

Differential Reinforcement of Fixed-Interval Interresponse Times:
Effects on Choice

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ABSTRACT

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Eight rats were exposed to a concurrent-chains procedure. Half of the rats chose between a fixed-interval schedule that required low rates of responding in the paced terminal link and a simple fixed-interval schedule in the unpaced terminal link. The other half chose between a fixed-interval schedule that required high rates of responding and a simple fixed-interval schedule. Interresponse-time criteria were based on the percentiles of a baseline distribution of interresponse times obtained for each rat. The criteria increased in stringency across conditions. Consistent changes in response rates as the result of the interresponse-time criteria were not obtained. Therefore, preference between the paced and unpaced fixed-interval schedules could not be determined. It was concluded the most likely reason that effects of the pacing contingency were not observed is because the criteria were not sufficiently stringent.

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INTRODUCTION

Schedules of positive reinforcement may differ in many ways other than the number of responses required for reinforcement (e.g., on fixed-ratio or variable-ratio schedules) or the amount of time that must elapse before a response is reinforced (e.g., on fixed-interval or variable-interval schedules). Schedules may differ also in terms of the rate of responding required for reinforcement. Response-independent schedules, for instance, arrange a reinforcer delivery after some amount of time regardless of whether a response occurred. Other response-dependent schedules require either low or high rates of responding [i.e., a differential-reinforcement-of-low-rates (DRL) schedule or differential-reinforcement-of-high-rates (DRH) schedule, respectively] for reinforcement. This desired rate is achieved by setting either a lower or an upper limit on the rate of responding eligible for reinforcement. Such schedules will be referred to as “paced schedules,” as opposed to “unpaced schedules” that place no constraints on the response rate eligible for reinforcement. This is a deviation from the definition of paced schedules put forth by Ferster and Skinner (1957). They restricted their definition to schedules that place *both* upper and lower limits on the response rates required for reinforcement.

Schedules that differ in any of the aforementioned ways may differ also in terms of their value as reinforcers in themselves. In other words, subjects may *prefer* to respond on one type of schedule (e.g., with a more lenient response requirement) relative to another (e.g., with a more stringent response requirement). Preference can be measured using concurrent-chains procedures (Autor, 1960). In a common version of this procedure (Stubbs & Pliskoff, 1969) a trial starts with two response keys (lit the same color) that operate according to a single schedule (the initial link). After the schedule requirement is met on one of the two keys, a terminal-link schedule is arranged. For instance, if the response requirement during the initial link is completed on the right key, the right key changes color (signaling entry into the right terminal link), and the left key becomes dark and inoperative. If the response requirement is met on the left key, the left key changes color (signaling entry into the left terminal link) and the right key becomes dark and inoperative. A different schedule of food reinforcement operates in each of the terminal links.

The relative value of the terminal-link schedules is determined by the distribution of responding on the response keys during the initial link. Thus, if the schedule in the right terminal link was preferred, a larger number of responses should be allocated to the right response key during the initial link.

The relative value of response-rate requirements has been studied using various types of schedules. Some have measured choice for response-dependent versus response-independent schedules of reinforcement. These schedules do not require particular rates of responding in order for reinforcement to occur; however, the former typically results in low rates of responding because responses are not required for reinforcement. Neuringer (1969) used a concurrent-chains procedure to examine preference when given a choice between response-dependent and response-independent schedules. Pigeons were exposed to a terminal link that arranged a fixed-interval (FI) schedule of reinforcement and another terminal link that arranged an equal fixed-time (FT) schedule of reinforcement in which food was delivered after a fixed period independently of responding. Higher rates of responding were maintained by the FI schedule than the FT, and in this sense the birds chose between different response rates. Neuringer found that the birds were indifferent

between the response-dependent (FI) and response-independent (FT) schedules. In another phase of the study, the length of the FT interval varied so that the rate of reinforcement obtained during this terminal link was either lower or higher than that obtained from the FI schedule arranged in the other terminal link. Under these circumstances, pigeons preferred the schedule that yielded a higher rate of reinforcement regardless of whether the schedule required responding.

Grossbard and Mazur (1986) used an adjusting procedure to examine the effects of delay on the value of reinforcement. Value was operationally defined as the point at which the birds were indifferent between a standard delay to a small reinforcer and an adjusting delay to a large reinforcer. In one phase of the experiment, the standard delay to the small reinforcer consisted of a response-independent (FT) schedule, while the adjusting delay to the large reinforcer consisted of a response-dependent fixed-ratio (FR) schedule. When the time to reinforcement was the same for both schedules, a response-dependent delay (i.e., the FR schedule) to a large reinforcer was valued less than a response-independent delay (i.e., the FT schedule) to a small reinforcer. Requiring the birds to respond to produce the larger reinforcer (the FR schedule) reduced the value of the reinforcer to a greater extent than merely delaying the reinforcer on a response-independent basis (the FT schedule). On the basis of these results, a response-independent schedule should be preferred over a response-dependent schedule, at least when given a choice between an FT and an FR schedule.

Killeen (1968) used a concurrent-chains procedure to investigate the effects of *required* (rather than resultant) response rate on choice. Responses on either of two response keys during the initial link occasionally resulted in access to one of two terminal links in which equal variable-interval (VI) schedules were arranged. In addition, in one of the terminal links, a response after the interval had elapsed could not be reinforced unless a specified amount of time had elapsed since the previous response. That is, a constraint was placed on the rate at which pigeons could respond and be reinforced; the constraint required the pigeons to respond at low rates. Although the terminal links were successful in establishing large differences in response rates across the terminal links, responses were distributed equally across the two keys in the initial link. Thus, pigeons were indifferent between the two schedules despite the large differences in response rates.

Fantino (1968) also examined pigeons' preferences for paced and unpaced schedules. Equal and independent VI schedules operated on both keys during the initial link. A peck on either key after the current interval had elapsed arranged access to one of two terminal links. One terminal link required a certain number of responses to be emitted during a specified period of time in order for a reinforcer to be delivered. That is, depending on the condition, one of the two following schedules operated in one of the terminal links: A DRH or a DRL schedule. In both a specified number of responses had to occur within a period of 15 s. A larger number of responses had to be emitted in the DRH schedule. When access was arranged to the second terminal link, completion of a simple FI schedule resulted in reinforcement. This procedure allowed for a direct comparison of preference for a paced schedule (the DRH or DRL) versus an unpaced schedule (the FI). The pigeons preferred the unpaced terminal link.

Whereas Fantino (1968) presented pigeons with a choice between periodic (or fixed) schedules, one of which required a high rate of responding, Moore and Fantino (1975) examined choice between aperiodic (or variable) schedules, one of which was

response-independent, and one of which was response-dependent, requiring a high rate of responding. In this comparison, a variable-time (VT) schedule operated in one terminal link of the concurrent-chain schedule and a VI schedule with a limited hold on reinforcement operated in the other terminal link. The limited hold required the pigeon to complete 5 responses within 5 s after each interval had elapsed, and thus required high response rates. The first response after completion of the 5-response requirement resulted in reinforcement, but if the requirement was not met within the 5-s limited hold, a reinforcer was not delivered and the initial link was restored. The pigeons were indifferent between paced and unpaced schedules.

A follow-up experiment was then conducted to examine why pigeons preferred unpaced responding in periodic schedules (e.g., FR and FI schedules) in Fantino's (1968) experiment, but were indifferent between paced and unpaced responding in aperiodic schedules in Moore and Fantino's (1975) experiment. A concurrent-chains procedure was used to compare initial-link responding (i.e., preference) when the terminal links arranged periodic schedules that required responding early in the interval, and periodic response-independent schedules. In the first condition one terminal link arranged a response-dependent schedule in which completion of a required number of responses initiated an FI schedule (completion of which resulted in reinforcement). This can also be referred to as a tandem FR FI schedule, in which two schedule requirements are linked but are un signaled. The other terminal link arranged a response-independent FT schedule. In the second condition, signals were added to the same schedules, so they became chained rather than tandem schedules. When the initial response requirement of the schedule in the first terminal link was completed on the chained schedule, the keylight changed color when the FI schedule was initiated. In the other terminal link two FT schedules were linked. When the first FT schedule had elapsed, a stimulus change accompanied the onset of the second FT schedule that ended in the delivery of a reinforcer. In both the tandem and chained conditions, response-independent schedules were preferred to a similar extent. Moore and Fantino accounted for this preference in terms of temporal discrimination in periodic schedules of reinforcement. That is, the beginning of the interval becomes discriminative of a period in which reinforcement does not occur. When the pigeon is required to respond during this period (i.e., at the beginning of the interval when pausing typically occurs), it is aversive because it is a period during which reinforcement does not occur. In aperiodic schedules, however, temporal discrimination such as this is less likely to occur. In periodic schedules, the probability of reinforcement increases as a fixed amount of time elapses. In aperiodic schedules, the probability of reinforcement varies in time, dependent on the range of programmed interreinforcement intervals.

In summary, choice between response rates has been investigated various ways and has produced unclear results. In studies that assess choice between response-dependent versus response-independent schedules (Grossbard & Mazur, 1986; Moore & Fantino, 1975; Neuringer, 1969), and in those that examine more directly the effects of required response rates on choice (Fantino, 1968; Killeen, 1968), it was found that pigeons preferred the response-independent or unpaced schedules, or that they were indifferent. The current study was designed to contribute to the resolution of these discrepant findings by testing choice in a more direct and thorough manner.

STATEMENT OF THE PROBLEM

Previous literature that has examined preferences for response-dependent and response-independent schedules has produced mixed results. Killeen (1968) and Neuringer (1969) found that pigeons were indifferent when given the choice between response-dependent and response-independent schedules. However, Grossbard and Mazur (1986) found that pigeons valued an FT schedule more than an FR schedule that arranged comparable rates of reinforcement. It can be argued that these studies have not examined paced responding per se. Response-independent schedules are characterized by low rates of responding; however, the animal is not *required* to respond at a low rate. Likewise, the response-dependent schedules (e.g., FI or FR) are characterized by higher response rates but higher rates are not *required*.

Fantino (1968) examined preference for paced versus unpaced schedules of reinforcement and found preference for the schedule in which there were no constraints on response rates (i.e., the FI schedule over both the DRL and DRH schedules). However, Fantino used paced schedules in which a required number of responses had to occur within a specified period of time. The current experiment examined paced schedules in a different manner by arranging DRL and DRH schedules based on interresponse time (IRT) requirements. To gain reinforcement when an interval had elapsed, the time between the response that occurred after the interval had elapsed and the response before it had to fall within a specified limit. If this criterion was not met, a reinforcer was not delivered, and the IRT preceding each additional response continued to be evaluated. The limit was based on the distribution of IRTs during a baseline condition in which responding was unconstrained.

Moore and Fantino (1975) found no preference for an aperiodic schedule that required high response rates and one that was response-independent. One problem with their procedure was that no changeover delay was used. The changeover delay is a minimum period of time that must elapse before a response following a switch from one alternative to another alternative is reinforced. This may have resulted in what appeared to be indifference between the two alternatives because switching from one alternative to the other was reinforced by entry into a terminal link immediately following that changeover. This would have resulted in the allocation of an equal number of responses to each key during the initial-link. In addition, the paced schedule requirement again differed from that in the current experiment. Moore and Fantino arranged a VI schedule in which 5, rather than 1, responses had to be emitted, and these responses had to be emitted within 5 s.

