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University of Montana
PAUSING, TIME ALLOCATION, AND CONSTRAINT ON OUTPUT

by

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Reinforcement is the strengthening of behavior that results from the delivery of a reinforcer. However, the delivery of a reinforcer also produces a temporary cessation of the behavior that produced the reinforcer: the postreinforcement "pause" (PRP). Schedules of reinforcement define the relationship between behavior and its reinforcing consequences. Simple schedules provide reinforcement either for a specified amount of behavior (fixed-ratio schedule or FR), or the first response after a specified amount of time has elapsed (fixed-interval schedule or FI).

While FR and FI schedules impose different relations between responding and reinforcement, previous research indicates that PRP duration may be controlled by the time between reinforcers or the interreinforcement time, regardless of the scheduling arrangement. Other research suggests that pause duration may be controlled by only the portion of the interreinforcement time spent responding (work time) and not the entire interval. However, it is difficult to measure the actual time spent responding as research in this area typically defines responses as discrete units (key pecks in pigeons and lever presses in rats) with no real temporal properties.

In the present study reinforcement was provided for a continuous response: lever holding. Time spent responding was defined as the time the lever was held down. Lever holding requirements per reinforcer ranged from 16 sec to 90 sec across experimental conditions. Under these conditions, reinforcement was provided for cumulative lever holding that met the specified duration. For each of these conditions in which stable pausing was obtained, the average time between reinforcers was computed and used as the fixed interval value for the successive condition (yoked-FI). Under the yoked-FI conditions, reinforcement was provided for the first lever holding response after the fixed interval elapsed. A comparison was made between PRP duration and work time and interreinforcement time under different scheduling arrangements with similar interreinforcement times. Results showed that mean interreinforcement time provided a better estimate of pause duration than did work time under either scheduling arrangement.
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Behavior is any activity of an organism; operant behavior is any identifiable unit of behavior that is controlled by its consequences (Skinner, 1938). A reinforcer is a stimulus change that affects operant behavior antecedent to that stimulus change; reinforcement is the strengthening of operant behavior that results from the delivery of a reinforcer (Skinner, 1953; Zeiler, 1977).

The relationship between behavior and its reinforcing consequences defines a schedule of reinforcement. Reinforcement schedules typically arrange the delivery of a reinforcer after specific response or time requirements are met. Fixed-ratio (FR) schedules deliver reinforcers contingent on the emission of a fixed number of responses. Variable-ratio (VR) schedules deliver reinforcers contingent on the emission of a variable number of responses. Fixed-interval (FI) schedules deliver reinforcers contingent on the first response after a fixed interval of time has elapsed. Variable-interval (VI) schedules deliver reinforcers contingent on the first response after a variable interval of time has elapsed. These four basic schedules and various combinations of them are used to study the maintenance and temporal control of behavior (e.g., Nevin, 1973; Kelleher, 1966), response output and dynamics (Zeiler, 1977, 1979; Zeiler & Buchman, 1979), sensitivity of behavior to its consequences (e.g., Rider, 1977, 1980, 1982), choice behavior (e.g., Baum, 1974; Herrnstein, 1961,
While reinforcers, by definition, strengthen the behavior that precedes them, delivery of a reinforcer also produces a temporary cessation of the behavior that produced the reinforcer: the postreinforcement "pause." The duration of this pause is roughly proportional to the number of responses required or the amount of time that must pass for the delivery of the next scheduled reinforcer (e.g., Felton & Lyon, 1966; Nevin, 1973; Rider, 1980; Schneider, 1969; Skinner, 1938).

Schedules that provide reinforcers periodically, such as FR and FI schedules, are characterized by pronounced pauses immediately after reinforcement, followed by a relatively rapid rate of responding until the next reinforcer delivery. Postreinforcement pause duration increases monotonically with increases in the FI (Ferster & Skinner, 1957; Harzem, 1969; Innis & Staddon, 1971; Lowe & Harzem, 1977; Lowe, Harzem, & Spencer, 1979; Schneider, 1969; Shull, 1970, 1971; Skinner, 1938; Wilson, 1954) or FR (Boren, 1961; Felton & Lyon, 1966; Inman & Cheney, 1974; Mowrer & Jones, 1945; Powell, 1968, 1970; Weissman & Crossman, 1966). Schedules that provide reinforcers aperiodically, such as VR and VI schedules, are characterized by relatively short pauses after reinforcement, followed by steady responding until the next reinforcer delivery (Farmer & Schoenfeld, 1967; Ferster &
Skinner, 1957; Lachter, 1971; Mazur, 1983; Rider & Kametani, 1987). Rates and patterns of responding vary greatly as a function of the particular schedule in effect, but postreinforcement pausing is characteristic of all schedules, even when each response is reinforced (see Harzem & Harzem, 1981, Rider, 1987, and Shull, 1979, for reviews).

Postreinforcement pausing has been found to occur following various types of reinforcers, including water (Premack, 1962; Rider, DeGrandpre, & Kametani, 1986), intracranial brain stimulation (Blough, 1980; Schmidt, McCaleb, & Merrill, 1977), condensed milk (Harzem, Lowe, & Priddle-Higson, 1978), and miscellaneous trinkets (e.g., Long, Hammock, May, & Campbell, 1958). Postreinforcement pausing has been studied with a variety of species, including dogs (Salziger & Waller, 1962), cats (Molliver, 1963), chickens (Lane, 1961), horses (Meyers & Mesker, 1960), mynah birds (Hake & Mabry, 1979), rabbits (Inman & Cheney, 1974; Rubin & Brown, 1969), and octopus (Crancher, King, Bennett, & Montgomery, 1972).

