JOURNAL OF THE EXPERIMENTAL ANALYSIS OF BEHAVIOR 1993, 59, 349-359 NUMBER 2 (MARCH)

EFFECTS OF FIXED AND VARIABLE RATIOS ON HUMAN BEHAVIORAL VARIABILITY

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The effect that ratio schedules of reinforcement had upon variability of responding was investigated in college students. Subjects were paid $0.02 contingent upon completion of eight presses, distributed in any combination across two push buttons; 256 different sequences were possible. Sequence emission was reinforced according to fixed- and variable-ratio schedules. Ratio requirements of 1, 2, 4 and 8 were presented in alternate components of a multiple schedule. The variability engendered by variable-ratio schedules was also compared to that engendered by fixed ratios. Variability increased with ratio size, irrespective of whether the schedule requirement was fixed or variable. The data demonstrate the similarity between the determinants of human and nonhuman variability, and they illustrate the role of ratio size in determining variability in operant behavior.

Key words: behavioral variability, monetary reinforcement, verbal reports, fixed-ratio schedule, variable-ratio schedule, extinction, button press, adult humans

A given response never occurs in exactly the same way twice. Although variability is a fundamental characteristic of behavior, relatively little research has addressed this phenomenon, particularly with respect to humans. Some studies have shown that variability may be controlled by consequences, including a demonstration of reinforcement of novel responses emitted by porpoises (Pryor, Haag, & O'Reilly, 1969). Pigeons have also been operantly trained to emit random distributions of right and left responses (e.g., Neuringer, 1991; Page & Neuringer, 1985). In contrast, the present paper is concerned with variability in operant behavior that is not contingently related to reinforcement, but occurs as the result of environmental events such as exposure to a reinforcement schedule.

The explicit examination of variability dates at least to a 1937 study (Krechevsky, 1937a, 1937b) of variability in reinforced maze running. Studies in recent years have focused on schedule-controlled behavior in order to elucidate determinants of variability. For example, McSweeney (1974) found, in a study involving variable-interval (VI) schedules, that variability decreased as a function of deprivation. In some respects this replicated the work of Elliot (1934), who studied food deprivation and maze-arm selection. Antonitis (1951) demonstrated that variability in the location of rats' nose pokes along a 10-cm slot in a wall was greater when extinguished than when reinforced according to a fixed-ratio (FR) 1 schedule. Similarly, Notterman (1959) showed that variability in lever-pressing force increased during extinction, relative to FR 1 reinforcement.

Intermittent schedules have been shown to engender a degree of variability intermediate between the low levels observed on an FR 1 schedule and the high variability produced by extinction. For example, Stebbins and Lanson (1962) showed that the variability of lever releasing of rats under a variable-ratio (VR) 3 schedule was intermediate between the levels produced by FR 1 and by extinction. Using a procedure similar to that of Antonitis (1951), Eckerman and Lanson (1969) found further support for the generalization that FR 1 engenders minimal response class variability, relative to random-interval (RI) schedules arranging from 0.4 to 2.0 reinforcers per minute.

Many experiments addressing behavioral

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variability have utilized a "lamp matrix" procedure. Vogel and Annau (1973) conducted the first of these studies using a 4 × 4 matrix of stimulus lamps, with pigeons as subjects. Trials began with the upper left lamp illuminated, but responding on one key extinguished the presently illuminated lamp and illuminated the lamp immediately to the right; responding on the other key also extinguished the current lamp and illuminated the lamp below the current lamp. Reinforcers depended upon illuminating the lower right lamp, which could be accomplished by pecking each key three times. Pecking either key more than three times initiated a timeout. This procedure arranged reinforcement for any of 20 possible sequences of left and right pecks. Over time there was a marked decrease in the number of different sequences emitted by the pigeons, with each bird "locking into" a particular pattern. Variability with pigeons responding on an 8 × 8 lamp matrix procedure was maximal with extinction, minimal with an FR 1 schedule, and intermediate with FR 4 and with fixed-interval (FI) 2-min schedules (Schwartz, 1980, 1982a).

These studies demonstrated an inverse relation between measures of variability and reinforcement rate: Schedules of reinforcement that arrange food very frequently generate far less variability than those that arrange food less frequently. This has been demonstrated in several nonhuman species and with several experimental preparations (Antonitis, 1951; Eckerman & Lanson, 1969; Schwartz, 1980, 1982a).