The current study was designed to assess rats' preferences for paced versus unpaced FI schedules using a concurrent-chains schedule. Half of the rats were exposed to a paced terminal link in which low rates of responding on an FI schedule were required for reinforcement. The other half of the rats was required to respond at high rates on an FI schedule in the paced terminal link. Each rat was exposed to a series of pacing requirements that increased in stringency across conditions. For all rats, the unpaced terminal link consisted of a simple FI schedule without a requirement for a particular rate of responding.

GENERAL METHOD

Subjects

Eight experimentally naive male Sprague-Dawley rats were maintained at 80% (\pm 2%) of their predicted free-feeding body weights using an adjusted percentage procedure similar to that used by Davenport and Goulet (1964). Weights were adjusted on a monthly basis so that 80% of the weight gained by free-feeding age mates was added to the target weight of the experimental rats. The size of the adjustments ranged from 0 to 14 g and tended to decrease as the rats aged. The rats were housed individually under a 12:12 hr reversed light/dark cycle so that experimental sessions were conducted during the dark phase when rats normally are active.

Apparatus

Four identical MED-PC operant chambers with 2 retractable levers were used. The interior of each chamber was approximately 29 cm long, 22 cm high, and 24 cm deep with side walls and ceiling constructed of clear plastic and end walls of stainless steel. The floor consisted of 19 stainless steel rods, 0.5 cm in diameter, and spaced approximately 1.3 cm apart. Illumination was provided by a No. 1820 bulb located 17.8 cm from the floor on the back wall. On the front wall were two retractable levers, each with a minimum force requirement of 0.25 N, spaced 11.4 cm apart (5.7 cm from the middle of the wall) and positioned 8 cm from the floor to the top of the lever. Each lever was 4.4 cm wide, 1.3 cm thick, and when inserted, protruded 1.9 cm into the chamber. A white cue light (No. 1820) was positioned approximately 5 cm above each lever. Food pellets (45 mg, P.J. Noyes Co., Inc.) could be dispensed into a magazine centered on the front wall. The magazine was 5 cm high, 5 cm wide, approximately 3.2 cm deep, and placed in the center of the front wall with the bottom of the opening 7.6 cm from the floor. A light source and photocell inside the food magazine allowed detection of the rats' head entries into the magazine. To mask extraneous sounds, white noise (85 dB) was provided through a speaker located 12.7 cm above the floor on the right side of the back wall. Each chamber was enclosed within a ventilated, sound-attenuating shell. Experimental events were controlled and recorded using a computer in an adjacent room in conjunction with Med-PC for Windows software and interfacing.

Preliminary Training

The goal of preliminary training was to establish responding on both levers.

Magazine training. Magazine training, designed to establish the delivery of a food pellet as a reinforcing event, began with illumination of the houselight and onset of the white noise. At the outset of the first session, 5 pellets were delivered into the food magazine at consecutive 1-s intervals, to attract the rat to the magazine. When the rat's head entered the magazine, another pellet was delivered. All pellet deliveries were accompanied by an audible relay click. Subsequent pellets were delivered at regular intervals unless the rat's head entered the magazine prematurely (i.e., a differential-reinforcement-of-other-behavior, or DRO, schedule was programmed). Initially the interval was set to 5 s. If the rat's head entered the magazine before the interval elapsed, however, the interval was restarted. The DRO 5-s schedule continued until the rat's latency to retrieve the pellet (defined as the time between pellet delivery and head entry) was less than 2 s for 4 consecutive pellets. When the latency criterion was met, the interval was increased by 5 s. This procedure was repeated until the rat met the latency criterion for pellets delivered at 20-s intervals. At this point the schedule of inter-pellet

intervals was made variable, with intervals averaging 30 s and ranging from 2 s to 99 s. This variable schedule, and all subsequent variable schedules, consisted of 10 intervals that were derived from Fleshler and Hoffman's (1962) series. As before, premature head entries restarted the interval. Magazine training was complete when at least 20 pellets had been delivered by the variable DRO 30-s schedule and the last 4 pellets had been retrieved within 2 s of delivery.

Alternating levers. Each rat was trained to press the response levers under conditions with the white noise on and the houselight off. Either the left or right lever was inserted into the chamber; the operative lever was decided at random ($p = .5$), with the restriction that either lever could be operative no more than twice in succession. The cue light above the operative lever was illuminated. Initially, presses were reinforced continuously. Each press was followed by retraction of the lever, offset of the cue light, onset of the houselight, and delivery of a pellet. The reinforcement cycle ended 2 s after the rat's head entered the food magazine. The houselight then was turned off, either the left or right lever was inserted, and the cue light above the operative lever was illuminated. The continuous reinforcement schedule remained in effect until at least 20 pellets were obtained via each lever.

Thereafter, the schedule of reinforcement was changed to a VI 5-s schedule. Each lever-press was accompanied by 0.05-s offset of the cue light. Over several sessions, the VI parameter was increased in increments of 5 s until steady responding was observed on a VI 30-s schedule.

Concurrent levers. In the final training condition both levers were inserted and operative, the houselight was off, and the cue lights above both levers were illuminated. Presses on either lever produced a feedback stimulus (0.05-s offset of the associated cue light) and occasional food reinforcement arranged according to a procedure developed by Stubbs and Pliskoff (1969). A single VI 15-s schedule operated. When an interval elapsed, the reinforcer was assigned at random to either the left or right lever, so that a press on that lever was reinforced. With this procedure, presses on each lever were reinforced every 30 s on average, and the distribution of reinforcers across the two levers was equated regardless of the distribution of responses.

During the reinforcement cycle both levers were retracted, the cue lights were turned off, the houselight was turned on, and a pellet was delivered into the food magazine, accompanied by the offset of the white noise and a relay click. The cycle ended 2 s after the rat's head entered the magazine, at which point the levers were inserted, cue lights and white noise turned on, and the houselight turned off.

A changeover delay (COD) was imposed to prevent rapid switching from one lever to the other. A "changeover" occurred when one or more responses on one lever were followed by a response on the other lever. At this point, at least 2 s had to elapse before a response on the new lever was eligible for reinforcement.

Training with the concurrently available levers continued until the relative distribution of responses was within .10 of equality.

Concurrent-Chains Procedure

The experiment proper involved concurrent chains schedules. In the initial link of the chain, two levers were available concurrently. Completion of a VI schedule on one of the levers resulted in access to one of two terminal-link schedules. Completion of the terminal link resulted in food reinforcement. The distribution of responses across the two

levers in the initial link served as an index of the relative reinforcing efficacy of the two terminal-link schedules.

Initial link. During each initial link both levers were inserted and the houselight was on (note that the cue lights above the levers were off). Levers presses produced a feedback stimulus consisting of 0.05-s offset of the houselight, and occasional entry into a terminal-link schedule arranged according to a procedure developed by Stubbs and Pliskoff (1969). A single VI 30-s schedule operated. When an interval elapsed, the terminal-link entry was assigned at random to either the left or right lever, with the restriction that entry could be assigned to either lever no more than two times in succession. With this procedure, presses on each lever led to a terminal link every 60 s on average, and both terminal-link schedules were entered equally often regardless of the distribution of responses. As in preliminary training, a 2-s COD prevented rapid switching from one lever to another during the initial link.

Terminal link. Completion of the initial link on the left lever resulted in entry to the left terminal link, accompanied by onset of the cue light above the left lever, retraction of the right lever, and offset of the houselight. Conversely, entry into the right terminal link was accompanied by onset of the cue light above the right lever, retraction of the left lever, and offset of the houselight. Lever presses produced a feedback stimulus (0.05-s offset of the associated cue light) and occasional food reinforcement as described below. The stimulus conditions during the reinforcement cycle were the same as those prevailing in earlier conditions: Both levers were retracted, the cue lights were turned off, the houselight was turned on, and a pellet was delivered into the food magazine. The cycle ended 2 s after the rat's head entered the magazine, at which point another instance of the chain schedule was presented.

Each session lasted until 40 terminal links have been completed, equally divided between the left and right levers.

Experimental Conditions

The concurrent-chains procedure was used to allow the rat to choose between a terminal link containing a "paced-FI" schedule that constrained the response rates eligible for reinforcement and a terminal link containing a conventional "unpaced-FI" schedule. The four rats that emitted the lowest response rates during the baseline condition were assigned to the paced schedule that required high response rates: Only responses that rapidly followed other responses were eligible for reinforcement (DRH conditions). For the other rats (i.e., the rats that emitted the highest response rates during the baseline condition), the paced schedule required low rates: Only responses that were more temporally remote from previous responses were eligible for reinforcement (DRL conditions). For all rats (except T2), if a bias was observed for either the left or right terminal link during the baseline condition, the paced schedule subsequently was implemented in that terminal link. This criterion was not imposed for Rat T2 because of an experimenter error.

DRH. In the DRH condition, an FI 1-min schedule operated in which the first response after a minute elapsed produced a pellet only if the response was emitted *before* some specified period since the previous response. That is, a response resulted in the delivery of a pellet if (a) the FI interval had elapsed, and (b) if the IRT was less than the DRH criterion (i.e., the criterion that established the upper limit to the IRTs that were eligible for reinforcement). Interresponse times were calculated as the time between two

consecutive responses; thus, in each interval, a minimum of two responses was required for reinforcement.

Experimental conditions are presented in Table 1. In the baseline condition, a conventional FI 1-min schedule operated in which all IRTs were eligible for reinforcement. The baseline frequency distribution of IRTs (not including the time between the start of the session or reinforcement and the first response) for each rat was used to establish the IRT criteria imposed on the FI schedule in subsequent paced conditions. In the first paced condition, the eligible IRTs had to be less than the 80th percentile of the baseline distribution. Subsequent conditions restricted the IRTs further (< 60th percentile, < 40th percentile, and < 20th percentile). These percentile criteria are shown for each rat in Table 1.

Table 1

Summary of conditions for each rat, including the paced terminal-link lever, the percentile IRT criteria, and the number of sessions in each condition.

| DRL Rats | | | | | | | | | | | |
|----------|----------|-----------------------------|------|------------------|------|----------------------------------|-------|-------|-------|-------|----|
| Rat | Paced TL | Percentile IRT Criteria (s) | | | | Number of Sessions Per Condition | | | | | |
| | | 20th | 40th | 60 th | 80th | BL | >20th | >40th | >60th | >80th | BL |
| T3 | Right | 0.25 | 0.36 | 0.48 | 0.67 | 22 | 22 | 21 | 20 | 20 | 35 |
| T5 | Right | 0.19 | 0.30 | 0.47 | 0.85 | 25 | 20 | 23 | 23 | 20 | 21 |
| T8 | Left | 0.24 | 0.32 | 0.43 | 0.73 | 20 | 21 | 23 | -- | -- | 26 |
| T10 | Left | 0.22 | 0.32 | 0.44 | 0.74 | 26 | 20 | 20 | 20 | 23 | 28 |
| DRH Rats | | | | | | | | | | | |
| Rat | Paced TL | Percentile IRT Criteria (s) | | | | Number of Sessions Per Condition | | | | | |
| | | 80th | 60th | 40 th | 20th | BL | <80th | <60th | <40th | <20th | BL |
| T2 | Right | 1.60 | 0.79 | 0.44 | 0.28 | 20 | 20 | 20 | 24 | 21 | 20 |
| T6 | Left | 1.57 | 0.84 | 0.54 | 0.36 | 25 | 23 | 25 | 22 | 22 | 23 |
| T7 | Left | 0.86 | 0.50 | 0.31 | 0.21 | 26 | 20 | 21 | 20 | 20 | 22 |
| T9 | Left | 3.54 | 2.55 | 1.41 | 0.41 | 24 | 20 | 21 | 27 | 21 | 21 |

DRL. In the DRL condition, an FI 1-min schedule operated in which the first response after an interval elapsed produced a pellet only if the response was emitted *after* some specified period since the previous response. That is, a response resulted in the delivery of a pellet if (a) the FI interval had elapsed, and (b) if the IRT was greater than the DRH criterion (i.e., the criterion that established the lower limit to the IRTs that were eligible for reinforcement). As in the DRH condition, IRTs were calculated as the time between two consecutive responses; thus, in each interval, a minimum of two responses were required for reinforcement.

