JOURNAL OF THE EXPERIMENTAL ANALYSIS OF BEHAVIOR 2001, **75,** 235–246 NUMBER 2 (MARCH)

CHANGING BEHAVIOR WITHIN SESSION: CYCLICITY AND PERSEVERANCE PRODUCED BY VARYING THE MINIMUM RATIO OF A VARIABLE-RATIO SCHEDULE

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Four pigeons repeatedly chose between a fixed-ratio (FR) 20 and a variable-ratio (VR) 40 schedule of reinforcement, in which the minimum ratio of the VR cycled within each session. The minimum ratio ascended and descended (ASCDESC), descended and ascended (DESCASC), or remained constant (unchanging). In Phase 1, 2 birds (Group 1) were exposed to ASCDESC series and 2 birds (Group 2) were exposed to the DESCASC series. Choice proportions changed with the cycling minimum ratio for Group 2 but not for Group 1. In Phase 2, Group 1 subjects were exposed to the DESCASC series and Group 2 subjects were exposed to the unchanging condition. Although Group 1's choice proportions appeared to be undifferentiated in Phase 2, Group 2's choice proportions continued to cycle for more than 100 sessions. Group 2 subjects were then moved to the ASCDESC series in the third phase, and choice proportions cycled with the minimum ratio as in the first phase. The descending portion of the series was the more powerful determinant of cyclicity. Response rates also changed with the minimum component ratio, a finding that goes against the claim of universality of a rise-and-fall within-session pattern of responding. That preference varied despite the constancy of the average ratio requirement suggests nonlinear averaging in quantitatively representing a variable schedule's value. The strong perseverance observed also lends support to a growing body of literature on history effects.

Key words: choice, within-session responding, cyclicity, history effects, variable-ratio schedules, key peck, pigeons

Traditional research paradigms for studying choice in the experimental analysis of behavior have used either concurrent schedules or concurrent-chains schedules. Their major manipulations have often been systematic variations in rate of reinforcement. Such research has yielded interpretive principles such as the matching law (e.g., Herrnstein, 1961, 1970) and the delay-reduction hypothesis (e.g., Fantino, 1969). Results from several experiments, however, indicate that imbedded within the "rate of reinforcement" independent variable lie dimensions other than mean rate that are suitable for manipulation and study.

Herrnstein (1964) showed that pigeons given repeated choices between a fixed-interval (FI) schedule and a variable-interval (VI) schedule of equal arithmetic mean preferred the VI schedule. Although the rate of reinforcement was equal across the two alternatives, this preference was robust. Killeen (1968) showed that choice allocation was better described by the harmonic rate of reinforcement than by the arithmetic rate. When calculating the harmonic mean of a distribution, the smaller quantities are weighed more heavily. Consequently, two distributions with equal arithmetic means may have discrepant harmonic means.

The greater relative influence of smaller values is consistent with hyperbolic discount functions, proposed by Ainslie (1974) to apply to research on self-control, and subsequently extended to various choice procedures (Mazur, 1984, 1986). In hyperbolic discounting, the value of a schedule of reinforcement is inversely related to the delay to reinforcement. Mazur (1984, 1986), Mazur and Vaughan (1987), Field, Tonneau, Ahearn, and Hineline (1996), and Neuman, Ahearn, and Hineline (1997, 2000) found that hyperbolic discount functions described

We thank the Learning Lab Crew for helping to conduct this experiment. Special thanks to Claudia Cardinal and Margaret Martinetti for editorial assistance well beyond the call of duty.

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their results well, and in the Neuman et al. studies, were better than arithmetic averaging techniques. Taking their lead from Mazur and Vaughan (1987), Field et al. (1996) and Neuman et al. (1997, 2000) extended Mazur's findings to choice experiments with ratio schedules by dividing the ratio requirements by a constant rate of responding to arrive at a delay to reinforcement.

The extension to ratio schedules implicitly assumes that rate of responding does not vary during a session, and does not vary as a function of the minimum ratio requirements. However, Blakely and Schlinger (1988) found that response rates were lower when a ratio of 1 was among the components of a variable-ratio (VR) schedule, in comparison with a VR with an equal mean but with a minimum ratio of 7. Transforming a ratio to a delay by dividing by a constant rate may be innaccurate, therefore, in light of the findings that response rate varied in arithmetically equal VR schedules with different minimum ratios.

Research on minimum ratios in VR schedules has focused mainly upon choice proportions in fixed-ratio (FR) versus VR concurrent chains, and not on rate of responding. Several experiments in our laboratory (Ahearn, 1992; Ahearn, Hineline, & David, 1992; Field et al., 1996; Khutoryansky, Field, & Hineline, 1997) have examined the influence of smaller ratios within VR schedules. In a series of experiments, subjects repeatedly chose between an FR schedule and a VR schedule twice the arithmetic mean of the FR schedule (e.g., FR 30 vs. VR 60). The minimum and maximum ratios within the VR were manipulated across conditions, in a way that maintained a constant arithmetic mean. Field et al. altered the minimum VR ratio every 11 sessions, in an ascending and then descending fashion, or in a descending and then ascending fashion, and assessed preference for the FR schedule. Preference was found to be sensitive to the size of the minimum ratio of the VR: The proportion of FR choices increased and decreased as the minimum ratio of the VR increased and decreased.