It is unclear whether variability in human behavior is affected by reinforcement rate in the same manner as variability in the behavior of other species. Schwartz (1982b) studied humans with a 5 × 5 lamp matrix procedure and found that the two extremes of reinforcement rate (FR 1 and extinction) produced results that replicated those that had been obtained with nonhumans. However, experiments with reinforcement rates between extinction and FR 1 less clearly replicated the results of research with nonhunman species. Schwartz (1982b) compared sequence completion involving a random-ratio (RR) 2 to extinction and FR 1. Although high levels of stereotypy developed more slowly under RR 2 than under the FR 1 condition, variability rapidly declined to a low level and was essentially similar under the two schedules.

It is puzzling that experiments with humans have not replicated the well-documented inverse relation between reinforcement rate and response variability found with nonhumans. One interpretation of this discrepancy is that random-ratio schedules do not enhance variability relative to FR 1 because there is a fundamental difference in the way that reinforcement rate affects human versus nonhuman behavioral variability. Data from nonhumans comparing the variability induced by RR schedules to the variability induced by FR 1 schedules do not exist, so at present this possibility cannot be ruled out. An alternative possibility is that sensitivity to reinforcement rate has not been found with humans because RR 2 and FR 1 schedules both arrange very high reinforcement rates. It is possible that results comparable to those obtained with nonhumans could be obtained with humans by using a broader range of schedule parameters. There is also the possibility that other procedural differences in human versus nonhuman experimentation could be the key—differences involving type of reinforcer, instructions, or duration of exposure to experimental sessions (see Perone, Galizio, & Baron, 1988).

The present experiment further examined this issue of determining similarities and differences in human behavioral variability compared to nonhumans. The procedures used in this experiment reinforced sequence completion according to ratio schedules. Although specific sequences were not *explicitly* reinforced, some sequences *happened* to be followed by reinforcement, whereas others were not. It is possible that sequences that were followed by reinforcement became more or less likely to be repeated than sequences that did not happen to produce reinforcers. This was assessed by determining (a) whether the likelihood of repeating the sequence that produced reinforcement was either enhanced or reduced relative to whether the sequence had not been reinforced, and (b) whether the reemission probability was affected by the number of trials since the last reinforcer was delivered.

The lamp matrix experiments reviewed above permitted only four responses on each key per each eight-member sequence of left and right pecks. In contrast, the response unit

in the present experiment was defined as eight key presses distributed between two push buttons, without the four-response limit. Subjects viewed a matrix (depicted in Figure 1) that was structured such that any combination of eight responses moved the cursor to the outside of the figure (trials always began with the cursor in the upper left corner). Every left response moved the cursor on a computer display one square down, whereas every right response advanced the cursor to the right. Reinforcement depended not upon moving the cursor to the lower right corner, as in previous studies, but simply upon moving the cursor to the outside of the figure by emitting any of the 256 possible sequences of eight left and/or right responses.

The subject received reinforcement based on fixed- and variable-ratio sequence completions. The relation between ratio size and variability was investigated by presenting four schedule sizes during every session. The relative contribution of reinforcement rate and schedule periodicity to variability was also investigated by exposing subjects to a variety of both FR and VR schedules; this issue has received minimal prior attention (but see Eckerman & Lanson, 1969).

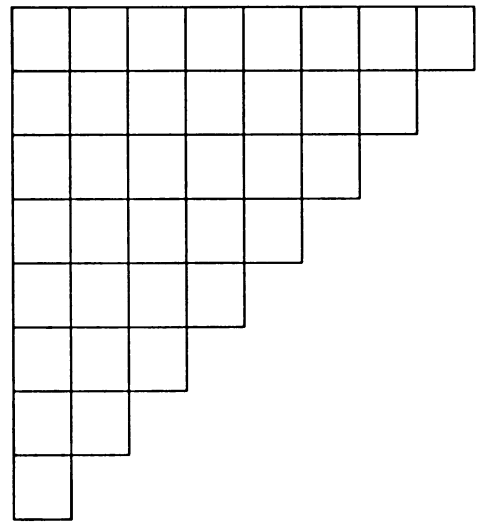


Fig. 1. A depiction of the matrix displayed to the subject on the computer screen. The cursor was initially located in the upper left block and moved one square to the right with every press of the right push button. Left presses moved the cursor down one square. Any combination of eight left and right presses caused the cursor to exit from the figure; exits were reinforced according to FR and VR schedules.

METHOD

Subjects

Five undergraduates served as subjects. Subjects were selected without regard for gender, but all subjects were male except M3. Applicants who had completed more than one course in psychology were rejected.

Apparatus

Experimental sessions took place in a windowless room (1.5 m wide by 4 m long). The subject was seated in front of a table with a green monochrome computer monitor and a response panel. The dimensions of the response panel were 30 cm wide by 9.5 cm high by 25 cm deep. The panel contained two push buttons, each 2.3 cm in diameter, with the center of the left button 10 cm from the left edge and 4.25 cm above the base of the panel. The center of the right button was 10 cm to the right of the center of the left button.