Table 1 shows that the first condition arranged a conventional FI 1-min schedule in which all IRTs were eligible for reinforcement and IRT distributions (not including the time between the start of the session or reinforcement and the first response) were obtained to establish the criteria imposed on the FI schedule in subsequent conditions for each rat. The IRTs became increasingly restricted in each condition (i.e., > 20th percentile, > 40th percentile, > 60th percentile, and > 80th percentile). These percentile criteria are shown for each rat in Table 1.

Equating rates of reinforcement. Because rates of reinforcement may differ when comparing paced and unpaced schedules (e.g., the rat may not meet the DRL or DRH criterion immediately after the interval has elapsed, resulting in a decrease in the rate of reinforcement in the paced terminal link), a yoking procedure was used to equate rates of reinforcement across both terminal links. The first session of conditions in which paced and unpaced schedules were compared operated as previously described. Beginning with the second session, intervals of the unpaced schedule were equated to the interreinforcement intervals (IRI), or time between subsequent reinforcer deliveries, obtained in the paced schedule of the previous session. This was done for each session, so that the intervals programmed in the unpaced terminal link were equal to the IRIs obtained in the paced terminal link of the previous session.

Stability criterion. The following stability criterion was used: After a minimum of 20 sessions, the last 9 sessions were split into 3 blocks of 3 sessions each. When the mean choice proportions (i.e., the number of responses in the initial link leading to the unpaced terminal link divided by the total number of responses in both initial links) of the 3 sessions in each block differed by no more than .05, and when no systematic upward or downward trend of the block means was detected through visual inspection, responding was judged stable.

RESULTS

All results are based on the stable sessions (i.e., the last 9 sessions) in each condition.

DRL Group's Terminal Links

It was expected that the DRL group's response rates in the paced terminal link would decrease relative to those in the unpaced terminal link as the IRT criterion became more stringent across conditions. Overall response rates and particularly running response rates showed that, in general, a decrease in response rates was observed. (This decrease can not be attributed to an decrease in reinforcement rates; the average duration of the terminal links is shown in Table 2.) However, there was little differentiation with respect to terminal link, except possibly in the cases of Rats T5 and T8. When baseline conditions were reinstated, rates slightly recovered toward baseline levels with the exception of T8.

Table 2

Mean terminal link durations and standard deviations (shown in parentheses) for stable sessions.

| | | DRL Rats | | | | | | | |
|------------------------|--|--------------|--------------|--------------|---------------|--------------|--------------|--------------|--------------|
| | | T3 | | T5 | | T8 | | T10 | |
| Condition | | Paced | Unpaced | Paced | Unpaced | Paced | Unpaced | Paced | Unpaced |
| BL | | 60.65 (0.34) | 60.95 (0.54) | 60.43 (0.10) | 60.62 (0.61) | 60.43 (0.14) | 60.37 (0.10) | 60.41 (0.17) | 60.42 (0.15) |
| IRT > 20 th | | 60.80 (0.48) | 62.05 (0.94) | 60.64 (0.41) | 61.11 (0.68) | 60.92 (0.71) | 62.89 (3.47) | 60.77 (0.46) | 61.24 (0.50) |
| IRT > 40 th | | 61.70 (1.28) | 62.50 (0.91) | 60.97 (0.67) | 63.01 (3.03) | 61.74 (1.28) | 65.09 (6.88) | 62.05 (2.26) | 62.16 (0.70) |
| IRT > 60 th | | 61.70 (0.68) | 63.24 (0.94) | 61.71 (0.59) | 62.90 (0.87) | -- | -- | 62.83 (3.51) | 66.77 (7.69) |
| IRT > 80 th | | 62.06 (0.65) | 63.19 (0.69) | 62.57 (0.83) | 67.82 (10.68) | -- | -- | 63.62 (1.94) | 66.51 (2.04) |
| BL | | 61.00 (0.47) | 61.67 (1.50) | 61.93 (2.61) | 61.44 (0.90) | 61.15 (0.63) | 60.75 (0.54) | 67.34 (5.27) | 61.14 (0.59) |

| | | DRH Rats | | | | | | | |
|------------------------|--|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|
| | | T2 | | T6 | | T7 | | T9 | |
| Condition | | Paced | Unpaced | Paced | Unpaced | Paced | Unpaced | Paced | Unpaced |
| BL | | 60.59 (0.25) | 60.50 (0.13) | 60.72 (0.28) | 60.52 (0.12) | 60.59 (0.22) | 60.41 (0.17) | 61.52 (0.28) | 60.66 (0.30) |
| IRT < 80 th | | 60.64 (0.25) | 61.41 (0.87) | 61.01 (0.32) | 61.84 (0.49) | 60.97 (0.38) | 61.44 (0.41) | 62.08 (0.50) | 62.70 (0.50) |
| IRT < 60 th | | 61.47 (0.61) | 64.89 (6.39) | 62.55 (1.18) | 67.48 (3.17) | 60.95 (0.34) | 61.33 (0.33) | 62.00 (1.40) | 62.70 (1.37) |
| IRT < 40 th | | 61.66 (0.77) | 63.29 (0.88) | 69.17(13.57) | 76.97(27.76) | 61.06 (0.36) | 61.63 (0.49) | 62.78 (4.14) | 65.04 (4.69) |
| IRT < 20 th | | 61.90 (0.60) | 62.98 (1.11) | 64.36 (1.39) | 65.93 (1.97) | 61.20 (0.33) | 61.89 (0.45) | 62.15 (1.18) | 63.47 (1.37) |
| BL | | 61.18 (0.43) | 62.06 (0.81) | 61.28 (0.79) | 62.09 (1.61) | 60.40 (0.15) | 60.46 (0.09) | 61.13 (0.53) | 66.04 (9.09) |

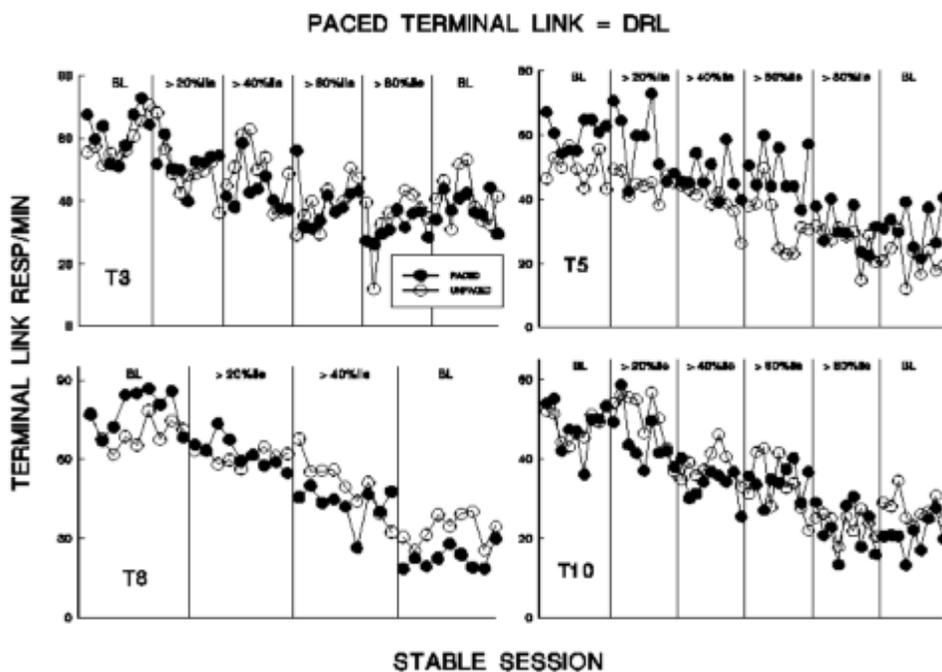


Figure 1. Overall terminal-link response rates of the rats in the DRL group across the stable sessions of each condition. The closed and open circles show rates in the paced and unpaced terminal links, respectively.

Overall response rates in the terminal links are shown in Figure 1. The rates of Rats T3 and T10 remained relatively undifferentiated with respect to the paced and unpaced terminal links, and either stayed the same or slightly increased during the return to baseline. For T5, the response rate in the paced terminal link was higher than in the unpaced terminal link throughout all conditions. Finally, the response rate was higher in the paced terminal link for T8 during baseline, but eventually dropped to slightly below the rate observed in the unpaced terminal link in the most stringent condition (IRT > 40th percentile) experienced by this rat. Rates remained differentiated in the subsequent return to baseline.

To further examine terminal-link responding, an analysis was conducted of pauses (the time between the entry into the terminal link and the first response), shown in Figure 2, and running response rates (the total number of responses in the interval divided by the length of the terminal link less the pause), shown in Figure 3. In addition, Table 3 shows the median pauses and interquartile ranges summarized across conditions.

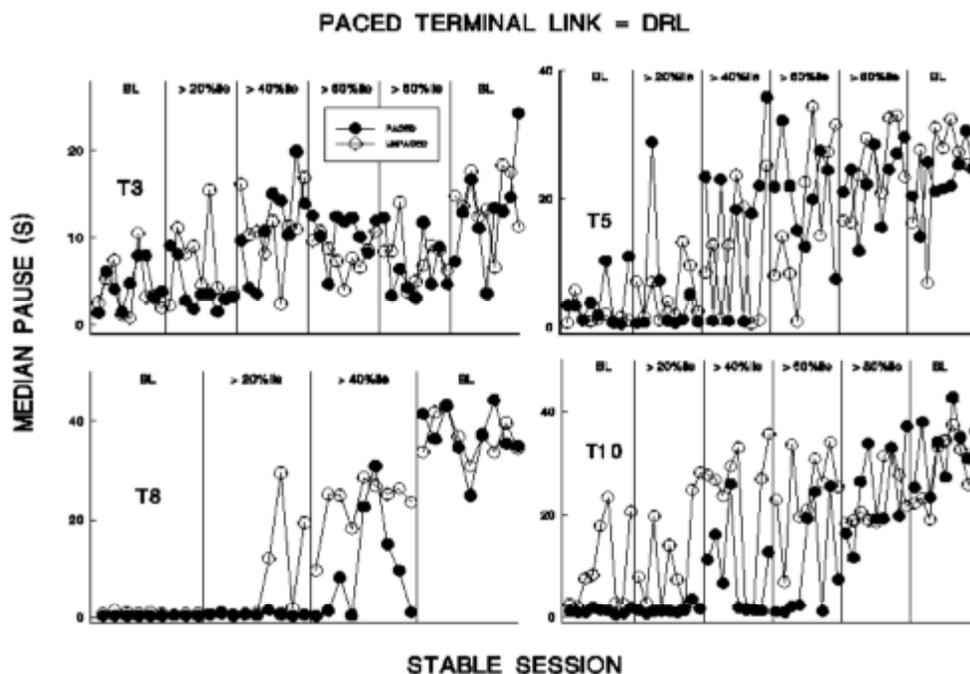


Figure 2. Median pauses of the rats in the DRL group across stable sessions of each condition. The closed and open circles show pauses in the paced and unpaced terminal links, respectively. Interquartile ranges are shown in Table 3.

