DETERMINANTS OF REINFORCER ACCUMULATION DURING AN OPERANT TASK

JENNIFER M. MCFARLAND AND KENNON A. LATTAL

WEST VIRGINIA UNIVERSITY

Responses by rats on an earn lever made available food pellets that were delivered to a food cup by responses on a second, collect, lever. The rats could either collect and immediately consume or accumulate (defined as the percentage of multiple earn responses and as the number of pellets earned before a collect response) earned pellets. In Experiment 1, accumulation varied as a function of variations in the earn or collect response requirements and whether the earn and collect levers were proximal (31 cm) or distal (248 cm) to one another. Some accumulation occurred under all but one of the conditions, but generally was higher when the earn and collect levers were distal to one another, particularly when the earn response requirement was fixed-ratio (FR) 1. In Experiment 2, the contributions of responses and time to accumulation were assessed by comparing an FR 20 earn response requirement to a condition in which only a single earn response was required at the end of a time interval nominally yoked to the FR interval. When 248 cm separated the earn and collect levers, accumulation was always greater in the FR condition, and it was not systematically related to reinforcement rate. In Experiment 3, increasing the earn response requirement with a progressive-ratio schedule that reset only with a collect response increased the likelihood of accumulation when the collect and earn levers were 248 cm apart, even though such accumulation increased the next earn response requirement. Reinforcer accumulation is an understudied dimension of operant behavior that relates to the analysis of such phenomena as hoarding and self-control, in that they too involve accumulating versus immediately collecting or consuming reinforcers.

Key words: accumulation, distance, travel, response requirements, effort, lever pressing, rats

An operant task typically consists of sequences in which completing a schedule requirement yields a single reinforcer, in close temporal proximity to the response and in close spatial proximity to the behaving organism, that then is obtained and consumed or otherwise utilized. These features are ones of sufficiency and convenience rather than necessity. For example, operant behavior can be established and maintained in the absence of any training and when reinforcers occur only after relatively long unsignaled delays following a response (Lattal & Gleeson, 1990). Similarly, food reinforcers need not be consumed following each completion of a schedule requirement but rather can be accumulated, then collected and consumed later (Killeen, 1974). The present experiments examined some of the variables that produce the accumulation of reinforcers of operant behavior, specifically, the temporal-spatial distance to the accumulated reinforcers, schedule requirements for earning and collecting reinforcers, and the interactions between these variables. Such accumulation has implications for analyzing not only operant contingencies in the laboratory but also such naturally occurring contingencies as those that result in self-control and hoarding.

A relation between responding and the spatial distance between response and consequence was suggested by Bremner and Trowell (1962) and Davidson, Davis, and Cook (1972). These investigators described an operandum for rats that minimized the distance between the operandum and reinforcer dispenser by incorporating the two into a single unit. They suggested that such an arrangement led to more rapid response acquisition. In neither report, however, were different distances between operandum and dispenser systematically manipulated. Roper (1975) found that greater distances (6 cm vs. 3.5 cm) between an operandum and either food or nest-building material decreased responding of mice under fixed-ratio (FR) schedules. These effects with food reinforc-

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Reprints may be obtained from Jennifer M. McFarland, Autism Training Center, Marshall University, Huntington, West Virginia 25755-2430 (E-mail: mcfarlan@marshall.edu) or Kennon A. Lattal, Department of Psychology, West Virginia University, Morgantown, West Virginia 26506-6040 (E-mail: klattal@wvu.edu).

ers, however, occurred only when the mice were maintained at 16 hr of food deprivation; at 22 hr of food deprivation, rate of responding was the same at both distances. That is, increasing deprivation, and thereby the effectiveness of the reinforcer, attenuated the effects of the delay to reinforcement that resulted from the greater distance to the reinforcer. Lattal and Williams (1997) also found that increasing food deprivation attenuated the effects of delayed reinforcement on response acquisition. Similarly, Mazur (1988) showed that increasing reinforcer amounts may attenuate the effects of corresponding increases in delays to reinforcement.

The effects of increased delays to reinforcement resulting from increasing the travel distance from the operandum to the food cup also may be attenuated by allowing completion of more than one schedule requirement before procuring the reinforcer. Under such a procedure, reinforcers are allowed to accrue; then, the several reinforcers thereby accrued can be obtained, or collected, in one trip to the food cup. Killeen (1974), Killeen, Smith, and Hanson (1981), and Killeen and Riggsford (1989) found that the relation between the number of food pellets that rats accrued before collecting and the travel distance could be described by a power function. With longer distances between the operandum and the feeder, the number of pellets accrued before collection by the animals increased, but not in simple direct proportion.

Delivering reinforcers after a response requirement is completed and at a location spatially distal from the operandum correlated with reinforcement confounds the response requirement with temporal changes inherent in either procedure. Killeen et al. (1981), for example, showed that similar effects were obtained when an FR requirement or a temporal requirement replaced a spatial requirement for obtaining reinforcers. Cole (1990) also showed how a temporal contingency can result in what he labeled hoarding. He arranged a schedule such that each interresponse time (IRT) of less than 1 s delivered a pellet to a food cup. IRTs greater than 1 s resulted in a 10-s period of signaled extinction. Because more than 1 s was required to move from the lever to the food cup and back, rats often produced several IRTs less than 1 s in succession, thereby allowing several pellets to accumulate before they were consumed. Cole suggested that his results were analogous to Killeen's (1974) finding that rats accumulated several reinforcers at a spatially remote location before obtaining them.

Several investigators have proposed that responses related to collecting the reinforcer following completion of the response requirement play a role in maintaining operant behavior. For example, Matthews, Shimoff, Catania, and Sagvolden (1977) suggested that differences between some instances of human and nonhuman schedule performance may be related to the absence of an explicit collect response in many studies of human operant behavior. They therefore required humans, upon completion of a schedule requirement, to make an explicit collect response to obtain points that served as reinforcers. In combination with other variables, this collect response was suggested to result in schedule performance that often resembled that of other nonhuman species. Although they labeled their collect response as consummatory, others have proposed that such collect responses precede consumption but are not necessarily themselves consumptive. For example, Lattal and Abreu-Rodrigues (1997) found that the pattern of responding under a variable-interval schedule depended in part on whether or not a pigeon oriented to a hopper by placing its head in the hopper before food was delivered according to a concomitantly available fixed-time schedule. Schaal, Shahan, Kovera, and Reilly (1998) similarly concluded that responding during unsignaled delays to reinforcement was determined by hopper-oriented responses that, in effect, shortened the delay to consumption.

EXPERIMENT 1

Previous experiments relating pellet accumulation to the spatial distance between an earn lever and a food cup and, when distance is constant, to the response requirement on the earn lever are limited in several ways. Both Killeen (1974) and Cole (1990) studied accumulation only under FR 1 schedules on the earn lever. Although Killeen et al. (1981, Experiment 1) reported increased accumulation with increasing FR requirements, the food cup always was located near the earn lever. The role of an explicit collect response following completion of the earn response sequence also is relatively unexplored. Killeen and Cole simply delivered each reinforcer to the food cup as it was earned, without a second, collect, response. Killeen et al., however, allowed pellets to accumulate behind a door that was opened following completion of an FR requirement on a second, collect, lever. Pellet accumulation was greater with increasing FR requirements on the collect lever. Cole found that accumulation was slightly more likely when each response resulted in the immediate delivery of a pellet to the hopper as opposed to accumulating the pellets and delivering them at the end of a bout of earn responses. In Experiment 1 we investigated the effects on reinforcer accumulation of distance between the earn lever and food cup and different response requirements on the earn and collect levers.

Method

Subjects

Four experimentally naive female albino rats, 120 days old at the beginning of the experiment, were housed in separate cages providing continuous access to water. Each rat was maintained at 80% of its ad libitum weight.