Research with primate subjects raises some interesting questions as to the generality of schedule control. Humans and monkeys often do not display the same stereotypical patterns of responding seen in nonhuman subjects (i.e., the break-run patterns of responding typified by rat and pigeon subjects under FR and FI schedules). Nonetheless, both monkeys (e.g., Laursen, 1972) and humans (e.g., Leander,

Variables identified to account for the departure of response patterns of adult human subjects from the response patterns of nonhuman subjects have included the introduction of verbal instructions (Baron, Kaufman, & Stauber, 1969;
Matthews, Shimoff, Catania, & Sagvolden, 1977), and the use of self-instruction (Latives & Weiss, 1963). Thus, the development of verbal behavior appears to coincide with the changes in schedule-controlled response patterns in the human subjects. Another factor influencing human performance on periodic schedules appears to be the particular history of responding under different schedules (Weiner, 1969).

Pausing does not result from fatigue and it does not represent a recovery period from past responding. When two different FR requirements regularly alternate, pause duration is relatively short following the larger FR and relatively long following the smaller FR (Alferink & Crossman, 1975; Crossman, 1971; Crossman & Silverman, 1973; Dews, 1958; Ferster & Skinner, 1957); Findley, 1962; Keehn, 1964, 1965; Patrikiou & Keehn, 1964; Inman & Cheney, 1974; Rider, 1979, 1983; Weissman, 1960). Thus, pause duration appears to be controlled by upcoming schedule requirements rather than by the schedule requirement just completed (Griffiths & Thompson, 1973; but see Rider, 1987 for some qualifications).

Pause duration exceeds the time devoted to collecting or consuming the reinforcer. This implies that the reinforcer functions as a discriminative stimulus that signals the unavailability of the reinforcer for some period of time and/or as an inhibitory stimulus that temporarily
suppresses responding (Harzem & Harzem, 1981).

Several studies have examined the discriminative effects of reinforcers with percentage-reinforcement or reinforcement-omission procedures. Such procedures modify traditional reinforcement schedules by omitting a percentage of the scheduled reinforcers. Often, a blackout or other stimulus change is presented in lieu of the omitted reinforcer. In this way, responding following a reinforcer delivery can be compared with responding following a blackout or other stimulus. Thus, if a reinforcer functions simply as a discriminative stimulus, the stimulus replacing the reinforcer should function in a comparable manner. However, pauses are shorter and response rates higher following blackouts or other stimuli that replace the omitted reinforcer (omission effect) than following the reinforcer itself (Davenport, Flaherty, & Dyrud, 1966; Davenport & Thompson, 1965; Kello, 1972; McMillan, 1971; Staddon & Innis, 1966, 1969). For example, Kello (1972) employed an FI 2-minute schedule that occasionally replaced food delivery with either a blackout, a blackout plus the light and "click" of the solenoid-operated food magazine, or no stimulus. Pauses after food was omitted without a replacement stimulus were the shortest in duration. Pauses were longer following either a blackout or a blackout plus light and "click" of the food magazine. Pauses were longest following food delivery. This omission effect suggests that
in addition to its discriminative functions, delivery of a reinforcer also inhibits responding.

If reinforcers function as discriminative stimuli that signal the temporary unavailability of another reinforcer, then a question arises as to what aspect of the experimental situation the reinforcer signals: number of responses or work required for another reinforcer, or the time that typically passes before another reinforcer is forthcoming. Several studies have attempted to separate the effects of response number and interreinforcement time on postreinforcement pause duration. These experiments have produced equivocal results.

Barrett (1976) employed a conjunctive FI adjusting-FR schedule in which reinforcers were delivered when both FI and FR requirements were completed. Initial FR requirements, ranging from 90 to 900, were decreased during the postreinforcement pause until the first post-pause response occurred. Thus, longer pauses resulted in smaller response requirements. Pause duration increased with increases in the initial FR requirement up to about FR 300. Because of these increased pause lengths, interreinforcement time remained relatively unchanged as initial FR requirements increased to FR 300. But with initial FR requirements larger than 300, pause duration decreased, even though the relatively short postreinforcement pauses resulted in larger response requirements. The corresponding
increases in interreinforcement time were substantial. Similarly, running rates at first increased as the initial FR requirement was raised but declined at initial FR requirements larger than 300. Thus, although interreinforcement time remained relatively unchanged at small and intermediate initial FR values, pause duration and running rate both increased with increasing FR values. These results suggest that pause duration may have been differentially reinforced, since longer pauses lowered the response requirement. But since these effects were only obtained with initial FR requirements of 300 or less, they also indicate that the extent to which pause duration can be differentially reinforced is limited.

Crossman, Heaps, Nunes, and Alferink (1974) used a two-component multiple schedule to study the effects of response number on postreinforcement pause duration. Multiple schedules arrange successive presentations of two or more schedules, with each schedule correlated with a different exteroceptive stimulus. In the Crossman et al. experiment, one component of the multiple schedule was an FR, the value of which was varied from FR 25 to FR 300 over experimental conditions; the other component was an FR 2-plus-timeout, where the first post-pause response initiated a timeout or blackout of varying duration. The first response after the timeout was reinforced. In Experiment 1, timeout duration matched the median "work" time (i.e., the time between the
first post-pause response and reinforcer delivery) that was obtained under the simple FR of the other component. This procedure kept work times relatively equal in both components of the multiple schedule. In Experiment 2, timeout duration was varied to create interreinforcement intervals that matched the median time between reinforcers obtained under the simple FR of the other component. Thus, while in the FR 2-plus-timeout component, after the postreinforcement pause was terminated the duration of the subsequent timeout was adjusted to produce an interreinforcement interval that matched the time between reinforcers obtained under the previous simple FR component. This procedure kept interreinforcement times relatively equal in both components of the multiple schedule. Pause duration in each component increased as the FR requirement was increased. However, pauses were generally longer in the simple FR component than in the FR 2-plus-timeout component in both experiments. With either work times or interreinforcement times equated, one difference between the multiple-schedule components was the number of responses required per reinforcer: 25 to 300 responses in the simple FR component, and two responses in the FR 2-plus-timeout component. The authors concluded that it is not the time between the first post-pause response and reinforcer delivery or the time between successive reinforcer deliveries that controls postreinforcement pause duration,
but the number of responses required per reinforcer. However, this conclusion should be taken with caution. Changes in stimuli (i.e., the blackout in the FR 2 component) signaled changes in the schedule requirement, thus providing the animal with different information than that in the simple FR component. Differences in the response requirement in the two components were confounded with this difference in the stimuli associated with the two components.