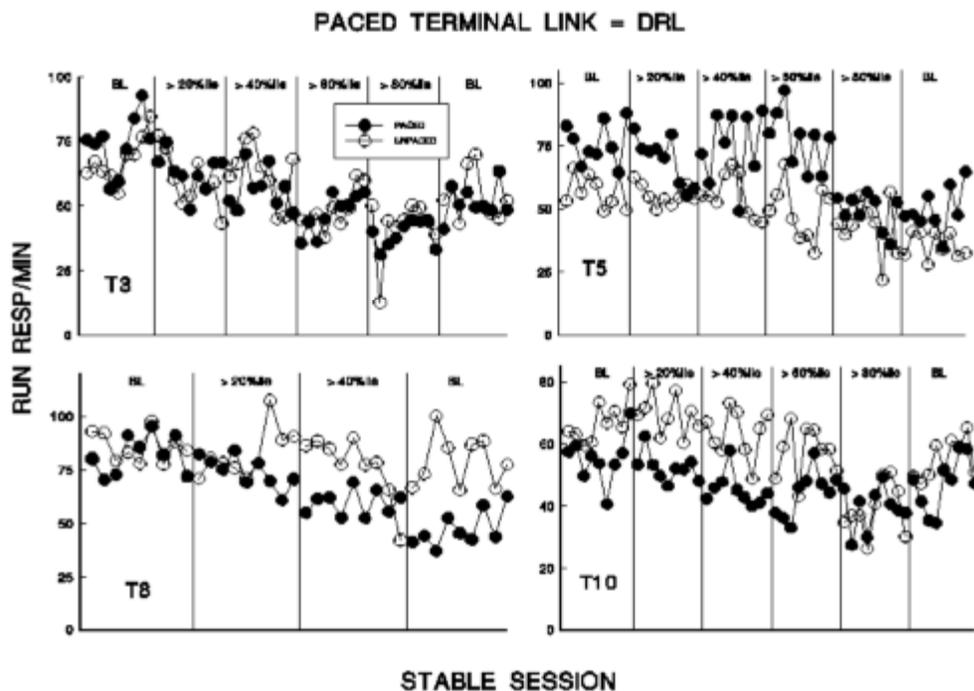


Figure 3. Average running response rates of the rats in the DRL group across stable sessions of each condition. The closed and open circles show run rates in the paced and unpaced terminal links, respectively.

Table 3

Median terminal-link pauses and interquartile ranges (shown in parentheses) for the stable sessions (DRL rats only).

| Condition | T3 | | T5 | | T8 | | T10 | |
|----------------------|-----------------------|-----------------------|-----------------------|-----------------------|------------------------|------------------------|------------------------|------------------------|
| | Paced | Unpaced | Paced | Unpaced | Paced | Unpaced | Paced | Unpaced |
| BL | 3.75 (1.12-16.60) | 2.34 (0.59-14.31) | 1.99 (0.49-22.10) | 1.30 (0.47-13.06) | 0.36 (0.29-0.52) | 0.81 (0.45-23.10) | 1.01 (0.50-2.66) | 11.31 (1.61-29.84) |
| IRT>20 th | 3.39 (1.10-19.00) | 6.46 (1.01-16.68) | 1.20 (0.44-18.25) | 3.31 (0.57-19.50) | 0.52 (0.34-15.44) | 2.95 (0.47-27.10) | 1.25 (0.76-5.94) | 7.05 (1.35-31.42) |
| IRT>40 th | 10.74 (2.77-22.93) | 10.86 (1.78-20.16) | 22.33 (0.92-37.72) | 11.87 (0.51-29.65) | 5.34 (0.40-31.13) | 21.97 (4.16-33.69) | 2.17 (0.85-32.74) | 24.41 (1.42-38.17) |
| IRT>60 th | 11.10 (2.45-23.19) | 8.05 (1.43-17.00) | 22.34 (1.87-35.76) | 17.59 (0.57-37.23) | -- | -- | 2.17 (0.76-27.5) | 28.34 (1.34-39.85) |
| IRT>80 th | 5.68 (1.56-17.22) | 8.10 (1.85-15.89) | 21.62 (7.96-35.98) | 25.15 (7.63-36.97) | -- | -- | 24.44 (11.35-38.53) | 22.00 (13.69-36.42) |
| BL rep | 11.88 (3.19-23.03) | 14.05 (2.39-22.24) | 22.28 (1.38-33.00) | 26.18 (8.98-35.76) | 36.56 (14.19-47.91) | 36.82 (25.53-45.66) | 33.19 (18.12-46.13) | 28.05 (20.08-42.83) |

Pauses were relatively short in the first two conditions and increased for all rats (albeit to a lesser extent for T3) across conditions. For Rats T3 and T5, pause durations remained undifferentiated with respect to the terminal link. Rat T8 began to pause for a longer period of time in the unpaced terminal link during the last few sessions of the first

experimental condition. These pauses remained higher in the subsequent condition, until baseline conditions were reinstated. Rat T10 showed a similar pattern, with pauses being longer in the unpaced terminal link during baseline and in subsequent sessions until the most stringent experimental condition (and return to baseline), during which pauses became undifferentiated with respect to terminal link.

Throughout many of the conditions, running response rates, or run rates, were lower in the paced terminal link for Rats T8 and T10. This differentiation began during the first experimental condition for T8 and remained throughout the final condition. For T10 the differentiation was observed throughout baseline and until the most stringent condition was implemented. During this condition, rates in both terminal links converged and decreased relative to the former conditions. Rates then increased, but did not completely recover, during the replication of baseline. Also, the run rate during the paced terminal link tended to decrease across conditions for both T8 and T10, while the run rate in the unpaced terminal link remained unchanged (i.e., until the rates converged for T10 in the most stringent condition, as previously discussed).

The run rates of Rat T3 decreased across conditions and recovered slightly during the return to baseline. With respect to the terminal links, the rates remained undifferentiated.

Rat T5 had a higher run rate in the paced terminal link until the most stringent condition (i.e., IRT > 80th percentile), where the rates decreased and converged. During the replication of baseline, rates did not increase to previous levels, but did slightly diverge as in previous conditions.

Figure 4 shows the median IRTs, excluding the pauses. Table 4 shows the median IRTs and interquartile ranges summarized across conditions. For Rats T3 and T10, the median IRT in the paced terminal link increased across conditions, but only became differentiated with respect to the terminal links in the most stringent condition. During the return to baseline, the median IRTs decreased slightly to previous levels for both rats.

For T5, the median IRTs remained shorter and unchanged in the paced terminal link. The median IRTs in the unpaced terminal link, however, increased across the last three conditions (including the replication of baseline).

For Rat T8, the median IRTs initially were shorter in the paced terminal link. Across conditions, the IRTs in each terminal link converged, with the paced IRT becoming slightly longer across conditions. In the replication of baseline, the median IRT was longer in the paced terminal link (the opposite of what was observed in the first baseline condition).

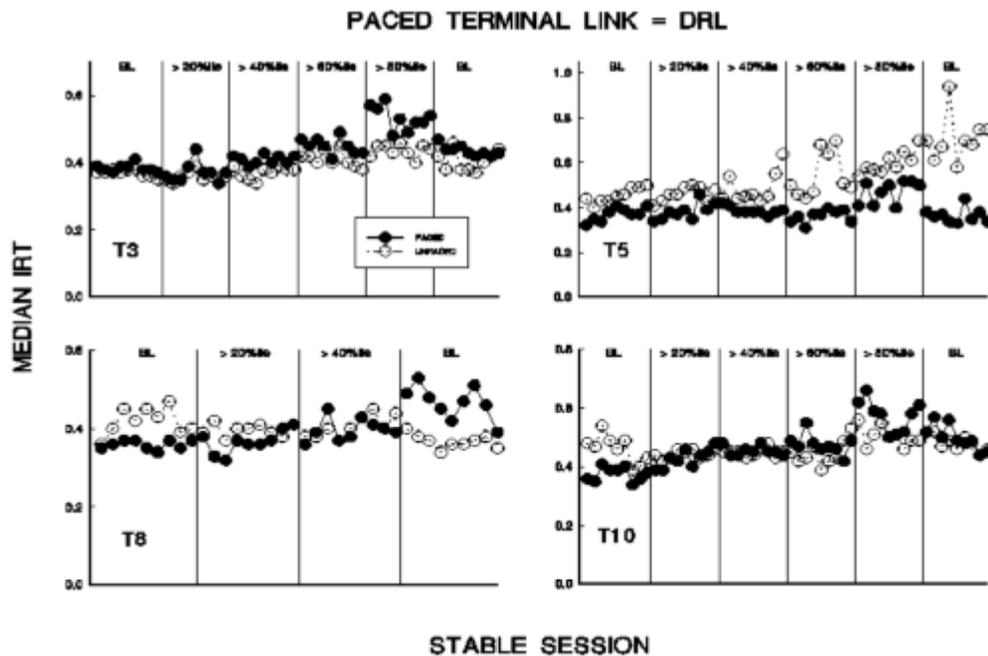


Figure 4. Median IRT of the rats in the DRL group across stable sessions of each condition. The closed and open circles show medians in the paced and unpaced terminal links, respectively. Interquartile ranges are shown in Table 4.

Table 4

Median terminal-link IRTs and interquartile ranges (shown in parentheses) for the stable sessions (DRL rats only).

| Condition | T3 | | T5 | | T8 | | T10 | |
|----------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|
| | Paced | Unpaced | Paced | Unpaced | Paced | Unpaced | Paced | Unpaced |
| BL | 0.38 (0.27-0.58) | 0.37 (0.26-0.62) | 0.38 (0.22-0.71) | 0.45 (0.29-0.79) | 0.36 (0.24-0.59) | 0.42 (0.28-0.61) | 0.37 (0.25-0.62) | 0.46 (0.29-0.88) |
| IRT>20 th | 0.37 (0.26-0.56) | 0.36 (0.25-0.60) | 0.38 (0.25-0.66) | 0.46 (0.29-0.80) | 0.36 (0.25-0.61) | 0.40 (0.27-0.59) | 0.42 (0.30-0.70) | 0.44 (0.29-0.79) |
| IRT>40 th | 0.41 (0.31-0.59) | 0.37 (0.26-0.57) | 0.38 (0.25-0.67) | 0.48 (0.31-0.86) | 0.39 (0.26-0.69) | 0.40 (0.28-0.59) | 0.45 (0.33-0.79) | 0.45 (0.31-0.81) |
| IRT>60 th | 0.45 (0.31-0.73) | 0.40 (0.28-0.68) | 0.36 (0.25-0.59) | 0.51 (0.33-0.92) | -- | -- | 0.48 (0.34-0.87) | 0.44 (0.32-0.80) |
| IRT>80 th | 0.53 (0.36-0.94) | 0.44 (0.31-0.76) | 0.46 (0.28-0.99) | 0.59 (0.38-1.09) | -- | -- | 0.57 (0.36-1.09) | 0.50 (0.34-1.0) |
| BL rep | 0.44 (0.33-0.67) | 0.40 (0.29-0.67) | 0.36 (0.22-0.81) | 0.69 (0.39-1.49) | 0.46 (0.30-0.86) | 0.37 (0.27-0.55) | 0.49 (0.35-0.95) | 0.48 (0.34-0.84) |

DRL Group's Initial Link

Because response rates were not differentiated clearly with respect to the paced and unpaced terminal links, systematic changes in choice were not expected. For Rats T3 and T5, preference for the paced terminal link was observed across all experimental conditions. For T8 and T10, preference for the unpaced terminal link (or a trend towards this in the case of T8) was observed, especially in the most stringent condition experienced by T10. When baseline conditions were reinstated, baseline preferences recovered only for T5 and possibly T10. Accompanying the unsystematic changes in choice proportions observed across rats was a systematic decrease in initial-link response rates.

