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PAUSING UNDER VARIABLE-RATIO SCHEDULES: INTERACTION OF REINFORCER MAGNITUDE, VARIABLE-RATIO SIZE, AND LOWEST RATIO

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Pigeons pecked a key under two-component multiple variable-ratio schedules that offered 8-s or 2-s access to grain. Postreinforcement pausing and the rates of responding following the pause (run rates) in each component were measured as a function of variable-ratio size and the size of the lowest ratio in the configuration of ratios comprising each schedule. In one group of subjects, variable-ratio size was varied while the size of the lowest ratio was held constant. In a second group, the size of the lowest ratio was varied while variable-ratio size was held constant. For all subjects, the mean duration of postreinforcement pausing increased in the 2-s component but not in the 8-s component. Postreinforcement pauses increased with increases in variable-ratio size (Group 1) and with increases in the lowest ratio (Group 2). In both groups, run rates were slightly higher in the 8-s component than in the 2-s component. Run rates decreased slightly as variable-ratio size increased, but were unaffected by increases in the size of the lowest ratio. These results suggest that variable-ratio size, the size of the lowest ratio, and reinforcer magnitude interact to determine the duration of postreinforcement pauses.

Key words: postreinforcement pause, variable-ratio schedule, lowest ratio, reinforcer magnitude, run rate, key peck, pigeons

Research on postreinforcement pauses (PRPs) under fixed-ratio (FR) schedules has shown that PRPs are directly related to FR size (e.g., Felton & Lyon, 1966) and inversely related to reinforcer magnitude (e.g., Powell, 1969) and food deprivation (Sidman & Stebbins, 1954). Moreover, the effects of FR size and reinforcer magnitude have been shown to interact. Powell (1969) exposed pigeons to FR schedules of different sizes that programmed 2.5-s and 4-s access to grain. The results showed that PRPs increased more rapidly with FR size when 2.5 s of grain was programmed than when 4 s of grain was available.

Studies have shown that PRPs under variable-ratio (VR) schedules are also a function of ratio size and reinforcer magnitude (e.g., Blakely & Schlinger, 1988; Priddle-Higson, Lowe, & Harzem, 1976). Using pigeons, Blakely and Schlinger demonstrated that briefer access to mixed grain produced increases in PRPs as VR size increased. Priddle-Higson et al. showed with rats that higher concentrations of a milk solution increased PRPs as VR size increased. In these studies, VR size varied together with the size of the lowest ratio in the distribution of ratios comprising each VR schedule. (VR schedules are composed of a sequence of ratios in an irregular order.) Thus, it was unclear whether the effects were due to increases in VR size, increases in the lowest ratio, or some combination of the two variables. Results from the Blakely and Schlinger study suggested that the lowest ratio can affect PRPs. Postreinforcement pausing under VR 70 schedules was measured as a function of reinforcer magnitude. When the distribution of individual ratios included a ratio of one, PRPs were brief and unaffected by reinforcer magnitude. When the distribution did not include a ratio of one (the lowest ratio was seven), PRPs increased, as did the differences in PRPs due to differences in reinforcer magnitude. Although it appeared that changes in the lowest ratio were responsible for the effects, the conclusion was tentative because the other ratio values in the VR distributions were not identical and could have contributed to the effect. Thus, the extent to which the effects of reinforcer magnitude on PRPs depends on VR size, the size of the lowest ratio, or some combination of the two is unknown.

The present study was carried out to investigate the role of these previously confounded variables and to replicate prior work (e.g., Blakely & Schlinger, 1988). The effects on PRPs of reinforcer magnitude were evaluated in two groups. In Group 1, VR size was varied

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Table 1

The individual ratios of each schedule for Groups 1 and 2.

