HUMAN PERFORMANCE ON CONJUNCTIVE FIXED-INTERVAL FIXED-RATIO SCHEDULES

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Eighteen young adults performed a lever-pulling task for money. Subjects were initially exposed to a fixed-interval 80-second schedule and subsequently to one of three conjunctive schedules in which the added fixed-ratio requirement was set at either 10, 80, or 120 responses. Three fixed-interval response patterns emerged: high constant rate, intermediate rate, or low rate, with most subjects displaying the last. Conjunctive performance was related to the subjects' prior fixed-interval patterns and the conjunctive ratio requirements. Low-rate subjects tended to optimize reinforcement (maximum reinforcers for minimum responses) on conjunctive schedules. Response rate was directly related to ratio requirements. Subjects' performance closely corresponded to their verbal statements of the contingencies.

Key words: conjunctive schedules, fixed-interval performance, history effects, verbal behavior, lever pull, adult humans

Ferster and Skinner (1957) defined the conjunctive fixed-interval fixed-ratio schedule (conj FI FR) as one in which a response is reinforced only after the passage of a given time interval and the completion of a given number of responses. The conjunctive schedule is analogous to many human work situations, in that a period of time is available to do a given amount of work. People may distribute their work within that time in many fashions: get it over with quickly, wait until the last moment, or work steadily throughout the allotted period.

Infrahuman research has focused on the initial findings of Herrnstein and Morse (1958) that the addition of an FR requirement to an FI reduced both responding and reinforcer frequency, and altered the pattern of responding within the interval. Herrnstein and Morse also found an inverse relation between the size of the ratio and response rate. Responses and reinforcement decreased even when the number of responses required by the ratio was less than the mean number generated by the simple FI schedule. The response pattern consisted of a postreinforcement pause followed by

a burst of high rate responding, after which responding decreased to a slow steady rate that endured until the reinforcer was delivered.

Barrett (1975) removed and reinstated the component schedules in a conjunctive schedule. The resultant data closely resembled those reported by Herrnstein and Morse (1958). Under the conj FI FR condition, responding was characterized by an initial pause followed by a high rate of responding that decreased to a lower steady rate until the reinforcer was delivered. Conj FI FR response rates were lower than corresponding FI rates; however, interreinforcement time was unaffected.

Zeiler and Buchman (1979) conducted a parametric analysis of conjunctive schedule control with pigeons. The FI component was varied between subjects, with values ranging from 5 to 30 min. The FR requirement was varied within subjects, with values ranging from 25 to 400 responses. They found that overall response rate first increased as a function of the size of the ratio but then decreased with further increments, regardless of the size of the interval. This bitonic function contrasts with the monotonic relation described by Herrnstein and Morse (1958) and was attributed to the interaction of response-requirement and reinforcement-frequency functions. Larger ratio requirements increased responding so long as reinforcement frequency remained unaffected. Still larger ratios decreased reinforce-

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ment frequency, thus decreasing response output.

No data are available on human performance on the conj FI FR schedule. Performance on a schedule characteristic of other species may not be characteristic of humans, who are often insensitive to reinforcement-schedule control (Matthews, Shimoff, Catania, & Sagvolden, 1977). For example, humans may not display a "scaloped" response pattern when exposed to an FI schedule, their sensitivity to this schedule being determined by many factors in addition to the schedule (Baron, Kaufman, & Stauber, 1969; Long, 1963; Matthews et al., 1977; Poppen, 1972; Weiner, 1962, 1964, 1969). The factors responsible for human performance on the conjunctive schedule may be the same as other species, or additional variables may be important for a complete account.

METHOD

Subjects

Nine male and nine female college students who answered an advertisement soliciting persons for a "problem solving experiment" served. They were told that they could earn approximately \$3.00 to \$4.00 per hour depending upon their performance. The subjects ranged in age from 19 to 32 yr; the mean age was 24 yr. The subjects had no previous history of responding on a reinforcement schedule in an experimental situation.

Apparatus

The experimental chamber was a sound-attenuated room measuring 4 m by 4 m, lighted by eight 60-W fluorescent rods. Solid-state programming and recording apparatus (BRS-Foringer) was in an adjoining room. Responses were automatically recorded on counters and cumulative recorders.

Subjects were seated before a table upon which was mounted a metal console, 55 cm high by 38 cm wide. The upper panel of the console sloped away from the subject at a 30° angle. In the center of the upper panel was a digital counter with an adjacent green jewel lamp. A red jewel lamp was in the upper left corner of the panel. In the lower vertical panel was a brass Lindsley manipulandum, requiring a pull of 125 g through a distance of .75 cm to close a microswitch.