In a second study (Khutoryansky et al., 1997) the minimum ratio was changed every session. Once again, choice proportions tracked the changing minimum ratio of the VR. Even when the minimum ratio was held constant during the second phase, choice continued to cycle well after the ratios ceased to change. The ''cyclic perseverance'' seen in this experiment—''cyclic'' because the proportion of FR choices changed with the schedule, ''perseverance'' because choice proportions continued to cycle during the unchanging condition as if the schedule components continued to change—were obtained in only eight exposures to the sequence of changing ratios.

A within-session cyclic pattern of responding was first demonstrated by Staddon (1964). In that experiment, the rate of reinforcement of a VI schedule changed cyclically as a function of time, in a sinusoidal fashion. Response rates varied as a function of the number of reinforcers per hour. The cyclicity that Staddon induced, however, was a direct function of manipulating rate of reinforcement, whereas Field et al. (1996) and Khutoryansky et al. (1997) manipulated the smallest component ratios and not explicitly the rate of reinforcement. Moreover, it is not clear whether Staddon kept the minimum component interval constant within the session.

If choice is sensitive to these minimum components, within-session changes in choice should correspond to within-session changes in the minimum ratio, comparable to cyclical changes seen when the values change every 1 or every 11 sessions. A cyclic pattern of choice might be developed more strongly by exposure to more cycles, and might persist longer. In the present experiment, the minimum component ratio of a VR schedule changed every five trials within a session in either an ascending and then descending fashion, a descending and then ascending fashion, or remained constant. In addition, changes in rate of responding were assessed and compared to results from previous studies (Blakely & Schlinger, 1988; Field et al., 1996; Neuman et al., 1997, 2000).

METHOD

Subjects

Four white Carneau pigeons with prior experimental histories served as subjects. They were obtained from the Palmetto Pigeon Plant and were designated as C7, M1, M4, and M5. Previously, they had served in experiments investigating choice between FR and VR schedules utilizing a concurrent-chains procedure. They were maintained at approximately 80% of their free-feeding weights throughout by supplemental feedings at the end of the day.

Apparatus

Each of four identical Gerbrands pigeon operant chambers was equipped with three translucent response keys, spaced evenly along the back wall and 22.5 cm from the floor. Only the two outside keys were used in these experiments; the center key was dark and inoperative throughout. The two operative response keys (left and right) could be illuminated either yellow or red using 28-V lamps with translucent plastic covers. A grain hopper, accessible through a circular opening 5 cm in diameter, 10 cm below the center response key, provided 2.75 s of access to mixed grain as the reinforcer. During food delivery, both side keys were dark and two 28-VDC lamps illuminated the hopper. Each chamber was contained within a sound-attenuating cabinet, which was equipped with a fan that ventilated the chamber and provided some masking noise during sessions. Experimental procedures were arranged and recorded via a personal computer in an adjacent room. Experimental events were programmed with Med-PC® for Windows (Versions 1.06, 1.13, 1.14, and 1.15) running on a Pentium®-class personal computer.

Procedure

Because all of the subjects had previous history in concurrent-chains procedures, there were no preliminary training phases. After completing a prior experiment, the subjects were maintained at their experimental body weights for several weeks before the current experiment began.

The procedure resembled a concurrent-chains schedule with an FR 20 and a VR 40 as the terminal links. Each session entailed 45 discrete trials (nine blocks of five trials). The FR 20 was correlated with the red key, and the VR 40 was correlated with the yellow, with sides randomized across trials. A trial began with the illumination of both keys, and the initial links were concurrent FI 3-s schedules. Thus, the first peck on one key after 3 s had elapsed produced a transition to the terminal link with the key color unchanged and the other key turned off. Pecks on the dark key during the terminal link had no programmed consequences. Completion of the terminal-link schedule turned off the keylight, turned on the hopper lights, and produced access to mixed grain, which was followed immediately by the next trial.

Table 1
The ratios of the VR schedule and their order of presentation.

	ASCDESC series		DESCASC series		Unchanging series	
Trials	Smaller value	Larger value	Smaller value	Larger value	Smaller value	Larger value
1–5	1	79	20	60	10	70
6–10	5	75	15	65	10	70
11–15	10	70	10	70	10	70
16–20	15	65	5	75	10	70
21–25	20	60	1	79	10	70
26–30	15	65	5	75	10	70
31–35	10	70	10	70	10	70
36–40	5	75	15	65	10	70
41–45	1	79	20	60	10	70

The VR schedule consisted of two components that changed across trials in five-trial blocks. The two components increased or decreased in a manner that maintained an arithmetic mean of 40. Three series were used: (a) an ascending and then descending series (ASCDESC), (b) a descending and then ascending series (DESCASC), or (c) a condition in which the two components were constant throughout the session (unchanging). Table 1 shows these series and the VR schedule ratios. If the initial link on the VR side was completed, the program randomly selected without replacement one of the two ratios that comprised the VR during that trial. Stability of responding was assessed through visual examination of graphs showing the relative proportion of initial links completed across the two alternatives. Table 2 summarizes the phases with the number of sessions in each phase for each subject.

RESULTS

Phase 1: Choice Proportions

Figure 1 shows the average proportion of initial links completed for the fixed alternative for five-trial blocks within a session, av-

Table 2

Sequence and number of sessions (in parentheses) for each subject.