Schedule	Individual ratios									
Group 1										
VR 20	10	12	14	16	18	22	24	26	28	30
VR 50	10	18	24	34	44	54	64	74	84	94
VR 80	10	24	40	56	72	88	104	120	136	150
VR 110	10	33	55	77	99	121	143	165	187	210
Group 2										
VR 30	1	14	18	23	27	31	36	42	47	61
VR 30	4	14	18	23	27	31	36	42	47	58
VR 30	7	14	18	23	27	31	36	42	47	55
VR 30	10	14	18	23	27	31	36	42	47	52

while the lowest ratio was held constant. In Group 2, the size of the lowest ratio was varied while VR size was held constant. In addition to PRPs, run rates (the rates of responding following the PRP) were collected to provide a more complete profile of the interaction of reinforcer magnitude, VR size, and the size of the lowest ratio.

METHOD

Subjects

Six female White Carneau pigeons served as subjects. Birds were maintained at approximately 80% of their free-feeding weights and were individually housed with unlimited access to water and grit in a constantly illuminated room. Both groups comprised 3 birds each (P510, P20, and P5 in Group 1 and P3005, P137, and P99 in Group 2). All birds had previous exposure to VR schedules.

Apparatus

Sessions were conducted in three three-key chambers measuring 38 cm high, 41 cm wide, and 40 cm long. Only the right key (BRS/LVE) on the intelligence panel of each chamber was used. The key, which could be transilluminated red or green by an IEE projector, was 11 cm from the side wall and 25 cm above the floor and could be operated with a force of 0.2 N. A 6-cm by 6-cm aperture, centered on the front wall 10 cm from the floor, permitted feeding from the grain hopper. When raised, the hopper was illuminated with a 7-W bulb and provided access to mixed grain. The keylight was not illuminated when access to grain was available. Ambient illumination was provided by a 7-W houselight centrally located on the ceiling of each chamber. A Grason-Stadler white noise generator (Model 901B) provided masking noise through a speaker mounted on the back wall of each chamber. An exhaust fan mounted behind the intelligence panel ventilated each chamber. A PDP-8A® minicomputer (Digital Equipment Corporation), equipped with SUPERSKED® software (State Systems, Inc.) and relay interfacing, scheduled experimental events and collected data.

Procedure

Birds were exposed to multiple (*mult*) VR VR schedules in which the VR values in the two components were always equal. Either 2-s or 8-s access to grain was available in each component. Within each experimental condition, the keylight was red during one of the components and green during the other. The VR schedules were composed of 10 individual ratios presented in random order within blocks of 10 reinforcers. The initial schedule component of each session was also determined at random. Thereafter, components alternated after every 10 reinforcers, and sessions terminated after two exposures to each component (i.e., 40 trials).

Subjects in Group 1 were exposed to *mult* VR 20 VR 20, *mult* VR 50 VR 50, *mult* VR 80 VR 80, and *mult* VR 110 VR 110 schedules. The lowest ratio was always 10. The individual ratios of each VR schedule approximated an arithmetic progression (see Table 1); some individual ratios were adjusted to give the appropriate VR size. Each bird received all *mult* schedules in a different order across conditions. The key color correlated with 2-s access to grain, which was unchanged across conditions, was red for 1 bird (P510) and green for the other 2 (P20 and P5).

Birds in Group 2 were exposed to four *mult* VR 30 VR 30 schedules. In one *mult* VR 30 VR 30 schedule, the lowest ratio in both schedule components was 1; in the other three *mult* schedules, the lowest ratios were 4, 7, and 10, respectively. Each distribution of individual ratios approximated an arithmetic progression (see Table 1), although the largest ratio was adjusted such that the VR size was always 30. Each bird was exposed to all four *mult* schedules in a different order; thus, the size of the lowest ratio was varied across conditions. The key color associated with 2-s access to grain was red for Bird P137 and green for Birds P3005 and P99.

In both groups, mean PRPs and run rates (PRP and reinforcer durations were excluded from run times) were recorded in each schedule component. Conditions for both groups were changed after a minimum of 10 sessions with no visible trend in PRPs over the last five sessions.