Procedure

All subjects were initially exposed to an FI 80-sec schedule for 10 sessions. At the eleventh session they were divided into three groups of six subjects, each group receiving a different FR component, 10, 80, or 120 responses, added to the FI 80-sec.

To control for possible differential FI response patterns between groups, a matching procedure equated the number of high- and low-rate FI responders in each group. Subjects were exposed to a FI schedule in cohorts of six and their median response rate was determined for their tenth session. The three subjects whose response rate was above the median (high rate) were randomly distributed among the three conjunctive groups, as were the three subjects below the median (low rate). All subjects were exposed to their respective conjunctive schedule for 10 sessions.

At the start of the first session all subjects were instructed as follows:

By responding on this console [experimenter points], you will be able to earn money. Your task is to accumulate points on this counter [experimenter points to counter]. Points can be earned by operating this lever [experimenter pulls lever one time]. Each time a point is earned, it will register on the counter and the green lamp [experimenter points] will be briefly illuminated. Each point is worth nine cents. Points will only be available after the red lamp [experimenter points] comes on indicating the commencement of the session. When the red lamp goes off the session is over and no more points will be available. The session will be thirty minutes long.

Questions were answered by either reading the appropriate parts of the instructions or by telling the subject, "That's up to you to figure out." Subjects were asked to leave books, watches, and other distracting materials outside the experimental room.

Sessions were 30 min long. Subjects attended a minimum of five sessions per week. When subjects had more than one session a day, the sessions were separated by at least one hr. Subjects were paid by check according to their earnings on the task at the completion of their participation in the study. After completing the project, subjects were given a questionnaire, similar to that of Leander, Lippman, and Meyer (1968), asking them to rank a series

of five statements according to the degree to which they represented the conditions for earning points in Sessions 1 to 10 and 11 to 20. Open-ended questions asking the subjects to describe their strategy for earning points and any changes they may have noticed were also included. The statements described fixed- and variable-intervals, fixed- and variable-ratios, and a combination condition.

RESULTS

Response rate and the distribution of responses within the FI were determined for each subject. The 80-sec FI was divided into four 20-sec quarters plus an overtime (OT) period. During the simple FI condition, only responses that produced points registered in the OT period. During the conjunctive condition, responses were registered into the OT period when the ratio requirement was not completed by the time the 80-sec interval had elapsed. Responses were cumulated for each of these time periods and converted to percentages of total responses. Figure 1 shows the distribution of responses across the FI quarters for the final FI and final conjunctive sessions. The final session represented stable performance for most subjects, in that the response pattern (see below) shown on the last session also occurred on at least the final three sessions in 32 of 36 cases.

Upon analysis of both temporal patterning (Figure 1) and response rate data from the tenth FI session (Figure 2), three general categories of FI responding emerged: a high-constant pattern, an intermediate pattern, and a low-rate pattern. The high-constant FI pattern was characterized by response rates exceeding 80 per min with less than 30% of responses occurring during the fourth quarter plus the OT period. Figures 1 and 2 indicate that three subjects (ER, SR, TK) displayed this pattern. The intermediate FI pattern was characterized by response rates of greater than 10 but less than 80 responses per min, with 30% to 70% of responses occurring during the fourth quarter plus OT period. Five subjects (SS, DM, FF, WZ, SA) exhibited the intermediate pattern. The low-rate pattern was characterized by response rates of five or less per min with at least 85% of responses occurring during the fourth quarter plus OT. Ten subjects (EK, JS, JF, ES, JP, KC, SK, AA, MG, PK) displayed the low-

rate pattern. Although the matching procedure used to assign subjects to groups was simply a median split into high- and low-rate responders, the net effect was an even allocation across groups of patterns defined by rate and distribution.

The effect of the added FR conjunctive component depended upon the existing FI patterns and the size of the FR requirement. Overall, 17 of 18 subjects increased their response rate in the conjunctive condition over that in the FI condition. Across groups, the rate of conjunctive responding was directly related to the size of the FR requirement. Conjunctive responding near the optimal rate occurred for nine of ten low-FI-rate subjects. (Optimal rate is defined as the lowest response rate necessary to obtain all available reinforcers within the 30-min session; it is shown as the darker portion of the bars in Figure 2.)

