*EFFECTS OF REINFORCEMENT AMOUNT ON ATTACK INDUCED
UNDER A FIXED-INTERVAL SCHEDULE IN PIGEONS*

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Key pecking by pigeons was maintained on a chained fixed-interval 4-min (12-min for 1 subject) fixed-ratio 1 schedule of food presentation. Attacks toward a restrained and protected conspecific were recorded. In the first experiment, the amount of food presented per interval was manipulated across phases by varying the number of fixed ratios required in the terminal link of the chain. Measures of attack for all pigeons during the fixed-interval component increased monotonically as a function of food amount. In the second experiment, two different food amounts alternated within each experimental session under a multiple schedule. For both pigeons in this experiment, measures of attack were higher during the component that delivered the larger food amount per interval. The differences in levels of attack induced by the two food amounts in Experiment 2, however, were not as great as in Experiment 1; apparently this was because attack during the first interval of each component was controlled in part (P-5626) or entirely (P-7848) by the reinforcement amount delivered at the end of the previous component. Attack was also a function of the location of the interfood interval within the session. For both pigeons, attack tended to decrease throughout the session. The results of both experiments suggest that attack is an increasing function of reinforcement amount under fixed-interval schedules, but that this function may be influenced by the manner in which reinforcement amount is manipulated, by the duration of the interfood interval, and by the location of the interfood interval within the experimental session. In general, these results are compatible with theories of induced attack and other schedule-induced behavior that emphasize aversive after-effects of reinforcement presentation.

Key words: schedule-induced attack, schedule-induced behavior, reinforcement amount, fixed-interval schedule, key peck, pigeons

The behavioral effects of intermittent positive reinforcement are not restricted to responses that produce, or closely precede, the scheduled reinforcer. A variety of activities are induced by, or occur as adjuncts to, intermittently scheduled reinforcing stimuli. Included in this class of schedule-induced, or adjunctive, behavior are excessive drinking (polydipsia), aggression toward animate and inanimate objects, escape from positive reinforcement, wheel running, eating unpalatable objects, and drug taking. These activities have been observed in many different species and under a variety of different intermittent schedules, and they tend to share a number of common characteristics. For example, they typically occur at high probability during

periods just after reinforcer presentation, they develop only when reinforcement is intermittent, and they apparently are not adventitiously maintained by the scheduled reinforcer (see Falk, 1971; Staddon, 1977; Wetherington, 1982, for reviews). Induced activities do not usually occur during sessions in which reinforcers are not presented or under conditions in which subjects receive, in one lump sum, all of the reinforcers that normally would be delivered during a comparable period of exposure to an intermittent schedule (see Cohen & Looney, 1984).

Intermittent reinforcement appears to be necessary for the production and maintenance of schedule-induced behavior; thus, a majority of the research in this area has involved investigations of effects of *schedule variables*. Schedule-induced behavior occurs under a variety of time- and response-based schedules, and extensive analyses of the effects of both temporal and response parameters have been reported (see Wetherington, 1982). Schedule-induced behavior is also controlled by variables associated with the scheduled event itself, or what might be called *consequence variables*. Included in this class of

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variables are the amount of the scheduled reinforcer and the degree to which the subject has been deprived of it. The literature on the effects of these factors, however, is not nearly as extensive as that on schedule variables and consists mainly of investigations of induced drinking in rats.

When studied as a function of food deprivation, induced drinking usually is an inverse function of body weight (e.g., Falk, 1969; Freed & Hymowitz, 1972; Roper & Nieto, 1979; Wayner & Rondeau, 1976). A similar relation has been reported with attack in pigeons (Cherek, Thompson, & Heistad, 1972; Dove, 1976). When investigated as a function of reinforcement amount, induced drinking by rats usually increases (Bond, 1973; Couch, 1974; Flory, 1971; Hawkins, Schrot, Githens, & Everett, 1972; Rosellini & Burdette, 1980; Yoburn & Flory, 1977). A few studies, however, have reported that drinking decreases (Falk, 1967; Freed & Hymowitz, 1972) or does not change systematically as a function of food amount (Keehn & Colotla, 1971). The reasons for these exceptions are not particularly clear, but perhaps they relate to different procedures or different measurement strategies.

Extensive analysis of the effects of reinforcement amount on schedule-induced behavior other than drinking in rats remains to be accomplished. One study examined effects of two different reinforcement amounts on attack in pigeons induced by various fixed-time (FT) schedules of food presentation (Robinson, Flory, & Dunahoo, 1990). In that experiment, more attack occurred during conditions in which the larger food amount was presented per interval.

The relative scarcity of investigations of consequence-variable effects on attack and other schedule-induced behavior is surprising, especially in view of the extensive analyses of schedule-variable effects on a variety of induced activities in many different species. Given that schedule-induced phenomena have received a great deal of theoretical attention (e.g., Azrin, 1961; Falk, 1969, 1971; Hutchinson, Azrin, & Hunt, 1968; Killeen, 1975; Staddon, 1977) and that most accounts of schedule-induced behavior tend to view the various induced activities as functionally similar, more extensive analyses of conse-

quence-variable effects across activities and species seems to be indicated.

The results of the Robinson et al. (1990) study suggest that schedule-induced attack may be positively related to reinforcement amount. However, a complete characterization of the function relating induced attack to food amount has not been reported. The purpose of the present set of experiments, then, was to examine the effects of reinforcement amount on schedule-induced attack in pigeons across a wide range of amounts. In Experiment 1, the effects of differing food amounts, presented under fixed-interval (FI) schedules, were assessed across experimental phases. In Experiment 2, two different food amounts, also presented under FI schedules, alternated within experimental sessions.

