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INTERLOCKING SCHEDULES: THE RELATIONSHIP BETWEEN RESPONSE AND TIME REQUIREMENTS[1]

DAVID P. RIDER

UNIVERSITY OF KANSAS

Rats were exposed to an interlocking fixed-ratio 150 fixed-interval 5-minute schedule of food reinforcement and then to yoked variable-ratio schedules in which individual ratios corresponded exactly to the ratios of responses to reinforcement obtained on the interlocking schedule. After additional training with the interlocking schedule, the rats were exposed to yoked variable-interval schedules in which intervals corresponded to the intervals between successive reinforcements obtained on the second interlocking schedule. Response rates were highest in the yoked VR condition and lowest in the yoked VI, while intermediate rates characterized the interlocking schedule. Break-run patterns of responding were generated by the interlocking schedule for all subjects, while both the yoked VR and VI schedules produced comparatively stable local rates of responding. These results indicate that responding is sensitive to the interlocking schedule's inverse relationship between reinforcement frequency and responses per reinforcement.

Key words: interlocking schedules, reinforcement frequency, responses per reinforcement, yoked variable-ratio schedules, yoked variable-interval schedules, lever press, rats

In an interlocking (*interlock*) schedule, reinforcement is arranged by two simple schedules operating dependently, such that progress made on either schedule alters the other's requirement for reinforcement (Ferster and Skinner, 1957, p. 728). Published research with interlocking schedules has emphasized fixed-ratio (FR) and fixed-interval (FI) components, in which progress made in either component decreases linearly the requirement for reinforcement of the other component (Berryman and Nevin, 1962; Powers, 1968). Thus, in *interlock* FR 150 FI 5-min, for example, the response requirement immediately after reinforcement is 150, but this requirement decreases at the rate of one response per 2 sec. If no responding has occurred after 5 min, reinforcement is forthcoming for the next response. Similarly, the interval requirement immediately following reinforcement is 5 min, and this decreases by 2 sec each time a response occurs. Thus, if 2 min have elapsed and 30 responses have occurred since the previous reinforcement, the response requirement stands at 60 and the interval requirement at 2 min. Figure 1 is a diagrammatic comparison between *interlock* FR FI and simple FR and FI schedules of reinforcement (based on Skinner, 1958).

As Morse (1966) emphasized, an important feature of any reinforcement schedule is the temporal relation between the reinforced response and the immediately preceding response. Morse concluded that interval schedules differentially reinforce relatively long interresponse times (IRTs) and thus low rates; ratio schedules differentially reinforce comparatively short IRTs and thus higher rates of responding. In interlocking schedules, by comparison, the contingencies placed on responding are an interacting combination of ratio and interval requirements, and so reinforcement probability increases as a function of both short IRTs (in response bursts) and long IRTs. Thus, a simple prediction of overall response rates in interlocking schedules cannot be made.

However, Berryman and Nevin (1962) and Powers (1968) showed that response rate in interlocking schedules is sensitive to changes in the parameters of the FR and FI components. Rate of responding increased as the initial interval requirement increased, and the schedule

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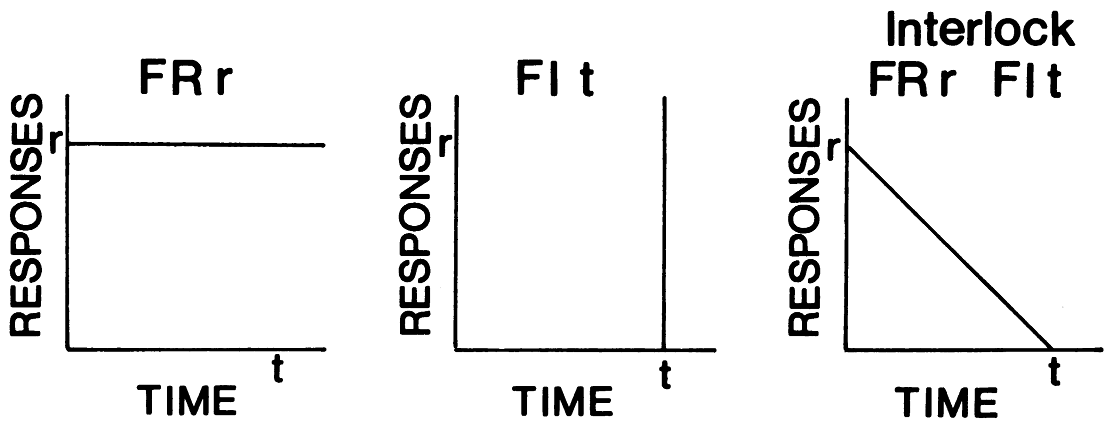