Shull (1970) compared simple FI schedules to tandem FR 1 FI schedules (response-initiated FI schedules), in which reinforcers were contingent on the completion of an FR 1 requirement followed by an FI requirement that ranged from 3.75 seconds to 60 seconds over experimental conditions. The FI requirement that followed the FR 1 was considered the portion of the interreinforcement interval devoted to responding: the work time. While interreinforcement time under simple FI schedules is unaffected by postreinforcement pause duration, time between reinforcers under response-initiated FI schedules would be shortest if the response initiating the FI component occurred immediately after reinforcement. Instead, postreinforcement pause duration increased as the FI requirement increased, both under simple FI schedules and under the response-initiated FI schedules, and generally occupied about half to two-thirds of the total interreinforcement interval. Shull concluded that pause
duration was controlled by the work time. But since pause duration was roughly a constant proportion of the total interreinforcement interval, regardless of the scheduling arrangement, pause duration may have been controlled by the overall time between reinforcer deliveries.

Harzem, Lowe, and Spenser (1978) attempted to reinforce minimum postreinforcement pause durations differentially. The first post-pause response was reinforced provided a minimum interval of no responding had passed; otherwise, responses were reinforced according to an FI schedule. The time requirements of each of these components were varied individually. FI values ranged from 15 seconds to 480 seconds, and minimum postreinforcement pause requirements ranged from 10 seconds to 50 seconds. Pause durations under these complex schedules were compared to pause durations under simple FI schedules. Although the complex schedules provided differential reinforcement of long pauses, pause duration was consistently shorter under the complex schedules than under the simple FI schedules. For example, under a complex schedule that reinforced the first response after a postreinforcement pause of 20 seconds or longer, or the first response after 60 seconds regardless of pause length, pauses were substantially shorter than under the simple FI 60-second schedule. Fewer pauses met the 20-second requirement stipulated by the complex schedule than when the 20-second requirement was absent. This may have
resulted from the fact that, under the complex schedule, some responses were reinforced after about 20 seconds, thereby reducing the average interreinforcement time from that obtained under the simple FI schedule. Thus, these results provide clear support for the notion that interreinforcement time controls postreinforcement pausing.

Neuringer and Schneider (1968) manipulated the number of responses required per reinforcer in an FI schedule and the time between reinforcers in an FR schedule. Blackouts of varying duration were placed between nonreinforced responses in an FI 30-second schedule to control the number of responses that could occur per reinforcer, while keeping the time between reinforcers constant. Blackouts were used similarly in an FR 15 schedule to manipulate the minimum time between reinforcers, while keeping the number of responses per reinforcer constant. Thus, as blackout duration increased in the FR 15 schedule, interreinforcement time increased; as blackout duration increased in the FI 30-second schedule, number of responses per reinforcer decreased. Under the FR 15 schedule, postreinforcement pause duration increased with longer blackouts, and hence longer times between reinforcers, even though the number of responses per reinforcer remained the same. Under the FI 30-second schedule, postreinforcement pause duration was unaffected by blackout duration. Thus, these results further support the conclusion that pause duration is
controlled primarily by the interreinforcement interval and not by the number of responses required per reinforcer.

Consistent with this conclusion, research with simple reinforcement schedules has shown that postreinforcement pause duration generally increases as a monotonic function of interreinforcement time, whether the schedule requirement is time-based (Ferster & Skinner, 1957; Harzem, 1969; Innis & Staddon, 1971; Lowe & Harzem, 1977; Lowe, Harzem, & Spencer, 1979; Schneider, 1969; Shull, 1970, 1971; Skinner, 1938; Wilson, 1954) or response-based (Boren, 1961; Farmer & Schoenfeld, 1967; Felton & Lyon, 1966; Inman & Cheney, 1974; Mazur, 1983; Mowrer & Jones, 1945; Powell, 1968, 1970; rider & Kametani, 1984, 1987; Weissman & Crossman, 1966). While FR and FI schedules impose different relations between responding and reinforcement, both types of schedules make reinforcers available after progressively longer intervals of time, and progressively larger FR requirements take progressively longer to complete. Perhaps the most salient feature of any experimental situation is the frequency of reinforcement (Herrnstein, 1970), or its reciprocal, the interreinforcement interval. Therefore, postreinforcement pause duration under both time-based and response-based schedules may be controlled by a feature common to both types of schedules: the average interreinforcement time.

Findings of Killeen (1969), Nevin (1973), and Rider (1980) suggested that postreinforcement pause duration is
controlled similarly by the average time between reinforcer deliveries, regardless of the scheduling arrangement. Killeen (1969) ran FR schedules and then yoked FI schedules from the interreinforcement times obtained under the FR schedules. Pause durations were approximately the same under both the FR schedules and the yoked-FI schedules. Nevin (1973) analyzed data from Berryman and Nevin (1962) that were obtained from FI, FR, and interlocking FR FI schedules. Interlocking FR FI schedules combine FR and FI requirements such that responding reduces the time between successive reinforcers and passage of time reduces the number of responses required per reinforcer. Regardless of these diverse scheduling arrangements, pause duration increased linearly as a function of the average interreinforcement interval. Rider (1980) found that pause duration was linearly related to the average interreinforcement times obtained under alternative FR FI over a broad range of schedule parameters. Alternative FR FI schedules provide reinforcers contingent on the completion of either the specified FR or FI requirement, whichever is met first. That is, reinforcement is provided by either an FR or an FI schedule, depending on the subject's rate of responding. Still, pause duration was a good linear function of the average time between reinforcers and unaffected by the proportion of reinforcers obtained from the FR and FI components. Overall rate of responding
and running rate, by contrast, were highly sensitive to the schedule requirement that was met most frequently. The highest response rates occurred when most of the reinforcers were obtained from the FI component. Nonetheless, pause duration was unaffected by the reinforcement contingency.