During experimental sessions, the experimenter was located in an adjoining room, separated from the subject's area by a closed door. The experimenter's room contained a microcomputer that arranged and recorded all experimental events. The computer was interfaced to the response panel via solder connections between keyboard and push button contacts.

Procedure

Subjects were asked to read and sign an informed consent form prior to the start of the first session. An important feature of this document was a clause that held that in addition to money earned during each experimental session, the subject would be paid a $1.50 participation fee for each session. The document also indicated that the participation fee would be withheld until the conclusion of the experiment; failure to complete the experiment would result in forfeiture of all retained participation fees. After signing this document, the subject was then exposed to an experimental session. Following the first session, the subject was paid for the session and given the opportunity to withdraw from the experiment.

At the beginning of each session, "Press Either Button to Begin Session" was displayed on the computer monitor. Pressing a button cleared the screen and displayed the following instructions:

> Thank you for agreeing to help me with my experiment. The object of this experiment is to earn as much money as possible. The money you earn will be reflected on the counter which will be displayed on the screen. Money is earned by pressing the left and/or right red pushbuttons. Furthermore, the only time money is earned is when the solid white square exits the figure. Whenever money is earned, the amount will be two cents.
>
> Please perform the experiment until a message appears on the screen indicating that the session has ended.
>
> PLEASE DO NOT DISCUSS THIS EXPERIMENT WITH ANYONE.
>
> Thank you, and enjoy your session.
>
> **PRESS A PUSHBUTTON TO CONTINUE**

The instructions remained on the screen until the subject pushed a button. Following the instruction display, the screen cleared and "Time for a 10″ Break" was displayed in the center of the screen. Ten seconds later the screen cleared and the experimental display was drawn.

The matrix (Figure 1) consisted of eight rows of squares. The top row of the matrix consisted of eight squares, and each successively lower line contained one less square than the prior line, left justified, with the last row containing one square. Cumulative within-session earnings were displayed on an on-screen counter centered above the matrix display. The counter consisted of "Money Earned: $X.XX" (where X represents a digit).

A small cursor (0.5 cm by 0.5 cm) was centered in the upper left matrix square at the beginning of each trial. Pressing the left button moved the cursor down one square, and pressing the right button moved the cursor one square to the right. Eight presses, distributed in any pattern ranging from all left presses to all right presses, moved the cursor out of the matrix. The cursor remained outside of the matrix for 250 ms. On trials ending without reinforcement, the cursor disappeared for 2 s, followed by its reappearance in the upper left square. On trials in which reinforcement occurred, the offset of the cursor was followed by a display, directly beneath the money counter, of the words, "2 Cents Earned." This message flashed on and off every 250 ms for 2 s. The money counter incremented by 2 cents at the end of the 2-s reinforcer display, the cursor returned to the upper left corner, and the next trial began. Button pressing had no programmed consequences during the 2-s gap between cursor offset and the initiation of the next trial.

The cursor disappeared from the matrix whenever a press followed the preceding press by less than 70 ms. The cursor reappeared in the upper left square after 2 s, and a new trial was begun. This contingency was designed to reduce the incidence of pushing both buttons essentially simultaneously (which would advance the cursor two squares at once). The instructions for subjects M4 and M5 differed from those of the other subjects in that they also stated, "Do not press the buttons at an extremely high rate—if you press too rapidly, the cursor will exit the screen before reaching the edge of the figure. This will not cost you money, but will slow you down." This pair of subjects also received supplemental feedback when they pressed the buttons with intervals of less than 70 ms between each press: "You Pressed Too Fast" flashed beneath the money counter during the 2-s timeout.

Sessions lasted approximately 30 min and terminated following 300 trials, grouped into four blocks of 75 trials. Each subject was exposed to FR 1 and to VR 2, 4, and 8 during each of the eight sessions of initial VR exposure. (FR 1, when discussed with respect to sessions in which VR schedules were also presented, will subsequently be referred to as VR 1 in order to simplify presentation.) Each VR value was presented for 75 trials per session. The component ratios of each VR were rectangularly distributed, with components ranging from one to one less than twice the VR size (e.g., VR 8 component ratios ranged from 1 to 15). The ratio required to earn each reinforcer was randomly selected from the rectangular distribution after each reinforcer. Stimuli correlated with the VR or FR value in effect were presented along the left and right edges of the monitor display (see Table 1).

VR and FR values were incompletely counterbalanced across sessions and subjects (Christensen, 1980), as illustrated in Table 2. Over the course of four sessions, each subject

Table 1

The ASCII graphics characters presented along the left and right borders of the screen as multiple schedule stimuli during FR and VR schedule presentations.