Apparatus

The chamber was 30.4 cm wide by 30.4 cm high by 248 cm long. The two side walls and the top of the chamber were constructed of plywood and painted brown. A clear plastic panel across the length of the top allowed viewing of the rats. The front and rear (work) panels were aluminum. The floor consisted of stainless steel bars, 0.3 cm in diameter, spaced 1.5 cm apart. The side walls were mortised such that the rear aluminum panel could be moved in 31-cm steps to a distance of 248 cm from the front one. The two work panels were configured identically. One Gerbrands Model G6312 rat lever, requiring a force of approximately 0.18 N to operate, was located on the midline, with its center 8.8 cm from the chamber floor. A 7.5-W 110-VAC light, covered by a white shield, was located with its center 11.4 cm above the floor and 3.8 cm to the left of the lever. A tone generator was located with its center 11.4 cm from the floor and 5.1 cm to the right of the lever. An aperture (3.1 cm square) allowed access to a 3.1-cm cubic space, described hereafter as the food cup. The aperture was located in the lower left corner of the panel directly below the light and with its base 3.1 cm from the chamber floor. Pellets were dispensed from a Gerbrands Model G5100 pellet dispenser through this opening only in the front panel. Pellets were never dispensed to the aperture in the rear panel. General illumination was provided throughout each session by three 25-W 110-VAC lightbulbs located in a removable hood that could be placed on the clear plastic in the top of the chamber. The operation of a window-mounted air conditioner provided masking noise. Experimental conditions and data collection were accomplished with a Tandy 1000 TX computer using MED-PC™ programming hardware and software. The computer and a cumulative recorder were located in a room adjacent to the one housing the chamber.

Procedure

With the front panel located 31 cm from the rear panel, each rat first was trained to obtain pellets from the food cup, and then lever pressing on the front-panel lever was shaped. Next, lever pressing on the rear-panel lever was shaped. During each session subsequent to shaping the responses, completion of the schedule requirement on the rear-panel lever, hereafter designated the earn lever, led to the opportunity to obtain pellets by responding on the front-panel lever, hereafter designated the collect lever. Onset of the front and rear panel lights accompanied by a 0.1-s tone from the tone generator on the rear panel indicated completion of the first schedule requirement on the earn lever and, therefore, availability of a pellet for responding on the collect lever on the front panel. Each subsequent completion of a schedule requirement on the earn lever also resulted in a 0.1-s tone presentation. Once a pellet was available, one or more responses, depending on the schedule requirement, on the collect lever released a single pellet into the food cup. When all of the earned pellets were thus collected, the panel lights were extinguished. Once this happened, further responses on

Table 1

Sequence of conditions, number of sessions, earn response rates, and travel time for each condition for each rat in Experiment 1. The distance is that between the earn lever and food cup. Data are from the last six sessions of each condition.

Rat	Earn	Collect	Distance (cm)	Sessions	Response rate (per min)		Travel time to collect pellets (s)	
					Mean	Range	Mean	Range
J1	FR 1	FR 1	31	15	4.66	4.21–4.89	2.62	2.18–3.02
	FR 20	FR 1	31	10	40.83	32.63–51.36	1.89	1.70–2.23
	FR 1	FR 1	248	10	4.87	4.59–5.95	4.26	3.67–4.68
	FR 20	FR 1	248	12	37.13	33.37–39.78	4.42	4.12–4.77
	FR 1	FR 1	31	10	4.55	3.90–5.33	2.07	1.88–2.29
	FR 1	FR 20	31	10	2.89	2.72–2.98	3.32	2.76–4.05
	FR 1	FR 1	248	10	5.03	4.44–5.67	3.90	3.57–4.25
	FR 1	FR 20	248	10	2.35	1.98–2.49	4.70	4.33–5.04
J2	FR 1	FR 1	31	11	3.55	2.78–4.01	3.05	2.59–3.32
	FR 20	FR 1	31	10	32.26	25.72–32.29	2.34	2.22–2.72
	FR 1	FR 1	124	10	2.58	2.14–2.81	2.40	2.69–3.15
	FR 10	FR 1	124	10	10.59	8.29–13.35	4.00	3.70–4.25
	FR 10	FR 1	31	10	17.76	16.51–19.18	1.87	1.75–1.93
	FR 1	FR 1	31	14	2.40	1.85–3.08	2.09	1.98–2.24
	FR 1	FR 15	31	10	1.57	1.30–1.81	3.05	2.77–3.44
	FR 1	FR 1	124	10	2.70	1.07–3.99	2.65	2.52–2.86
	FR 1	FR 15	124	10	1.31	1.12–1.43	4.70	3.83–5.25
J3	FR 1	FR 1	31	10	6.02	5.59–6.28	1.86	1.71–2.08
	FR 1	FR 20	31	13	2.48	2.19–2.64	4.26	3.58–5.19
	FR 1	FR 1	248	12	3.83	3.61–4.44	8.36	6.63–10.45
	FR 1	FR 20	248	10	5.96	4.32–8.04	11.11	8.33–12.50
	FR 1	FR 1	31	10	4.39	4.16–4.57	2.41	2.16–2.60
	FR 20	FR 1	31	10	44.62	40.04–48.39	2.36	2.12–2.53
	FR 1	FR 1	124	10	8.09	4.28–11.51	5.65	4.00–9.00
	FR 15	FR 1	124	15	18.61	15.61–22.36	6.15	5.50–6.46
	FR 15	FR 1	31	12	33.06	27.39–42.96	2.59	2.41–3.97
J4	FR 1	FR 1	31	10	4.14	3.52–4.85	3.15	2.91–3.43
	FR 1	FR 20	31	10	2.48	2.09–2.71	3.74	3.19–4.75
	FR 1	FR 1	248	10	4.27	3.06–4.95	5.31	4.46–6.63
	FR 1	FR 20	248	11	2.98	2.97–2.99	5.47	4.33–9.70
	FR 1	FR 1	31	12	4.06	2.64–4.97	2.37	2.12–2.85
	FR 7	FR 1	31	10	11.62	10.39–12.98	2.53	2.27–2.77
	FR 1	FR 1	124	10	2.79	2.52–3.07	4.86	4.10–6.22
	FR 7	FR 1	124	10	7.30	5.30–8.62	4.05	3.58–4.59

the collect lever were without effect until another pellet was earned by completing the schedule requirement on the earn lever on the rear panel. Responses could be distributed without experimenter constraint between the earn and collect levers. Thus, it was possible for a rat to earn multiple pellets before emitting one or more collect responses and to collect all or only some of the pellets that were thus available before emitting more earn responses.

Eight or nine conditions were studied with 2 rats each. These conditions, the number of sessions at each, and their sequence are shown in Table 1. Distances of 31 cm and either 124 cm or 248 cm were studied in combination with earn response requirements of FR 1 or FR *n*, where the collect requirement always was FR 1. The value of *n* was determined empirically and represents the largest value that did not result in disruptions in ratio runs on the earn lever. A distance of 31 cm between the earn lever and the food cup hereafter is described as the proximal condition, and a distance of 124 cm or 248 cm is described as the distal condition. The same distances also were combined with collect response requirements of FR 1 or FR *n*, where the earn response requirement always was FR 1.

Two rats (J1 and J2) were exposed to variations in the earn lever requirement first, and 2 rats (J3 and J4) were exposed to variations in the collect lever requirement first. Each condition was in effect for at least 10 sessions and until the percentage of multiple earn responses, defined in the Results section below, did not vary systematically over at least six sessions. When the distal conditions were in effect, the rear panel was moved from 31 cm to the longer distance in 31-cm steps over several sessions to the final distance of 124 cm or 248 cm before the distal condition actually began. Rats J2 and J3 ceased responding reliably when an FR 20 earn requirement was programmed in the distal condition. The FR requirement therefore was reduced to 10 (J2) or 15 (J3) for the duration of the condition. Following this latter condition, a third proximal condition was conducted for Rats J2 and J3 with the lower valued FR schedule in effect.

Each session ended after the delivery of 60 pellets, with the following exception. If a rat had earned, for example, 58 pellets, and then earned three more pellets without an intervening collect response, the rat was allowed to collect all three of the earned pellets, for a total of 61. Under such circumstances, each rat was allowed to earn up to 70 pellets. Sessions occurred 6 days per week at approximately the same time each day.

Results

There are two primary effects to be considered. First, how did the manipulations affect the likelihood of the rat earning more than one reinforcer before collecting? This was assessed by comparing the number of reinforcers obtained after one or after more than one earn response requirement was met. The latter was labeled a multiple earn response, and it was recorded whenever more than one pellet was earned before a collect response intervened. The percentage of multiple earn responses per session was calculated by dividing the number of pellets collected in groups of two or more by the total number of pellets earned in the session. This index does not distinguish between instances in which two pellets were earned prior to collection and instances in which more than two were earned prior to collection. The second effect to be considered was the magnitude of any such accumulation. This was measured as the number of pellets earned per collect bout, that is, visits to the collect lever.