Five of six subjects on conj FI 80-sec FR 10 showed an increased response rate, although one showed slightly decreased response rate, compared to their FI performance (Figure 2). All three subjects who had developed the low-rate FI pattern (EK, JS, JF) and one who had developed the intermediate FI pattern (SS) approximated the optimal response rate of 7.5 responses per min on the conj FI 80-sec FR 10. The other two subjects (one high-FI-rate pattern and one intermediate) responded at rates much greater than the optimal rate.

The distribution of responses varied across subjects on conj FI 80-sec FR 10, as shown in Figure 1. The high-FI-rate subject (ER) continued to respond constantly throughout the interval. Both intermediate-FI-rate subjects (DM, SS) showed extended postreinforcement pauses and made most responses in the last quarter of the interval. Of the three low-FI-rate subjects, one (EK) continued to make extended postreinforcement pauses; one (JS) displayed a "reverse scallop," making most responses in the first quarter of the interval; and one (JF) responded at a steady pace throughout.

All subjects on conj FI 80-sec FR 80 increased response rates over those of the FI condition (Figure 2). Three subjects (ES, JP, KC), all previously displaying the low-FI-rate pattern, produced terminal rates near the optimal rate of 60 responses per minute, whereas three subjects (SK, FF, SR), one each of the high-, intermediate-, and low-FI-rate patterns, re-

sponded at rates substantially beyond what the contingency required.

The distribution of responses across subjects on conj FI 80-sec FR 80, shown in Figure 1, was less varied than in the previous group. Four subjects (SR, FF, KC, SK) responded at a steady pace throughout the interval; one had previously developed the high-FI-rate pattern, one the intermediate FI rate, and two the low FI rate. Of the two remaining low-FI-rate subjects, one (JP) continued to show extended postreinforcement pauses, making most responses in the last quarter, and one (ES) developed a "reverse scallop" pattern.

All subjects on conj FI 80-sec FR 120 increased response rate from the terminal FI rate (Figure 2). Four subjects, three low-FI-rate and one intermediate, responded near the optimal rate of 90 responses per minute. The remaining two subjects, one high-FI-rate and one intermediate, produced rates much higher than optimal. All subjects, regardless of previous FI pattern, produced high constant response patterns, although some variations occurred (see Figure 1).

In the final FI session, only one subject (JF) obtained less than 95% of the available points; whereas in the final conjunctive session, three

Fig. 1. Distribution of responses within the fixed-interval for the final sessions of subjects on FI 80-sec and conj FI 80-sec FR 10 (left column), conj FI 80-sec FR 80 (middle column), and conj FI 80-sec FR 120 (right column).

Fig. 2. Fixed-interval and conjunctive response rate for the final sessions of subjects on FI 80-sec and conj FI 80-sec FR 10 (top row), conj FI 80-sec FR 80 (middle row), and conj FI 80-sec FR 120 (bottom row). Optimal response rate for each schedule (see text) is shown by the dark bottom portion of each bar. The numbers in parentheses indicate the percentage of the possible reinforcers actually obtained.

subjects (EK, JS, SA) obtained less than 95% of the available points (Figure 2). When switched from the FI to the conjunctive condition, five subjects increased their points, 11 subjects earned an equal number, and two subjects decreased points earned.

Subjects' performance on the FI and conjunctive schedules was generally related to their correct verbalization of the contingencies. Subjects ranked five statements (describing an FI, VI, FR, VR, or combination) according to the degree to which they described the conditions for earning points in Sessions 1 to 10 and 11 to 20. As shown in Table 1, low-FI-rate subjects all selected the FI statement; nine of ten selected the FI + FR combination as descriptive of the conjunctive condition, and nine responded near the optimal conjunctive rate. All five intermediate-FI-rate subjects also selected the FI statement; two selected the FI + FR combination for the conjunctive condition and responded near the optimal rate, whereas three selected other statements and responded well beyond the optimal rate. Of the three high-FI-rate subjects, two selected the VR statement for both conditions; one selected the FI statement and reported she pulled the lever to "count" the interval.

DISCUSSION

The present study indicates that three FI response patterns are discernible, based on response rate and distribution of responses throughout the interval, and that such patterns are related to subsequent conjunctive-schedule performance. Previous studies have described two general patterns of human FI performance: high-rate responding, characterized by high constant rates with no postreinforcement pause; and low-rate responding, characterized by lower response rates with a postreinforcement pause for all or part of the succeeding interval. The latter category may be divided into those subjects who display a "DRL-like pattern" and those who show some postreinforcement pause but also respond several times during the interval, which we have termed "intermediate." Efforts to determine the variables responsible for human FI responding (e.g., Lowe, 1979; Matthews et al., 1977; Poppen, 1972; Weiner, 1969) have focused only on the high- and low-rate patterns. A more complete account may also need to

Table 1

Fixed-interval and conj FI-FR response patterns, and subjects' selection of a questionnaire statement that "best described the schedule." H = high-FI-rate, I = intermediate-FI-rate, L = low-FI-rate, RS = reverse scallop; see text. The statements described a fixed-interval (FI), variable-interval (VI), fixed-ratio (FR), variable-ratio (VR), or a combination schedule. Asterisks designate those subjects responding near the optimal conjunctive rate; see Figure 2.