Subject	Phase 1	Phase 2	Phase 3
Group 1			
C7	ASCDESC (145)	DESCASC (166)	
M1	ASCDESC (143)	DESCASC (165)	
Group 2			
M4	DESCASC (140)	Unchanging (166)	ASCDESC (88)
M5	DESCASC (144)	Unchanging (164)	ASCDESC (89)

eraged over the first 10 sessions, the tenth 10 sessions, and the last 10 sessions of Phase 1. The relative number of initial-link completions was nearly identical to the relative rate of responding in the initial links because the subjects usually waited long enough that the first response moved them to the terminal links. The five trials used to compute any one proportion corresponded to the five trials in a session that had the same minimum VR component value. The solid stepped lines represent the minimum ratio of the VR, as it ascended and descended, descended and ascended, or remained constant within a session. Five-trial averages provided much more stable measures than averages over other portions of a block (e.g., the last trial of a block).

Although it was anticipated that the proportion of FR choices would be low when the minimum ratio was 1 or 5 and high when the minimum ratio was 15 or 20, choice proportions for C7 and M1 were undifferentiated. Graphically, a change in preference with the change of minimum ratio would be represented by the FR choice points lying on the steps corresponding to the minimum ratio. In contrast, the bottom two rows of panels of Figure 1 show that the proportion of FR choices changed with the minimum ratio for M4 and M5. By the middle block of 10 sessions, preference for the FR began to follow the changing minimum ratio of the VR.

Phase 1: Correlations

To assess the strength of the relation between choice proportions and the size of the minimum ratio, correlation coefficients (Pearson *r*s) were computed separately for the ascending and descending portions of successive 10-session blocks. These coefficients were calculated from session-by-session data instead of 10-session averages. They are graphically represented in Figure 2.

Correlations for C7 and M1 did not deviate systematically from zero and did not indicate any consistent differential effects. In contrast, the descending-series correlations for M4 and M5 were positive by the third block and remained so for nearly the whole phase. The descending series produced stronger correlations than the ascending series, particularly for M5.

Phase 2: Choice Proportions

Figure 3 shows the proportion of FR choices as a function of five-trial blocks in Phase 2. M1's choices, once again, were undifferentiated with respect to the changing minimum ratio. Near the end of this exposure, an analysis revealed that a strong position bias had developed. Preference for the FR by C7, however, did show hints of sensitivity to the changing minimum ratio. In the last 10 sessions shown, as well as in earlier sessions not shown, the proportion of FR choices was highest during the first five-trial block, decreased during the session, and then increased in the final five-trial block. This pattern for C7 took nearly 100 sessions to emerge, as opposed to about 30 for M4 and M5 during Phase 1.

For M4 and M5, the prior DESCASC series is represented by a dotted line, and the current unchanging series is shown by the solid horizontal line. If the previous training had no effect on present choice, choice would follow the solid line. However, preference for the FR continued to cycle as it had in Phase 1. This pattern held with one exception: Sometimes, the preference for the FR did not increase during the second half of the session but remained near indifference (.5).

Phase 2: Correlations

The correlation coefficients for Phase 2 are shown in Figure 4. They increased for C7, but not for M1, as would be expected from Figure 3. The last seven blocks of sessions show positive correlations for C7 although, as in Phase 1, the descending series correlation was almost always higher. For M4 and M5, correlations were computed between the choice pro-