In evaluating the two measures of accumulation, it should be noted that the two do not necessarily covary in a simple way. One is a relative and the other an absolute measure. Thus, both a high and a low number of reinforcers earned per collect response could be reflected as the same value of percentage of multiple earn responses. For example, two bouts of 30 collect responses each (with an FR 1 earn requirement) and 30 bouts of two collect responses each both would yield 100% multiple earn responses, but the reinforcers earned per collect response would be 30 and two, respectively. Furthermore, a low number of reinforcers per collect response, say two, could be obtained if the percentage of multiple earn responses was 100%, as in the preceding example, or if considerably fewer of the reinforcers were obtained after multiple earn responses. For example, an average of two reinforcers per collect response would occur if 10 bouts of four collect responses each occurred with 20 bouts of one collect response each. Here, the percentage of multiple earn responses would be 66.66%.

In this and the two subsequent experiments, the instances of multiple accumulations before a collect response bout were not distributed systematically within sessions in each condition. In all conditions of each of the three experiments, the accumulated reinforcers were depleted once the rat began responding on the collect lever following termination of a bout of earn lever responding and before returning to the earn lever.

The percentage of multiple earn responses during the last six sessions of each condition is shown in Figure 1 as a function of the earn response requirement and relative location of the earn and collect levers. Accumulation was more likely when (a) there was a lower earn response requirement, irrespective of the distance between the earn and collect levers, and (b) the distal condition was in effect, given that the earn response requirement was the same at the two distances, irrespective of the value of the earn response requirement. There were two exceptions to this latter observation. First, the difference between proximal and distal FR 1 conditions was slight for Rats J3 and J4. These 2 rats had a higher per-

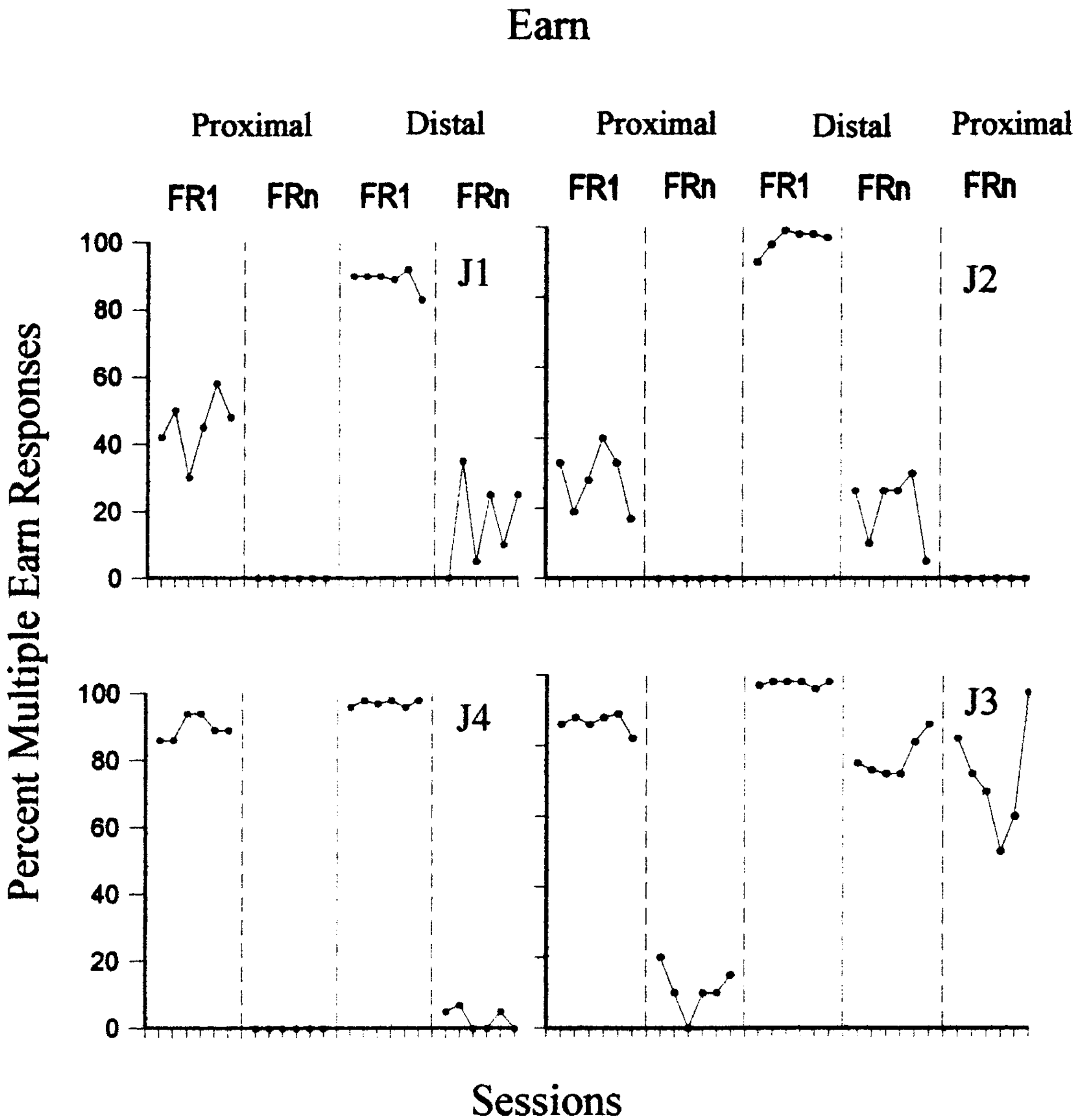

Fig. 1. Percentage of multiple earn responses that occurred before a collect response during the last six sessions for each rat in Experiment 1 during the conditions in which the earn response requirement was varied.

centage of earn responses than those of Rats J1 and J2 in the proximal FR 1 condition, presumably because of an order effect resulting from the differences in the sequences of exposure to the conditions. Second, when the proximal FR n condition was reinstated for Rat J3 at the end of this part of the experiment, the percentage of multiple earn responses dropped and then again increased. Then, due to an experimenter error, the condition was terminated before responding stabilized.

Figure 2 shows the number of reinforcers earned before a collect response, calculated as the mean of the last six sessions of each condition. These data generally coincided with the percentage of multiple earn responses shown in Figure 1, but there were some exceptions. More pellets per collect response occurred (a) in the distal condition than in