The good linear fit between postreinforcement pause duration and interreinforcement time across simple FI and FR schedules and complex interlocking and alternative schedules raised the possibility that interreinforcement time controls pausing independently of the particular schedule of reinforcement. However, in a direct comparison of FI and FR schedules with comparable interreinforcement times, Capehart, Eckerman, Guilkey, and Shull (1980) found that the relation between pausing and interreinforcement time differed between the schedules. The slopes of lines relating pause duration to interreinforcement time were typically (but not always) steeper for FR schedules than for FI schedules. Thus, Capehart et al. concluded that interreinforcement time does not control pausing comparably under FR and FI schedules.

Some problems in methodology and interpretation of data may force qualification of the conclusion drawn by Capehart et al. (1980). Their findings do not necessarily imply that interreinforcement time does not control pausing under either schedule, but only that the relation of pausing to
interreinforcement time may be mitigated by the scheduling arrangement (cf. Rider & Kametani, 1984). The results of Capehart et al. (1980) are consistent with this possibility, as are those of Berryman and Nevin (1962), Killeen (1969), and Rider (1980).

Perhaps more serious are several methodological problems and limitations with the Capehart et al. (1980) study. In the first of two experiments, a comparison was made of pause duration as a function of interreinforcement time obtained under FR and yoked-FI schedules. Included in this comparison were data obtained from multiple FR FI schedules. Each pigeon subject was exposed to two multiple FR FI conditions in which each component alternated with every five reinforcer deliveries. The FR component was either FR 50 or FR 100. The value of the FI component was adjusted daily to match the average time between reinforcers obtained under the previous session’s FR component. Thus, high rates of responding under the FR component of a session resulted in a relatively short FI component in the following session; low rates of responding under the FR component of a session resulted in a relatively long FI component in the following session. Pause durations obtained under the separate FR and FI components of the multiple schedule were included with data obtained from simple FR and yoked-FI schedules. Responding in each component of multiple schedules has been shown to interact with responding in the.
other component, and is not comparable to responding maintained by simple schedules of reinforcement (Reynolds, 1961; Rilling, 1977). Such interactions are likely to have affected the results obtained by Capehart et al. (1980). Furthermore, the conclusion of Capehart et al. (1980) that pausing is not controlled comparably by interreinforcement time under FR and FI schedules was based on steeper least-squares linear-regression slopes obtained from the FR schedules. Gut this was true for only two of three subjects.

In the second experiment of the Capehart et al. (1980) study, postreinforcement pause duration under simple FR schedules was compared with pause duration under yoked-VI schedules. The yoked-VI schedules arranged reinforcement by using ten different interreinforcement intervals obtained from the FR schedule, presented as a repeating series. Thus, a comparison was made between a response-based schedule (FR) and a time-based (yoked-VI) schedule where interval values of the time-based schedule were obtained directly from the response-based schedule. Lines relating pause duration to interreinforcement time were steeper for pausing under the FR schedules than under the yoked-VI schedules for three of the four pigeons used in this second experiment. Because these two different schedules provided similar times between reinforcers, yet with steeper lines relating pause duration to interreinforcement time under the
FR schedules, Capehart et al. (1980) again concluded that pausing is controlled by something other than time between reinforcer deliveries. However, the variable intervals of the yoked-VI schedules may have been responsible for the differences in pausing produced by the two schedules. Aperiodic schedules typically produce shorter postreinforcement pauses than periodic schedules (Farmer & Schoenfeld, 1967; Ferster & Skinner, 1957; Lachter, 1971; Mazur, 1983). In fact, Rider and Kametani (1987) made a direct comparison of pausing under periodic and aperiodic schedules and performed the same least-squares linear-regression analysis that Capehart et al. (1980) used. For all six of Rider and Kametani’s (1987) rats, the slopes of lines relating pause duration to interreinforcement time were steeper for the periodic schedules than for the aperiodic schedules, even though both schedules were response-based.

Shull (1979) offered an account of postreinforcement pausing that emphasizes the remaining response requirement or time to reinforcement following the pause. Responding under periodic reinforcement schedules can be compartmentalized into two classes of activities: terminal behavior that is directed toward the scheduled reinforcer and nonterminal behavior that is directed toward other reinforcers (Staddon & Simmelhag, 1971). Nonterminal behavior presumably consumes most of the postreinforcement
pause while terminal behavior occupies most of the remainder of the interreinforcement interval. Shull (1979) suggested that postreinforcement pause duration is not controlled by the entire reinforcement interval, but by only that portion of the interval occupied by terminal behavior: the work time.

Many theoretical developments in recent years have emphasized duration of responding or the allocation of time to various activities as the fundamental unit of behavior (e.g., Allison, 1976; Allison, Miller, & Wozny, 1979; Baum & Rachlin, 1969; Eisenberger, Karpman, & Trattner, 1967; Mazur, 1982; Premack, 1965, 1971; Rachlin, 1978; Rachlin & Burkhard 1978; Timberlake & Allison, 1974). Some empirical evidence, in fact, suggests that time allocated to an activity may be a more basic unit of measure than actual numbers of discrete responses (Baum, 1973, 1975, 1976; Baum & Rachlin, 1969; Brownstein & Pliskoff, 1968).