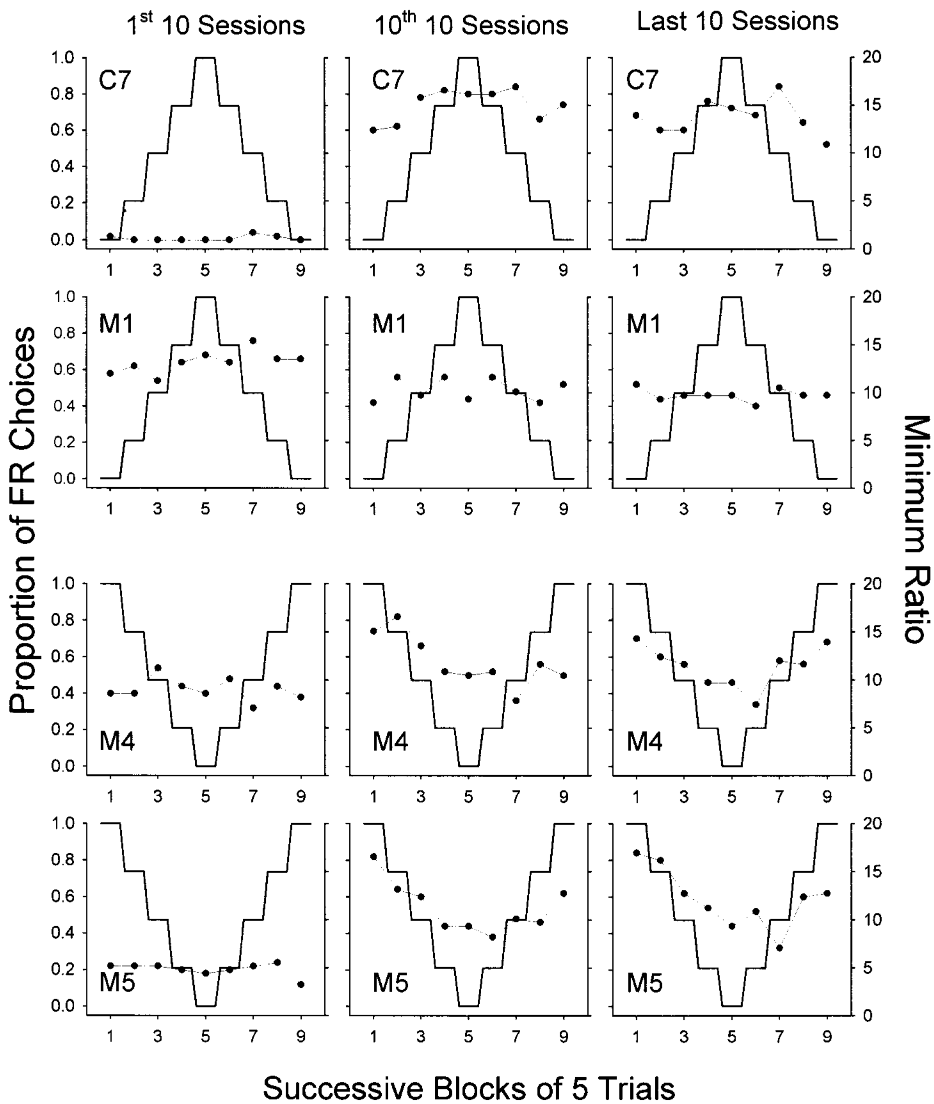

Fig. 1. Phase 1 choice proportions: the proportion of FR choices (circles with solid lines, plotted against the left *y* axis) across successive five-trial blocks within sessions, averaged across the first, tenth, and last blocks of 10 sessions. The minimum component ratio of the VR is plotted against the right *y* axis (solid line).

portions from Phase 2 and the minimum ratios from Phase 1. These correlations describe the strength of any historical effect between the current choice proportions and the cycle from the previous phase. For M4, the correlations decreased only slightly across the entire phase, whereas they eventually disappeared for M5. Correlations in the descending series were higher and remained high longer.

Phase 3: Choice Proportions and Correlations

Figure 5 presents the first, fifth, and last 10-session averages for Phase 3. During the first 10 sessions, choice proportions continued to be influenced by the previous exposure to the DESCASC series. By the last 10 sessions, however, choice proportions reversed and began to change with the changes in the minimum ratio.

Phase 3 correlations are presented in Figure 6. Correlations increased with exposure to the ASCDESC series, and consistent with earlier findings, the correlations in the descending portion were greater than those in the ascending portion.

Within-Session Changes in Rate of Responding

To determine the possible effect of within-session changes in response rate on choice proportions, an analysis was conducted using a ''proportional difference'' measure. Using only responses and time during the terminal links (starting immediately upon transition to the terminal link), the average rate of responding per session was computed. The rate in each trial (first trial of session, second trial, etc.) was then expressed as a proportion of the overall average. One was subtracted from this proportion to obtain the difference between the average response rate in a single trial and the overall session rate. These measures were averaged for each successive trial across the last 45 sessions of each phase. A value of 0 indicates that the rate during a particular trial did not differ from the average of the session. A value greater than 0 indicates a higher rate, and a value less than 0 indicates a lower rate. The computations standardized each subject's data so that no one session, or group of sessions, could have undue influence. Figures 7 and 8 present these measures during FR and VR choice trials separately, along with the changing minimum ratios (the ''steps'') during all phases.

Although there were systematic changes in response rate, there was no consistent evidence for the within-session patterns described by McSweeney and her colleagues (e.g., McSweeney, 1992; McSweeney, Weatherly, & Swindell, 1996). Response rates during VR choice trials for C7 (Phase 2), for M1 (Phases 1 and 2), for M4 (Phases 1 and 3), and for M5 (Phases 1 and 3) appeared to change with the changing minimum ratio. In Phase 2, the minimum ratio remained fixed for M4 and M5; the dashed line represents the prior cycling values. Although M1's choice proportions appeared to be indifferent to changing minimum ratio (Figures 1 and 3), response rate was sensitive to the changing minimum ratio in Phase 2. Although choice proportions changed within session for M4 and M5 during Phase 2 (Figure 2), response rates, high at the start of a session, decreased and then were fairly constant thereafter.