Schedule type	Schedule value	ASCII value	Character appearance
VR	1	23	‡
	2	20	¶
	4	64	@
	8	15	☼
FR	1	158	Pt
	2	234	Ω
	4	235	δ
	8	237	ϕ

was exposed to each of the four VR values in each of the four serial-presentation positions, with each value following every other value exactly once. Each subject received the same sets of four sequences, but the order in which each subject received the sequences was varied. The order of presentation recycled after every fourth session such that the order of VR presentations during Session 5 was the same as during Session 1.

Following exposure to eight sessions of the multiple VR schedule, subjects received four multiple FR sessions, counterbalanced in the same way as the VR components and sessions; this was followed by another four sessions of VR.

The screen cleared at end of each session and the following display was generated: "Thank You for Your Participation. You Earned $X.XX." The subject was then paid the amount of money displayed on the screen.

Data Analysis

Response variability was indexed by the proportion of differing sequences and by the proportion of dominant sequences. Proportions were computed for each block of 75 trials and then averaged across the four blocks of trials that comprised each session. For example, if three different sequences were emitted within a block of 75 trials, the proportion of different sequences for that block would be .04 (3/75); this value would then be averaged with the corresponding values from the remaining three blocks within the session. The dominant sequence was defined for each block as the sequence that occurred most frequently within that block; the dominant sequence was

Table 2

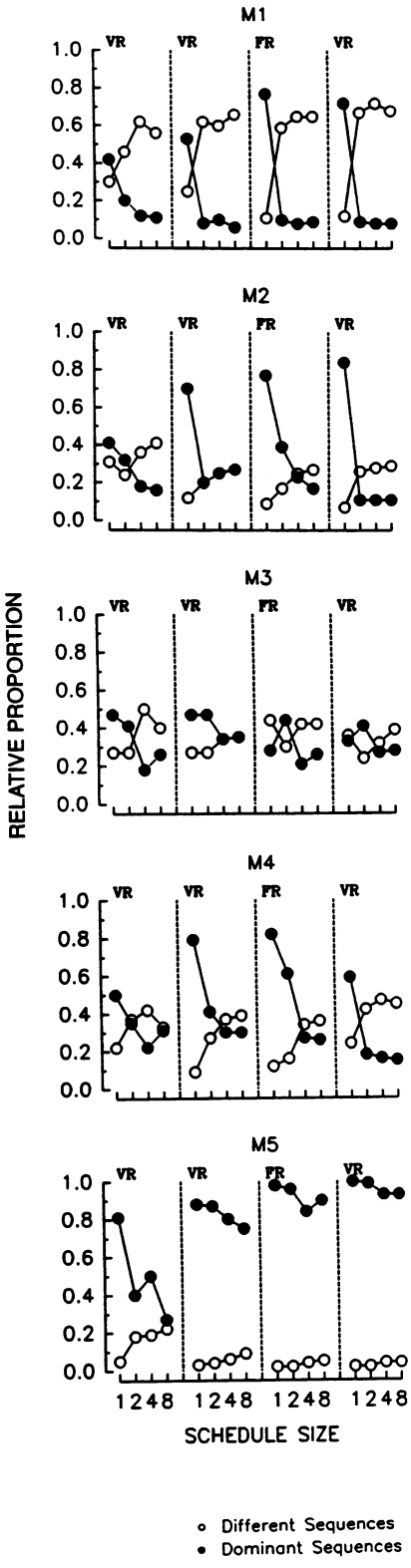
The order of presentation of each schedule size within successive four-session blocks; the order differed across subjects. Upon completion of the four-block cycle, the order of presentation was repeated.

Subject	Session	Schedule size			
M1	1	1	2	4	8
	2	8	1	2	4
	3	4	8	1	2
	4	2	4	8	1
M2	1	2	4	1	8
	2	4	8	2	1
	3	8	1	4	2
	4	1	2	8	4
M3	1	4	8	2	1
	2	8	1	4	2
	3	1	2	8	4
	4	2	4	1	8
M4	1	1	2	8	4
	2	2	4	1	8
	3	4	8	2	1
	4	8	1	4	2
M5	1	2	4	1	8
	2	4	8	2	1
	3	8	1	4	2
	4	1	2	8	4

generally consistent across blocks and sessions. The proportion of the dominant sequence was averaged across the four blocks within each session to determine the average proportion of dominant sequences for the session. Calculation of the proportion of different and dominant sequences within a block was sometimes based upon data from fewer than 75 trials because of a programming error that led to occasional data-recording errors. It was possible to identify trials containing such errors, so those trials were omitted from analysis. The data of M1, M2, and M3 were corrected for the recording error; the data of M4 and M5 did not require adjustment.