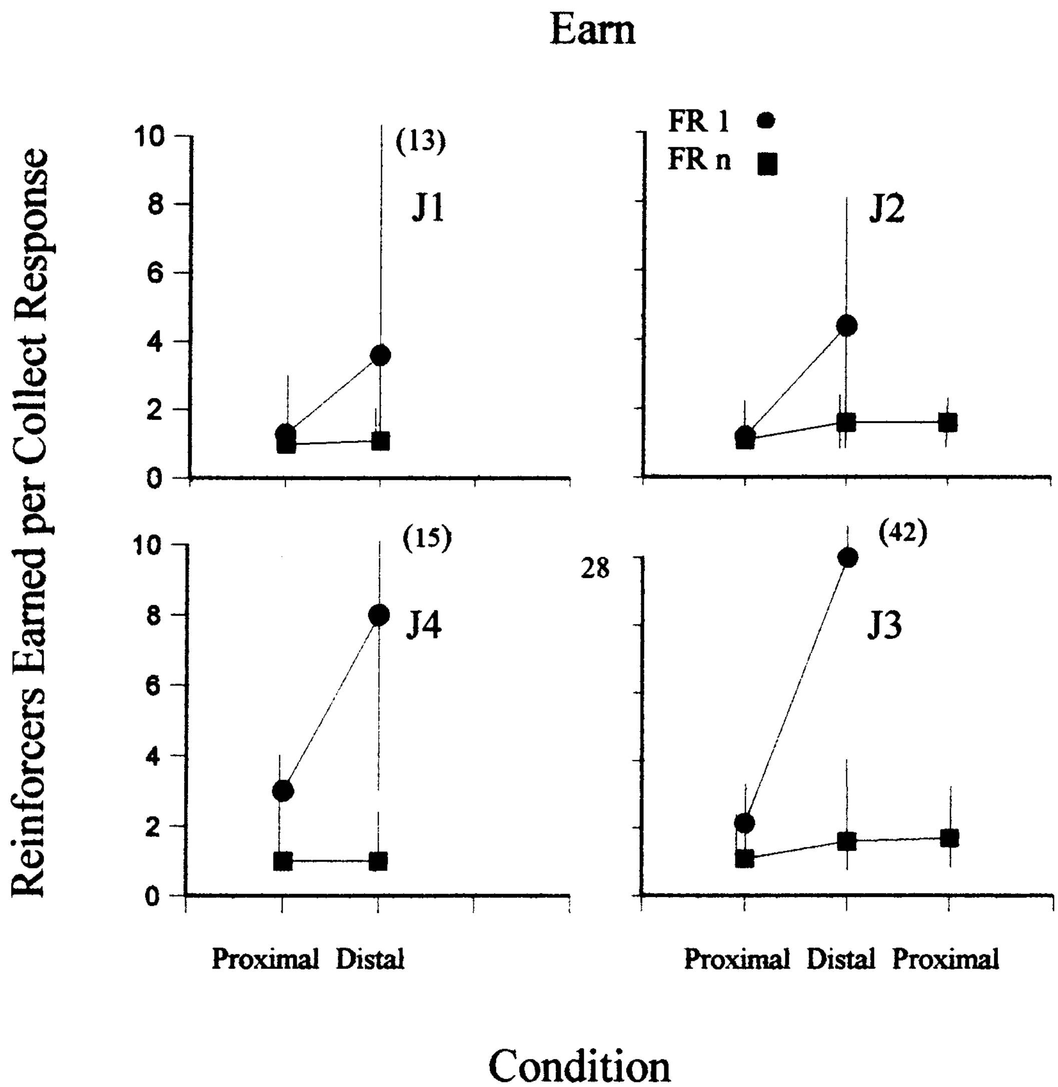

Fig. 2. Mean and range of the number of reinforcers earned before a collect response during each condition for each rat in Experiment 1 during the condition in which the earn response requirement was varied. Data are from the last six sessions of each condition. Numbers in parentheses indicate the upper limit of the range for the indicated conditions.

the proximal condition when the earn requirement was FR 1 and (b) in the distal condition when the earn requirement was FR 1 versus FR *n*. The number of pellets earned per collect response was low in both proximal and distal conditions when FR *n* was in effect.

Figures 3 and 4 show the same measures for the same 4 rats when the earn lever schedule was FR 1 and the collect lever was either FR 1 or FR *n*. Accumulation was least likely when the proximal condition was in effect with the FR 1 collect response requirement. The percentage of multiple earn responses did not differ appreciably from one another for the other three conditions for Rats J1 and J2, although for both Rats J3 and J4 accumulation was slightly higher in the distal than in the proximal FR *n* condition. These differences between Rats J1 and J2 and J3 and J4 could reflect the different sequences in which exposure to variations in the earn and collect lever requirements occurred. Figure 4 shows that, on average, more pellets were earned per collect response in the proximal condi-

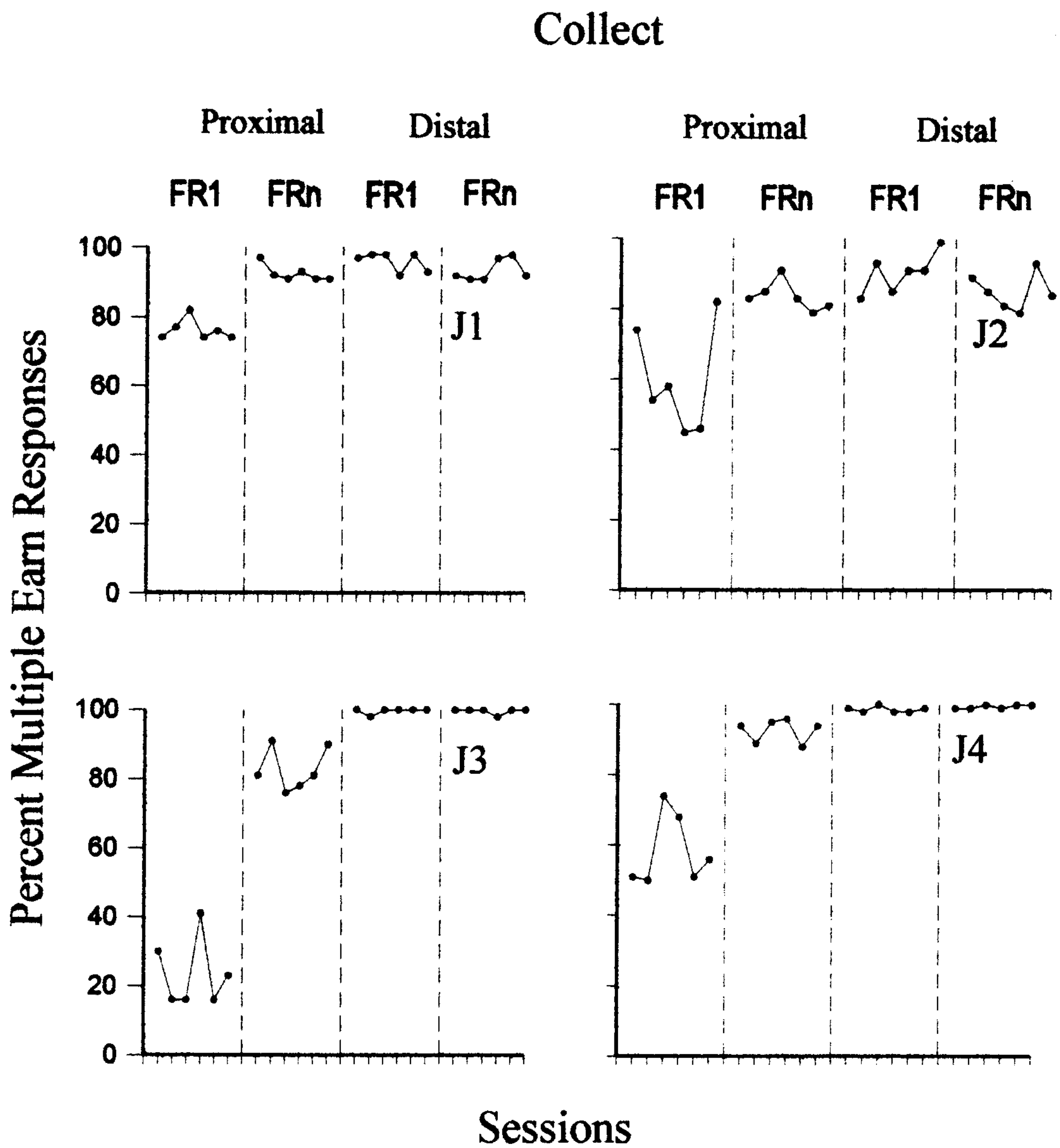

Fig. 3. Percentage of multiple earn responses that occurred before a collect response during the last six sessions for each rat in Experiment 1 during the conditions in which the collect response requirement was varied.

tion when the FR n requirement was in effect and in the distal condition (compared to the proximal condition) regardless of the collect response requirement. Rat J1 was the exception, in that it had equal accumulation in the distal condition and in the proximal condition when the collect requirement was FR n. The number of reinforcers earned per collect response in the distal condition was equal for FR 1 and FR n collect requirements for 3 of the 4 rats.

The proximal and distal FR 1 requirement appeared in both sequences of manipulations of the earn and collect response requirements. The effects replicated one another in that the percentage of multiple earn responses was higher in the distal conditions and the number of pellets earned per collect response requirement was consistently higher in the distal conditions.

Response rates on the earn lever and travel time from the last response on the earn lever

