EFFECTS OF REINFORCER DURATION ON RESPONDING IN TWO-LINK CHAINED INTERVAL SCHEDULES

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Each of five pigeons was exposed to two or more durations of access to mixed grains on two-link, chained, interval schedules in which both links were identical fixed-interval or variable-interval schedules. Response rates were an increasing function of reinforcer duration for both initial and terminal links. For both types of interval schedules, initial-link response rates were more sensitive to reinforcer duration than were terminal-link response rates. The present results, together with prior ones, suggest that chaining and choice procedures are each sufficient for demonstrating substantial sensitivity of responding to changes in reinforcer duration.

Key words: reinforcer duration, chain schedules, variable-interval schedules, fixed-interval schedules, key peck, pigeons

The effects of reinforcer duration on responding have been examined in several studies with responding reinforced on simple variable-interval (VI) and fixed-interval (FI) schedules, on concurrent schedules, and on multiple schedules. When simple VI schedules have been used either different subjects have been exposed to different reinforcer durations or the same subjects have been exposed to a series of conditions with reinforcer duration varied across conditions. In either case, reinforcer duration has had only a modest effect upon response rates. For example, Jenkins and Clayton's (1949) group data suggested that longer durations sustain higher rates of responding: with reinforcer durations of two and five sec, they obtained response rates (on a VI 1-min schedule) of 40 and 52 responses/minutes, respectively. Comparable effects of reinforcer duration were reported with simple FIs, under some conditions, by Collier and Siskel (1959). Stebbins, Mead, and Martin (1959) reported a more robust effect with a FI 2 schedule: as reinforcer amount (sucrose concentration) increased tenfold, one rat's re-

sponse rate increased threefold and the second rat's response rate increased fourfold. On the other hand, Keesey and Kling (1961) and Catania (1963) found little or no effect of reinforcer duration. Indeed some studies have reported a nonmonotonic effect of reinforcer amount of responding; i.e., with sufficiently large reinforcers rate of responding may decline (e.g., Guttman, 1953), presumably due to satiation. With concurrent schedules different reinforcer durations are associated with otherwise equivalent and concurrently available VI schedules. Here sensitivity to reinforcer duration is obvious (e.g., Catania, 1963; Fantino, Squires, Delbrück, & Peterson, 1972; Schneider, 1973). Indeed, relative response rates on each of the two schedules (the number of responses on one schedule divided by the sum of the responses on both) sometimes equal or "match" relative reinforcer duration (the duration of reinforcement provided on one schedule divided by the sum of the durations on both), as they did for two of three pigeons in Catania (1963).

Other investigators have used multiple schedules of reinforcement in which equal VI or FI schedules alternate but in which reinforcer duration is different in the two components. Although some of these studies have found little or no sensitivity of overall response rates to reinforcer duration (e.g., Jensen & Fallon, 1973, and Lowe, Davey, & Harzem, 1974, with rats, and Staddon, 1970, with pigeons)—under some circumstances even finding an in-

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This research was conducted while the authors were at the University of California, San Diego and was supported by NIMH Grant MH-20752 to the University of California, San Diego. Reprints may be obtained from either Karl W. Lendenmann, The Longwoods Research Group Limited, 2161 Yonge Street, Toronto, Ontario, Canada, or Edmund Fantino, Department of Psychology, C-009, University of California, San Diego, La Jolla, California 92093.

verse relation between response rates and reinforcer amount (see Osborne, 1978, for a discussion)—Merigan, Miller, and Gollub (1975) showed that large effects could be obtained. Specifically, Merigan *et al.* assessed the effects of reinforcer duration on responding in a multiple VI 2-min VI 2-min schedule (mult VI 2-min VI 2-min) under three conditions. In one condition the two components of the multiple schedule were arranged on separate keys, and the duration of each component was brief (5-sec). Thus, the schedule alternated back and forth, mimicking, in some respects, a concurrent schedule (except that, in a concurrent schedule, the subject's responding controls the alternation). In this condition, Merigan *et al.* obtained matching of relative response rates to relative reinforcer duration in three of four pigeons. Only an intermediate degree of sensitivity to duration (comparable to that reported by Shettleworth and Nevin, 1965, also with pigeons and multiple schedules) was obtained, however, when both 5-sec duration components were scheduled on the same key or when the two components were scheduled on separate keys but component duration was 2-min instead of 5-sec.