Despite growing emphasis on the temporal structure of behavior, few studies have employed continuous responses with real temporal properties in a free-operant situation. Consequently, a clear distinction between time devoted to terminal behavior and time devoted to nonterminal behavior under standard reinforcement schedules is difficult because terminal behavior typically consists of discrete responses, usually key pecks or lever presses. The execution of such discrete responses consumes such a small amount of time that
measures of response duration are trivial. Consequently, work time has been estimated by subtracting postreinforcement pause duration from the entire interreinforcement interval (Shull, 1979). This method of estimating work time ties the work-time and interreinforcement-time variables together, so that a separation of their potential effects on pausing is impossible. Pause duration, for example, will necessarily be better correlated with interreinforcement time than this estimate of work time because the interreinforcement time is the sum of the pause time and the estimated work time. A less ambiguous assessment of the relation between pause duration and work time could be made with an estimate of work time that is not derived from the interreinforcement time.

Rider and Kametani (1984) reinforced a continuous response, lever holding by rats, instead of the usual discrete lever-press or key-peck response. Reinforcers were contingent on holding the lever down for fixed, cumulative durations. Work time was estimated as the time in which the lever was held down. This estimate of work time is not derived from interreinforcement time and so correlations between pause length and this estimate of work time will not be necessarily poorer than correlations between pause length and interreinforcement time. Hence, a more meaningful comparison of work time and interreinforcement time as
predictors of pause duration is possible.

The pattern of responding generated by the lever-holding response of Rider and Kametani (1984) resembled patterns generated by FR schedules for discrete responses. Breaks in lever holding reliably followed each reinforcer delivery and the mean duration of these postreinforcement pauses generally increased with the scheduled hold requirement. The relation between pause duration and scheduled hold requirement was comparable to that characteristic of other schedules that provide reinforcers periodically. Thus, these findings extended the generality of the break-run pattern of responding and the relation between pause duration and schedule requirement to schedules providing reinforcers contingent on a continuous response.

The mean time between reinforcer deliveries provided a good estimate of postreinforcement pause duration, based on coefficients of determination derived from least-squares linear-regression analysis. The good linear fit between pause duration and interreinforcement time obtained by Rider and Kametani (1984) supported similar previous findings (Nevin, 1973; Rider, 1980). Work time provided consistently poorer linear fits to pause duration. Using the same lever-holding response, Rider and Kametani (1987) scheduled reinforcers contingent on fixed or variable cumulative lever-holding durations. Patterns of responding under those scheduling arrangements were similar to response patterns
commonly observed under FR and VR schedules of reinforcement for discrete responses. Once again, interreinforcement times provided consistently better predictors of postreinforcement pause durations, based on coefficients of determination from least-squares linear-regression analyses.

The present study employed the lever-holding response used by Rider and Kametani (1984, 1987) to obtain unambiguous estimated of work time. Rats were trained with food deliveries contingent on lever holding for fixed, cumulative durations. Postreinforcement pausing under these fixed-duration requirements was compared to pausing under FI schedules, the values of which were yoked to the mean interreinforcement time obtained under fixed-duration requirements. This within-subjects yoking procedure permitted comparison of the relations among postreinforcement pause duration work time, and interreinforcement time under response-based and time-based reinforcement schedules.
METHOD

Subjects

Six experimentally naive male albino Sprague-Dawley rats were maintained at 80 per cent of their free-feeding weights. The rats were approximately 120 days old at the start of the experiment. They were housed individually in wire cages and received a daily cycle of 15 hours light and 9 hours darkness.

Apparatus

An experimental chamber constructed of Plexiglas and stainless steel was enclosed in a Coleman ice chest. The chamber measured 23.5 cm long, 20.5 cm wide, and 19.4 cm high. A Gerbrands G6312 Rat Lever, 5.1 cm wide and 1.3 cm thick, protruded 1.4 cm from the front wall of the experimental chamber. The lever was situated midway between the side walls of the chamber, 4.7 cm above the grid floor. Reinforcers, 45-mg Noyes Precision Food Pellets, were dispensed into a food receptacle located 7.1 cm to the right of the center of the lever. A houselight, centered 9.5 cm above the lever provided general illumination during experimental sessions. A fan attached to the ice chest ventilated the experimental area. White noise inside the chamber was provided to mask extraneous noise. Electromechanical equipment located across the room was used to control reinforcement contingencies and collect data.
**Pretraining**

Each rat received two 60-minute sessions in which a reinforcer was delivered with each lever press and at 60-second intervals independently of responding (conjoint fixed ration 1 fixed time 60 seconds). Any rat not pressing the lever after the conjoint FR 1 FT 1 sessions were shaped for successive approximations of lever pressing. After all rats were pressing the lever, each received two 60-minute sessions in which FR 1 was in effect. Reinforcers in subsequent sessions were contingent on holding the lever down for specified durations. The lever-holding duration requirement was increased gradually to 15 seconds over the course of four to six 60-minute sessions.

**Experimental Procedures**

The first experimental condition after pretraining consisted of a fixed-duration lever-holding requirement of 15 seconds for each rat. Reinforcers were contingent on cumulative lever-holding durations: a reinforcer was delivered when the cumulative time spent lever holding reached the specified duration requirement, regardless of the number of times the lever was pressed and then released. For example, with the 15-second fixed-duration requirement, a reinforcer would be delivered after a continuous lever-holding response of 15-seconds duration or after five separate lever-holding responses of 3-seconds duration each.
The second experimental condition consisted of a yoked-FI requirement for each rat. A within-subjects yoking procedure was used so that each subject's performance under the yoked-control condition could serve as its own control for performance under the preceding fixed-duration requirement (cf. Rider, 1977, 1982). The value of each rat's yoked FI was determined individually by the mean time between reinforcer deliveries obtained by the rat during its last five sessions of responding under the fixed-duration requirement. Yoked-FI schedules provided reinforcers contingent on the first lever-holding response that occurred after the FI had elapsed. If lever holding was occurring the moment the FI elapsed (i.e., the lever was down), a reinforcer was delivered immediately. If lever holding was not occurring the moment the FI elapsed (i.e., the lever was up), a reinforcer was delivered the next time the lever was pressed. In either case, the next FI began with reinforcer delivery.