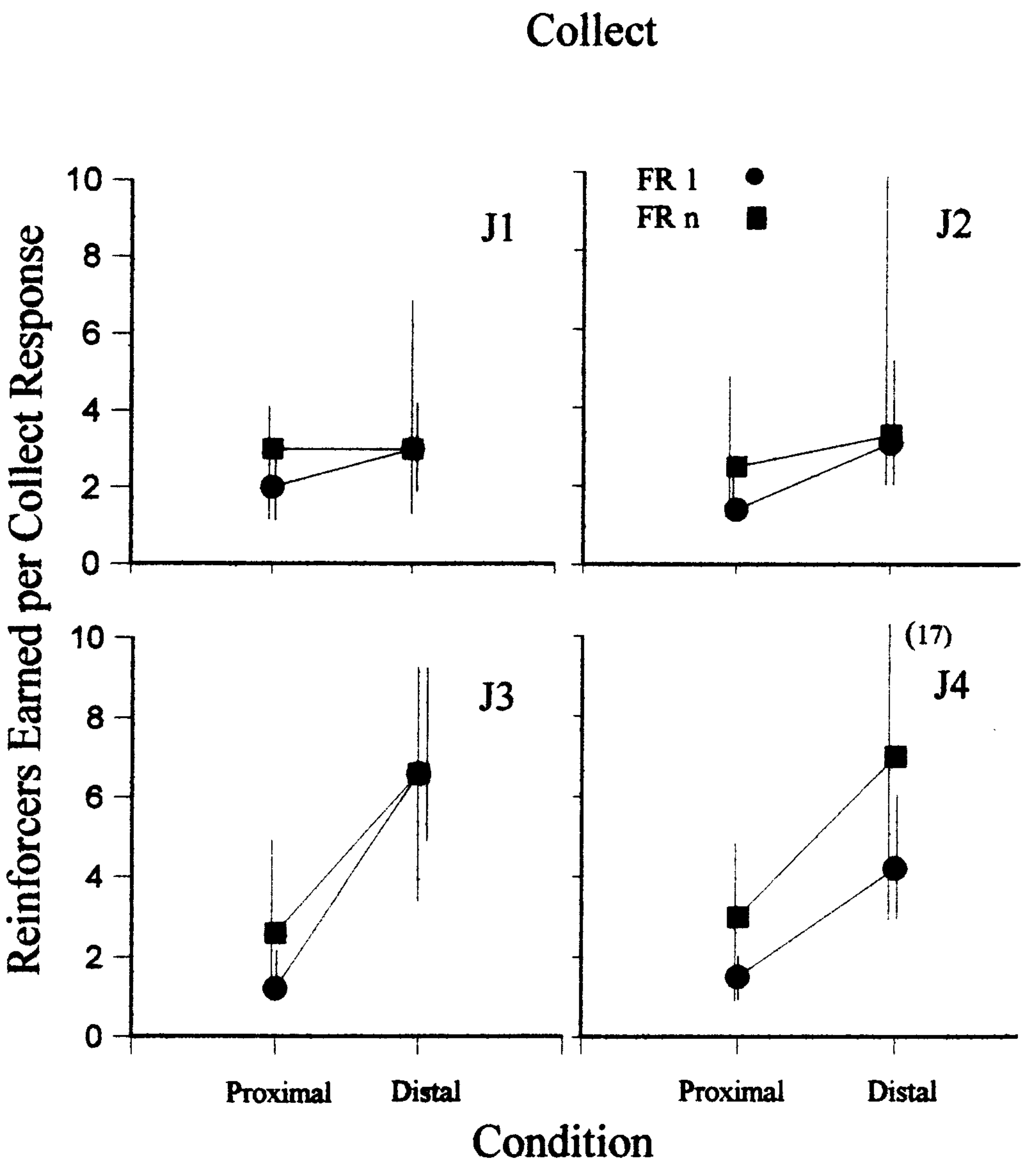

Fig. 4. Mean and range of the number of reinforcers earned before a collect response during each condition for each rat in Experiment 1 during the condition in which the collect response requirement was varied. Data are from the last six sessions of each condition.

to the first response on the collect lever in each bout are shown in Table 1. Response rates were calculated by dividing the total number of earn lever responses by the total session time. Response rates on the earn lever were lower under the earn FR 1 than under the FR *n* regardless of distance, but were higher under the collect FR 1 than the FR *n* (except for Rat J3 under the distal condition). Travel times were defined as the time from the last response on the earn lever to the first response on the collect lever. These travel times were almost twice as long, on average, when the food cup was distal, as opposed to proximal, to the earn lever, although the absolute differences were rather small. For the conditions in which the earn lever requirement was manipulated, the mean travel time for proximal conditions was 2.40 s and for distal conditions it was 4.47 s.

When the collect lever requirement was manipulated, the mean travel times for proximal and distal conditions were 2.94 s and 5.77 s.

Discussion

The FR 1 earn response requirement combined with an FR 1 collect response requirement replicated Killeen's (1974) findings, including that some rats accumulated means of about six or seven pellets at the 248-cm distance before collecting them. The other results extend Killeen's findings by showing how accumulation varies as a function of variations in response requirement on the earn and collect levers in combination with the distance between the two levers. In general, but with the exceptions noted in the Results, accumulation was more likely when the earn and collect levers were distal from one another and when the earn response requirement was smaller (FR 1). Accumulation also was more likely when, in the proximal condition, the collect response requirement was higher, replicating the finding of Killeen et al. (1981, Experiment 1). This difference in accumulation with the increased collect response requirement was attenuated, however, by increasing the distance between the earn and collect levers.

A 0.1-s tone and light onset immediately followed completion of the first earn requirement, and a 0.1-s tone followed the meeting of each subsequent earn requirement before a collect response. Such a stimulus change may be important in the accumulation of pellets (see Jackson & Hackenberg, 1996). Both Killeen (1974) and Cole (1990) delivered a pellet to the food cup immediately after each earn response, thereby also providing a stimulus change with each earn response. Furthermore, Cole found that the likelihood of accumulation was somewhat lower when each response earned a pellet but the pellets were held until the end of a bout (i.e., without any stimulus change following responses) and then delivered at 0.5-s intervals, compared to a condition in which each pellet was delivered to the hopper immediately after each earn response.

The present experiment examined pellet accumulation as a function of the response requirement on both the earn and collect levers and travel distance. Imbedded in any analysis involving either response requirements or spatial variables are temporal variables. In the second experiment we therefore attempted to isolate the contributions to pellet accumulation of response and time requirements associated with an FR requirement on the earn lever.

EXPERIMENT 2

Killeen et al. (1981, Experiments 2 and 3) suggested that the delay, or waiting time, to food rather than the response requirement per se determined pellet accumulation. In their second experiment, Killeen et al. found that increasing the waiting time between completing the earn lever requirement and access to accumulated pellets increased the number of pellets accumulated per bout of earn lever responding. They did not, however, compare waiting time alone to a condition involving a response requirement on the earn lever, and their analysis was limited to a condition in which the earn lever and food cup were proximal to one another. The present experiment also was conducted to investigate the contributions of the response requirement and the delay to food inherent in the FR requirement to the accumulation of food pellets. In this experiment we directly compared waiting time to waiting time plus a response requirement, and did so with the earn lever and food cup both proximal to and distal from one another.

Method

Subjects and Apparatus

Three experimentally naive female albino rats, as described in Experiment 1, were used. The apparatus was as described in Experiment 1.

Procedure

Following response shaping and initial training as described in Experiment 1, with the food cup 31 cm from the earn lever and an FR 1 schedule always in effect on the collect lever, each rat was exposed to the following procedure. During odd-numbered sessions, an FR 20 schedule was in effect on the earn lever. During even-numbered sessions, a yoked-interval schedule was in effect. The distribution of interreinforcer intervals that were obtained during the preceding session, when the FR schedule was in effect on the earn lever, constituted the yoked-interval interreinforcer interval distribution for that session. To minimize responding during the yoked-interval schedule, a 5-s period of nonresponding on the earn lever was required before an earn response could make the pellets available for delivery. During sessions in which the FR schedule was in effect on the earn lever, the houselights were extinguished. The houselights were flashing (on for 1 s and then off for 1 s) throughout each yoked-interval session.

Following completion of the above manipulations with the food cup located 31 cm from the earn lever, the panel containing the food cup was moved in 31- to 62-cm increments per session until it was 248 cm from the earn lever for Rats J8 and J9 and to a final distance of 124 cm for Rat J10. This distance was used for Rat J10 because at 248 cm this rat ceased responding on the earn lever. During the distal condition, the FR and yoked-interval schedules were in effect as described for the proximal condition.

The proximal and distal conditions were in effect for 20 sessions (10 with the FR and 10 with the yoked-interval schedule) for Rats J8 and J10. For Rat J9, the distal condition also was in effect for 20 sessions but the proximal condition was in effect for 28 sessions (14 each with FR and yoked-interval schedules). The criteria for changing conditions were as in the first Experiment, as were the session duration and frequency.

Results

Figure 5 shows the percentage of reinforcers during each of the last six sessions of each condition that were collected after multiple earn responses during both the FR and yoked-interval conditions. The data were calculated as described for Figure 1 above. Only Rat J9 accumulated a significant number of multiple reinforcers after an earn response when the food cup was 31 cm from the earn lever, and such accumulation occurred almost exclusively during the FR schedule. When the food cup was distal to the earn lever, the likelihood of the rats' accumulating more than one pellet before making a collect response increased substantially in the FR condition. In the yoked-interval condition, accumulation increased markedly in the distal condition for Rat J9 but only minimally for Rats J8 and J10.