RESULTS

Variability as a function of ratio requirement is presented in Figure 2. Each data point is the average of four 75-trial exposures to a particular ratio value; each panel presents data averaged over four sessions. An exception to this was Subject M1, who inadvertently received five exposures to VR 1 and three exposures to VR 2 during Sessions 5 through 8



(the second VR panel). Open circles represent the proportion of different sequences, and filled circles represent the proportion of the dominant sequence.

Subjects M1, M2, M4, and M5 clearly displayed sensitivity to VR size on at least one of the two measures of variability. In each of these cases, fewer different sequences were emitted, and the dominant sequence was emitted more reliably during exposure to VR 1 components than during VR 8 components. This schedule sensitivity was especially evident during early sessions and generally declined by the final four sessions. By the final four sessions, 3 of the 5 subjects (M1, M2, and M4) produced roughly equivalent levels of variability during exposures to VR 2, 4, and 8, but displayed appreciably less variability during VR 1 components. Comparing the first block of VR exposures to the final block of VR exposures also indicates that the differentiation between the level of variability induced during VR 1 components and the higher components increased for these 3 subjects. The other 2 subjects (M3 and M5) showed progressively less differentiation between the high and low values. During FR exposures, all subjects displayed a relation between schedule size and variability that was very similar to that displayed during VR components.

An evaluation of whether the overall degree of sequence variability changed as a function of extended exposure to the experiment is presented in Figure 3. The proportions of different sequences and of the dominant sequence, averaged over the four components of each session without regard for schedule size, are plotted as a function of successive sessions. Each point is the result of averaging the different sequence and dominant sequence proportions for all four components presented during a particular session. Only Subject M5 displayed any appreciable decrease in variability as the experiment progressed. This subject emitted a dominant sequence on less than 65% of all trials during the first four sessions, but by the

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Fig. 2. The proportion of different and dominant sequences as a function of schedule size. Data from each of four 75-trial exposures to a schedule size within a four-session block are averaged. The schedule values were presented within a multiple schedule, with the order of component presentation different across subjects.

final four sessions M5 emitted a dominant sequence on more than 95% of all trials. A similar analysis failed to reveal systematic within-session trends in the behavior of most subjects; only M5 showed a systematic trend across blocks. Initially, this subject's variability declined across session quarters, but with successive blocks of sessions, this trend leveled off. By the final four sessions, this subject's variability was essentially unrelated to serial position.

Reinforcement and Repetition Probability

A second major issue addressed by this study was the extent to which reinforcement affected the likelihood of emission of particular sequences. That is, when a sequence produces a reinforcer, is it more likely to occur on subsequent trials? This was examined by calculating the probability that the most recently reinforced sequence would be repeated on successive trials until another reinforcer was delivered. The probability of repeating nonreinforced sequences as a function of ordinal position was also calculated and then subtracted from the probability of repeating reinforced sequences to yield a measure of the effect of reinforcer delivery on repetition probability. This approach assumes that the probability of repeating reinforced versus nonreinforced sequences should be different if reinforcement influences repetition probability.

The calculations may be illustrated by considering three response sequences that were followed by a reinforcer and that were then followed by two more sequences: LLLLRRRR RRRRLLLL LLLLLLLL (reinforcer) LLLLLLLL RRRRLLLL (reinforcer). The probability of repeating reinforced sequences would be computed by comparing the reinforced sequence (LLLLLLLL) to the sequence occupying the first ordinal position following reinforcement (LLLLLLLL). The sequences are the same so the probability of repeating a reinforced sequence in the first