The third experimental condition consisted of a new fixed-duration requirement for each rat. This condition was followed by another yoked-FI requirement, and this cycle of experimental conditions in which fixed-duration requirements alternated with yoked-FI requirements was repeated. Experimental conditions were changed when postreinforcement pausing appeared stable. Pausing was considered stable only when the mean postreinforcement pause duration from each of
five consecutive experimental sessions deviated no more than 15 per cent from the overall mean of those five session means and no trend in pause duration was detected. Stable pausing was not obtained under some fixed-duration requirements. In such cases, the value of the fixed-duration requirement was lowered and training continued until stable pausing was obtained. A yoked-FI requirement never was imposed until pausing under a fixed-duration requirement had stabilized. The sequence of experimental conditions, fixed-duration and

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Insert Table 1 about here
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yoked-FI values used for each, and the number of sessions each condition was in effect are given in Table 1.

Both fixed-duration and yoked-FI requirements were programmed with an interval timer commonly used to program VI schedules (c. Clark & Caudill, 1960). For fixed-duration requirements, the interval timer pulled a punched tape when and only when the lever was held down. A reinforcer was delivered when the lever of a microswitch on the interval timer dropped into a hole in the tape. For yoked-FI requirements, the interval timer pulled a punched tape continuously until the microswitch lever dropped into a hole in the tape. Then, a reinforcer was delivered the next time the rat lever was down, at which time the interval timer
again pulled the punched tape.

Time spent lever holding was recorded by a running-time meter that operated whenever the lever was down. Postreinforcement pause time was recorded by another running-time meter that operated during the time between a reinforcer delivery and the next lever-holding response. Because reinforcers were delivered while the lever was held down, some latency between reinforcer delivery and release of the lever was inevitable. Thus, pauses were never terminated by responses made within 0.5 seconds after a reinforcer delivery. This delay prevented pause termination by relatively slow reaction time to reinforcer delivery. Time between the start of a session and the first lever-holding response was recorded as a pause and included in calculating mean postreinforcement pause durations.

Cumulative records of lever holding were generated by treating each 0.5-second interval of time in which the lever was held down as an analog of a single discrete response. Pulses generated at 0.5-second intervals were routed through the normally open circuit of the lever to the stepping pen of a cumulative recorder so that the response pen advanced one step (0.25 mm) per half second of lever holding. Lever-holding responses with durations less than 0.5 second did not necessarily register on the cumulative record.

Experimental sessions lasted until the first reinforcer delivery after 60 minutes, or after 75 minutes even if a
reinforcer was not delivered. With few exceptions, sessions were conducted seven per week at about the same time each day.

RESULTS

All data presented are means from the last five sessions in which stable pausing was obtained. Figure 1 presents postreinforcement pause duration plotted with respect to time spent lever holding per reinforcer. Closed circles represent pausing under fixed-duration requirements; open circles represent pausing under yoked-FI requirements. Solid and dashed lines drawn through each set of data points were derived by the method of least squares and are fitted to pause data from fixed-duration and yoked-FI requirements, respectively. Corresponding linear-regression equations and coefficients of determination, \( r^2 \), are provided in Table 2. The coefficient of determination indicates the proportion of variance in pause duration accounted for in terms of variation in lever-holding time. Lever holding was maintained under fixed-duration requirements as long as 40 seconds to 60 seconds for four of the six rats, and as long as 30 seconds for the remaining two rats. At longer fixed-duration requirements, lever holding was erratic and pausing
unstable, with most of the lever holding occurring early in sessions and ceasing altogether later in sessions.

Postreinforcement pause duration generally increased with lever-holding time per reinforcer, both under fixed-duration requirements and under yoked-FI requirements than under the yoked-FI requirements. Slopes of least-squares linear-regression lines were steeper under the yoked-FI requirements than under the fixed-duration requirements for four of the six rats. For Rat 202, slopes of the two lines were virtually identical; for Rat 203, the slope of the lines obtained under fixed-duration requirements was steeper than the slope obtained under yoked-FI requirements.

Postreinforcement pause duration is plotted with respect to mean interreinforcement time in Figure 2. Least-squares linear-regression are drawn through the data points as before, -------------------------------

Insert Figure 2 about here
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and the corresponding equations and coefficients of determination are provided in Table 2.

Postreinforcement pause duration increased with interreinforcement time, both under fixed-duration requirements and under yoked-FI requirements. Without exception, interreinforcement time accounted for more variance in pause duration than lever-holding time did, both for fixed-duration requirements and for yoked-FI
The slopes of lines relating pause duration to interreinforcement time under yoked-FI requirements were steeper than those relating pause duration to interreinforcement time under fixed-duration requirements for each rat. The difference in slopes reflects a difference in the rate at which pause duration changed with changes in interreinforcement time. As interreinforcement time increased under the two different scheduling arrangements, pause duration tended to increase more rapidly under yoked-FI requirements than it did under fixed-duration requirements.