Figure 5 shows the choice proportion for the paced terminal link. This was calculated by dividing the total number of responses on the lever that provided access to the paced terminal link by the total number of responses on both levers. Therefore, if a rat was indifferent between the paced terminal link and the unpaced terminal link (i.e., an equal number of responses were made on each lever during the initial link), the choice proportion would be .5. Choice proportions greater than .5 and less than .5 would be indicative of preference for the paced terminal link and unpaced terminal link, respectively.

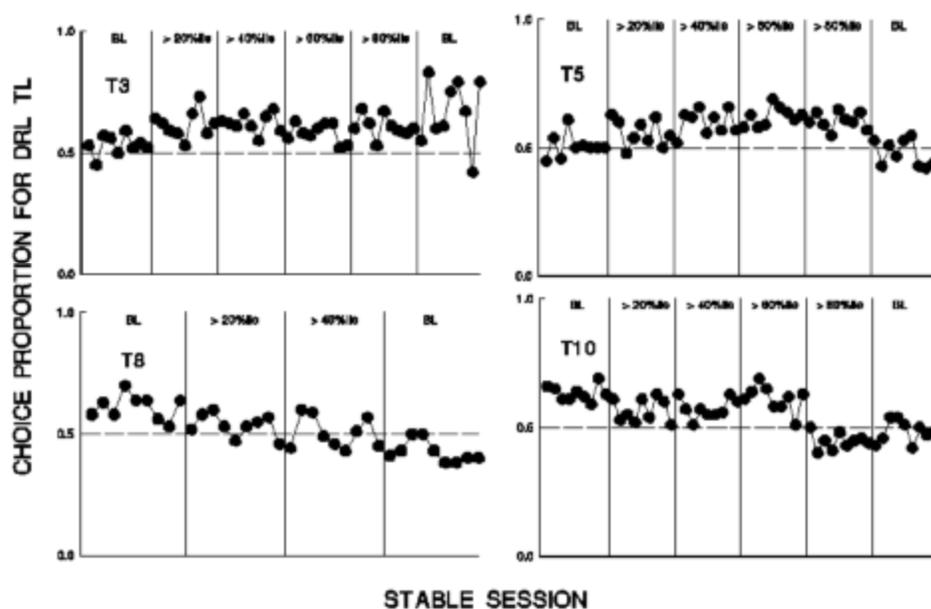


Figure 5. Choice proportion for the paced (DRL) terminal link. Points on the dashed line (i.e., choice proportion of .5) indicate indifference between the terminal links. Points above and below the dashed line indicate preference for the paced and unpaced terminal links, respectively.

Because the terminal links were the same in baseline, it was expected that the rats would be indifferent between them, resulting in choice proportions of .5. Only Rats T3

and T5 showed such performance. Rats T8 and T10, however, preferred one terminal link (i.e., their choice proportions were greater or less than .5). Because of this preference, or bias, the paced schedule was implemented in the preferred terminal link in subsequent conditions.

The choice proportions of Rats T3 and T5 also were affected similarly across conditions. That is, the choice proportion increased to above .5 across the first three conditions, and then remained relatively unchanged throughout the remainder of the experimental conditions (i.e., conditions excluding the two baseline conditions). When the baseline condition was replicated, T5's choice proportion decreased to approximately .5 (a successful replication of baseline), while T3's choice proportion remained unchanged (instead becoming more variable).

The choice proportion of Rat T10 remained unchanged until the most stringent condition (i.e., IRT > 80th percentile), during which it decreased from above .5 to slightly below .5. During the replication of baseline, the choice proportion increased slightly, but did not recover to that observed during baseline.

Across the experimental conditions, the choice proportion for Rat T8 gradually decreased to .5 and then decreased below .5 during the replication of baseline (i.e., the baseline choice proportion was not replicated).

Figure 6 shows the absolute response rates on both levers during the initial link. In general, rats' response rates on both levers decreased to less than 1 response per minute across conditions, with the exception of Rat T3. The response rates of T3 decreased to a lesser extent, with the rate on the lever leading to the paced terminal link becoming more variable in the last two conditions.

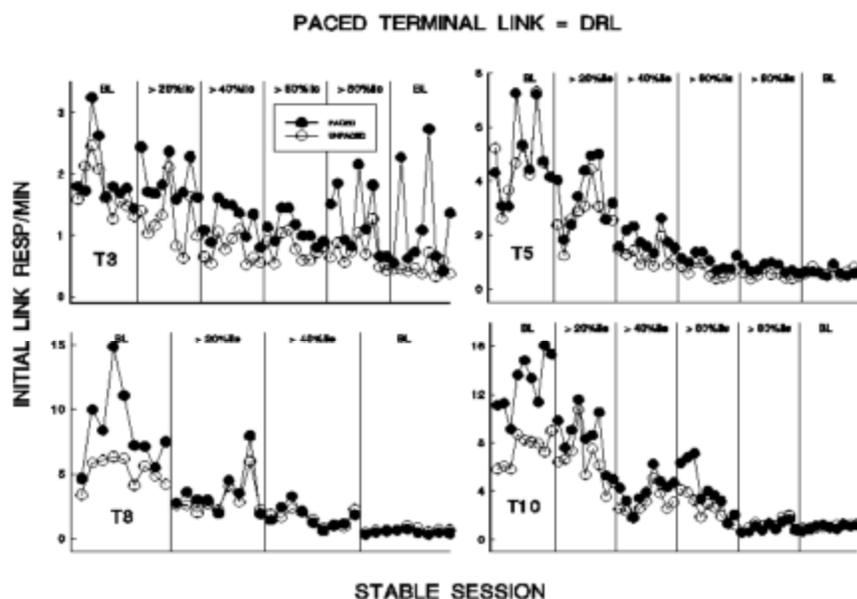


Figure 6. Initial-link response rates of the rats in the DRL group across stable sessions of each condition. The closed and open circles show rates in the paced and unpaced terminal links, respectively.

DRH Group's Terminal Links

It was expected that the DRH group's response rates in the paced terminal link would increase relative to those in the unpaced terminal link, as the IRT criterion became more stringent across conditions. Overall response rates or running response rates showed that this occurred for T7 and T9 only. When baseline conditions were reinstated, rates slightly recovered to those observed in the initial baseline condition for T9 only.

Overall response rates in the terminal links are shown in Figure 7. For Rats T2 and T6, a general decline in terminal-link response rates is observed across the first two to three conditions and no differentiation across the paced and unpaced terminal links is observed, except in baseline. For these rats and Rat T9, response rates were lower in what would become the paced terminal link in the subsequent conditions.

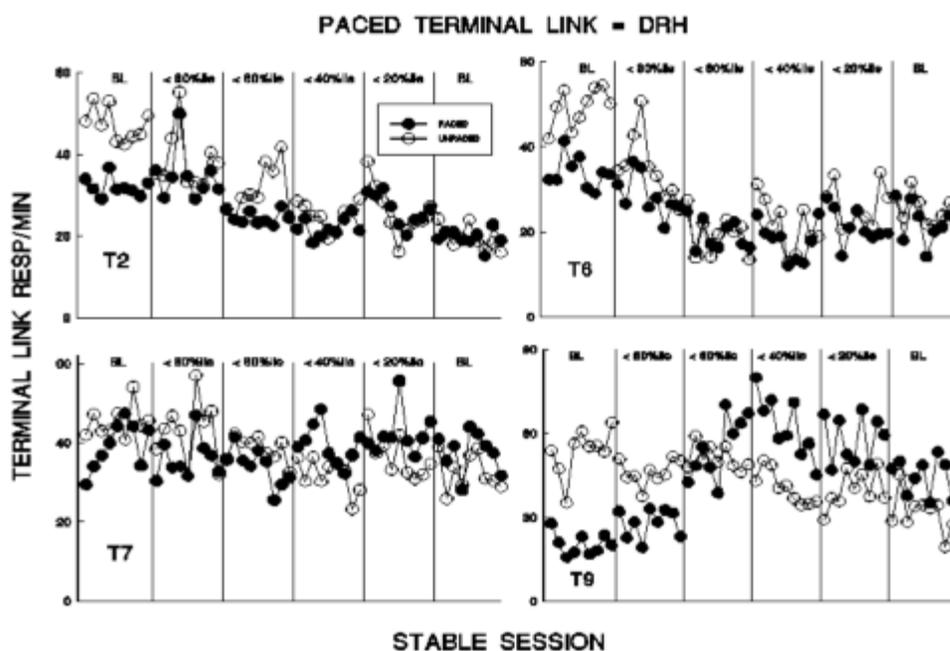


Figure 7. Overall terminal-link response rates of the rats in the DRH group across the stable sessions of each condition. The closed and open circles show rates in the paced and unpaced terminal links, respectively.

Rat T9 responded in accord with the programmed contingencies. That is, response rates in the paced terminal link increased across the first few conditions, and remained unchanged, but higher than the response rate in the unpaced terminal link, during the two most stringent conditions. When baseline was reinstated, rates in both terminal links decreased, but did not converge.

Response rates across the two terminal links remained unchanged and undifferentiated across all conditions for Rat T7.

Figure 8 shows pauses and Table 5 summarizes pauses and interquartile ranges across conditions. In general, pauses tended to increase across conditions for all rats. Little differentiation in pauses across the terminal links was observed for all of the rats except T2 and T7. For both of these rats, pauses tended to be longer in the paced terminal link. For T2, this was observed in baseline and across all subsequent conditions. For T7, the differentiation developed during exposure to the experimental conditions, and remained throughout the replication of baseline.