EXPERIMENT 1

In Experiment 1, the amount of food was manipulated systematically across phases. Key pecking by pigeons was maintained by a two-link chained schedule of food presentation; the initial link was an FI schedule and the terminal link was a fixed-ratio (FR) $1 \times n$ schedule. The amount of food per interval was examined by manipulating n , the number of consecutive pecks that produced food in the terminal link.

METHOD

Subjects

Three adult male White Carneau pigeons (*Columba livia*), P-5626, P-7848, and P-1313, served as subjects. Each of these subjects had previous experience key pecking under intermittent schedules of food presentation. Each subject was paired randomly with another bird that served as its target. All birds were housed individually with water and health grit continuously available. Subjects were maintained at approximately 80% of their free-feeding body weights by providing, as needed, supplemental grain in the home cage after experimental sessions. Food was continuously available for the target birds.

Apparatus

An experimental space (36.0 cm by 40.0 cm by 27.0 cm) was enclosed in a light- and sound-attenuating chamber. One wall was fit-

ted with a standard BRS-Foringer three-key stimulus panel. The right key, located 8.0 cm from the right wall and 25.0 cm above the floor, could be transilluminated either white or red. Pecks with a force of at least 0.19 N on this key were defined as responses. The other two keys were dark and inoperative during these experiments. Two white house-lights, each 10.0 cm from a side wall and 7.0 cm apart, were located above the stimulus panel. Another white houselight was placed at the center of the back wall. An aperture (4.5 cm by 5.5 cm), into which a food hopper could be raised, was located 15.0 cm below the center key, 10.0 cm above the floor. Reinforcement consisted of 4-s access to mixed grain, during which the houselights and key-light were turned off and a white light illuminated the food hopper.

The apparatus for restraining the target birds and for recording attack was similar to those described by Azrin, Hutchinson, and Hake (1966) and by Webbe, DeWeese, and Malagodi (1974). The restraining unit consisted of a rectangular box constructed of clear Plexiglas mounted on a spring-loaded metal plate. The unit was positioned behind the rear wall with one end facing the experimental space. Access to the target was provided through a rectangular opening (25.5 cm by 11.5 cm) in the rear wall. A micro-switch was located under the metal plate such that displacements of the unit with a force that exceeded 1.25 N activated the micro-switch and were recorded as attacks.

Each target bird was restrained within the unit with foam cushions positioned below it and to its rear. An opening on the top of the unit closest to the experimental space allowed for the extrusion of the target bird's head, neck, and upper breast. A bib, constructed of synthetic white fur, was attached to the target so that the exposed breast region was entirely covered. A Plexiglas shield was mounted 3.0 cm in front of the target bird's face and in the same plane as the rear wall of the chamber. This shield had a semi-circular opening with a 3.0-cm radius cut into it and was positioned so the fur-covered breast of the target was exposed through the opening, but the head of the target was protected. This arrangement allowed contacts of sufficient force against either the breast region or the shield to activate the microswitch

while safeguarding against injury to the target bird. Visual inspection of early sessions via a video monitor revealed that, at the specified force requirement, movements of the target did not activate the microswitch, but most of the contacts by the experimental bird were recorded reliably.

Continuous white noise was present in the surrounding room to mask extraneous sounds, and a ventilation fan provided air circulation within the experimental space. All experimental events were programmed and recorded by electromechanical equipment located in a separate room.

Procedure

All experimental subjects had prior key-pecking experience, so no initial training was necessary. Each experimental pigeon was exposed to a chained FI t FR $1 \times n$ schedule of food presentation. Under this schedule, in the presence of a white keylight, the first key peck after t min had elapsed turned the keylight red, and each of the next n key pecks produced reinforcement. After n reinforcer presentations, the keylight turned white and the cycle was repeated. The value of t was 4 min for P-5626 and P-1313 and 12 min for P-7848.¹ The initial value of n for each subject was one. Changeover contingencies were programmed such that key pecks within 5 s after an attack in the presence of the white keylight could not change the keylight to red, and pecks in the presence of the red keylight could not produce grain.

The amount of food delivered per interval was manipulated across experimental phases by manipulating the value of n . The values of n for each subject, the order of exposure to those values, and the number of sessions in

¹ The FI value for P-7848 initially was 4 min. Manipulation of n from 1 to 24 under this schedule had little effect on measures of attack. For this subject, attack levels at all n values were relatively high. Because several investigators have reported that attack induced by time-based schedules is bitonically related to interfood interval and that peak levels of attack occur at intervals between 2 and 4 min (e.g., Cherek, Thompson, & Heistad, 1973; Flory, 1969), measures of attack in this subject may have been at ceiling levels at all n values. The FI duration for this subject, therefore, was increased to 12 min in hopes of producing a more intermediate level of attack and, hence, a more sensitive baseline against which to assess the effects of n . When the interval value was increased to 12 min at an n of 1, mean attack magnitude for the last 15 sessions decreased from 118.7 to 64.2.

Table 1

The order of conditions and the number of sessions under each condition for all subjects in Experiment 1. Each subject responded under a chained FI t FR $1 \times n$ schedule of food presentation. Sessions ended following 15 intervals and usually were conducted 5 days per week unless otherwise indicated.