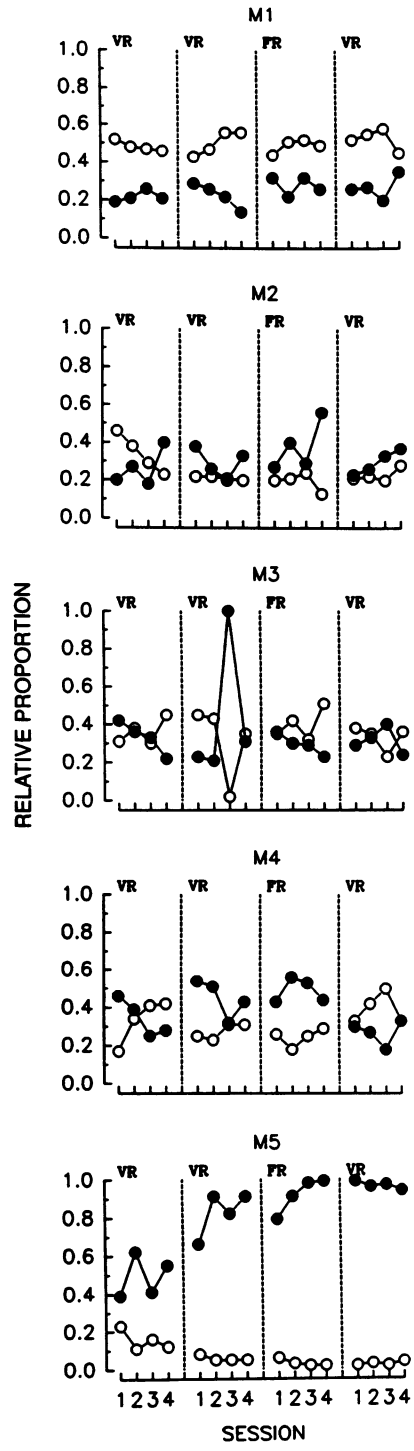

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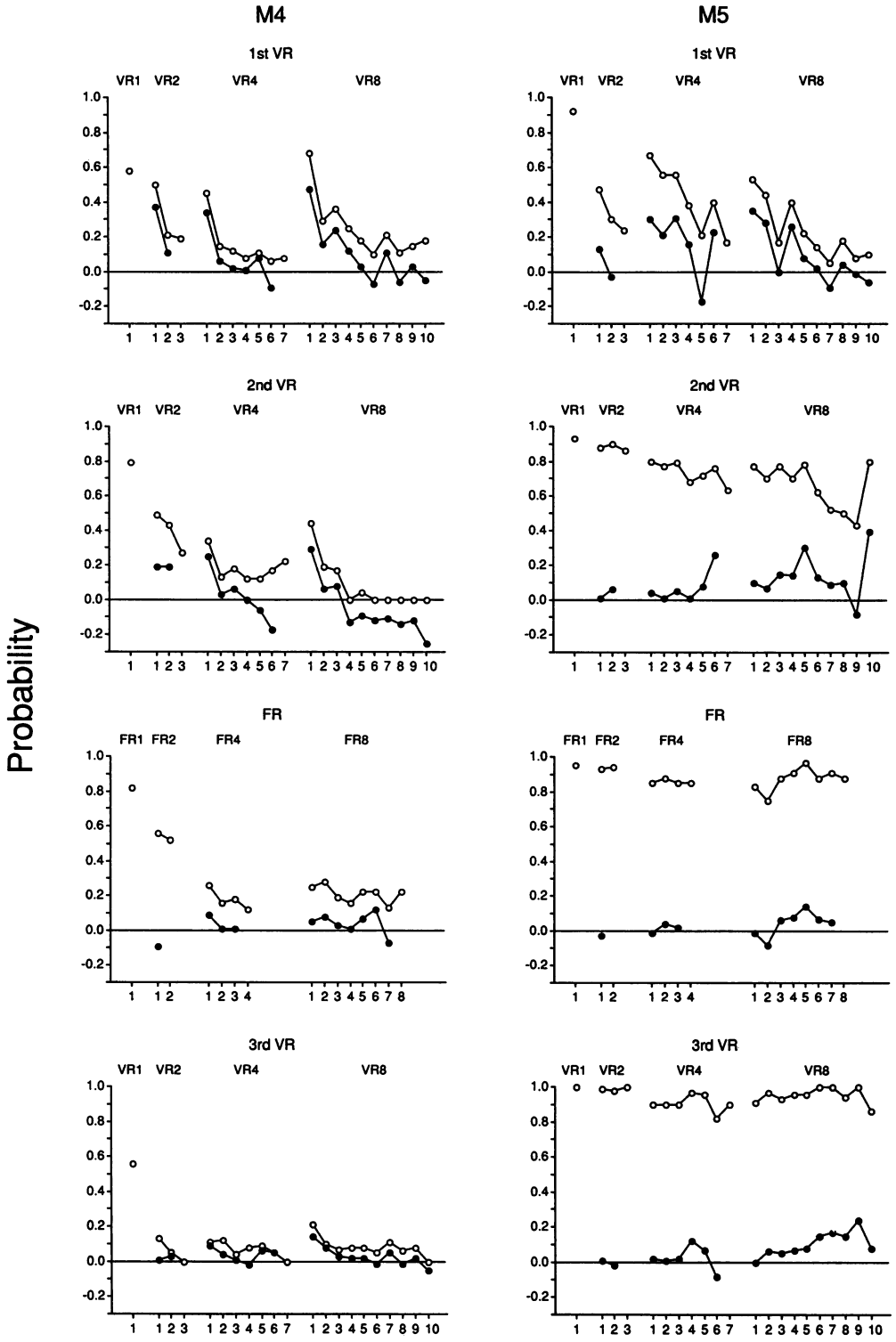
Fig. 3. The proportion of different and dominant sequences as a function of sessions. Within each session, data are averaged across schedule sizes. This presentation facilitates assessment of trends in variability as a function of extended experimental exposure.