Fig. 1. Diagrams of reinforcement contingencies in fixed-ratio, fixed-interval, and interlocking schedules. Responses and time are plotted cumulatively on the y-axis and x-axis, respectively. The lines on the diagrams indicate reinforcement (in fixed-ratio) or reinforcement availability (in fixed-interval and interlocking schedules).

approached a simple FR schedule; responding decreased as the initial ratio requirement increased, and the schedule approached a simple FI schedule.

In simple FR, the number of responses per reinforcement is fixed by the ratio size. In simple FI, reinforcement frequency, or reinforcements per hour, is fixed by the interval length. When FR and FI schedules are interlocked, however, reinforcement may be forthcoming after the emission of variable numbers of responses and after variable intervals of time. Neither responses per reinforcement nor reinforcement frequency is fixed by the schedule parameters. A relatively high rate of responding produces reinforcement after a short period of time, but only after a relatively large number of responses. Conversely, a low response rate produces reinforcement after only a few responses, but only following an extended period of time. In *interlock* FR 150 FI 5-min, reinforcement theoretically can occur at any point within a range of one to 150 responses, or can become available for the next response at any time between the minimum time needed to complete at the least, 149 responses, and 5 min, at the most.

Interlocking schedules are distinguished, though, from variable-ratio (VR) and variable-interval (VI) schedules in that the relationship between time and responses from reinforcement to reinforcement is fixed by the interlocking schedule. The amount of time between any two successive reinforcements is determined by the number of responses that occurred, and *vice versa*. This fixed relationship between the number of responses and time between successive reinforcements can be expressed by the equation:

$$1 = \frac{r}{R} + \frac{t}{T}, \qquad (1)$$

where R is the schedule's initial response (FR) requirement, T is the initial time (FI) requirement in seconds, and r and t are the number of responses and the number of seconds, respectively, between any two successive reinforcements.

This equation illustrates the trade-off between responses and time between successive reinforcements, and thus between responses per reinforcement and reinforcements per hour. As response rate increases, the number of responses between successive reinforcements (r) increases, time between successive reinforcements (t) decreases, and reinforcement frequency increases. No such trade-off exists in simple ratio or interval schedules. Increased responding in ratio schedules decreases time between successive reinforcements (t) without affecting the number of responses between successive reinforcements (r). By comparison, increased responding in interval schedules increases the number of responses between successive reinforcements (r) without affecting reinforcement frequency.

The present study sought to determine if responding is sensitive to this relationship between responses and time to reinforcement. Performances on an interlocking schedule were compared to those generated by yoked VR and VI schedules in which this relationship between responses and interreinforcement time was lacking, but that otherwise matched exactly the ratios and intervals at which reinforcements were obtained on the interlocking schedule.

METHOD

Subjects

Three male albino rats, seven to eight months old at the start of the experiment, were maintained at approximately 80% of their free-feeding weights. The animals, all experimentally naive, were obtained from Mid-Continent Research Animals, Shawnee, Kansas.

Apparatus

A standard Lehigh Valley Electronics rat chamber containing a response lever and pellet dispenser was enclosed in a sound-attenuating chest. A houselight illuminated the chamber; masking noise and ventilation were provided by an externally attached fan. Noyes laboratory pellets (45 mg) served as food reinforcers.

Data were recorded and contingencies scheduled by standard electromechanical relay equipment located in the same room as the chamber.