Pigeon	n value	Sessions
P-5626 $t = 4$ min	1	138
	8	83
	16 ^b	78
	24 ^{a,b}	44
	1	120
	16 ^a	47
	1 ^{a,b}	51
	4	32
P-7848 $t = 12$ min	1	120
	8	61
	16 ^a	32
	24 ^a	27
	1	32
	8 ^a	52
	1 ^a	34
P-1313 $t = 4$ min	1	117
	8	58
	16 ^a	92

^a Sessions conducted every other day.

^b Sessions ended after 10 intervals.

all conditions of Experiment 1 are shown in Table 1. Birds P-5626 and P-7848 were exposed to an ascending series of n values from 1 to 24 in increments of 8. The effects of $n = 16$ and $n = 8$ were redetermined once for P-5626 and P-7848, respectively. The effects of $n = 1$ were redetermined twice for each bird. Bird P-5626 then was exposed to an $n = 4$ condition. Bird P-1313 was exposed to n values of 1, 8, and 16. After 92 sessions under the $n = 16$ condition, this subject was removed from the experiment because of illness.

Sessions usually were conducted 5 days per week, except at larger values of n , when sessions were conducted every other day to insure that the body weights of the subjects at the beginning of each session were comparable across experimental conditions. It is possible that any observed difference in attack induced by different n values may have resulted from the change in the schedule of sessions required at the larger n values. Therefore, sessions were also conducted every other day during one of the exposures to $n = 1$ for both P-5626 and P-7848 and during

the second exposure to $n = 8$ for P-7848. Phases at lower n values in which sessions were conducted every other day allowed comparisons of the effects of different n values under conditions in which there was no difference in the schedule of sessions. Each session terminated following completion of the 15th cycle, except at larger n values for P-5626, when the number of intervals per session was reduced to 10.

Two measures of attack served as dependent variables in the present experiment: the number of attacks per interval with attack (hereafter referred to as attack magnitude) and the proportion of intervals with at least one attack. These measures capture two different characteristics of induced attack; the former depicts the average level of attack within an interval once attack has been initiated, and the latter estimates the tendency to initiate attack within a given interval. Attacking was considered stable (i.e., experimental conditions were changed) when at least 15 sessions had occurred with no systematic trends in both measures of attack, as determined by visual inspection of daily plots and cumulative records.

RESULTS AND DISCUSSION

Temporal patterns of key pecking in the presence of the white keylight were typical of those maintained under FI schedules (e.g., Ferster & Skinner, 1957). Topographical characteristics of attack were similar to those reported in other studies (e.g., Dove, 1976), and primarily consisted of forceful pecking against the protective shield and the exposed bib. Representative cumulative records of responding by P-7848 are presented in Figure 1. These records are from conditions when n was 1, 8, and 16. There are two records from each condition. In each pair, key pecks stepped the response pen in the upper record, and attacks stepped the response pen in the lower record. In addition to illustrating temporal patterns of key pecking, these records also show that attacking usually occurred in bursts shortly after the last food presentation of an interval (i.e., upon illumination of the white keylight) and terminated abruptly sometime before the onset of key pecking. This pattern was typical of all 3 subjects. None of the birds attacked in the presence of the red keylight.

Fig. 1. Sample cumulative records from Experiment 1 for P-7848 from portions of individual sessions when n was 1, 8, or 16. Shown are two records from each condition. In the upper record of each pair, each key peck stepped the response pen, each attack briefly deflected the event pen, and each food presentation briefly deflected the response pen. In the lower record of each pair, each attack stepped the response pen and each food presentation briefly deflected the event pen. The response pens of both records reset following the last food presentation of each interval.

Comparison of the records in Figure 1 across different n values reveals that more attacks occurred when larger amounts of food were delivered per interval. This effect is illustrated more clearly in Figure 2, which shows both measures of attack as a function of the amount of food presented per interval, or n , for all experimental subjects. Both measures of attack increased monotonically as a function of n in all subjects. The attack magnitude functions can be characterized as increasing to a maximum at some intermediate n value, and remaining at or near that maximum with further increases of n . Note that for P-1313 the function for attack magnitude increased with each increase in n , up to 16, the last value examined with this bird.

The proportion functions in Figure 2 show that, for all birds, when conditions arranged for intervals terminating in multiple grain cycle presentations (when $n > 1$), attack occurred in nearly every interval (i.e., proportion values usually were near 1.0). In contrast, when $n = 1$, attack occurred in fewer intervals per session. Thus, in addition to increasing the amount of attack per interval once it was initiated, a major effect of programming multiple grain cycle presentations was to increase the likelihood of initiating attack.

The data from the phases at lower n values when sessions were conducted every other day (P-5626 and P-7848) and when sessions ended after 10 intervals (P-5626) suggest that the increases in attack actually occurred as a function of increases in n rather than as a function of some characteristic of the different conditions required at the larger n values. For example, levels of attack for P-5626 at $n = 1$ when sessions were conducted every other day more closely resembled those at $n = 1$ when sessions were conducted 5 days per week than those at $n = 16$ when sessions were conducted every other day. Thus, it cannot be argued, for instance, that the higher levels of attack observed at larger n values were due simply to deprivation of the opportunity to attack that resulted from conducting sessions every other day.