Based on the work reviewed thus far, it appears that use of a choice procedure (or short-duration multiple-schedule procedures) increases the likelihood of obtaining a robust effect—comparable to matching—of reinforcer duration upon response rate. This conclusion is supported by two studies of reinforcer duration utilizing the concurrent-chains procedure developed by Autor (Note 1, 1969) and reviewed by Fantino (1977). In this procedure choice is measured in terms of rate of response during two equal concurrently available schedules (the initial links of the chains) each leading to a different, separately available, stimulus. The stimulus of each terminal link is associated with its own schedule of primary reinforcement. Neuringer (1967) used a variant of this procedure in which a single peck on either of two initial links (choice phase) produced an FI 5-sec terminal link. In Schwartz (1969), the initial links were FI schedules and the terminal links fixed-ratio schedules. In both studies different reinforcer durations were associated with the two terminal links. Both found that whereas choice varied directly with reinforcement duration, rates of responding in the terminal links were insensitive to changes in

duration. Thus, results with the concurrent-chains procedure seem to provide a "within-procedure" demonstration that reinforcement duration affects choice in a behaviorally impressive way but has relatively little effect on responding in single-key comparisons.

Choice procedures are not the only ones that allow the effects of reinforcer duration on behavior to emerge clearly. Osborne (1978) has pointed out that single-operandum procedures may also provide clear results if the effects of reinforcer duration on nondirected interim activities and directed terminal activities (Staddon & Simmelhag, 1971) are considered separately. Several studies employing runways have also obtained clear effects of reinforcer amount on runway speed (e.g., Crespi, 1942; Logan, 1960). If the runway does provide a sensitive apparatus for studying the effects of reinforcer amount, perhaps it is the chain-like character of the runway that is responsible. If so, responding in the links of a simple two-link chain schedule should also be highly sensitive to reinforcement duration. The present study was conducted as a systematic investigation of the effects of reinforcer duration on responding in two-link chains with both fixed- and variable-interval schedule components. Such a study also permits assessment of the relative sensitivity to reinforcer amount of responding in the initial vs. terminal links of the chain. Findley (1962) found a much clearer effect on responding in the initial link of a chain VI VI schedule when the rate of reinforcement was varied in the terminal link with reinforcer duration constant. The present study holds reinforcer rate constant while varying reinforcer duration in the terminal link.

METHOD

Subjects

Five pigeons, maintained at approximately 80% of their free-feeding weights, served. All pigeons had previous experience on intermittent schedules of reinforcement (with reinforcer durations in the range of 2.75 to 4.0 sec).

Apparatus

A standard Gerbrands laboratory apparatus for pigeons, which measured 15 by 15 by 18 in. (30 by 30 by 38 cm) was used. The front wall of the chamber contained two translucent Gerbrands response keys mounted 3.75 in. (9 cm)

apart and 8.5 in. (21 cm) from the floor of the cage. The right key could be illuminated by either green or red bulbs. The left key remained unlit for all sessions. Key pecks meeting a standard force requirement of at least 15 N were required to operate the key. The chamber also contained a solenoid-operated hopper (Gerbrands Magazine) for food reinforcement (mixed grains), which came to 2 in. (5 cm) above the floor, as well as two 6-W miniature ceiling lamps for chamber illumination.

Procedure

Schedules were two-link chains in which the two links were identical. For two pigeons, the schedule was Chain FI 30-sec FI 30-sec, and each of the other three pigeons were exposed to one of the following chain schedules: FI 90-sec FI 90-sec; VI 2-min VI 2-min, and VI 4-min VI 4-min. Key color was always green in the initial link and red in the terminal link. Duration of reinforcement (presentation of a Gerbrands magazine full of mixed grains) was varied in a semirandom order over three values, 2 sec, 5 sec, and 8 sec, except that a 3-sec duration was also used for one pigeon and another pigeon was exposed to durations of 2 and 8 sec only. Sessions were conducted daily.

Each reinforcement duration was in effect until visual inspection of the response rates and cumulative records indicated that response rates were stable over the last ten sessions, which took an average of 18 sessions. The daily sessions lasted until 30 reinforcers had been delivered. A 3-sec blackout followed each food delivery. A masking noise was used, and standard programming equipment was housed in an adjoining room.

RESULTS

The magazine durations are written above each bar in Figure 1 and the sequence of durations from left to right represents the order in which the durations were presented. The data shown are averaged over the last ten sessions of

Fig. 1. In order of exposure from left to right, duration of hopper presentation (written above bars) and resultant ten-session mean response rates for each of five pigeons. Deviation lines give the standard error of the mean. The left-hand side of the figure gives the initial-link data and the right side shows the terminal-link data.

each condition (transition data were not particularly informative). Responses per minute as a function of magazine duration are shown for both initial and terminal links.