Procedure

The lever-press response was shaped for all three rats. They were then exposed to four sessions in which each response was reinforced, and two sessions at each of the following FR requirements: 5, 10, 20, and 30. All 12 pretraining sessions were terminated with the thirtieth reinforcement. Subsequent experimental sessions terminated with the first reinforcement after 60 min and were conducted seven days per week at approximately the same time each day.

After pretraining, the schedule was changed to *interlock* FR 150 FI 5-min. The interlocking schedule was programmed by a rotary stepping switch that advanced one position each time a response occurred or after 2 sec had elapsed. The one hundred forty-ninth operation of the stepping switched latched a relay that made reinforcement available for the next response, reset the stepping switch, and deactivated the 2-sec timer. The next response delivered reinforcement, unlatched the relay, and reactivated the 2-sec timer.

Table 1 shows the number of sessions that each subject was observed on the interlocking schedule, and during subsequent phases of the experiment. In all cases, training was continued until each subject's range of response rates across five consecutive sessions was no more than 10 to 13% of the five-day mean and when no consistent trend was present.

During training on the interlocking schedule, the number of responses emitted between successive reinforcements was recorded. The list of numbers for the last five sessions was randomized and used to prepare an individual VR tape for each rat. Performance was observed with these individualized yoked VR schedules, after which the interlocking schedule was reintroduced.

During the second exposure to *interlock* FR 150 FI 5-min, the number of seconds that elapsed between successive reinforcements was recorded. A yoked VI tape was made based on the five final sessions of these data in the same way as that described for the yoked VR tape. Performance was observed on the individualized yoked VI schedules, after which subjects were returned for a third time to the interlocking schedule.

Table 1 summarizes the values of the yoked VR and VI schedules for each subject, together with the range of ratios and the range of intervals for each schedule.

Table 1

Schedule parameters and number of sessions in each condition. The ranges of ratio and interval values are listed parenthetically for each rat's yoked VR and yoked VI schedule, respectively.

Rat	*Schedule*	*Sessions*
1	*Interlock* FR 150 FI 5-min	31
	VR 75.2 (25-113 responses)	26
	Interlock FR 150 FI 5-min	41
	VI 180.5 (72-298 sec)	96
	Interlock FR 150 FI 5-min	44
2	*Interlock* FR 150 FI 5-min	34
	VR 52.9 (8-85 responses)	35
	Interlock FR 150 FI 5-min	112
	VI 149.1 (93-272 sec)	22
	Interlock FR 150 FI 5-min	50
3	*Interlock* FR 150 FI 5-min	23
	VR 94.6 (42-128 responses)	36
	Interlock FR 150 FI 5-min	76
	VI 117.2 (47-185 sec)	115
	Interlock FR 150 FI 5-min	28

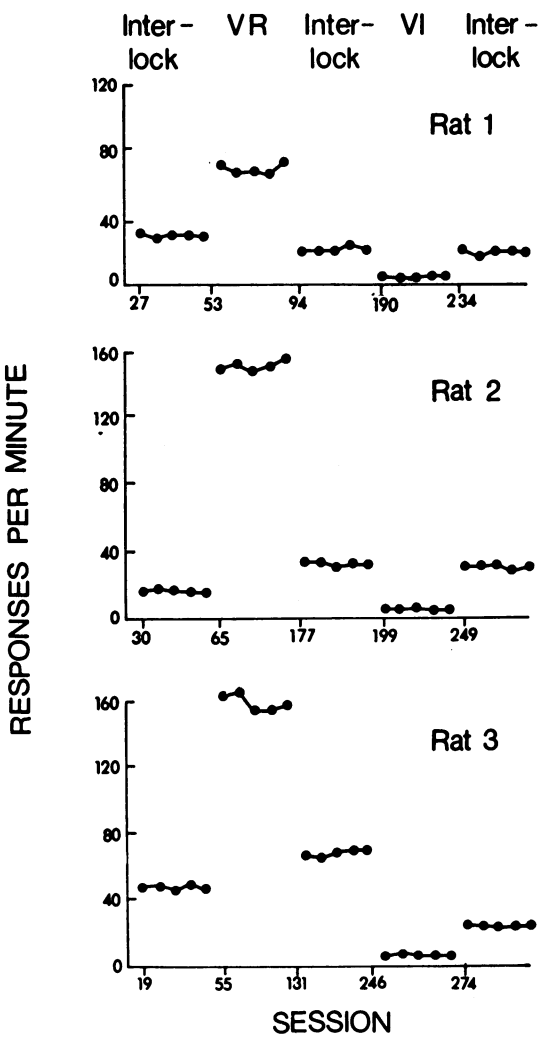

Fig. 2. Overall response rates during the final five sessions in each experimental condition.