Although P-1313 had to be removed from the experiment before being exposed to all conditions, the data for this bird warrant closer examination. This bird attacked occasionally during the early sessions of the $n = 1$ condition, but did not attack during the final

Fig. 2. Measures of attack for each experimental bird during Experiment 1 as a function of the amount of food delivered per interval (n , number of feeder operations). In each graph, the closed symbols represent the number of attacks per interval with attack (attack magnitude) and correspond to the left y axis; the open symbols represent the proportion of intervals with attack (attack proportion) and correspond to the right y axis. In each graph, the circles (connected by lines), triangles, and squares are data from the first, second, and third determinations, respectively, of the various values of n (see Table 1). Each point represents a mean for the last 15 sessions from that condition, and vertical lines represent 95% confidence intervals. The absence of a vertical line indicates that the 95% confidence interval fell within the area covered by the symbol.

Fig. 3. Attack magnitude (closed symbols, left y axis) and attack proportion (open symbols, right y axis) for each of the last 15 sessions of the $n = 1$ condition and each of the first 15 sessions of the $n = 8$ condition for P-1313 during Experiment 1.

22 sessions of this phase. When n was increased to eight, attacking occurred in the first session and persisted for the remainder of this phase. When n was increased to 16, attack magnitude increased further. After 92 sessions under this condition, both key pecking and attacking began to decrease until this subject failed to engage in either activity. Probe sessions at other n values failed to restore key pecking or attacking. The results presented in Figure 2 for this bird include only those sessions prior to the sudden decrease and subsequent cessation of key pecking and attacking.

The development of attack in P-1313 as a result of changing n from one to eight is shown in Figure 3. This figure shows session-by-session plots of both attack measures for the last 15 sessions of the $n = 1$ condition and the first 15 sessions of the $n = 8$ condition. This figure reveals that the zero levels of attack observed when $n = 1$ were substantially increased by the first session when n was increased to eight. Attack continued to occur at similar levels throughout this phase.

Key-peck data for each bird under all conditions are provided in Figure 4. For both P-

5626 and P-7848, responses per minute generally decreased and postreinforcement pauses generally increased as a function of n . These effects were more pronounced for P-7848 than for P-5626. For P-1313, key-peck rates increased and pause times decreased when n was increased from one to eight. When n was increased to 16, key-peck rates decreased and pause times changed very little.

In summary, Experiment 1 revealed two major effects of increasing the amount of food per interval on schedule-induced attack: (a) Attack magnitude was a direct function of the amount of food per interval, with this measure increasing to a maximum at some n value and remaining at high levels with further increases in n , and (b) the probability of initiating attack was higher when conditions arranged for the delivery of multiple grain cycles rather than a single cycle.

EXPERIMENT 2

In Experiment 1, schedule-induced attack was a monotonic increasing function of the amount of food presented under an FI sched-

Fig. 4. Key-peck measures for each experimental bird from Experiment 1 plotted as a function of n . The closed symbols indicate responses per minute and correspond to the left y axis; the open symbols represent the average postreinforcement pause per interval in minutes and correspond to the right y axis. All other characteristics are the same as in Figure 2.

ule when food amount per interval was manipulated across experimental phases. Experiment 2 was conducted to determine if a similar relationship would occur when food amount was varied within sessions. In Experiment 2, intervals ending in two different food amounts ($n = 1$ and $n = 16$) were examined within the context of a multiple schedule.

METHOD

Subjects and Apparatus

P-5626 and P-7848 served as experimental subjects. Each was maintained at 80% of its free-feeding body weight. Each subject was paired with a target pigeon. For P-5626, the target was the same as in Experiment 1; for P-7848, the target was different than in Experiment 1. The target for P-5626 became ill midway through this experiment and was replaced. Home cage conditions and the supplemental feeding regimens were the same as in Experiment 1. The apparatus used in this experiment was the same as that used in Experiment 1.

Procedure

After completion of the sequence of conditions listed in Table 1, P-5626 and P-7848 were exposed to a two-component multiple schedule in which chained FI FR $1 \times n = 1$ and chained FI FR $1 \times n = 16$ components alternated irregularly within experimental sessions. The FI schedules used for each bird were the same as in Experiment 1 (P-5626, FI 4 min; P-7848, FI 12 min). The component that began the session was determined randomly. Components alternated irregularly and lasted either two, three, or four intervals. A 30-s timeout followed each component, except the last component of the session. During the timeouts that separated components, both attacks and key pecks were recorded but had no programmed consequences. For P-5626, a clicking sound accompanied the $n = 16$ component; for P-7848 the clicker accompanied the $n = 1$ component. Sessions were terminated after 18 intervals had occurred (nine in each component). Changeover contingencies in Experiment 2 were identical to those in Experiment 1.

Because differences in both measures of attack under $n = 1$ and $n = 16$ conditions were not as great as those obtained in Experiment 1 (see Results and Discussion section of Experiment 2), the timeouts separating components were lengthened to 60 s after 51 sessions for P-5626 and after 47 sessions for P-7848. This condition lasted 33 sessions for P-5626 and 30 sessions for P-7848. The target for P-5626 was replaced on the ninth session of this condition.

Fig. 5. Measures of attack for both experimental birds under the multiple schedule employed in Experiment 2. The upper graphs show attack magnitude and the lower graphs show attack proportion. In each graph the open bars represent data averaged over all of the intervals of each condition. The data represented by the solid bars are averaged over all of the intervals from each condition excluding the first interval of each component (the first interval of each session was included). The data represented by the striped bars are averages from the first intervals of each component (excluding the first interval of the session). The data are means from the last 15 sessions of the multiple schedule in which 60-s timeouts separated components. All other display characteristics are the same as in Figure 2.

RESULTS AND DISCUSSION

Temporal patterns of attacking and key pecking for both birds were similar to those obtained in Experiment 1; attacks tended to occur during the very early portions of the interval, and key-peck patterns were typical of those maintained by FI schedules.