M4
M5
1st VR
2nd VR
FR
3rd VR
VR1 VR2 VR4 VR8
FR1 FR2 FR4 FR8
Probability
Trials Since Reinforcement

postreinforcement ordinal position is 1. The reinforced sequence (LLLLLLLL) is then compared to the sequence in the second postreinforcement position (RRRRLLLL) and classified as different, yielding a repetition probability of 0 for the second ordinal position following reinforcement. The analysis of the reinforced sequence stopped at the second ordinal position due to the delivery of the next reinforcer; if a subsequent reinforced sequence was followed by three sequences prior to another reinforcer delivery, the analysis of that sequence would continue through the third ordinal position.

A similar set of calculations may be performed on the sequences that were not immediately followed by reinforcement. First, each nonreinforced sequence may be categorized with respect to whether it was repeated on the next trial. LLLLRRRR, RRRRLLLL, and LLLLLLLL were not repeated on the immediately following trials, so the probability of repeating a nonreinforced sequence on the next trial was 0. The probability of repeating a nonreinforced sequence two trials later may be calculated. LLLLRRRR was followed two trials later by LLLLLLLL, yielding a repetition probability of 0. RRRRLLLL was not included in the calculation because a reinforcer was delivered.

The specific effect of reinforcement at each ordinal position may then be computed by subtracting the probability of repeating a nonreinforced sequence from the probability of repeating a reinforced sequence. The difference in repetition probability on the first trial following reinforcement was 1 (1 − 0) and was 0 (0 − 0) on the second trial following reinforcement, indicating that reinforcement increased repetition probability on the immediately following trial but had no effect on repetition probability two trials following reinforcement. Negative values indicate that reinforcement produced a relative decrease in repetition probability relative to nonreinforcement.

The filled circles of Figure 4 show the effect of reinforcement on repetition probability for Subjects M4 and M5 (M1, M2, and M3 are not shown due to occasionally missing data). The rectangular distribution of ratio components permits examination of repetition probabilities through the third, seventh, and 15th ordinal positions following reinforcement for VR 2, 4, and 8 and the second, fourth, and eighth positions for FR 2, 4, and 8. The probability of repeating a nonreinforced sequence can be computed for one less ordinal position than is possible for a reinforced sequence. Consequently, the probability of repeating a reinforced sequence is plotted in Figure 4 for one more ordinal position than has been plotted for the nonreinforcement effect measure. The number of opportunities to categorize sequences declines as a function of ordinal position, so presentation of data for VR 8 was limited to the 10th ordinal position. This ensured that all data points in Figure 4 are based upon at least 10 sequences. Data for both measures are plotted for a comparable number of ordinal positions because the effect of reinforcement could be calculated through the 10th ordinal position. The data plotted for M4 indicate that the probability of repeating the sequence that produced reinforcement was typically increased by reinforcement to the greatest extent on the trial immediately following reinforcement. The increase in repetition probability following reinforcement declined over subsequent trials, often to near 0. The effect of reinforcement on repetition probability on the first trial following reinforcement was greatest during the first two blocks of VR exposure and declined during the subsequent FR and VR exposures. Across all blocks of sessions and schedule sizes (except FR 2), it can be seen that reinforcement increased the likelihood of repeating a sequence above the baseline likelihood of repeating a nonreinforced sequence. This effect declined over successive trials, and in many cases reinforcement actually decreased the likelihood of repeating a

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Fig. 4. Relations between reinforcement and sequence repetition as a function of trials since reinforcement and schedule size, plotted as a function of successive four-session blocks. Open circles indicate the probability of repeating the most recently reinforced sequence on the nth trial since reinforcement. Filled circles reflect the effect of reinforcement on repetition probability. The effect of reinforcement on repetition probability was computed by subtracting the probability of repeating a nonreinforced sequence from the probability of repeating a reinforced sequence. Data for M4 and M5 are presented because there are no missing data for these subjects.

sequence after several nonreinforced trials. On lower schedule sizes, reinforcement increased the likelihood of repetition at almost all numbers of trials since reinforcement. Particularly during VR 8, however, the probability of repetition after about six trials postreinforcement decreased relative to nonoccurrence of the sequence.