RESULTS

Figure 2 shows the daily overall mean response rates for each rat during the final five sessions in each condition. For all three rats, introduction of the yoked VR was correlated with substantial increases in responding over rates generated by the interlocking schedule. The return to *interlock* FR 150 FI 5-min decreased responding for all three rats, while response rates in the yoked VI were still lower for all rats. The final return to *interlock* FR 150 FI 5-min increased responding over yoked VI levels for all rats.

Figure 3 shows obtained reinforcement frequency and responses per reinforcement for all three rats across all experimental conditions. Data are from the last five sessions in each condition. Reinforcement frequency remained roughly constant across all three interlocking schedule conditions and the yoked VI condition for all three rats. Responses per reinforcement remained roughly constant across all interlocking schedule conditions and the yoked VR condition for all rats. But for all animals, reinforcement frequency was highest in the yoked VR condition and responses per reinforcement lowest in the yoked VI condition. That is, when the number of responses per reinforcement was prescribed by the yoked

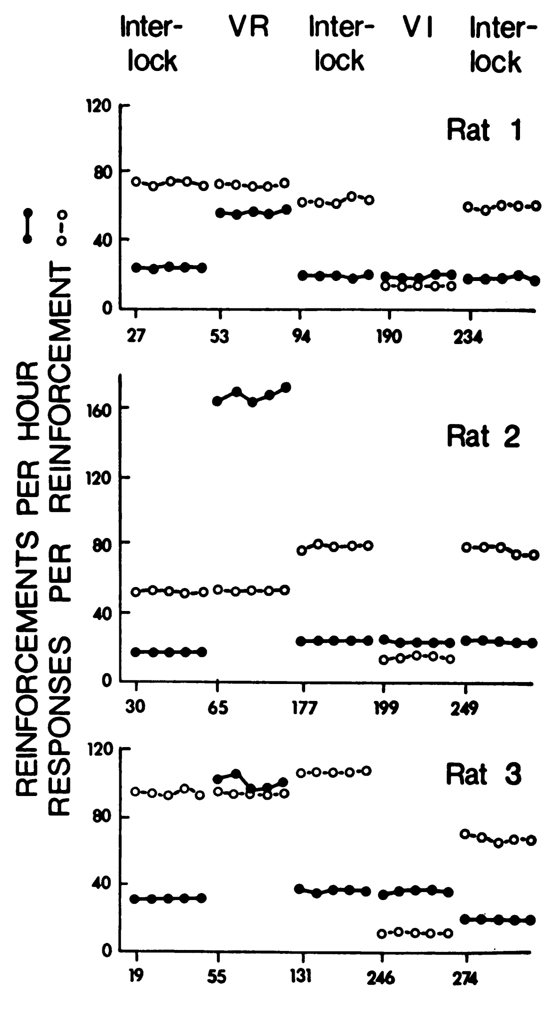

Fig. 3. Reinforcements per hour and responses per reinforcement in the final five sessions in each experimental condition.

VR schedule, response rate, and hence reinforcement frequency, rose. When reinforcement frequency was prescribed by the yoked VI schedule, response rate and responses per reinforcement decreased.

Each exposure to the interlocking schedule resulted in a break-run pattern of responding for all three rats, *i.e.,* long postreinforcement pauses (PRPs) were followed by a high rate of responding until the next reinforcement. These results are consistent with those reported by Berryman and Nevin (1962). Response rates on the yoked VR schedules were high and stable, with very short PRPs. Long PRPs occurred for all animals on the yoked VI schedules, possibly reflecting the absence of short intervals in the VI tapes (see Table 1), typically followed by low, stable rates of responding.