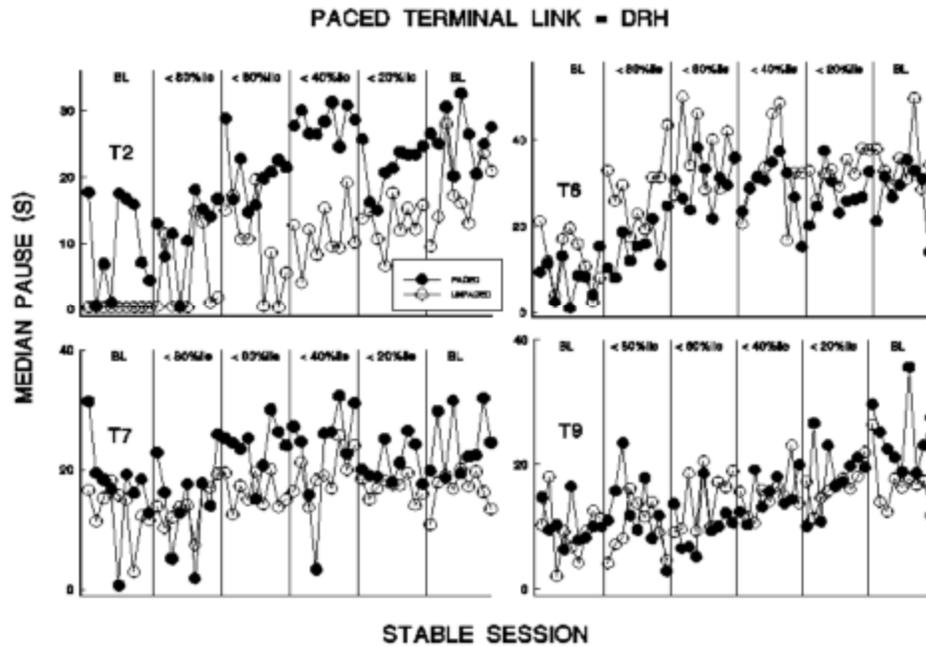


Figure 8. Median pauses of the rats in the DRH group across stable sessions of each condition. The closed and open circles show pauses in the paced and unpaced terminal links, respectively. Interquartile ranges are shown in Table 5.

Table 5

Median terminal-link pauses and interquartile ranges (shown in parentheses) for the stable sessions (DRH rats only).

| Condition | T2 | | T6 | | T7 | | T9 | |
|----------------------|------------------------|-----------------------|------------------------|------------------------|------------------------|------------------------|------------------------|-----------------------|
| | Paced | Unpaced | Paced | Unpaced | Paced | Unpaced | Paced | Unpaced |
| BL | 8.31 (0.58-22.25) | 0.32 (0.25-0.47) | 6.73 (0.94-23.42) | 13.72 (0.66-27.56) | 17.23 (0.72-29.40) | 12.99 (1.87-22.28) | 10.19 (2.29-20.14) | 9.30 (1.98-19.08) |
| IRT<80 th | 12.78 (0.77-23.50) | 0.61 (0.32-18.68) | 16.32 (1.33-25.67) | 28.91 (13.33-42.12) | 16.03 (0.94-26.99) | 13.85 (5.82-22.16) | 12.69 (2.89-22.92) | 10.52 (2.17-19.55) |
| IRT<60 th | 19.84 (9.60-30.32) | 11.05 (0.48-24.92) | 29.66 (18.77-41.72) | 35.07 (20.16-51.20) | 23.59 (12.60-34.67) | 17.18 (9.16-26.12) | 9.59 (2.45-19.42) | 13.88 (3.22-25.43) |
| IRT<40 th | 27.94 (17.59-86.01) | 11.02 (0.85-25.91) | 30.47 (19.31-42.31) | 33.85 (19.26-49.12) | 23.86 (10.36-36.40) | 18.59 (9.97-28.00) | 15.23 (7.18-26.01) | 15.22 (7.20-25.16) |
| IRT<20 th | 20.91 (7.16-29.03) | 13.51 (0.89-24.86) | 26.77 (18.19-38.12) | 33.33 (18.90-48.26) | 21.26 (13.63-29.39) | 17.00 (10.93-24.73) | 19.18 (6.71-30.07) | 16.41 (8.18-23.99) |
| BL rep | 26.30 (15.61-34.97) | 18.50 (5.88-29.89) | 30.30 (17.19-40.56) | 35.97 (21.03-49.50) | 24.76 (15.17-35.94) | 16.94 (9.86-26.57) | 24.91 (14.85-37.21) | 16.50 (6.72-25.55) |

Run rates are shown in Figure 9. Across conditions, run rates in the paced terminal link increased to above those in the unpaced terminal link for Rats T7 and T9. This divergence remained throughout the replication of baseline, while rates in both links slightly decreased for T9. Rat T2 showed a slight decline in run rates across conditions, but no differentiation across terminal links, while T6 showed a lower run rate in the paced terminal link during baseline and all subsequent conditions.

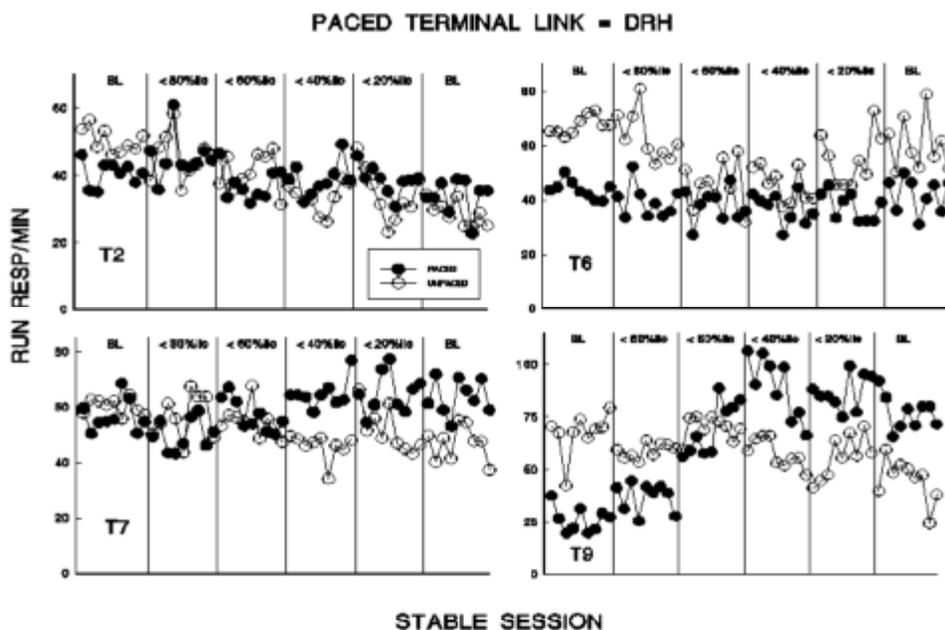


Figure 9. Average running response rates of the rats in the DRH group across stable sessions of each condition. The closed and open circles show run rates in the paced and unpaced terminal links, respectively.

Figure 10 shows the median IRTs, excluding the pauses. Table 6 shows the median IRTs and interquartile ranges summarized across conditions. During baseline, the median IRTs of Rats T2, T6 and T9 were longer in what would become the paced terminal link. For T2 and T6, these IRTs remained unchanged throughout all conditions. The median IRT in the unpaced terminal link, however, gradually increased across conditions for T2. Rat T9 showed an abrupt decrease in the median IRT across the first three conditions. In all subsequent conditions, the median IRT remained low, and below that observed in the unpaced terminal link (which remained low and relatively unchanged across conditions). For T7, the median IRTs in the paced terminal link remained unchanged across conditions, while the median IRTs in the unpaced terminal link increased to levels above those in the paced terminal link across the last two experimental conditions, ceasing to increase further when the baseline condition was reinstated.

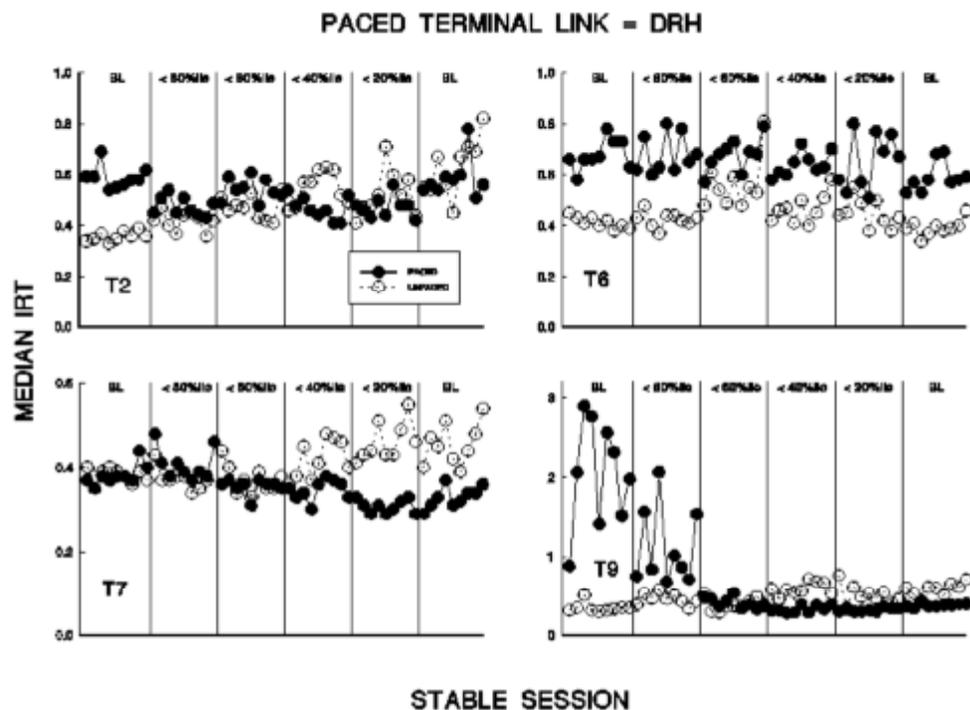


Figure 10. Median IRT of the rats in the DRH group across stable sessions of each condition. The closed and open circles show medians in the paced and unpaced terminal links, respectively. Interquartile ranges are shown in Table 6.

Table 6

Median terminal-link IRTs and interquartile ranges (shown in parentheses) for the stable sessions (DRH rats only).

| Condition | T2 | | T6 | | T7 | | T9 | |
|----------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|
| | Paced | Unpaced | Paced | Unpaced | Paced | Unpaced | Paced | Unpaced |
| BL | 0.58 (0.31-1.31) | 0.36 (0.26-0.81) | 0.67 (0.39-1.28) | 0.41 (0.27-0.79) | 0.38 (0.24-0.73) | 0.38 (0.24-0.73) | 1.97 (0.59-3.21) | 0.33 (0.20-0.84) |
| IRT<80 th | 0.47 (0.31-0.99) | 0.41 (0.26-1.01) | 0.67 (0.38-1.30) | 0.42 (0.29-0.86) | 0.40 (.24-.77) | 0.38 (0.24-0.71) | 0.97 (0.31-2.22) | 0.45 (0.22-1.10) |
| IRT<60 th | 0.54 (0.32-1.24) | 0.46 (0.27-1.15) | 0.67 (0.40-1.27) | 0.54 (0.34-1.19) | 0.35 (0.25-0.70) | 0.37 (0.24-0.72) | 0.39 (0.19-1.02) | 0.37 (0.22-1.04) |
| IRT<40 th | 0.46 (0.30-1.10) | 0.53 (0.29-1.37) | 0.63 (0.37-1.16) | 0.47 (0.33-1.01) | 0.34 (0.24-0.67) | 0.41 (0.26-0.83) | 0.32 (0.18-0.28) | 0.58 (0.28-1.20) |
| IRT<20 th | 0.47 (0.26-1.03) | 0.50 (0.27-1.30) | 0.62 (0.35-1.21) | 0.44 (0.30-0.98) | 0.31 (0.19-0.67) | 0.45 (0.26-0.88) | 0.32 (0.18-0.68) | 0.49 (0.26-1.23) |
| BL rep | 0.57 (0.32-1.30) | 0.59 (0.30-1.57) | 0.58 (0.35-1.09) | 0.39 (0.28-0.79) | 0.33 (0.21-0.69) | 0.45 (0.26-0.89) | 0.32 (0.18-0.68) | 0.49 (0.26-1.23) |

DRH Group's Initial Link

It was expected that preference for either the paced or unpaced terminal link would be observed for Rats T7 and especially T9 because response rates in the paced terminal link appeared to be under the control of the IRT contingency for these rats. Unlike the DRL group, the changes in paced terminal-link response rates were not accompanied by collateral changes in unpaced terminal-link rates. Changes in preference for either terminal link, however, were not observed for any of the rats in the DRH group.