Subject	FI Pattern	Conj. Pattern	FI Statement	Conj. Statement
ER	H	H	VR	VR
DM	I	I	FI	FI
SS	I	I	FI	FI + FR*
EK	L	I	FI	FI + FR*
JS	L	RS	FI	FI + FR*
JF	L	I	FI	VI + VR*
SP	H	H	FI	FR
FF	I	H	FI	FI + VR
ES	L	RS	FI	FI + FR*
JP	L	H	FI	FI + FR*
KC	I	H	FI	FI + FR*
SK	L	H	FI	FI + FR
TK	H	H	VR	VR
WZ	I	H	FI	FI + FR*
SA	I	H	FI	FR
AA	L	H	FI	FI + FR*
MG	L	H	FI	FI + FR*
PK	L	H	FI	FI + FR*

consider the "intermediate" category, which more closely resembles the classic infrahuman "scallop."

The increased conjunctive response rate as a function of ratio size is similar to the findings of Zeiler and Buchman (1979), who described a bitonic output function in which rates first increased and then decreased with increasing ratio size. It is likely that, with even larger ratio and interval requirements, we would also have found a point at which response output declined. Herrnstein and Morse (1958) found only an inverse relation between response output and ratio size. Differences in schedule parameters, as well as species and individual variables, make direct comparison of these studies difficult.

Patterns of conjunctive responding differed in the current study as compared to previous research. Herrnstein and Morse (1958), Barrett (1975), and Zeiler and Buchman (1979) provide similar descriptions of conjunctive FI-FR response patterns: an initial pause followed by a period of high-rate responding and then a decrease to a lower rate until reinforcement. In

the present study, several conjunctive response patterns emerged, with no one exclusively representing all subjects. Regardless of the ratio requirement, the three subjects who displayed high FI rates continued to respond at high undifferentiated rates. Otherwise, subjects in the conj FI 80-sec FR 10 group produced the greatest variety of response distributions, displaying pause-and-run, steady-pace, or run-and-pause patterns. The same patterns were exhibited by the subjects in the conj FI 80-sec FR 80 schedule, though most emitted high constant rates. Little variability was apparent in response patterns produced by the conj FI 80-sec FR 120 subjects, as all exhibited high constant response patterns. Such a pattern is necessary to maximize reinforcement at higher ratio values. At lower ratio values, a variety of response patterns are equally effective and are probably controlled by any of numerous factors that have been shown to affect FI performance (Poppen, *Note 1*).

Conjunctive-schedule performance appeared to be related to the prior schedule control exhibited by the FI; this provides another example of history effects (Weiner, 1969) occurring in complex schedules (Poppen, 1982). Since the differences in FI-schedule control were not produced by experimental procedures, the relationship between such control and subsequent conjunctive performance is a matter for further study. For example, FI-schedule control could be manipulated by giving subjects prior experience on FR or DRL schedules (Weiner, 1969) and observing the effects on subsequent conjunctive control. The means by which prior schedules exert their effects is also an area needing further research. One promising direction concerns the subjects' verbalization of the contingencies. Such a formulation may serve as a "rule" (Skinner, 1969), which affects performance on subsequent schedules.

It is apparent that adult human subjects generally approximate the contingency requirements and optimize reinforcement on conj FI FR schedules, though the limits of such control were not determined. Such contingency control was closely related to the subjects' verbalization of the contingencies to which they had been exposed. There was good correspondence between "saying" and "doing" (Risley & Hart, 1968). It is not possible from the present study to determine the direction of influence between verbal and nonverbal behavior. That

is, the subjects' behavior may have come under contingency control that they subsequently tacted, or they may have emitted various verbal "hypotheses" that controlled subsequent behavior, or there may have been an interaction between these modes of behavior. Further research, in which verbal and motor performance are simultaneously monitored, is needed to clarify the development of "rules" and their interaction with contingencies (Lowe, 1979; Skinner, 1969).

REFERENCE NOTE

1. Poppen, R. *The fixed-interval scallop in human affairs*. Manuscript submitted for publication.

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