DISCUSSION

The inverse relationship between the number of responses between successive reinforcements and the interreinforcement interval, formulated in equation (1), is the formal characteristic of interlocking schedules that distinguishes them from simple ratio and interval schedules. The present study sought to determine if responding is, in fact, sensitive to this relationship by determining whether responding on *interlock* FR 150 FI 5-min is different from responding generated by yoked VR and VI schedules arranged according to each rat's performance on the interlocking schedule. The large differences in responding across the experimental conditions indicate that responding was sensitive to this relationship.

Individually, the ratio and interval components that make up an interlocking schedule affect responding by two opposite contingencies: by the ratio contingency, reinforcement is approached only by responding; by the interval contingency, reinforcement is approached only by the passage of time. By themselves, these contingencies produce widely different rates of responding, as exemplified by the rates generated by the yoked VR and VI schedules. Since response rates in the interlocking schedule were intermediate to those obtained with the yoked VR and VI schedules, it is evident that both of the interlocking schedule's contingencies influence responding.

How each of these contingencies, or the relationship between them, makes contact with responding, though, is unclear. An extension of Morse's (1966) analysis of schedules in terms of the differential reinforcement of classes of IRTs does not provide an unambiguous prediction of interlocking schedule performance because reinforcement probability increases as a function of both short and long IRTs in interlocking schedules. By compromise, the schedule could be expected to contact responding by reinforcing short IRTs on some occasions and long IRTs on others, and thus generate a rate of responding that is intermediate to that generated by comparable ratio and interval schedules. However, the break-run pattern of responding characteristic of responding on interlocking schedules suggests that reinforcement nearly always follows a short IRT.

The inverse relationship between responses and time to reinforcement can be viewed as a self-limiting property of interlocking schedules. Occasional pauses accompanying high rates of responding would be strengthened by the schedule's interval contingency, just as occasional bursts of responding that may accompany low rates would be strengthened by the ratio contingency. Such an analysis would predict a pattern of responding in which high and low local rates of responding alternate, with reinforcement occasionally following each. Again, the usual break-run pattern of responding seems to provide evidence against such an analysis.

In the present study, reinforcement consistently followed a high local rate of responding during stable interlocking schedule performance. Similarly, reinforcement contacted high response rates in most interlocking schedule parameters studied by Berryman and Nevin (1962). Powers (1968) modified the interlocking schedule so that reinforcement could be delivered either by a response or by the clock, thus permitting pauses to be followed directly by reinforcement. In spite of this arrangement, high rates of responding typically preceded reinforcement. Thus, the interlocking schedule's ratio contingency, it appears, contacts responding directly.

But since reinforcement rarely follows low rates or pauses, the schedule's interval contingency may only affect responding indirectly. For example, long PRPs may be strengthened by the short ratios that, as a consequence, follow them. Conversely, short PRPs may be weakened by the long ratios that follow them. The rate of responding after the PRP (running rate) may be affected in the same way. Low running rates may be strengthened by the small ratios of responses to reinforcement that accompany them, and high rates may be weakened by the comparatively large ratios that accompany them. In simple FR, neither PRP length nor running rate has a bearing on the response requirement. However, when an interval requirement is interlocked with the FR, the ratio requirement decreases directly with the PRP length and inversely with the running rate. Furthermore, as the interlocking schedule's interval requirement is shortened, pausing and decreased running rates result in more and more substantial decrements in the response requirement. In support of this analysis, progressively longer PRPs and lower running rates were obtained in FR 36, *interlock* FR 36 FI 4-min, and *interlock* FR 36 FI 2-min (Berryman and Nevin, 1962).

In summary, the present results indicated that overall rates of responding in an interlocking schedule were intermediate between those of comparable VR and VI schedules, and further that these intermediate rates were characterized by a break-run pattern, rather than a steady pattern of responding. These findings provide clear evidence that responding is influenced by the interlocking schedule's inverse relationship between reinforcement frequency and responses per reinforcement. However, definite conclusions about the ways in which the schedule's contingencies make contact with responding to produce these outcomes must await further research.

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