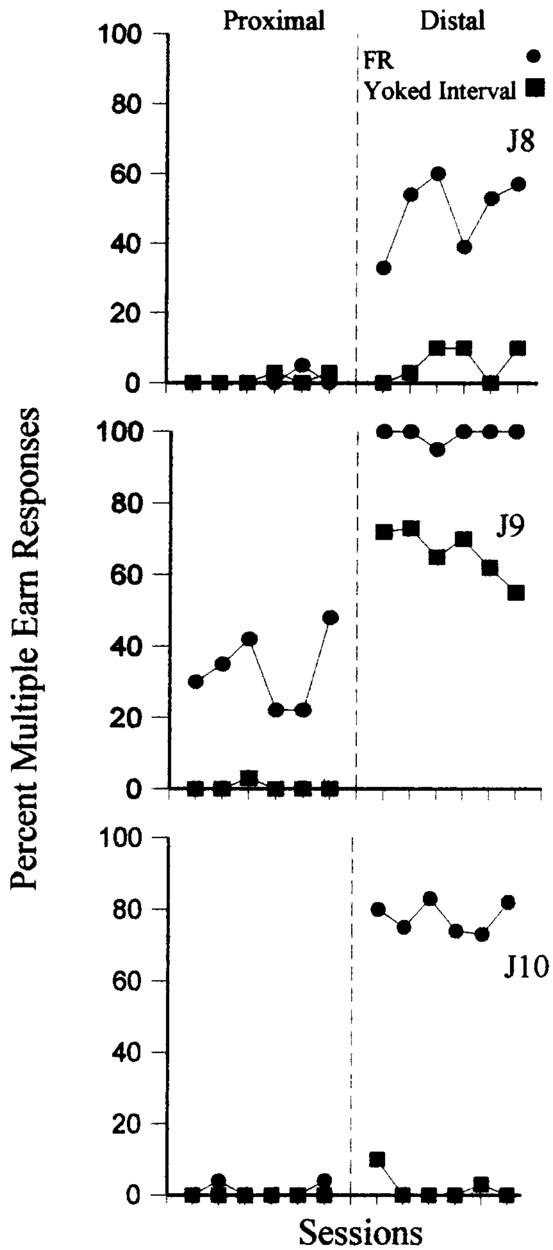

Fig. 5. Percentage of multiple earn responses that occurred before a collect response for Rats J8, J9, and J10 during the last six sessions of the FR (circles) and yoked-interval (squares) schedules of the proximal and distal conditions.

Figure 6 shows the number of reinforcers accumulated before a collect response, calculated as a mean of the last six sessions of

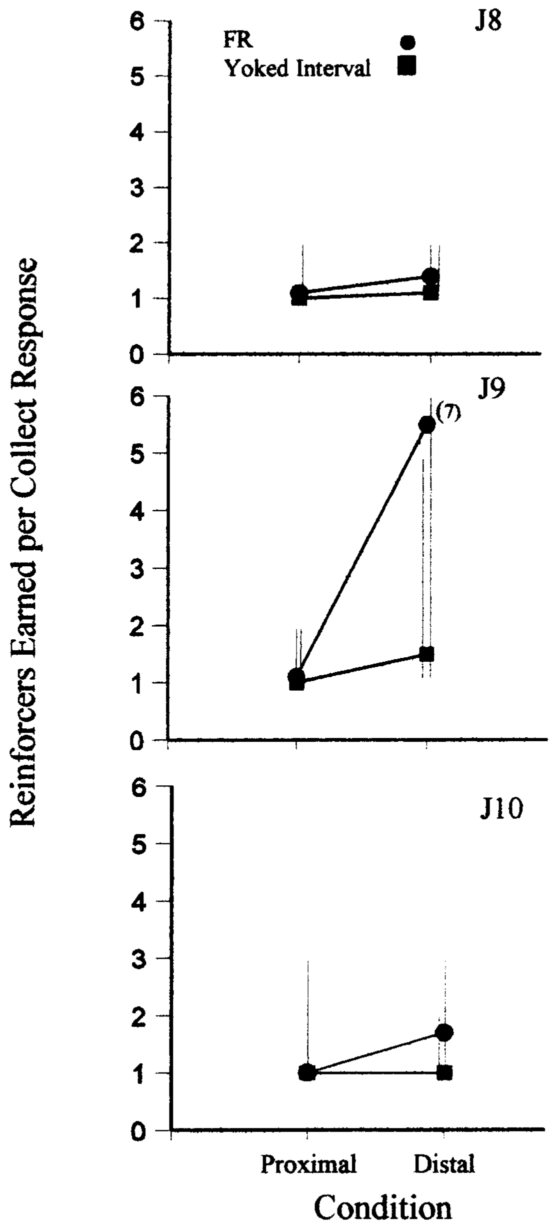

Fig. 6. Mean and range of the number of reinforcers earned before a collect response during the FR (circles) and yoked-interval (squares) schedules for the last six sessions of each condition of Experiment 2.

each condition. The highest number consistently occurred under the FR earn requirement in the distal condition, but this effect was small relative to the yoked-interval condition for Rats J8 and J10.

Table 2 provides earn response rates and travel time as means of the last six sessions at each condition. These measures were calculated as described in Experiment 1. Response rates on the earn lever were always higher under the FR 20 schedule than under the yoked-interval schedule. Travel time during the yoked-interval schedule was not recorded. Earn lever response rates were two to seven times higher during the FR than during the yoked-interval schedule, regardless of the proximity of the earn lever to the food cup. As in Experiment 1, travel time to collect pellets was longer when the food cup was 248 cm from the earn lever; however, when it was only 124 cm (for Rat J10), travel time was similar for the two conditions.

Table 2 also provides reinforcement rates, which reflect delays to reinforcement. Reinforcement rates were similar in the FR and yoked-interval sessions in the proximal condition for Rats J9 and J10. In the distal condition, the rate of reinforcement was higher in the FR sessions than in the yoked-interval sessions for Rats J9 and J10. Reinforcement rates for J8 in the distal condition were equal in the two schedules.

Discussion

The results with the FR 20 earn requirement replicate the findings in Experiment 1 that accumulation was greater when the earn and collect levers were distal from one another. Killeen et al. (1981) found that increasing delays to reinforcement brought about by increasing the work requirement on the earn lever controlled the number of pellets accumulated, leading them to observe, "it was clearly delay, not effort, that controlled [pellet accumulation] in this study" (p. 66). With both the FR and yoked-interval schedules in the proximal condition of the present experiment, multiple earn responses were similar for 2 of 3 rats, and reinforcers earned per collect response were almost identical for all 3 rats. Despite these behavioral similarities across subjects, Rat J10 had a lower reinforcement rate in the yoked-interval schedule than in the FR schedule, and Rat J8 had the opposite relation between schedule and reinforcement rate. Rat J9 had virtually identical reinforcement rates in the two schedules in the proximal condition and yet produced more multiple earn responses under the FR schedule. These results differ from Killeen et al.'s conclusion in that here reinforcement

Table 2

Sequence of conditions, number of sessions, earn response rates, travel time, and reinforcement rates for each condition for each rat in Experiment 2. The distance is that between the earn lever and food cup.

Rat	Collect	Distance (cm)	Sessions	Response rate (per min) Mean	Range	Travel time to collect pellets (s) Mean	Range	Reinforcement rate (per min) Mean	Range
J8	FR 20	31	10	43.18	26.55–55.32	2.39	2.23–2.83	2.19	1.80–2.53
	YI	31	10	7.37	4.22–11.26			3.04	2.81–3.28
	FR 20	248	10	25.21	22.11–27.5	5.04	4.39–6.07	0.99	0.86–1.19
	YI	248	10	3.51	2.56–4.47			0.96	0.81–1.08
J9	FR 20	31	14	70.49	54.53–87.44	2.25	2.02–2.60	2.65	1.83–3.34
	YI	31	14	24.80	11.72–36.01			2.41	2.10–2.79
	FR 20	248	10	57.37	42.88–64.76	7.86	6.89–9.60	2.64	2.00–3.03
	YI	248	10	30.27	11.75–43.83			1.60	1.30–1.85
J10	FR 20	31	10	53.91	44.71–58.68	3.44	3.15–3.87	2.23	1.86–2.33
	YI	31	10	7.36	3.09–12.23			1.97	1.73–2.12
	FR 20	124	10	39.45	32.98–45.19	3.29	3.08–3.64	1.54	1.30–1.80
	YI	124	10	15.49	14.10–17.64			1.10	1.00–1.32

rate was not related to accumulation in the proximal condition. For Rat J9, response reuirement was related to accumulation despite equal reinforcement rates in the two proximal conditions.