Figure 5 shows measures of attack for both birds as a function of n during the multiple

schedule. The data from sessions in which timeout durations were 30 s were nearly identical to those when the timeout durations were 60 s. Thus, only data from the latter condition are presented. The open bars in the upper panels of Figure 5 show that, as in Experiment 1, overall attack magnitude was greater when $n = 16$ than when $n = 1$. The difference in this measure of attack for these

two food amounts, however, was not as great as in Experiment 1. For P-5626 this was because attack magnitude when $n = 16$ was lower in Experiment 2 than in Experiment 1. Conversely, for P-7848, attack magnitude when $n = 1$ was higher in Experiment 2 than in Experiment 1. The open bars in the lower panels of Figure 5 show that the difference between the proportion of intervals with attack when $n = 1$ and $n = 16$ was not nearly as great as that obtained in Experiment 1; in Experiment 2 this measure of attack was just slightly higher during the $n = 16$ component.

The analysis presented in Figure 5 suggests a possible source of control over the reduced effect of food amount in Experiment 2, particularly in the case of attack magnitude. The solid bars present attack measures from the $n = 1$ and $n = 16$ components when the data from the first interval of each component exposure were eliminated. That is, data from all intervals preceded by timeouts (which were preceded by delivery of the alternate food amount) were excluded from the analysis. These data are from conditions that resembled those in Experiment 1; each interval was preceded by and terminated with the same food amount. Comparison of the solid and the open bars in Figure 5 shows that, for both pigeons, differences in attack magnitude between the two components were greater when the data from the first intervals of each component exposure were eliminated than when they were included. When analyzed this way, the data from Experiment 2 for attack magnitude more closely resembled those from Experiment 1. The difference in the proportion of intervals with attack for both pigeons was also greater when the data from the first interval were eliminated (lower panels of Figure 5) than when they were included. The difference in this measure for both pigeons still was relatively small, however, and the data were more variable than those from Experiment 1.

The striped bars in Figure 5 show measures of attack during the first interval of each component exposure only. Each of these intervals ended in one food amount, but began with a timeout that was preceded by delivery of the other food amount. Thus, the striped bars at $n = 1$ are from intervals that ended with the smaller food amount and were preceded by the larger food amount, whereas the striped

bars at $n = 16$ are from intervals that ended in the larger food amount and were preceded by the smaller food amount. For both pigeons, attack magnitude during the $n = 1$ component was higher during the first intervals than during remaining intervals (striped vs. solid bars at $n = 1$). In contrast, attack magnitude during the $n = 16$ component was lower during the first intervals than during the remaining intervals (striped vs. solid bars at $n = 16$). These data suggest that the amount of attack in the first intervals of each component was controlled, at least in part, by the amount of food delivered at the end of the previous interval, despite the timeouts that separated components. Furthermore, note that attack magnitude for P-5626 was comparable during the first intervals of each component, whereas attack magnitude for P-7848 actually was higher during the first intervals of the $n = 1$ component than during the first intervals of the $n = 16$ component.

Although Experiment 2 was not designed explicitly to study effects of past and upcoming reinforcer amounts on schedule-induced attack, the data from Figure 5 suggest that attacking in a given interval under the multiple schedule may have been a joint function of these two food amounts. Under the multiple schedule of Experiment 2, four distinct types of interfood intervals were arranged: (a) intervals that were preceded by and ended with $n = 1$, (b) intervals that were preceded by $n = 1$ and ended with $n = 16$, (c) intervals that were preceded by $n = 16$ and ended with $n = 1$, and (d) intervals that were preceded by and ended with $n = 16$. Although intervals that began and ended with the same food amount occurred more frequently, there were a sufficient number of intervals that were preceded by and ended with different food amounts to warrant further analysis.

Figure 6 presents attack magnitude as a function of the four interval types that occurred in Experiment 2. This figure shows that, for both birds, this measure of attack was lowest during intervals that were preceded by and ended with the smaller food amount and was highest during intervals that were preceded by and ended with the larger food amount. For P-5626, intermediate levels of attack were induced during the interval types that were preceded by and ended with differ-

Fig. 6. Attack magnitude for both pigeons as a function of the four interval types arranged in Experiment 2. Values above the x-axis point labeled "1-1" are from intervals that were preceded by and ended with the smaller reinforcement amount ($n = 1$); those above "1-16" are from intervals that were preceded by the smaller reinforcement amount and ended with the larger reinforcement amount ($n = 16$); those above "16-1" are from intervals that were preceded by the larger reinforcement amount and ended with the smaller reinforcement amount; those above "16-16" are from intervals that were preceded by and ended with the larger reinforcement amount. All other display characteristics are as in Figure 5.

ent food amounts. Furthermore, levels of attack were similar during these intervals regardless of whether they were preceded by the larger reinforcer amount and ended with the smaller reinforcer amount or vice versa.

Thus, for this bird, it appears that attacking in a given interval was controlled jointly by the past and upcoming reinforcer amount; a larger amount at the beginning or at the end of an interval increased attacking to a similar degree. In contrast, for P-7848, attack magnitude during intervals that were preceded by the smaller food amount was similar regardless of the food amount that ended the interval, and attack magnitude during intervals that were preceded by the larger food amount was similar regardless of the food amount that ended the interval. For this bird, then, attacking in a given interval was controlled primarily by the past reinforcer amount; larger reinforcer amounts were followed by more attack regardless of the upcoming reinforcer amount.