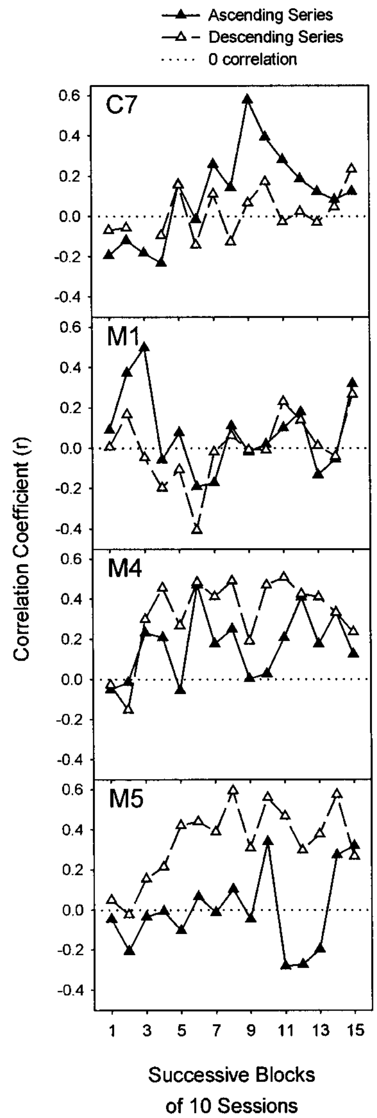

Fig. 2. Phase 1 correlations: Pearson *r*s between choice proportions and minimum VR ratios across successive blocks of 10 sessions for Group 1 (C7 and M1, top panels) and Group 2 (M4 and M5, bottom panels) calculated for the individual ascending and descending series of minimum ratios.

Blakely and Schlinger (1988) also found that response rates changed with changes in the minimum ratio of a VR, along with changes in the pause between reinforcement and

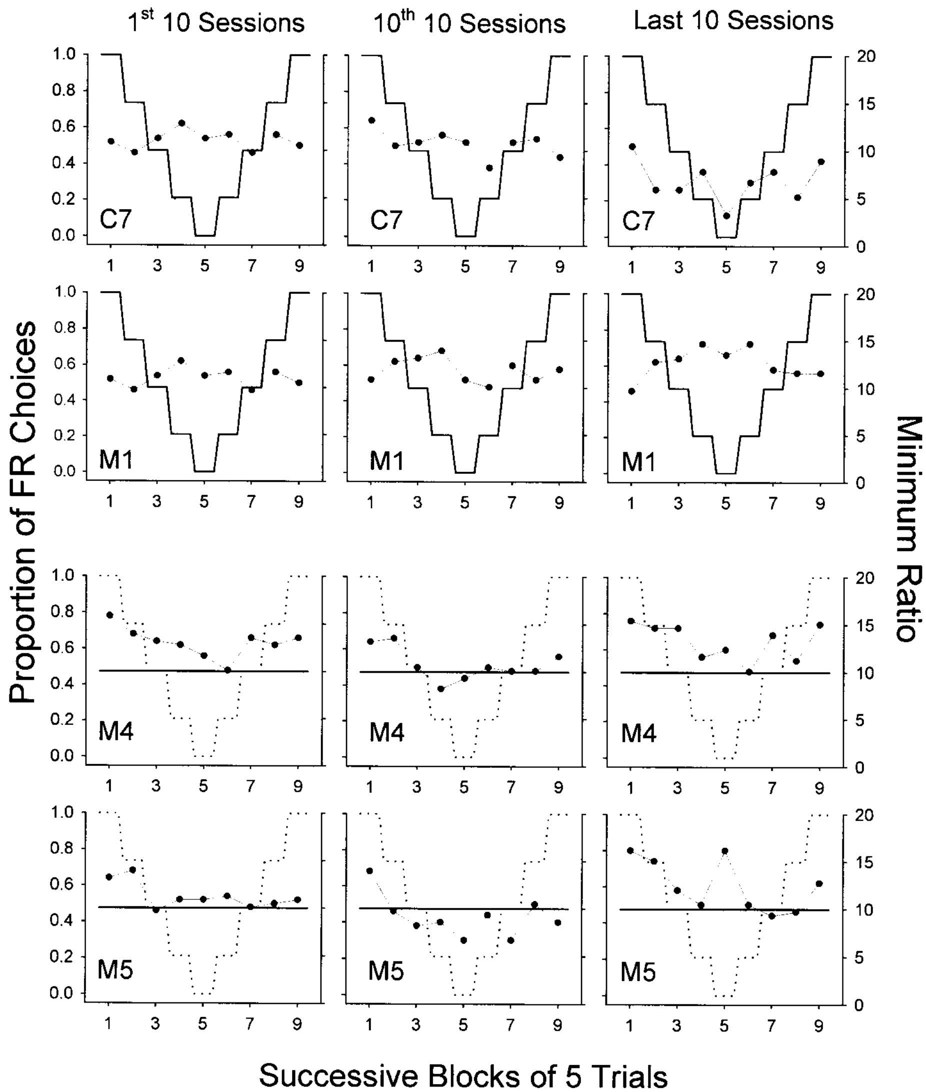

Fig. 3. Phase 2 choice proportions: the proportion of FR choices across successive five-trial blocks within sessions, averaged across the first, tenth, and last blocks of 10 sessions. The minimum ratio of the VR is plotted against the right *y* axis (solid line), and the prior series (DESCASC) is plotted as a dotted line for Group 2 (M4 and M5).

responding (the postreinforcement pause or preratio pause; PRP). To investigate the possibility that differential pausing was obtained and influenced overall rates, a conditional pause analysis was completed for each subject for Phases 1 and 2. Mean pauses between the completion of the initial link and the first peck in the terminal link were computed. Although some systematic changes were seen within subject, no general conclusions were warranted. Overall, it appeared that the rate changes were a function of minimum ratios and not PRP.