Decreasing reinforcement rate was not always sufficient to increase accumulation in this experiment. For example, reinforcement rate for Rat J9 decreased by 33% between the proximal and distal yoked-interval schedules, and yet accumulation increased in the distal condition. For Rat J10, between these same two conditions reinforcement rate decreased by 45% but accumulation remained near zero in both conditions. These data provide further evidence that reinforcement rate is not the sole determinant of accumulation.

When the earn and collect levers were distal from another, accumulation was consistently higher under the FR schedule than under the yoked-interval schedule. The yoking procedure equated reinforcement rates in this condition only for Rat J8. Despite more frequent reinforcement under the FR schedule than under the yoked-interval schedule, Rats J9 and J10 also accumulated more reinforcers under the FR schedule. In that longer delays (i.e., lower reinforcement rates) would be expected to yield more accumulation than shorter ones, the present findings suggest that the FR response requirement, and not delay or reinforcement rate, primarily determined reinforcer accumulation.

These findings of spatial and temporal variables operating together to control operant behavior are consistent with those from at least one other procedure involving spatial as well as temporal requirements. Undermatching to the more frequently reinforced of two responses in a concurrent schedule with a changeover delay is the most common finding with such schedules (e.g., Baum, 1974). But when changing from one schedule to the other involved moving around a barrier separating the two operanda, Baum (1982) found overmatching rather than undermatching, suggesting that a spatial changeover requirement, which is inherently also a temporal requirement, has different effects from a simple temporal requirement alone. In both Baum's (1982) experiment and the present Experiment 2, overlaying an additional response requirement onto a temporal requirement changed the outcome relative to that obtained with the temporal requirement alone.

EXPERIMENT 3

With the earn requirement constant, pellet accumulation in Experiment 1 was greater with greater distances between the earn and collect levers. A similar finding was obtained in Experiment 2, but the effect was much larger with the FR schedule than with the yoked-interval schedule. In Experiment 3, we

Table 3

Sequence of conditions, number of sessions, earn response rates, and travel time for each condition for each rat in Experiment 3. The distance is that between the earn lever and food cup. The barrier is described in the text. Numbers in parentheses indicate the order in which the conditions occurred for each rat.

Rat		Distance (cm)	Sessions	Response rate (per min)		Travel time to collect pellets (s)	
				Mean	Range	Mean	Range
J5	(2)	31	20	7.63	6.89–8.34	1.39	1.17–1.67
	(1)	248	21	10.47	8.39–12.19	3.53	3.00–3.93
J6	(1)	31	20	6.12	5.63–6.48	1.55	1.31–1.86
	(2)	248	22	8.38	6.33–9.25	3.28	3.16–3.41
J7	(2)	31	20	10.64	10.00–12.71	1.33	1.26–1.43
	(1)	248	30	8.68	8.24–9.02	3.88	3.58–4.09
	(3)	248[a]	10	9.30	5.37–12.18	4.43	3.84–5.97

[a] Barrier present.

further examined the generality of the effect obtained when the earn requirement was held constant in Experiments 1 and 2. This was done by employing a resetting progressive-ratio (PR) schedule in which each earned reinforcer increased the next earn requirement, and each collect response that delivered a reinforcer reset the earn requirement to one. Under this schedule, accumulation systematically increases the earn requirement, and frequent collection ensures a low earn requirement. Because this schedule mitigates against accumulation, it seemed to offer a strong test of the role of increasing distance on reinforcer accumulation.

Subjects and Apparatus

Three experimentally naive female albino rats, as described in Experiment 1, were used. The apparatus was as described in Experiment 1.

Procedure

Following response shaping with the food cup 31 cm from the earn lever, as described in the first experiment, each rat was exposed to a resetting PR schedule on the earn lever. Under this PR schedule, the earn response requirement was one at the beginning of each session and increased by one after the completion of each ratio requirement until the rat responded on the collect lever. After all pellets earned had been collected, the response requirement was reset to one and the progression began anew. An FR 1 schedule always was in effect on the collect lever, that is, each collect response produced one of the accumulated pellets. Following training on the resetting PR schedule with the food cup at distances of 31, 124, and 248 cm from the earn lever for five sessions each, each rat was exposed to the 31- and 248-cm distances (the proximal and distal conditions, respectively) in different orders for at least 20 sessions each, as shown in Table 3. A 124-cm distance was in effect for 20 sessions before (Rat J5) or between (Rats J6 and J7) the other two distances (without the barrier), but this manipulation did not yield data different from the 31-cm distance, and it will not be discussed further.

Rat J7 was exposed to the condition in which the food cup was 248 cm from the earn lever for 30 sessions. Following this, it was exposed for 10 sessions to a condition in which a solid metal plate (barrier) (10.16 cm by 30.48 cm by 0.50 cm) was placed 31 cm from the earn lever, requiring the animal to climb over the barrier to reach the panel containing the collect lever and food cup. The criteria for changing conditions were as in the first experiment, as were the session duration and frequency.

Results

Figure 7 shows that percentage of multiple earn responses increased during the distal condition, despite the progressively increasing earn requirement with continued accumulation. Adding the barrier for Rat J7 further increased this measure.

Figure 8 shows the number of reinforcers

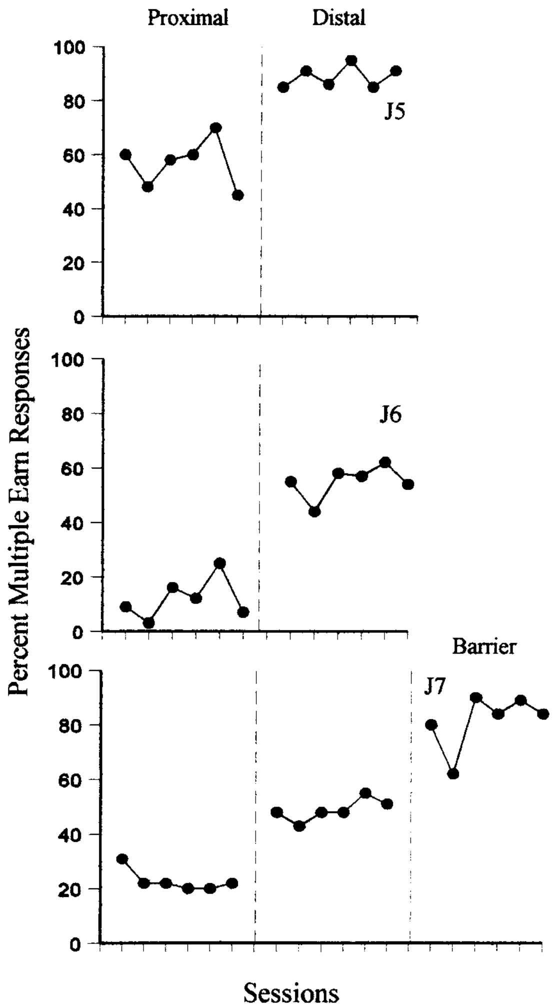

Fig. 7. Percentage of multiple earn responses that occurred before a collect response during each condition for each rat in Experiment 3. Data are from the last six sessions of each condition. Rat J7 was exposed to the barrier described in the text during the condition so labeled.