The amount of attack in a given interval in Experiment 2 was controlled not only by the amount of reinforcement presented at the beginning (both pigeons) and at the end (P-5626) of an interval, but also by the location of the interval within the session. Figure 7 presents the mean number of attacks per interval for both components as a function of the ordinal position of the interval within the session. This measure is influenced both by attack magnitude and by the proportion of intervals that contain attack. Consistent with the data presented in Figures 5 and 6, the mean number of attacks in a given interval tended to be higher if that interval occurred during the $n = 16$ rather than during the $n = 1$ component; this was the case in 14 of the 18 intervals for both pigeons. For both pigeons the number of attacks per interval tended to decrease across the session. This was the case in particular for P-5626, but also occurred to a lesser extent for P-7848 following an increase early in the session. Interestingly, for both pigeons, differences in the amount of attack induced as a function of food amount were smaller in the last four or five intervals than during most of the rest of the session; for P-5626 there essentially was no difference in this measure for the two components during the last four intervals. Note also that, for P-7848, there were a few intervals other than those near the end of the session in which the mean number of attacks under the $n = 1$ component was similar to, or actually higher than, the mean number of attacks under the $n = 16$ component (Inter-

Fig. 7. Mean number of attacks for both subjects as a function of interval number within a session. Values were obtained by averaging the number of attacks that occurred in a given interval number over the last 15 sessions for those intervals that ended with $n = 1$ (open circles) and for those intervals that ended with $n = 16$ (closed circles).

vals 3, 4, and 11). Although the reasons for this are not clear, it may be relevant that there were several instances in which these intervals served as the first interval of a component (see Figures 5 and 6).

For P-5626, very few attacks occurred during the timeouts between components. An average of 4.2 and 3.5 attacks per minute occurred during the 60-s timeouts that followed

the $n = 1$ and $n = 16$ components, respectively. These data are similar to those of DeWeese (1977), in which very little hose biting in monkeys occurred during timeouts that followed each food presentation under an FI schedule, but biting did occur at the onset of the FI-correlated stimulus. P-7848, however, attacked some during the timeouts, but there was no clear difference in the tendency to attack during timeouts that followed the $n = 1$ or the $n = 16$ components. For this bird, an average of 30.0 and 33.4 attacks per minute occurred during the 60-s timeouts that followed the $n = 1$ and $n = 16$ components, respectively.

Key-peck data under the multiple schedule for both birds are presented in Figure 8. In general, these data replicate those from Experiment 1 for these 2 birds. Under the multiple schedule, key-peck rates were lower and pause times were greater during the $n = 16$ component. Neither bird pecked during the timeouts between components.

GENERAL DISCUSSION

In both experiments, measures of induced attack were positively related to the amount of food reinforcement delivered according to an FI schedule. In Experiment 1, when the amount of food presented per interval (n) was examined across phases, attack increased to a maximum at some intermediate n value and remained at or near that level with further increases in n . In Experiment 2, when intervals terminating in two different reinforcement amounts alternated under a multiple schedule, measures of attack generally were higher in components providing the larger food amount, but the differences in measures of attack induced by the two food amounts examined in Experiment 2 were not as great as those obtained in Experiment 1. In Experiment 2, attacking in a given interval appeared to be controlled both by the preceding and the upcoming reinforcer amount for 1 pigeon (P-5626) whereas for the other pigeon (P-7848), attacking in a given interval appeared to be controlled primarily by the preceding reinforcer amount. In both experiments, key-peck rates and postreinforcement pause durations were inversely and positively related to reinforcement amount, respectively (except for P-1313 during Experiment 1).

Fig. 8. Key-peck measures for both experimental birds under the multiple schedule of Experiment 2. The upper graphs show responses per minute, and the lower graphs show the postreinforcement pause per interval (in minutes). All other display characteristics are the same as in Figure 5.

The data from Experiment 1, in general, are similar to those reported by Robinson et al. (1990) in showing a direct relation between reinforcement amount and schedule-induced attack. These data extend those of Robinson et al. and suggest that attack induced under time-based schedules of food presentation is a direct function of food amount across a wide range of values. When viewed in the context of the majority of data on schedule-induced drinking by rats under comparable experimental conditions (Bond, 1973; Couch, 1974; Flory, 1971; Hawkins et al., 1972; Rosellini & Burdette, 1980; Yoburn

& Flory, 1977), there is reason to suspect that such a direct relation may be characteristic of schedule-induced behavior in general, at least when reinforcement amount is manipulated across experimental sessions. Stronger statements regarding the generality of such a relation, however, await similar investigations with schedule-induced activities other than attacking in pigeons and drinking in rats.

A common interpretation of schedule-induced attack suggests that schedules of intermittent positive reinforcement can function aversively (e.g., Azrin, 1961; Azrin et al., 1966; Richards & Rilling, 1972). This view suggests

that attack is elicited during periods of low reinforcement probability under intermittent schedules in much the same way that it is elicited by more traditional aversive stimuli such as electric shock. Support for this notion is provided by observations that experimental subjects will escape from intermittent reinforcement (e.g., Appel, 1963; Azrin, 1961; Thompson, 1964) and that presentation of stimuli correlated with intermittent schedules of positive reinforcement can have punishing effects (Thompson, 1965), as well as by findings that attack is produced by delivery of electric shock and other noxious stimuli (e.g., Azrin, Hake, & Hutchinson, 1965; Azrin, Hutchinson, & Sallery, 1964; Ulrich & Azrin, 1962).