DISCUSSION

Characterizing the Value of Variable Schedules

In the present experiment, the VR schedule had an arithmetic mean of 40 throughout the experiment, yet behavior changed as the

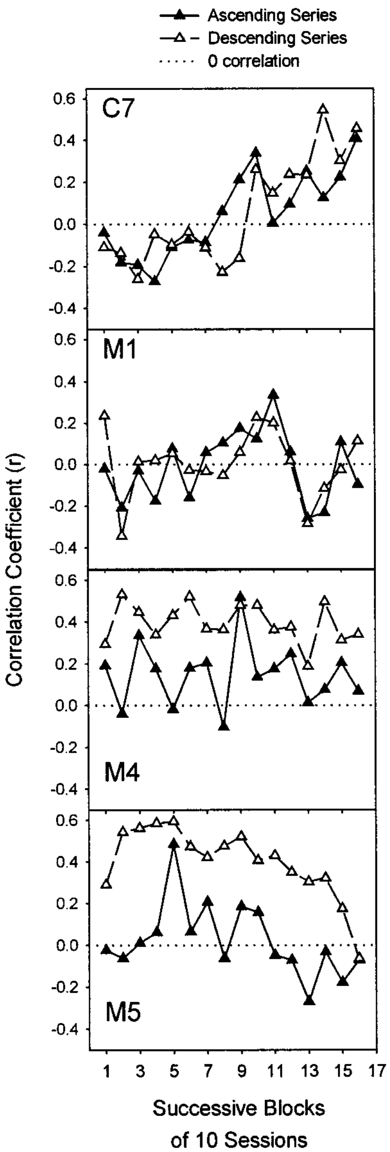

Fig. 4. Phase 2 correlations for Group 1 (top panels) and Group 2 (bottom panels). Pearson *r*s for Group 2 (M4 and M5) were calculated using the choice proportions from Phase 2 and the minimum ratios from Phase 1.

minimum ratio of this schedule changed. This raises the question of how a variable schedule's value should be calculated (Herrnstein, 1961; Killeen, 1968; Mazur, 1984, 1986; Mazur & Vaughan, 1987). Mazur's *V* and the harmonic rate of reinforcement (Killeen, 1968) would have predicted, qualitatively, the cycling preferences observed in Group 2. Both of these computations, however, are silent about the insensitivity found in Group 1 in Phase 1 and the persistent cyclicity of Group 2 in Phase 2.

Determinants of Cyclicity

As the preference for the FR schedule changed within a session, most notably with M4 and M5 in the first and third phases and with C7 in the latter part of the second phase, consistency emerged mainly when a subject was exposed to the descending portion of the series. This indicates that choice was sensitive not only to changes in minimum ratio after some exposure but also to the sequence of those changes. Preference tended to increase when reinforcers were occasionally produced with fewer and fewer responses. In contrast, when work requirements were increasing (e.g., the ascending portion), the preference appeared to be less influenced by the changes.

These results are consistent with those obtained in our laboratory with different subjects (Field et al., 1996) and a different arrangement of changes. During the ascending series of the Field et al. experiment, preference for the FR at any particular set of VR ratios was less than preference for the FR at the same set of ratios during the descending portion. Even though the VR components were identical, preference for the FR was also a function of whether the minimum ratio was increasing or decreasing.

Within-Session Changes in Response Rate

The typical within-session increases and decreases in response rate reported by McSweeney and her colleagues (e.g., McSweeney, 1992; McSweeney et al., 1996) were not seen in this experiment. In fact, our results indicate a sensitivity to the minimum ratio that is manifested not only in relative choice proportions but also in response rate, and contradicts the suggestion by McSweeney that within-session changes are a universal phenomenon.

These changes in response rate also affect our consideration of Mazur's hyperbolic decay formula. In computing Mazur's *V*, the delay to reinforcement is sometimes computed by taking the ratio requirement and dividing by a constant; that constant is assumed to be a constant response rate, which transforms

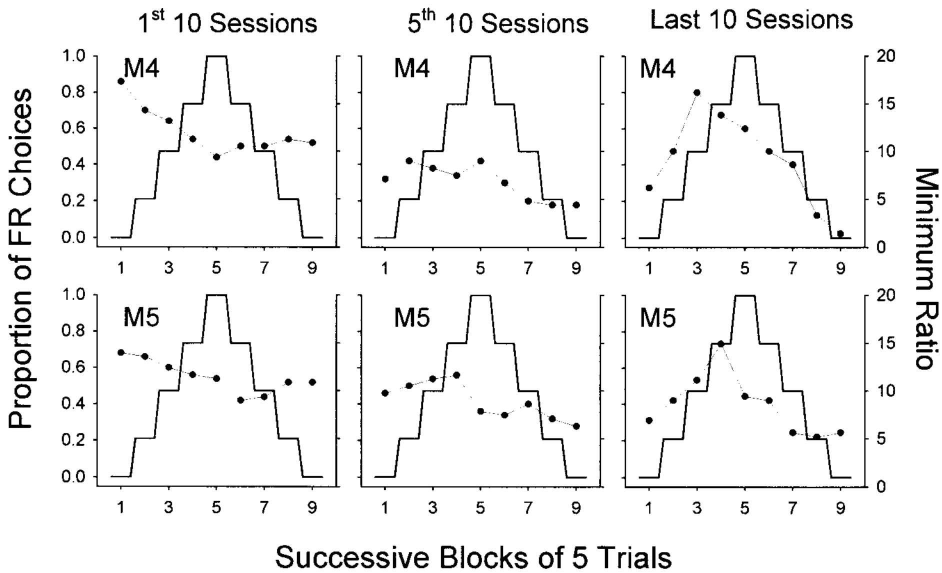

Fig. 5. Phase 3 choice proportions: Group 2. Details as in Figure 1.

the ratio into a delay. This transformation was first suggested by Mazur and Vaughan (1987) and was used by Field et al. (1996) and Neuman et al. (1997, 2000). This transformation assumes that rate of response is linearly related to ratio requirement, such that the delay to completing a work requirement of 100 would be 10 times the delay of completing a work requirement of 10. Given the variation in rate observed here, the transformation from a response ratio to a delay may be more complicated.