Note the consistency and systematic relationships in the initial-link data. For example, during the initial links each subject's 8-sec response rates are greater than the subject's 5-sec response rates, which in turn are greater than the subject's 2-sec response rates. Although there is a similar trend for the terminal-link performances, there are also several exceptions.

When data for replications of the same magazine duration are averaged within subjects, the generally linear and increasing data in Figure 2 result for both the initial and terminal-link data. Least-squares regression lines were obtained for response rates as a function of reinforcer durations for these initial and terminal-link performances averaged within subjects and are also shown in Figure 2 (except for Bird 3 which was exposed to only two reinforcer durations). The equations and percentages of variance accounted for by each equation are given near the lines.

Whereas the slopes for initial and terminal-link lines are often similar, the intercepts are much larger for the terminal links, indicating a higher average rate of responding on the food-reinforced link, even at low reinforcer durations. Moreover, the terminal-link data are generally more variable, as indicated by the distribution of the data points, and the percentages of variance accounted for by each line. The initial-link functions account for an average (across four functions) of 94% of the variance, whereas the terminal-link functions account for an average of only 67% of their respective variance.

Initial-link intercepts are often close to zero, indicating that initial-link performance is maintained weakly with a 2-sec magazine duration. For example, for three of the five birds, less than five responses per minute were made in the initial link when the magazine duration was 2-sec, and only one of five pigeons responded more than 10 times per minute at this duration. Cumulative records (not shown) indicated that patterns of responding in both the initial and terminal links of the FI schedules were of the typical break-and-run variety generated by shorter FI durations (e.g., Schneider, 1969). This was true for all the reinforcer du-

Fig. 2. The filled circles represent the initial-link and the unfilled circles the terminal-link mean response rates averaged within subjects over different replications, as a function of magazine duration. Regression lines, equations, and percentages of variances accounted for (in parentheses) are also given.

rations except during the initial links when the reinforcer duration was 2-sec and the response rates were low (in these cases there was sometimes a small reduction in obtained rates of reinforcement). On the VI schedules, the responding was uniform and constant.

A recent study by Nevin, Mandell, and Yarovsky (1981) examined the effects of terminal-link reinforcer duration on response rates in multiple chained schedules with random-interval (RI) components. They plotted the ratio of initial-link to terminal-link response rates as a function of terminal-link reinforcer duration (their Figures 2 and 6). Our data—with FI and VI components—are plotted in the same way in Figure 3. For each subject, the ratio increased with reinforcer duration, indicating that initial-link response rates are more sensitive than terminal-link response rates to changes in reinforcer duration.

DISCUSSION

Response rates in both links of chained interval schedules were highly sensitive to the reinforcer duration at the end of the chain. The sensitivity of terminal-link response rates to reinforcer duration differs from the relative indifference reported by Neuringer (1967) and by Schwartz (1969) using a concurrent-chains procedure. When Findley (1962) assessed response rates in a chain VI 4 VI X schedule with X varying across conditions from ½ to 8 minutes (but with reinforcer duration constant), he found that "the first operant was dramatically affected by the reinforcement conditions of the second operant" (p. 127) but found only a small effect on the second operant (his Figure 4, p. 128). The present results suggest that when reinforcer amount is varied, responding in both links may be strongly affected. The results in Figure 3 suggest that initial-link response rates are even more sensitive to changes in terminal-link reinforcer duration than are terminal-link response rates. These findings, for both FI and VI schedules, extend those of Nevin et al. (1981) who found the same result when they varied reinforcer duration in multiple chained interval schedules with RI components.

The primary aim of the present study was to assess the extent of sensitivity of response rates in the links of chained interval schedules to variations in reinforcer duration. The results

suggest that choice procedures are not necessary to obtain clear sensitivity. Since choice procedures—under some circumstances—do show matching of responding to duration (e.g., in Catania, 1963) apparently choice and chaining procedures are each sufficient, but not necessary, for demonstrating substantial sensitivity of responding to changes in reinforcer duration. Since the concurrent-chains procedure combines two features that enhance sensitivity to reinforcer duration—choice and

Fig. 3. Ratios of initial-link to terminal-link response rates as a function of terminal-link reinforcer duration for each of five pigeons.

chaining—we would expect responding to be especially sensitive to reinforcer duration with this procedure. Indeed, the two studies using the concurrent-chains procedure to assess the effects of reinforcer duration with pigeons have found matching (Schwartz, 1969) and even “overmatching” (Neuringer, 1967) of choice responses to relative reinforcer duration.

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Received February 27, 1981

Final acceptance September 21, 1981