At first glance, the present data seem to be incompatible with the notion that schedule-induced attack is controlled aversively. To the extent that conditions arranging relatively lower rates or amounts of positive reinforcement are less preferred (see Davison & McCarthy, 1988), they could be considered to be relatively more aversive. If attack was controlled aversively by conditions arranged in the present experiments, an inverse relation between food amount and attack would have been predicted.

Aversive functions of any given schedule of positive reinforcement, however, may be related to characteristics other than the overall amount of reinforcement per unit of time. Intermittent reinforcement necessarily involves transitions from periods of reinforcement to periods of extinction. Perhaps the aversiveness of any given postreinforcement period is related to conditions that prevail during reinforcement delivery, such that transitions from larger reinforcement amounts to extinction are relatively more aversive than transitions from smaller reinforcement amounts, an effect similar to negative behavioral contrast (e.g., Bloomfield, 1966). Such a view is consistent with the present data and with findings that the amount of attack during an extinction component of a multiple schedule is a direct function of the number of food presentations under an FR 1 schedule in the other component (Azrin et al., 1966).

The notion that intermittent schedules of positive reinforcement can function aversively might be viewed within the more general framework of the opponent-process theory of

motivation (e.g., Solomon & Corbit, 1974). In this view, presentation of "hedonically relevant" stimuli not only produce direct effects but also produce opposing aftereffects. These aftereffects serve a homeostatic function by counteracting direct effects of stimulus presentation. A variety of behavioral phenomena, including schedule-induced behavior, has been interpreted within the context of this view (e.g., Rosellini, 1985; Solomon, 1977). Among other things, this formulation suggests that the size of the opposing aftereffect is an increasing function of the magnitude of the stimulus (Solomon & Corbit, 1974). The positive relation between reinforcement amount and schedule-induced attack presented here suggests that the opponent-process theory may be an effective framework within which to view schedule-induced phenomena.

Other theories of schedule-induced phenomena also emphasize aftereffects of reinforcement. For example, Killeen and colleagues (Killeen, 1975; Killeen, Hanson, & Osborne, 1978) suggest that reinforcement termination produces "arousing" rather than aversive aftereffects. In their model, arousal is defined operationally by measuring activity by pigeons during exposure to FT schedules of food presentation. With repeated food deliveries, arousal accumulates to an equilibrium level that depends upon the magnitude of the arousal, its rate of decay, and the time between food presentation. This model also predicts that aftereffect size is related directly to the magnitude of the arousal-producing stimulus, a prediction consistent with the data presented here. The results of Experiment 1, then, are compatible with accounts of schedule-induced attack that emphasize aftereffects of reinforcement presentation and termination under intermittent schedules, and, in particular, with suggestions that such aftereffects are positively related to reinforcement amount.

Manipulations of reinforcement amount have been an important component of investigations of consummatory rate and schedule-induced behavior. A common finding is that measures of attack increase and then decrease as a function of parameter values under ratio (e.g., Cohen & Looney, 1973; Webbe et al., 1974) and time-based schedules (e.g., Flory, 1969). A similar function is typi-

cal for other schedule-induced behavior, particularly under time-based schedules (see Falk, 1969, 1971). It has been suggested that such a bitonic relation is a fundamental characteristic of schedule-induced behavior. Within this framework, it has also been suggested that reinforcement rate and reinforcement amount be viewed not as separate controlling variables but as components of a single controlling variable, the "consummatory rate" (Falk, 1969). For example, this view predicts that a given amount of reinforcement presented at 2-min intervals will produce a comparable level of schedule-induced behavior as twice that amount of reinforcement presented at 4-min intervals.

The monotonically increasing function between reinforcement amount and attack obtained in Experiment 1, however, is difficult to interpret within the context of the consummatory-rate hypothesis; measures of attack might have been expected to decrease at the larger food amounts (i.e., at higher consummatory rates). At the larger food amounts, however, attack continued to occur at maximum values despite the fact that consummatory rates for both pigeons far exceeded those typically sufficient to decrease schedule-induced behavior when only reinforcement rate is manipulated (e.g., Falk, 1966; Flory, 1969). Furthermore, data from studies on schedule-induced drinking (Bond, 1973) and attack (Robinson et al., 1990), in which different combinations of food amounts and interfood intervals were examined, also are not consistent with the consummatory-rate hypothesis. With respect to schedule-induced activities, then, it appears that schedule parameter and reinforcement amount function as separate controlling variables.

The results of Experiment 2, particularly when the data from the first interval of each component exposure were excluded from the analysis, generally agree with those from Experiment 1. Under conditions in which intervals began and ended with the same reinforcement amount, larger reinforcement amounts induced more attack, regardless of whether or not these intervals occurred within the context of a multiple schedule. The data from the first intervals of each component exposure (i.e., intervals that were preceded by and ended with different food amounts) have some implications regarding

the nature of control over attack by reinforcement amount. First, despite the timeouts between components, attack magnitude during these intervals was controlled primarily (P-7848) or partially (P-5626) by the amount of food presented at the end of the previous interval. Although some attack occurred during the timeouts (especially for P-7848), it was not controlled by the preceding food amount. Thus, it appears that the control of attack by the preceding food amount depended upon the presence of the FI-correlated stimuli. Second, for P-5626 (but not for P-7848), attack induced by the FI-correlated stimuli was also controlled by the size of the upcoming reinforcer; more attack occurred during stimuli correlated with the larger upcoming food amount. The data for this pigeon suggest that, under some conditions, aversive functions of the early portions of FI schedules are related directly to the size of the upcoming reinforcer.