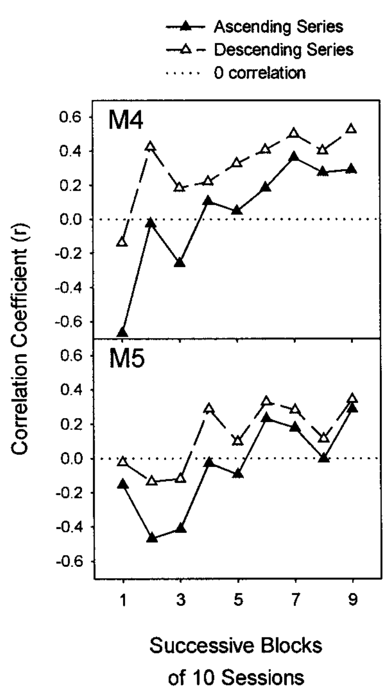

Fig. 6. Phase 3 correlations: Group 2. Details as in Figure 2.

In the present experiment, response rate increased with the minimum ratio, as found by Blakely and Schlinger (1988). This change, then, should be considered when computing value functions (like Mazur's *V*) for ratio schedules, because delay to reinforcement varies as a function of response rate. Response rate may increase with the increasing minimum ratio (and decreasing maximum ratio) because the larger work requirements present more opportunities for pausing, thus lowering rates. Further work may be required to separate any differential effects.

Perseverance in Choice Patterns

Current contingencies are viewed as an important determinant of current behavior, and this may be an unacknowledged assumption in the experimental analysis of behavior. The common use of experimentally experienced subjects can also be seen as evidence of this implicit presumption. Juxtaposed with this view is one that seeks to investigate history

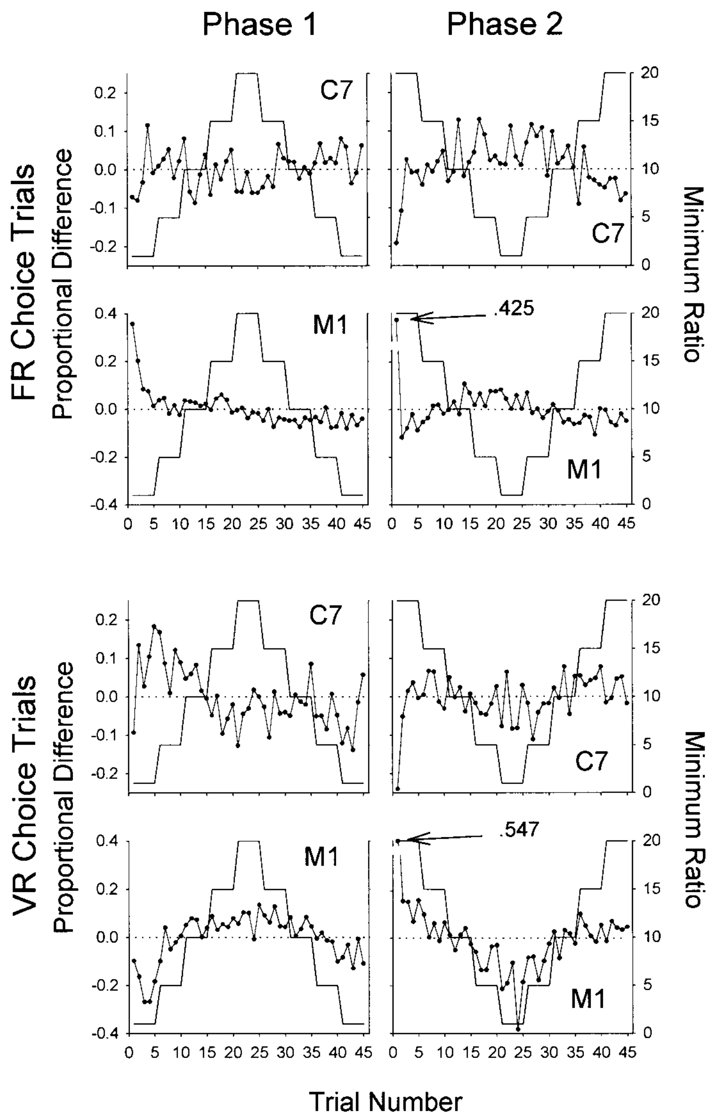

Fig. 7. Response-rate changes: Group 1. The change in response rate (left *y* axis, plotted as circles with a solid line) as a function of the trial number for C7 and M1 for Phases 1 and 2 for FR (top graphs) and VR (bottom graphs) choice trials. Response rate was computed as an average proportional difference between the rate in a trial and the rate within a session. (See text for a description of the proportional difference measure.) Data are averaged over the last 45 sessions of the exposure. Note the break in the *y* axis for M1. The solid stepped line represents the changing minimum VR ratio and is plotted on the right *y* axis.

effects, or the relative influence of past circumstances on current behavior.