RESULTS

Figure 1 shows mean PRPs under both components for all birds in Group 1 (left panels) and Group 2 (right panels). In general, PRPs in the 2-s reinforcer component increased systematically with VR size for subjects in Group 1. For Subject P5, mean PRPs were higher in the VR 50 condition than in the VR80 or VR 110 conditions. When they occurred, increases in PRPs in the 8-s component were smaller. For subjects in Group 2, PRPs in the 2-s component increased as the size of the lowest ratio increased. The largest increase occurred generally between the first two conditions. No consistent increases in PRPs occurred in the 8-s reinforcer component.

Figure 2 shows mean run rates under each component for all birds in Group 1 (left panels) and Group 2 (right panels). For subjects in Group 1, run rates were higher in the component with 8-s reinforcer for all birds except P510 under the VR 20 condition. In general, run rates decreased slightly with increases in VR size under both components, although this effect was greater for the 2-s than for the 8-s component. No consistent differences in run rates due to increases in the lowest ratio were observed for subjects in Group 2, although run rates were generally higher in the component with the 8-s reinforcer.

DISCUSSION

Results showed that the duration of PRPs was inversely related to reinforcer magnitude. These findings are consistent with previous investigations of pigeons responding under FR schedules (Powell, 1969) and VR schedules (Blakely & Schlinger, 1988). In Group 1, differences in PRPs produced by different reinforcer magnitudes increased with VR size. These differences resulted largely from increases in PRPs in the 2-s reinforcer component. Similar effects of varying VR size were reported in previous research with pigeons (Blakely & Schlinger, 1988) and rats (Priddle-Higson et al., 1976), although in these studies VR size and the size of the lowest ratio varied in the same direction. In Group 2, VR size did not vary and differences in PRPs as a function of reinforcer magnitude became larger with increases in the lowest ratio. Again, these differences resulted primarily from increases in PRPs in the 2-s reinforcer component. Hence, the results of Groups 1 and 2 suggest that VR size and the size of the lowest ratio can interact independently with reinforcer magnitude to determine PRPs, and that the changes in PRPs reported in previous research (e.g., Blakely & Schlinger, 1988; Priddle-Higson et al., 1976) were likely due to both variables.

The present results and those of previous work on VR schedules (e.g., Blakely & Schlinger, 1988; Priddle-Higson et al., 1976) may be understood in terms of Mazur's (1982) molecular analysis of performance under ratio schedules. Mazur suggested that the momentary probability of responding under ratio schedules is determined by a subject's proximity in time to the next reinforcer. With ratio schedules, proximity to a reinforcer is tantamount to the number of responses remaining to that reinforcer. In particular, the probability of responding should be inversely related to reinforcer proximity, and the duration of PRPs should therefore be directly related to reinforcer proximity.

In Group 1, reinforcer proximity (i.e., the number of responses remaining to the next reinforcer) was varied for all individual ratios