The reason or reasons for the lack of control by the upcoming reinforcer amount for P-7848 are not completely clear. It is quite possible that control over attack by the upcoming reinforcer amount was reduced by the relatively large FI used with this pigeon. It is also possible, however, that the multiple-schedule stimuli simply did not gain control over attack. Nevertheless, despite the evidence that reinforcement amount and reinforcement rate should be viewed as separate controlling variables, differences in the data for P-5626 and P-7848 in Experiment 2 suggest that reinforcement rate may modulate the degree of control over attack by the upcoming reinforcement amount. Indeed, relations between reinforcement rate and effects of past and upcoming reinforcement amount on schedule-induced attack might be a topic of further, more systematic, inquiry.

That effects of reinforcement amount can be modulated by the manner in which it is manipulated is not surprising. For example, several investigators have shown that effects of within-session manipulations of reinforcement amount on operant and schedule-induced behavior can differ from those seen when this variable is manipulated across experimental sessions, and that effects of reinforcement amount can depend upon the presence or absence of discriminative stimuli correlated with the size of the upcoming re-

inforcer (e.g., Bonem & Crossman, 1988; Perone & Courtney, 1992; Reid & Staddon, 1982). Interestingly, studies comparing effects of across- and within-session manipulations of food amount on schedule-induced drinking by rats have yielded data both consistent and inconsistent with those presented here (Reid & Dale, 1983; Reid & Staddon, 1982). In those experiments, drinking (an "interim" activity) and head in feeder (a "terminal" activity) by rats were measured during FT schedules of food presentation. When food amount was manipulated across experimental sessions, the data were similar to those from Experiment 1 presented here (and similar to those often reported with drinking by rats); more drinking tended to occur under conditions that arranged the larger of two food amounts. Opposite effects, however, were obtained when food amount was manipulated within sessions. Under constant stimulus (mixed-schedule) conditions, when intervals ending with a larger food amount were interspersed with intervals ending in a smaller food amount within experimental sessions, less drinking and more head-in-feeder activity occurred following the larger food amount. When stimuli were correlated with the number of food pellets that ended a given interval (multiple-schedule conditions), less drinking and more head-in-feeder activity occurred during intervals that preceded and followed delivery of the larger food amount.

Because the present study was not designed as a replication of the Reid and Dale (1983) or the Reid and Staddon (1982) studies, direct comparisons are difficult. Indeed, there are several possible reasons for differences in the results of those studies and the results of Experiment 2 presented here, including differences in the particular procedures, apparatus, behavioral measures, and species used. One difference that may be particularly important is that the FI interfood intervals used in the present study (4 and 12 min) differed substantially from the FT interfood intervals used in those studies (30, 60, and 120 s). Perhaps at shorter interfood intervals, conditions that are optimal for competition between schedule-induced and operant behavior, effects of within-session manipulations of reinforcement amount differ from those at longer interfood intervals.

Although the possibility of functional differences among schedule-induced activities seems to be remote, differences in within-session effects of food amount on schedule-induced attack and schedule-induced drinking suggest that such a possibility cannot be completely dismissed. The bulk of experimental evidence on schedule-induced behavior, including the data from Experiment 1, provide a compelling case that a variety of schedule-induced activities belong to a functionally coherent class of behavior. In a small number of studies, however, dissimilarities among schedule-induced activities have been reported. For example, some investigators have found that attack by rats does not develop under conditions that reliably produce polydipsic drinking and that induced drinking by pigeons fails to develop under conditions that reliably induce attack (Hymowitz, 1971; Knutson & Schrader, 1975; Yoburn & Cohen, 1979). Furthermore, administration of some drugs (e.g., benzodiazepines) can produce effects on drinking by rats and monkeys (Bacotti & Barrett, 1976; Barrett & Weinberg, 1975) that differ from those on attack by pigeons (Moore, Tychsen, & Thompson, 1976). Although such differences may relate primarily to procedural variables, the data from these experiments, along with those from Experiment 2, suggest the possibility that there may be conditions under which there are functional differences between schedule-induced drinking and schedule-induced attack.

Finally, attack for both pigeons (particularly P-5626) tended to decrease throughout the session in Experiment 2, perhaps as a function of satiation (see Dove, 1976). Similar within-session changes in operant behavior (e.g., McSweeney & Roll, 1993) and in schedule-induced behavior (e.g., Reid & Staddon, 1982) have also been reported. Interestingly, this effect appeared to interact with the effects of reinforcement amount. Although both pigeons continued to attack during the later intervals of the session, albeit at lower levels, differences in attack induced by the $n = 1$ and $n = 16$ components were diminished during those intervals. It is possible, then, that differential effects of reinforcement amount on schedule-induced behavior depend upon the level of deprivation associated with that reinforcer.

In conclusion, the data from Experiment 1

suggest that attack induced under FI schedules is a monotonically increasing function of reinforcement amount. This function is consistent with accounts of schedule-induced behavior that have suggested that attack is induced by conditions that prevail at the transition between periods of reinforcement to nonreinforcement (i.e., reinforcement aftereffects) and that these aftereffects are directly related to reinforcement amount. The data from Experiment 2 suggest that effects of within-session manipulations of reinforcement amount are similar to those of across-session manipulations, but also suggest that, under some conditions, attack induced by a given period of nonreinforcement can be a function of both the preceding and upcoming reinforcement amounts and the location of that period within the session.

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