal, Shahan, Kovera, & Reilly, 1998), and both Bell and Grace et al. systematically measured only the rate of the target response (i.e., key pecking), although the latter reported the observation of these ''other'' responses. If the rate of these other responses had been measured and their resistance (in addition to key pecking) determined, results consistent with the present hypothesis may have been noted. The present response-strength interpretation, emphasizing the number of members comprising the operant response class, was applied only to studies in which similar reinforcement rates were obtained for each of two multiple-schedule components. Thus, the relation between reinforcement rate and the size of an operant response class in determining response strength is unclear, because the former controls resistance to change in a wide variety of situations (Nevin, 1992; Nevin & Grace, 2000).

Another description of the differential resistance to change observed in the present experiment must be discounted. It might be argued that the response sequence LRLR was more effortful than was the emission of variable response sequences, in that the pigeons changed over more when emitting the former and this increased effort resulted in relatively less resistance to change. In fact, the increase in the relative frequency of changeovers containing zero or one changeover and the relative decrease in LRLR and RLRL for Pigeons 11 and 14, as well as the dominance of LLLL for each pigeon, in the vary component during prefeeding are consistent with such a notion. A problem for this effort interpretation, however, is the increase in the relative frequencies of the response sequences LRLR and RLRL in the vary component during the VT conditions and that resistance-to-change differences between the two components during these conditions were greater than during prefeeding. This is problematic because even though changing over increased, relative to baseline, in the vary component during the VT conditions, relatively greater resistance still was obtained in this component than in the repeat component. If effort were modulating the present differential resistance, then greater resistance between the components should have occurred during prefeeding, but this did not occur. These findings suggest that any presumed differential effort between the two components was not independently responsible for the present results.

Several aspects of the present results bear generally on the analysis of operant variation. First, the decreased variation (in the vary component) as a function of prefeeding and the VT food deliveries had not yet been demonstrated. In past research, variation increased as response rates decreased (e.g., Neuringer, 1991), whereas the opposite relation was obtained here. Such disparate results suggest that not all manipulations that decrease the rate of operant varying will affect the quality of varying similarly. Second, the several observed stereotypies within an operant response class (e.g., beginning a sequence on the same key) both replicate earlier research and support the assertion that molecular analyses of the internal or serial order of behavioral variation might yield order when more molar measures of variation (e.g., U value) do not (cf. Machado, 1997). Third, that prefeeding increased response sequences containing the least number of changeovers and VT food delivery increased sequences with the highest suggests that although operant variation is the functional response class, all topographies within that class are not affected equally by the same or different environmental changes. Thus, it is necessary to consider the organization or structure of the constituent parts of at least some response classes for an adequate understanding of behavior (see also Machado, 1997; Shimp, 1976).

To summarize, the main finding of the present experiment was greater resistance to change of an operant response class consisting of varied response sequences than a class consisting of a single, fixed one. An interpretation of these results was advanced that describes the importance of the number of members of an operant response class. In addition, the significance of considering the structure or organization of an operant response class in determining the effects of environmental changes was discussed. This research also has implications for applied behavior analysis. One goal of applied behavior-analytic treatment is to create a range of responses that will persist following its removal (i.e., to produce a response class that is resistant to change). The relevance of the basic literature on resistance to change in devising such treatments has been discussed elsewhere (e.g., Mace, 1994, 2000; Nevin & Grace, 2000). The findings of the present study offer additional variables (i.e., response class size or variability of that class) to consider when generating such a treatment (see Holman et al., 1977, and Newman et al., 2000, for demonstrations of operant variation in applied settings). For example, if a response class consisting of several constituent parts is reinforced during treatment, it may better persist in the natural setting where the operating contingencies might require a somewhat different response than what was acquired during treatment; that is, generalization may be enhanced.

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