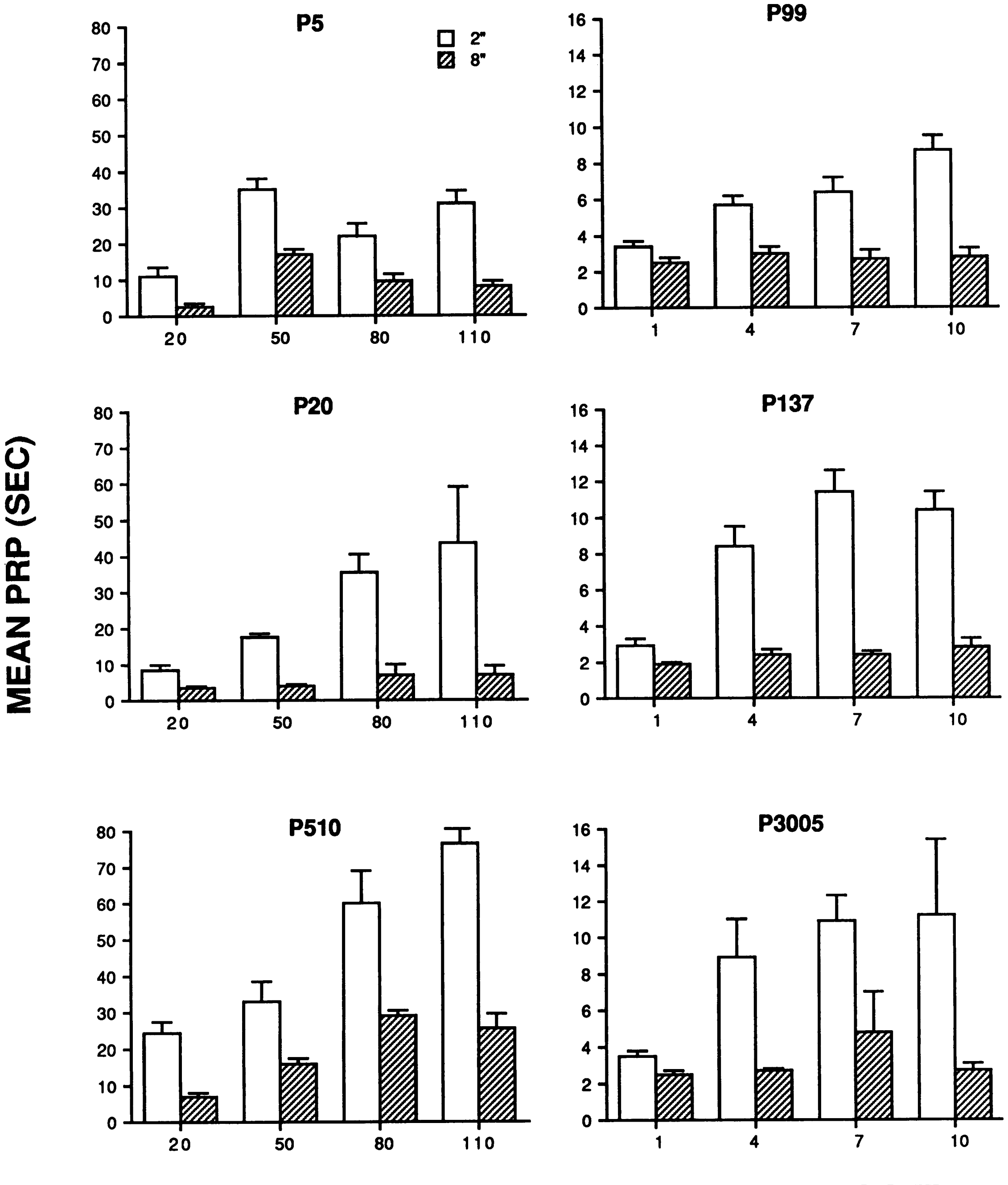

Fig. 1. Mean postreinforcement pauses in the 8-s and 2-s reinforcer components as a function of variable-ratio size for Group 1 (left panels) and the size of the lowest ratio for Group 2 (right panels). The mean of the last five sessions for each condition is presented for each schedule component. Vertical lines through the bars are the standard deviations. Note the different ordinate scales on the left and right panels.