Figure 3 presents the proportion of session time spent lever holding in relation to the scheduled fixed-duration requirement for each rat. Closed circles represent proportions obtained under fixed-duration requirements and open circles represent proportions obtained under yoked-FI requirements. These proportions are analogous to response rates obtained under schedules for discrete responding, since they are calculated by dividing total lever-holding time in a session by the total session time. In general, a greater proportion of session time was spent lever holding under each fixed-duration requirement than under the
corresponding yoked-FI requirement. However, lever-holding proportions were virtually identical under the fixed-duration requirement of 30 seconds and the corresponding yoked-FI requirement for Rat 202. Also, Rat 203 spent a smaller proportion of session time lever holding under the fixed-duration requirement of 22 seconds than under the corresponding yoked-FI requirement.

Figure 4 presents the proportion of post-pause time spent lever holding under fixed-duration requirements (closed circles) and corresponding yoked-FI requirements (open circles). These proportions were calculated by dividing time spent lever holding per session by the total session time minus time spent pausing per session. Hence, these proportions are analogous to running rates obtained under schedules for discrete responding. Generally, a greater proportion of post-pause time was spent lever holding under fixed-duration requirements than under yoked-FI requirements. However, there were a few exceptions where the proportion of post-pause time spent lever holding under a yoked-FI requirement exceeded that from the corresponding fixed-duration requirement.

Table 3 provides summary data for lever-holding time,
Mean postreinforcement pause durations per reinforcer were calculated for individual sessions; tabled values are means of those daily means from the last five sessions of each condition. All other entries are means per session from the last five sessions of each condition.

Cumulative records of lever holding by Rats 200, 202, and 203 are presented in Figures 5 through 8. These records are representative of lever holding across the range of fixed-

duration and corresponding yoked-FI requirements used in the present study. Figure 5 presents records for Rat 200 for fixed-duration requirements of 15 seconds and 60 seconds and records for the corresponding yoked-FI requirements. These records represent lever holding at the longest and shortest fixed-duration requirements studied. Figure 6 presents records for Rat 200 for a fixed-duration requirement of 45 seconds and the corresponding yoked-FI requirement. These
records show the largest difference in lever holding between a fixed-duration and corresponding yoked-FI requirements.

Figure 7 presents cumulative records for Rat 202 for lever holding under fixed-duration requirements of 30 seconds and 45 seconds and the corresponding yoked-FI requirements. These records are representative of responding under intermediate fixed-duration and yoked-FI requirements used in the present study.

Figure 8 presents cumulative records for Rat 203 for lever holding under fixed-duration requirements of 15 seconds and 22 seconds and the corresponding yoked-FI requirements. These records display the largest difference between the shortest fixed-duration requirement (15 seconds) used and its corresponding yoked-FI requirement, as well as the unusually long interreinforcement times obtained by this rat under the fixed-duration requirement of 22 seconds.
DISCUSSION

The present study employed a continuous response, lever holding, and compared performance under two different scheduling arrangements. Fixed-duration requirements specified the cumulative amount of lever holding that must occur per reinforcer, just as FR schedules for discrete responses specify the number of responses that must occur per reinforcer. As with FR schedules for discrete responses, fixed-duration requirements permit time between reinforcer deliveries to vary. Yoked-FI requirements specified the minimum time between reinforcer deliveries, just as FI schedules for discrete responses specify minimum interreinforcement intervals. Time spent lever holding per reinforcer was free to vary under the yoked-FI requirements of the present study, just as the number of responses per reinforcer is free to vary under FI schedules for discrete responses. A pause in lever holding reliably followed each reinforcer delivery under both scheduling arrangements. Mean duration of this postreinforcement pause increased with time spent lever holding and time between reinforcer deliveries under both fixed-duration and yoked-FI requirements. These results with a continuous response extend the generality of similar findings with discrete responses and standard FR and FI schedules (Boren, 1061; Felton & Lyon, 1966; Ferster & Skinner, 1957; Harzem, 1969; Inman & Cheney, 1974; Innis & Staddon, 1971; Lowe & Harzem,
Results of the present study also showed proportion of session time spent lever holding was greater under the fixed-duration requirements than under the corresponding yoked-FI requirements. Proportion of session time spent lever holding is analogous to rate of responding under reinforcement schedules for discrete responses. The present results are consistent with findings of previous studies in which discrete responses were used. Although FR schedules typically produce higher rates of responding than FI schedules with comparable reinforcement frequencies (e.g., Ferster & Skinner, 1957; Williams, 1968), FI schedules maintain higher rates of responding than FR schedules when reinforcement is very infrequent (Zeiler, 1977, 1979).

Results of the present research are consistent with findings of previous research using the continuous lever-holding response (Rider & Kametani, 1984, 1987) and extends those findings to FI schedules. All three studies with continuous responses have found similar functions relating postreinforcement pause duration to work time and to interreinforcement time. Interreinforcement time has provided a consistently better estimate of pause duration than has work time for fixed-duration requirements (Rider & Kametani, 1984, 1987), variable-duration requirements (Rider & Kametani, 1987), and the time-based requirements used in
the present study. The good linear fit between pause
duration and interreinforcement time obtained across all
three scheduling arrangements suggests that pause duration
may be controlled by interreinforcement time, regardless of
the particular scheduling arrangement.

Capehart, Eckerman, Guilkey, and Shull (1980) made a
direct comparison between FR and FI schedules and found
similar positive, linear relationships between
postreinforcement pause duration and interreinforcement
time, but slopes of lines relating pause duration to
interreinforcement typically were steeper for FR schedules
than for interval schedules. Those results led Capehart et
al. to conclude "that FR and FI or VI schedules do not
control pausing similarly even when the [interreinforcement
times] are similar" (1980, p. 72).

The present results contrast with those of Capehart et
al. (1980). Slopes of regression lines relating pause
duration to interreinforcement time were steeper for yoked-
FI requirements than for fixed-duration requirements. The
differences in slopes, although consistent across subjects,
were small, suggesting that any control over pausing exerted
by the scheduling arrangements was similarly small. The
differences in slopes obtained in the present study and
those obtain by Capehart et al. (1980) may indicate only
that the effects a particular scheduling arrangement might
have on pausing is trivial, at least when compared to the
effects exerted by interreinforcement time.