Figure 11 shows the choice proportion for the paced terminal link. In general, the choice proportion remained at, or near, .5 across all conditions. For Rats T2 and T6, the choice proportion decreased slightly across conditions, but failed to recover during the replication of baseline.

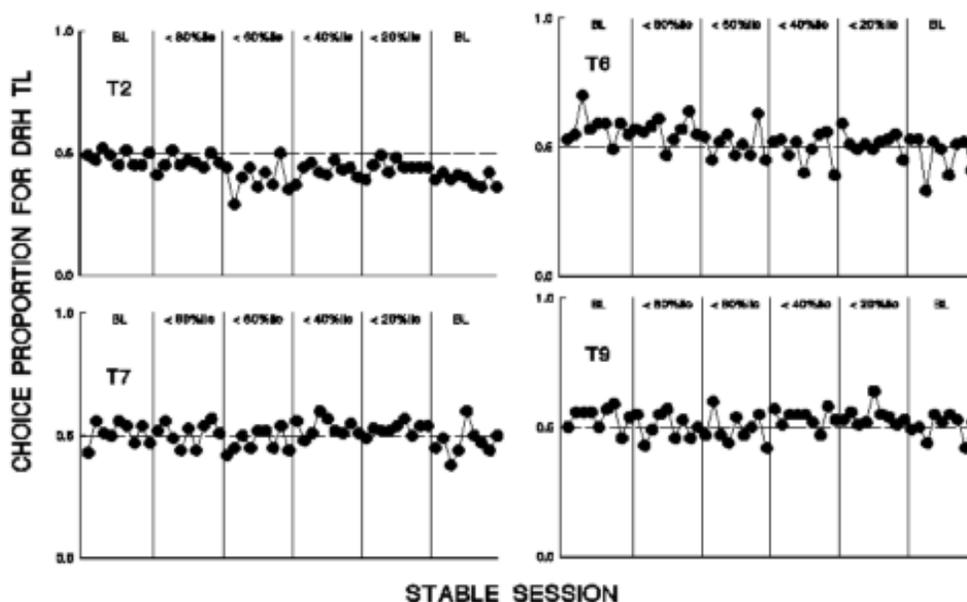


Figure 11. Choice proportion for the paced (DRH) terminal link. Points on the dashed line (i.e., choice proportion of .5) indicate indifference between the terminal links. Points above and below the dashed line indicate preference for the paced and unpaced terminal links, respectively.

Figure 12 shows the response rates on both levers during the initial link. As with the DRL group, response rates on both levers decreased across conditions, with the possible exception of T7.

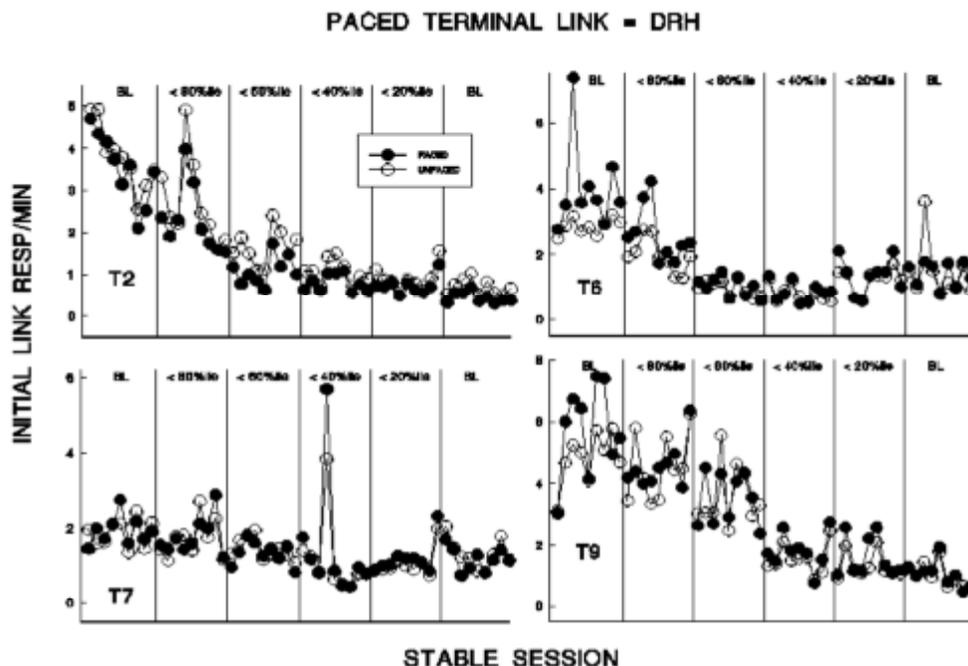


Figure 12. Initial-link response rates of the rats in the DRH group across stable sessions of each condition. The closed and open circles show rates in the paced and unpaced terminal links, respectively.

Figure 13 is a scatter plot relating the choice proportion for the paced terminal link to the relative reinforcement rate in the paced terminal link (i.e., reinforcement rate in the paced terminal link divided by the sum of the reinforcement rates in the both terminal links). This analysis was conducted to rule out the possibility that the unsystematic effects of IRT criteria on choice proportion was due to differences in reinforcement rates across the terminal links. In Figure 13, most of the data points lie on or near the vertical dashed line (at which the reinforcement rate is equal across both terminal links). This indicates that choice was not controlled by differences in reinforcement rates across the terminal links. This was expected because a yoking procedure was used to equate reinforcement rates across the terminal links (Table 2 shows that average duration of each terminal link across conditions).

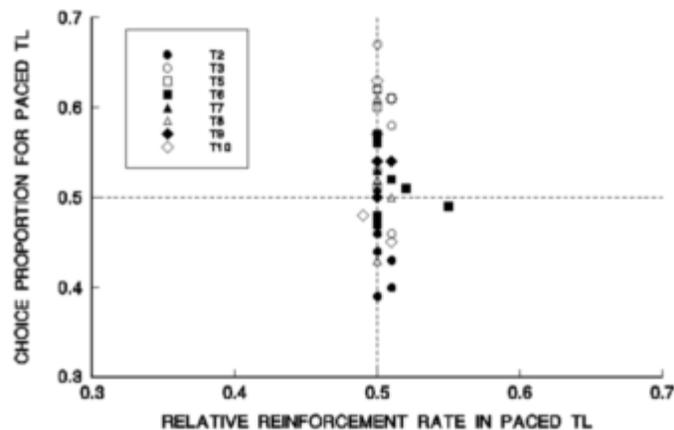


Figure 13. A scatterplot relating choice proportion for the paced terminal link to the relative reinforcement rate in the paced terminal link. Closed and open symbols represent rats in the DRH and DRL condition, respectively. Points on the horizontal dashed line represent conditions in which rats were indifferent between the terminal links. Points on the vertical dashed line represent conditions in which the reinforcement rate was equal across both terminal links.

In an attempt to explain why initial-link response rates decreased across conditions, initial-link response rates were related to terminal-link reinforcement rates for each rat in Figure 14. In general, the highest initial-link response rates were correlated with the highest terminal-link reinforcement rates, and conversely, a wider range of terminal-link reinforcement rates were related to the lowest initial-link response rates. In the cases of Rats T3, T6, T9, and T10, instances in which terminal-link reinforcement rates were lowest occurred in the unpaced terminal link (open symbols). The unpaced terminal-link durations were yoked to the previous session's average paced terminal-link duration. Often, the rats did not collect the reinforcer promptly after this interval had elapsed (see Table 2).

In other cases, the data points relating initial-link response rates to terminal-link reinforcement rates form clusters at the bottom right corner of the graph. This indicates that many of the rats (e.g., T2, T3, T7, and T9) responded at low response rates in the initial link, while still obtaining the high reinforcement rates in the terminal links.

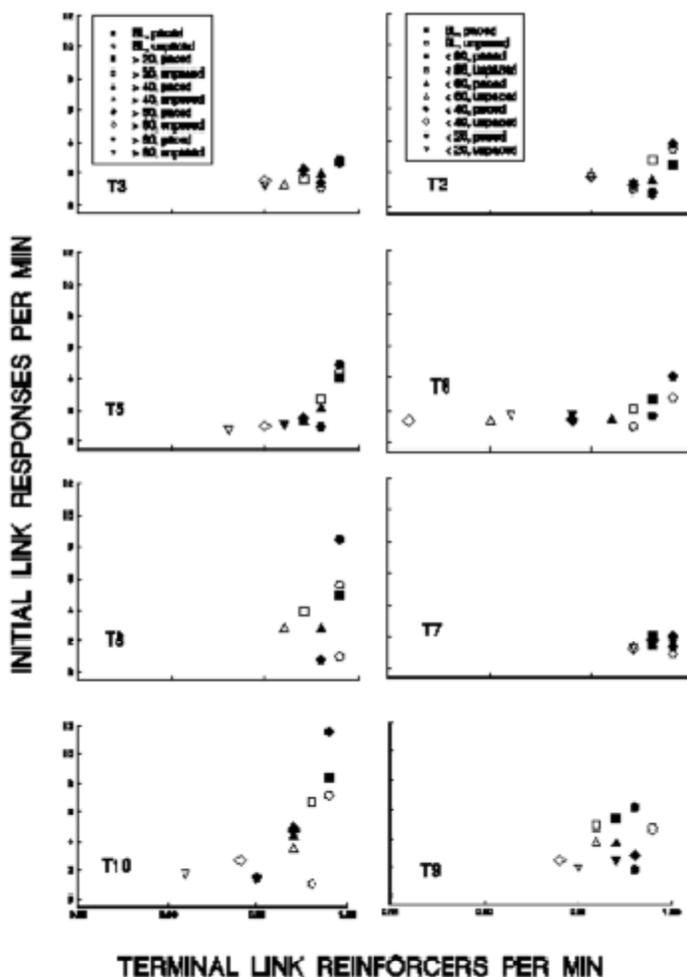


Figure 14. Scatterplots relating initial-link response rates to terminal link reinforcement rates. The scatterplots for the DRL and DRH rats are shown in the left and right columns, respectively. Closed symbols represent the paced terminal link (or initial-link response rate on the lever leading to the paced terminal link) and open symbols represent the unpaced terminal link (or initial-link response rate on the lever leading to the unpaced terminal link).

DISCUSSION

In the following summary of the results, discussion of response rates will refer to running response rates only because these rates primarily were affected by the pacing contingency.