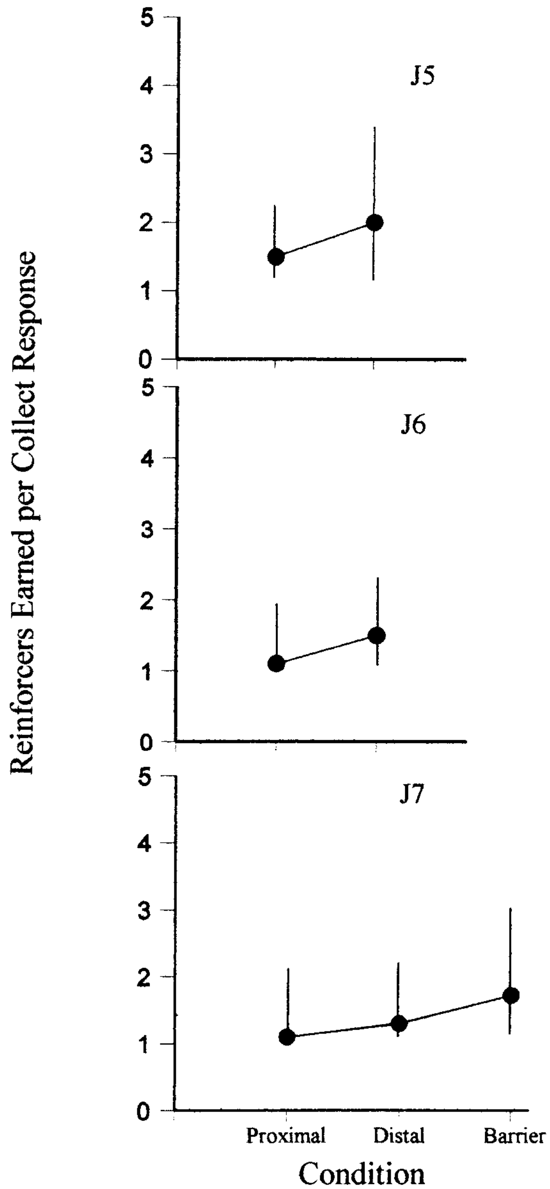

Fig. 8. Mean and range of the number of reinforcers earned before a collect response during each condition for each rat over the last six sessions of each condition in Experiment 3.

accumulated before a collect response, calculated as the mean of the last six sessions of each condition. This number increased at the greater distance between the two levers. Adding the barrier further increased the number of pellets accumulated before a collect response.

Table 3 provides earn response rates and travel time averaged over the last six sessions at the 31- and 248-cm conditions. These data were calculated as described in Experiment 1. Earn lever response rates were higher for Rats J5 and J6 when the earn lever was distal to the food cup but were lower for Rat J7. Travel time to collect pellets increased with increasing distance between the earn lever and food cup. That time increased further when the barrier was added.

DISCUSSION

At each distance at least an occasional multiple earn response requirement was met, thereby ensuring contact with the increasing response requirement of the PR schedule. The effects were qualitatively similar to those conditions of Experiments 1 and 2, in which the collect response requirement was FR 1, as it was in the present experiment. In Experiment 1, in which the collect response requirement was always FR 1, the number of multiple earn responses increased at the greater distance between the earn and collect levers (cf. Figures 1 and 7). Also, the numbers of reinforcers earned per collect response increased at the greater distance between the earn and collect levers (cf. Figures 2 and 8). Similarly, in Experiment 2, when the collect response requirement was FR 1, the number of multiple earn responses increased at the greater distance between the earn and collect levers (cf. Figures 3 and 7), and the numbers of reinforcers earned per collect response increased at the greater distance between the earn and collect levers (cf. Figures 4 and 8). These results suggest that, even when there are reasonably strong contingencies mitigating against accumulation (in the form of a resetting PR requirement), increasing the effort by increasing the distance and, in the case of Rat J7, adding a barrier that must be negotiated makes accumulation more likely.

GENERAL DISCUSSION

The simplest operant task in this series of experiments was one earn response plus one collect response to obtain one reinforcer. Increasing the distance between the earn lever and food cup increased accumulation under several conditions: when the earn or collect response requirement was either FR 1 or FR *n*, when either an FR or a yoked-interval schedule was in effect, and when a progressively increasing ratio requirement on the earn lever was reset by a collect response.

Two measures of accumulation were used in the present experiments: the likelihood (expressed as a percentage of total pellets earned) of two or more pellets accumulating before collection, and the actual number of pellets accumulated during each behavioral episode consisting of an earn response and its related collect response. This latter measure sometimes suggested only slight average effects on accumulation of the variables investigated. The former measure, however, suggested more reliable accumulation, even though the numbers of pellets accumulated was most often modest. Both Killeen (1974) and Cole (1990) measured only absolute numbers of pellets accumulated. As noted in the Discussion of Experiment 1, the magnitude of the accumulations by Killeen's rats when 240 cm separated the earn and collect levers, with an FR 1 response requirement on both, were, on average, similar to those obtained under equivalent conditions here, but Killeen did not comment on the percentage of pellets that were collected after single and multiple earn responses. A percentage measure of accumulation, like that used here, is a useful complement to absolute effects when such effects are small. For example, Cole's absolute effects were small, but a larger effect might be shown by considering an index that assesses the percentage of reinforcers that resulted from multiple earn responses as opposed to those that resulted from only one such earn response.

The present findings relate to those of previous experiments involving manipulations of what is sometimes labeled effort or work, although such labels often are difficult to define independently of functional outcomes of the contingencies thus labeled. In general, increasing response requirements while holding other variables constant attenuates operant behavior (e.g., Felton & Lyon, 1966; Miller, 1970). Such attenuation need not occur if other variables (e.g., reinforcer amount) are not held constant but instead are adjusted to counter the changes in work requirements. Most commonly, such adjustments are not controlled by the subject but by the investigator, either directly through parametric manipulations or through some a priori algorithm (e.g., Mazur, 1988). The present procedure suggests another method for compensating for increased effort by allowing a choice between collecting and consuming a reinforcer immediately or accumulating reinforcers and later consuming them collectively. Such choice procedures have proven valuable in the analysis of concurrent-schedule performance (e.g., Baum, 1982) and in the study of foraging (e.g., Wanchisen, Tatham, & Hineline, 1988).

Another issue relevant to effort or work, also raised by Killeen et al. (1981) and many others (e.g., Peele, Casey, & Silberberg, 1984), is that ratio response requirements or increasing spatial distance between earn and collect levers also involves changes in the time necessary to accrue reinforcers. Increasing the distance between the earn lever and the food cup increased the travel time between the two in addition to presumably increasing the physical energy expended in such a journey. A similar observation may be made of the ratio requirements on the earn and collect levers. Both Baum's (1982) analysis of travel times, described in the Discussion section of Experiment 2, and the results of Experiment 2 suggest that the effects of these two variables are not necessarily isomorphic; in fact, response requirements under some conditions may have effects beyond the temporal requirements simultaneously imposed by those response requirements (cf. Killeen et al., 1981).

The procedures used here and by Killeen (1974; Killeen et al., 1981) to study reinforcer accumulation may be related to both the self-control paradigm and to hoarding. Laboratory analogues of self-control (e.g., Rachlin & Green, 1972) involve contingencies similar to those analyzed here to the extent that in both situations larger reinforcer accumulations, in terms of either numbers of pellets for rats or the duration of food-hopper access for pigeons, involve a greater response requirement, a longer delay to reinforcement, or both. The two situations differ in that in the present experiment the same amount of food accrues in the final analysis, whereas in the self-control procedure an animal that consistently behaves impulsively finishes the session with a smaller amount of food than it would have had it exhibited greater self-control. Cole (1990) suggested that procedures similar to those studied here and in the self-control paradigm also operate in the hoarding of food by animals in natural settings. Hoarding has been said to occur whenever an organism transports and retains a quantity of food for some time before ingesting it (Ross, Smith, & Woessner, 1955). Because hoarding often is defined as involving handling and transportation, situations such as those studied here cannot represent a precise analogue of such ethological definitions of hoarding. Less literally, the present procedure does involve accumulating what is often considered to be a hoard of food. To the extent that the animal may be described as storing the food for later consumption by delaying its collection and consumption, it might be useful to examine, with the present accumulation procedure, those variables that have been shown to influence hoarding. One such variable, for example, is prior experience in hoarding. Killeen et al. (1981, Experiment 3) found that pellet accumulation was more likely if the rats had a prior history of accumulation. Similarly, in the present Experiment 1, the discrepancies between Rats J4 and J3 and Rats J1 and J2 during the proximal FR 1 condition shown in Figure 1, and between Rats J1 and J2 and Rats J3 and J4 during the proximal FR 1 condition shown in Figure 3, suggest an effect of hoarding history. In both cases, the rats with the previous history of reinforcer accumulation in the earlier conditions of Experiment 1 were more likely to have a higher percentage of multiple earn responses in the conditions noted. To the extent that there is a correspondence between variables that determine ethologically defined hoarding and those that determine reinforcer accumulation, a case might be made that the contingencies operating in the two circumstances are homologous. Until such time, however, Cole's assertion of a similarity between accumulation and hoarding must be regarded as tentative but with heuristic potential.

The value of the present procedures and findings do not depend solely on their relation to either self-control or hoarding, although their relations to both offer interesting possibilities for further experimental and conceptual analysis. The results do suggest that there are many unexplored or minimally explored dimensions to even simple learning tasks that, when analyzed, may lead to a richer understanding of both the empirical relations in and the conceptualization of operant behavior.

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