The notion that the presentation of a reinforcer results in a cessation of the response that produced the reinforcer appears to contradict the definition of a reinforcer. Cessation of the response that produces reinforcement also may appear detrimental to the organism. Postreinforcement pausing, at least under response-based schedules, results in a decreased frequency of scheduled reinforcement. Harzem and Harzem (1981) considered the potential biological utility of postreinforcement pausing. They argue that pauses from activities directed toward a specific reinforcer allow the organism time to survey the environment for other sources of the same reinforcer or for different reinforcers, and to detect potential danger:

"Inhibition by a reinforcer, although it may at first seem paradoxical - why inhibit a reinforcer-producing response? - has a biologically useful function. It enables a hungry organism to switch to other stimuli while feeding, and so to avoid the dreadful consequences of, say, oblivion to a fast-approaching predator. And looking up at the end of a delightful passage in the book one is reading helps one to reduce the chances of missing the train." (p. 119)

Rider in preparation has argued that the postreinforcement pause should not be viewed as a cessation of responding, but as a temporary shift to activities that are governed by
reinforcers other than the scheduled reinforcer. Termination of the postreinforcement pause after some period of time is affected by the same variables that affect other choice behavior: reinforcement frequency or its reciprocal, interreinforcement time. It follows that resumption of the measured terminal response, key pecking, lever holding, or book reading, represents another temporary shift to activities that are governed by the scheduled reinforcer.
REFERENCES


Killeen, P. (1969). Reinforcement frequency and contingency as factors in fixed-ratio behavior. Journal of the
Experimental Analysis of Behavior, 12, 391-395.


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### TABLE 2

#### Hold Time

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#### Interreinforcement Time

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FIGURE CAPTIONS

Figure 1: Postreinforcement-pause duration plotted against time spent lever holding per reinforcer. Data are means from the last five sessions of experimental conditions in which stable pausing was obtained. Corresponding least-squares linear-regression equations and coefficients of determination are provided in Table 2.

Figure 2: Postreinforcement-pause duration plotted against interreinforcement time. Data are means from the last five sessions of experimental conditions in which stable pausing was obtained. Corresponding least-squares linear-regression equations and coefficients of determination are provided in Table 2.

Figure 3: Proportion of session time spent lever holding. Data points denote means and vertical lines denote ranges from the last five sessions of experimental conditions in which stable pausing was obtained.

Figure 4: Proportion of post-pause time spent lever holding. Data points denote means and vertical lines denote ranges from the last five sessions of experimental conditions in which stable pausing was obtained.
Figure 5: Cumulative records of complete sessions of lever holding by Rat 200. Each record is representative of stable responding during the last five sessions of an experimental condition. The response pen advanced once per half second when the lever was held down; diagonal slashes of the pen indicate reinforcer deliveries.

Figure 6: Cumulative records of complete sessions of lever holding by Rat 200. Each record is representative of stable responding during the last five sessions of an experimental condition. The response pen advanced once per half second when the lever was held down; diagonal slashes of the pen indicate reinforcer deliveries.

Figure 7: Cumulative records of complete sessions of lever holding by Rat 202. Each record is representative of stable responding during the last five sessions of an experimental condition. The response pen advanced once per half second when the lever was held down; diagonal slashes of the pen indicate reinforcer deliveries.

Figure 8: Cumulative records of complete sessions of lever holding by Rat 203. Each record is representative of stable responding during the last five sessions of an experimental condition. The response pen advanced once per half second when the lever was held down; diagonal slashes of the pen indicate reinforcer deliveries.
Figure 5: Cumulative records of complete sessions of lever holding by Rat 200. Each record is representative of stable responding during the last five sessions of an experimental condition. The response pen advanced once per half second when the lever was held down; diagonal slashes of the pen indicate reinforcer deliveries.

Figure 6: Cumulative records of complete sessions of lever holding by Rat 200. Each record is representative of stable responding during the last five sessions of an experimental condition. The response pen advanced once per half second when the lever was held down; diagonal slashes of the pen indicate reinforcer deliveries.

Figure 7: Cumulative records of complete sessions of lever holding by Rat 202. Each record is representative of stable responding during the last five sessions of an experimental condition. The response pen advanced once per half second when the lever was held down; diagonal slashes of the pen indicate reinforcer deliveries.

Figure 8: Cumulative records of complete sessions of lever holding by Rat 203. Each record is representative of stable responding during the last five sessions of an experimental condition. The response pen advanced once per half second when the lever was held down; diagonal slashes of the pen indicate reinforcer deliveries.
Figure 1: Postreinforcement pause plotted with respect to lever-holding time.
Figure 2: Postreinforcement pause plotted with respect to interreinforcement time.
Figure 3: Proportion of session spent lever holding.
Figure 4: Proportion of post-pause time spent lever holding.
Figure 5: Cumulative records of lever holding for Rat 200.

Yoked-FI (from fixed-duration 60 seconds)

Fixed-duration 60 seconds

Yoked-FI (from fixed-duration 15 seconds)

Fixed-duration 15 seconds
Figure 6: Cumulative records of lever holding for Rat 200.
Figure 7: Cumulative records of lever holding for Rat 202.

Yoked-FI (from fixed-duration 45 seconds)

Fixed-duration 45 seconds

Yoked-FI (from fixed-duration 30 seconds)

Fixed-duration 30 seconds
Figure 8: Cumulative records of lever holding for Rat 203.

Yoked-FI (from fixed-duration 22 seconds)

Fixed-duration 22 seconds

Yoked-FI (from fixed-duration 15 seconds)

Fixed-duration 15 seconds