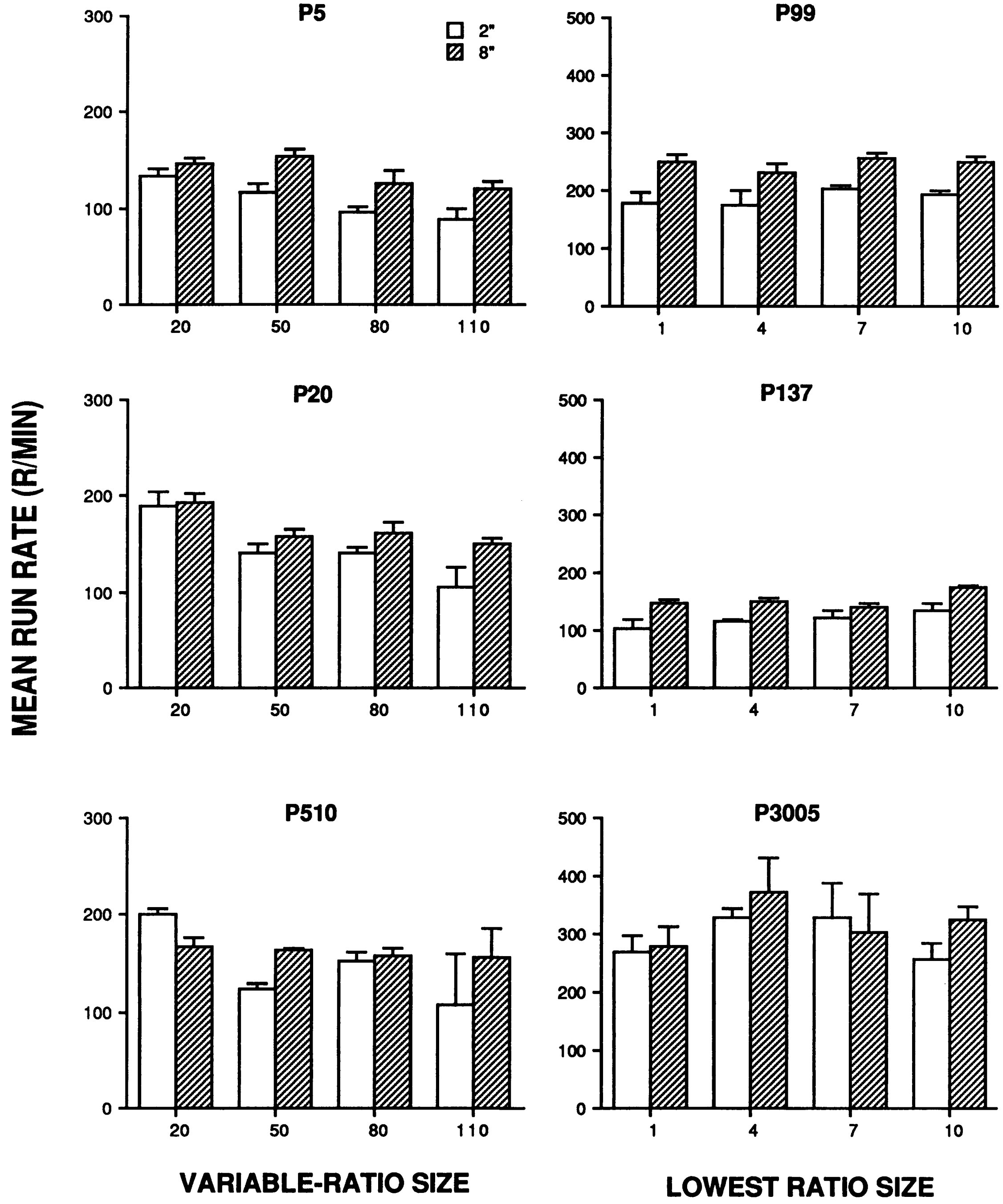

Fig. 2. Mean run rates (responses per minute) in the 8-s and 2-s schedule components for Group 1 (left panels) and Group 2 (right panels). The mean of the last five sessions for each condition is presented for each schedule component. Vertical lines through the bars are the standard deviations. Note the different ordinate scales on the left and right panels.

except the lowest (see Table 1). Thus, the number of responses remaining to the next reinforcer after any given response increased as VR size increased from VR 20 to VR 110. Reinforcer proximity was manipulated in Group 2 by varying the size of the lowest ratio. All other individual ratios (except the highest) were the same across conditions. Consistent with predictions based on Mazur's (1982) formulation, the duration of PRPs in both groups was directly related to variations in reinforcer proximity. The present results add to Mazur's analysis by showing that, with essentially equivalent VR schedules, increasing the size of the lowest ratio can increase the duration of PRPs. Mazur (1983) has also reported similar effects of manipulating the lowest ratio. When the initial FR component of a mixed-ratio (MR) schedule was relatively short (i.e., FR 2, FR 4, or FR 8), PRPs were brief relative to comparable FR schedules.