The panels portraying repetition data for M5 show data similar to those of M4, particularly during the first VR exposure and, to a lesser degree, during the second VR exposure. In both of these blocks of sessions, the effect of reinforcement on repetition declined as a function of trials since reinforcement. During FR sessions and the final block of VR sessions a different pattern emerged—the probability of repeating a reinforced sequence was largely unaffected by reinforcement.

DISCUSSION

This experiment demonstrated that human behavioral variability increases as a function of ratio size. This is consistent with accounts of nonhuman subjects and extends the evidence for cross-species generality of ratio size as a determinant of variability.

These results indicate comparability between the sensitivity of variability in human and nonhuman behavior to schedules of reinforcement. These results stand in contrast to those of Schwartz (1982b), in which variability in human behavior was not shown to be sensitive to ratio size. The reasons for this discrepancy are not clear, in part because the experimentation was not designed to factor out the many procedural issues that may have accounted for the differing results. Although the experimentation did not isolate the procedural differences that may have accounted for these discrepant results, there are several possibilities that could be tested. Probably the most important difference in the two experiments is the shape of the matrix and the degree of procedural constraint. Schwartz's 5 × 5 matrix included the four-per-key constraint that permits only 70 different sequences to be emitted. In contrast, the present experiment used a modified matrix that permits up to eight presses on each button, so that 256 different sequences could be reinforced. Thus, it is possible that Schwartz's matrix was not a sufficiently sensitive gauge of the effects of reinforcement schedules on variability.

A related possibility is that because Schwartz's matrix reinforced exiting at only one location (the lower right corner), subjects may have maintained a single pattern that caused the cursor to exit at this point. In contrast, the matrix used in the present experiments had nine exits. This may have supported more variability and discouraged locking into a limited number of routes leading to a single exit point.

A rather surprising but clear-cut result is that equivalent levels of variability were maintained during both VR and FR conditions. The variability induced by VR schedules apparently was not due to the varying numbers of response units required from reinforcer to reinforcer, because the FR schedules induced comparable levels of variability. The functional equivalence of these schedules in the present experiment suggests that rate of reinforcement controls the degree of variability induced by response-based schedules.

This experiment also provides a clearer understanding of the manner in which reinforcement rate affects behavioral variability by illustrating the effects of reinforcement on the likelihood of specific members of the reinforced class of behavior. Data from Subjects M4 and M5 were analyzed in a manner that illuminates the extent to which reinforcement affects the likelihood that the most recently reinforced sequence will be repeated after a given number of trials since reinforcement. It was found that reinforcement affected the likelihood of the most recently reinforced sequence, in relation to its baseline probability, as a function of trials since reinforcement. This is especially interesting because few studies have examined the effect of reinforcement upon individual members of a response class composed of members of equal effort and eligibility for reinforcement. Given that it is virtually axiomatic within behavior analysis that reinforcement increases the probability of recurrence of members of a response class such as lever pressing (Ferster & Skinner, 1957), analysis of the effects that individual reinforcers have upon specific members clearly merits closer attention.

The data presented in Figure 4 on repetition probability suggest a possible mechanism whereby variability is affected by schedule size. Reinforcement had the greatest effect on repetition during the first few trials following reinforcement; after several consecutive nonreinforced trials, however, the probability of

emission of the most recently reinforced sequence decreased below the baseline (i.e., nonreinforcement) probability of repetition. This may account for the greater variability engendered by high ratio sizes relative to lower ratio sizes, because on higher schedule values more sequences are emitted far enough from the reinforced sequence for extinction to decrease the probability of repetition. Almost all sequences engendered by lower ratio sizes are emitted within the range of trials during which reinforcement substantially increases repetition probability. Further support for this assertion (that changes in the effect of reinforcement on repetition probability influence variability) can be drawn by comparing data from M5 displayed in Figures 2 and 4. It can be seen that the greatest effects of reinforcement on repetition occurred during the same blocks of trials in which the greatest effects of ratio size on variability were obtained. The corresponding data for M4 less clearly support this possibility, particularly during the block of FR sessions. Although this relation between schedule effects on variability and repetition is correlational, it suggests interesting directions for future research.

The present research illustrates the importance of carefully examining apparent discrepancies between results obtained with different species. Additional research should be conducted to understand better the molecular characteristics of behavioral variability. Among the potential benefits that could derive from an enhanced understanding of variability would be a technology for systematically modulating variability in human behavior. Such a technology could have important implications in education and the arts, because it would facilitate development of creativity in endeavors in which creativity is beneficial. Conversely, it might be useful to foster consistency in critical behavior such as looking both ways when crossing an intersection. As the study of variability proceeds, additional principles and applications are likely to unfold.

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Received January 10, 1992
Final acceptance September 1, 1992