In the present experiment, the extent to which choice proportions continued to cycle for M4 and M5, even though the current contingencies were not cycling, adds to the growing body of literature supporting a consideration of history effects (e.g., Baron & Leinenweber, 1995; Wanchisen, Tatham, & Mooney, 1989). Although the effects were transient, they endured for M5 for over 150 sessions, which entailed nearly 8 months of experimentation. For M4, the cycling was still evident after 150 sessions. To dismiss these effects as transient may be a mistake. Tatham and Wanchisen (1998) termed this type of effect a "transition state," one in which behavior has "not yet reached a steady state follow-

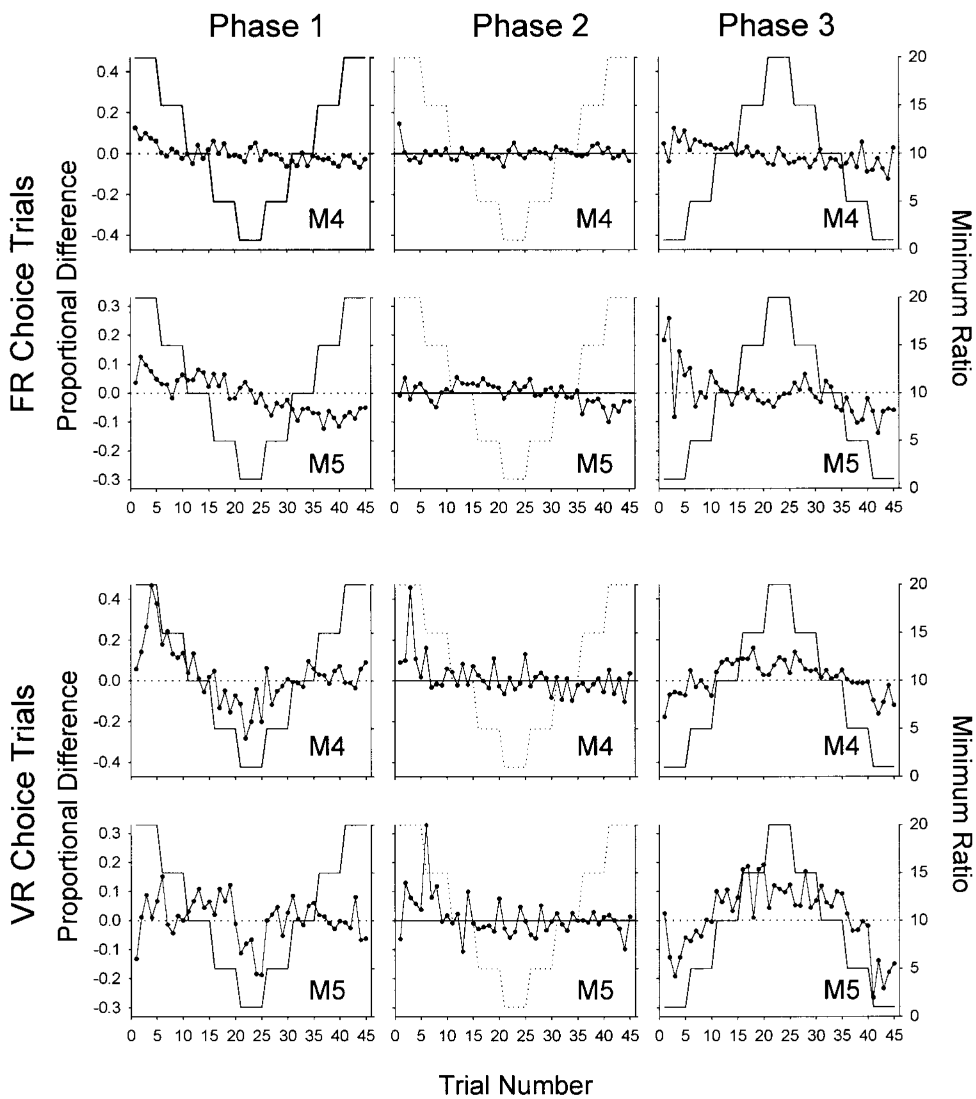

Fig. 8. Response-rate changes: Group 2. The dotted stepped lines in the middle four panels represent the prior series of changing minimum VR values. Other details as in Figure 7.

ing a change in contingencies'' (p. 242). Choice in the current experiment was clearly influenced by past exposure to particular contingencies. Moreover, the past exposure produced not just a fixed effect but a pattern of change within each session.

Certainly, an insensitivity to current contingencies would be maladaptive, but to be insensitive to historical contingencies would be just as devastating. There must be an adaptive utility to both types of sensitivities, and it seems likely that some conjunction of the two must affect current behavior. The present findings suggest that historical analyses of operant behavior should not be limited to fixed patterns of responding, but should be extended to within-session patterns and choice.

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Received February 28, 2000
Final acceptance February 12, 2001