Mazur's analysis of ratio schedule performance may also help to explain observed differences in run rates. In Group 1, increases in VR size produced small, albeit systematic, decreases in run rates (Figure 2, left panels), which is similar to other findings with ratio schedules (e.g., Mazur, 1983). In contrast, the results from Group 2 showed no consistent relation between run rates and the lowest ratio (Figure 2, right panels). In Group 1, proximity to reinforcement was varied only for responses after Response 10. In fact, VR size was incremented by increasing the size of individual ratios other than the lowest ratio (see Table 1). According to Mazur's model, reinforcer proximity not only affects the probability of responding after the completion of a ratio, but also the probability of responding within a ratio run (Mazur, 1983). Thus, we may assume that observed decreases in run rates in Group 1 were due to increases in within-ratio pausing produced by varying individual ratios in the VR configuration. In Group 2, proximity to reinforcement did not generally vary for responses after Response 10 and, consequently, run rates were unaffected. Although decreasing the lowest ratio decreased run rates in previous research (Blakely & Schlinger, 1988), no such effect was observed in the present study, perhaps because the relatively low VR size (i.e., VR 30) worked against long within-ratio pauses.

These results as well as those from other studies suggest that VR size and the size of the lowest ratio may interact. Postreinforcement pauses have been shown to increase with VR size when the lowest ratio was larger than one (e.g., Group 1 of the present study; Priddle-Higson et al., 1976), but not when the lowest ratio was one (Crossman, Bonem, & Phelps, 1987; Ferster & Skinner, 1957). Taken together, these findings suggest that when a VR schedule includes even a single ratio of one, the effects of VR size on PRPs are attenuated. Interestingly, the differential effects of unequal reinforcer magnitudes were also attenuated under VR schedules with a lowest ratio of one (e.g., Group 2 of the present study; Blakely & Schlinger, 1988). Therefore, the effects of both VR size and reinforcer magnitude on PRPs appear to depend on the size of the lowest ratio. Whether the effects of the lowest ratio also depend on VR size is as yet unknown.

The present results do show, however, that the effects of VR size and the size of the lowest ratio depend on reinforcer magnitude. Recall that PRPs in the 2-s reinforcer component were more sensitive than those in the 8-s component to increases in both VR size and the size of the lowest ratio. Specifically, varying VR size (Group 1) and the size of the lowest ratio (Group 2) systematically increased PRP duration only in the 2-s reinforcer component. Similar differences have also been observed in previous research with pigeons responding under VR schedules (Blakely & Schlinger, 1988) and FR schedules (Powell, 1969). Thus, it seems that the effects on PRPs of such powerful variables as VR size and the size of the lowest ratio may be either potentiated or attenuated by varying reinforcer magnitude.

In conclusion, the present results show that the duration of PRPs under VR schedules depends not only on VR size, but also on the size of the lowest ratio, both of which are manipulated by varying different aspects of reinforcer proximity. That the size of the lowest ratio is a factor has implications for PRPs under other ratio schedules that require a variable number of responses. For example, Mazur (1983) showed that PRPs were relatively insensitive to random-ratio (RR) size where ratios of one are always possible, although their density probably decreases as responses per reinforcer increases. The occasional ratio of one may account for PRP insensitivity to RR size. Moreover, quantitative comparisons of PRPs under FR schedules with those that require a variable number of responses (i.e., MR, RR, and VR schedules) must consider the size of the lowest ratio in the latter. If the size of the lowest ratio is small, PRPs may be brief and unaffected by average ratio size, and PRPs will differ considerably from those under FR schedules. If the size of the lowest ratio varies with average ratio size, both variables may combine to increase PRPs, which will therefore resemble those under FR schedules. Studying the interaction of average ratio size and the size of the lowest ratio should provide a more complete profile of the quantitative interaction of the two variables and permit more accurate predictions of PRPs under various schedules.

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