Implementation of a DRL pacing contingency on an FI 1-min schedule did not result in systematic effects on response rates across rats. Specifically, one of the following changes in rates was observed across conditions, depending on the rat: (a) a reduction in response rates in both terminal links, rather than in the paced terminal link only, followed by a recovery to baseline rates in the final condition (e.g., Rats T3 and T10), (b) a reduction in response rates in the paced terminal link only, without recovery to baseline rates in the final condition (e.g., T8), or (c) a small reduction in response rates

in the paced terminal link, particularly when the most stringent IRT criterion was imposed, and a slight trend toward baseline rates in the final condition (e.g., T5).

Inconsistencies in the effects of the DRL contingency on response rates were reflected in inconsistencies in choice proportions. Rats T3 and T5 appeared to prefer the paced terminal link across the experimental conditions, but only T5's choice proportion returned to previous levels when baseline conditions were reinstated in the final condition. Rat T10 preferred the unpaced terminal link, but not until the most stringent condition (i.e., IRT > 80th percentile). During the replication of baseline, choice proportions increased but fell short of baseline levels. Finally, T8 showed an increase in preference for the unpaced terminal link across conditions, however, in the final condition, the choice proportion continued to drop rather than recover to baseline levels.

The DRH pacing contingency affected the terminal-link response rates of just two rats. The rates of both T7 and T9 increased in the paced terminal link relative to response rates in the unpaced terminal link across conditions. Unfortunately, no changes in preference were observed for these rats. These results, although only obtained with two rats, would support the findings that suggest indifference between periodic schedules requiring high rates versus typical FI performance. The other two rats in this group were unaffected by the pacing contingency, and as would be expected under these circumstances, choice proportions also remained unchanged.

One possible explanation for why systematic changes in response rates were not observed is that the IRT criteria were not contacted by the rats. For example, when a VI schedule is arranged, a response after variable lengths of time may be eligible for reinforcement. Because the IRT preceding the response that occurs after an interval has elapsed must meet a criterion, and because the length of the programmed intervals are of various durations, it is more likely that each IRT (except possibly those emitted prior to when the minimum interreinforcement interval has elapsed) will meet the imposed criterion. This is less likely to occur when FI schedules are employed; subjects may become sensitive to the time that must elapse before a response can be reinforced. As a result, they are capable of promptly collecting reinforcers while responding without regard to the IRT criterion throughout the duration of the interval. All that is required is that the final IRT falls within the range of those eligible for reinforcement.

It also is possible that the IRT criteria (i.e., the 20th, 40th, 60th, and 80th percentiles of the baseline IRT distributions), especially in the case of the DRH group, were not stringent enough to generate changes in FI rates of responding. Typical patterns of responding on FI schedules include longer IRTs after the first response, which gradually shorten as the time to reinforcement decreases (i.e., the typical FI "scallop"). With respect to the DRH contingency, the long IRTs at the beginning of the interval may have resulted in IRT criteria that were greater than the IRTs typically emitted immediately prior to reinforcement. As a result, the rats could have been responding at rates high enough so that the last IRT (prior to the reinforced response) easily met even the most stringent criterion employed in the current experiment. Perhaps the rats would have been more likely to contact the IRT contingency if the percentiles were based on a baseline distribution of reinforced IRTs. Under these circumstances, the IRT criteria would not have been influenced by the long IRTs emitted at the beginning of the interval.

A comparison of the median reinforced IRT during baseline and the IRT criteria used in the current experiment revealed that this was not responsible for the lack of an

effect by the pacing contingency. For most of the DRH rats, the IRT criteria used in all but the most lenient condition (see Table 1) were lower than the median reinforced IRTs (0.77 for T2, 0.92 for T6, 0.68 for T7, and 2.93 for T9) during baseline. One exception was T2; the IRT criteria were lower than the median reinforced IRT in all but the two most lenient conditions. Therefore, according to this analysis, an effect of the DRH contingency on response rates at least during the two most stringent conditions would have been predicted. This is, in fact, what was observed for Rats T7 and T9.

For the DRL rats, the IRT criteria were higher than the median reinforced IRTs (0.59 for T3, 0.67 for T5, 0.54 for T8, and 0.46 for T10) in the most stringent condition only. Therefore, the DRL contingency should have affected response rates in this condition. This suggests that the general decline in response rates shown by the DRL rats, particularly in the earlier conditions, may not have been due to the pacing contingency. In light of these results, perhaps it would have been more appropriate to calculate the IRT criterion for the next condition based on the stable sessions of the most recent condition (i.e., rather than baseline). For instance, because response rates declined in the initial conditions, the IRTs may have already exceeded the criteria to be imposed in subsequent conditions. This would have precluded the rats' contact with the criteria, even in the most stringent conditions.

In any case, the IRT criteria used in the current experiment are discrepant from those used in previous studies that were successful in producing changes in response rates. For instance, Ferster and Skinner (1957) arranged a DRL contingency so that the IRT preceding the reinforced response on an FI schedule had to be no less than 4 s long. They observed that high terminal rates decreased, but a scalloped pattern of responding was maintained.

Similarly, Farmer and Schoenfeld (1964) measured reductions in response rates after adding a DRL contingency to the IRT preceding the reinforced response on an FI schedule. Substantial reductions in rates did not occur until this IRT had to be equal to or greater than 2 s. Reductions continued, defined by an inverse hyperbolic function, when IRTs as long as 24 s were required for the last response to be reinforced.

Stitzer and McKearney (1977) arranged tandem FI DRL and tandem FI DRH schedules in order to assess the effects of certain drugs on responding on these schedules. They arranged the pacing contingencies so that the IRT preceding the reinforced response had to be at least 4, 5, or 6 s to meet the DRL criterion and less than 40 ms (.04 s) to meet the DRH criterion. As with Ferster and Skinner's (1957) and Farmer and Schoenfeld's (1964) studies, these criteria were not based on baseline IRT distributions. However, they were more stringent than those employed in the current study and resulted in marked differences in response rates.

There also are possible explanations for the fact that the current procedure failed to systematically affect choice proportions, even under circumstances in which terminal-link rates were affected by the pacing contingency. It should first be noted that any observed changes in choice proportion were not the result of changes in relative terminal-link reinforcement rates. Figure 13 shows that the yoking procedure used in the current study successfully maintained approximately equal reinforcement rates across the terminal links.

First of all, initial-link response rates decreased across conditions for most of the rats, making it less likely that substantial differences in the number of responses allocated

to each lever in the initial link would be obtained. It is unclear why the initial-link response rates decreased in this manner. The relation between initial-link response rates and terminal-link reinforcement rates graphed in Figure 14 reveal that this decrease was not due to increases in terminal-link reinforcement rates.

Another aspect of the procedure that has been shown to work against obtaining substantial preferences when employing a concurrent-chains procedure is the arrangement of access to the terminal links according to the procedure used by Stubbs and Pliskoff (1969). This procedure ensures that an equal number of reinforcers are obtained from both terminal links; however, this procedure also has a tendency to reinforcer switching from one lever to the other in the initial link (McDevitt & Williams, 2001).

It is also likely that rats became sensitive to the programmed limitations on the sequence in which access to the terminal links occurred. That is, a particular terminal link could be entered no more than two times in succession, and when one terminal link was entered there was a 75% chance that access to the other terminal link would be arranged after completion of the next initial link. Perhaps more persistence on the lever that led to the preferred terminal link (assuming that there was one) would have resulted from allowing more variation in the sequence of terminal-link presentations (e.g., allowing access to the same terminal link as many times as 4 in succession).

In conclusion, the current study failed to establish clear effects of a pacing contingency on fixed-interval responding, and therefore could not contribute to the resolution of issues regarding choice between fixed-interval schedules that require particular response rates and those that do not. Various methods have been employed to increase or decrease response rates. In some cases, schedules are characterized by either low or high rates of responding (e.g., response-independent schedules or FR schedules, respectively) but do not require such rates (e.g., Grossbard & Mazur, 1986). In other cases, particular response rates are required for reinforcement to occur. Methods that require high or low response rates may require that the IRT preceding the reinforced response fall within some specified range of eligible IRTs (e.g., Killeen, 1968), that a particular number of responses occur within a fixed amount of time (e.g., Fantino, 1968), or that a number of responses occur within a specified period of time after the interval had elapsed to prevent the subsequent reinforcer from being canceled (e.g., Moore & Fantino, 1975).

A unique feature of the current experiment was that it calculated a range of IRT criteria based on the baseline IRT distributions generated by each individual rat. This was an attempt to improve upon the previous methods that typically arranged a single, somewhat arbitrary, IRT criterion. Unfortunately, the criteria selected in the current study were not stringent enough to produce clear changes in response rates. Future research might employ a similar procedure with one or more of the following adjustments. First, IRT criteria could be based on the baseline distribution of reinforced IRTs (rather than all of the IRTs emitted throughout the interval). Second, the percentiles that form the basis of the criteria could be adjusted so that the most stringent DRL condition requires IRTs to be greater than the 90th or the 95th percentile, and the most stringent DRH condition requires IRTs to be less than the 10th or 5th percentile. Third, the duration of the initial link or terminal link may be adjusted in an attempt to avoid decreases in initial-link responding observed in the current experiment. Finally, the number of successive

presentations of a particular terminal link could be increased beyond that used in the current study (i.e., no more than 2 in succession) in an attempt to decrease the predictability of the terminal link to which the next reinforcer will be assigned.

REFERENCES

- Autor, S.M. (1960). The strength of conditioned reinforcers as a function of the frequency and probability of reinforcement. Unpublished doctoral dissertation, Harvard University.
- Davenport, D.G., & Goulet, L.R. (1964). Motivational artifact in standard food-deprivation schedules. Journal of Comparative and Physiological Psychology, *57*(2), 237-240.
- Fantino, E. (1968). Effects of required rates of responding upon choice. Journal of the Experimental Analysis of Behavior, *11*, 15-22.
- Farmer, J.F., & Schoenfeld, W.N. (1964). Effects of a DRL contingency added to a fixed-interval reinforcement schedule. Journal of the Experimental Analysis of Behavior, *7*, 391-399.
- Ferster, & Skinner, B.F. (1957). Schedules of reinforcement. East Norwalk, CT, US: Appleton-Century Crofts.
- Fleshler, M., & Hoffman, H.S. (1962). A progression for generating variable-interval schedules. Journal of the Experimental Analysis of Behavior, *5*, 529-530.
- Grossbard, C.L., & Mazur, J.E. (1986). A comparison of delays and ratio requirements in self-control choice. Journal of the Experimental Analysis of Behavior, *45*, 305-315.
- Killeen, P. (1968). Response rate as a factor in choice. Psychonomic Society, *12*(1), 34.
- McDevitt, M.A. & Williams, B.A. (2001). Effects of signaled versus unsignaled delay of reinforcement on choice. Journal of the Experimental Analysis of Behavior, *75*, 165-182.
- Moore, J. & Fantino, E. (1975). Choice and response contingencies. Journal of the Experimental Analysis of Behavior, *23*, 339-347.
- Neuringer, A.J. (1969). Delayed reinforcement versus reinforcement after a fixed interval. Journal of the Experimental Analysis of Behavior, *12*(3), 375-383.
- Stitzer, M., & McKearney, J.W. (1977). Drug effects on fixed-interval responding with pause requirements for food presentation. Journal of the Experimental Analysis of Behavior, *27*, 51-59.
- Stubbs, D.A., & Pliskoff, S.S. (1969). Concurrent responding with fixed relative rate of reinforcement. Journal of the Experimental Analysis of Behavior, *12*, 887-895.