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TRANSITIONS FROM RICH-TO-LEAN SCHEDULES INCREASE ATTACK IN A LABORATORY MODEL OF SOCIAL AGGRESSION IN PIGEONS: II. FIXED-INTERVAL SCHEDULES

LAS TRANSICIONES DE PROGRAMAS RICOS A POBRES AUMENTAN EL ATAQUE EN UN MODELO DE LABORATORIO DE AGRESIÓN SOCIAL EN PALOMAS: II. PROGRAMAS DE REFORZAMIENTO DE INTERVALO FIJO

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Abstract

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Some of these data were collected in the Psychology Department at the University of North Carolina Chapel Hill. The authors would like to thank Linda A. Dykstra and Mitchell J. Picker for generously allowing us to use their laboratory facilities, William Prizer for help with data collection, and Justin Van Heukelom for help with the photograph of the attack apparatus. Correspondence should be addressed to Raymond C. Pitts, Ph.D., Department of Psychology, University of North Carolina Wilmington, 601 S. College Rd., Wilmington, NC 28403-5612; pittsr@uncw.edu; 910-962-7293.

Pigeons key pecked under two-component multiple fixed-interval (FI) schedules. Each component provided a different reinforcer magnitude (small or large), signaled by the color of the key light. Attacks toward a live, protected target pigeon were measured. Large- (rich) and small- (lean) reinforcer components alternated irregularly such that four different interval types (transitions) between the size of the immediately preceding reinforcer and the size of the upcoming reinforcer occurred within each session: lean-to-lean, lean-to-rich, rich-to-lean, and rich-to-rich transitions. The FI for each component was the same within each phase, but was manipulated across phases. For all pigeons, more attack occurred following the presentations of the larger reinforcer (i.e., during rich-to-lean and rich-to-rich transitions). For 2 of the 3 pigeons, this effect was modulated by the size of the upcoming reinforcer; attack following larger reinforcers was elevated when the upcoming reinforcer was small (i.e., during rich-to-lean transitions). This rich-to-lean effect on attack diminished or disappeared as the length of the FI schedule was increased (i.e., control over attack by the upcoming reinforcer size diminished with increases in the inter-reinforcement interval). For all pigeons and at all FIs, however, postreinforcement pauses were longest during the rich-to-lean transitions. These data (1) are consistent with the notion that postreinforcement periods during intermittent schedules function aversively and, thus, can precipitate aggressive behavior, and (2) suggest that rich-to-lean conditions may be especially aversive. They also indicate, however, that aversive effects of rich-to-lean transitions may differ across fixed-ratio (FR) and FI schedules, and that variables controlling attacking and pausing may not be isomorphic between these different schedule types.

Keywords: schedule-induced aggression, rich-to-lean transitions, postreinforcement pause, FI schedules, pigeons

Resumen

Palomas picotearon teclas bajo un programa múltiple de dos componentes intervalo fijo-intervalo fijo. Cada componente proporcionó una magnitud de reforzamiento diferente (pequeña o grande), señalada por el color de la luz de la tecla. Se midieron los ataques hacia una paloma objetivo viva y protegida. Los componentes de reforzamiento grande (rico) y pequeño (pobre) se alternaron de manera aleatoria de modo que ocurrieron cuatro tipos de intervalos diferentes (transiciones) entre el tamaño del reforzador inmediatamente anterior y el tamaño del reforzador próximo en cada sesión: transiciones de pobre a pobre, pobre a rico, rico a pobre y rico a rico. El intervalo fijo para cada componente fue el mismo dentro de cada fase, pero fue manipulado a través de las fases. Para todas las palomas, se produjeron más ataque después de las presentaciones del reforzador más grande (es decir, durante las transiciones de rico a pobre y de rico a rico). Para 2 de las 3 palomas, este efecto fue modulado por el tamaño del próximo reforzador; El ataque que siguió a los reforzadores más grandes se elevó cuando el próximo reforzador era pequeño (es decir, durante las transiciones de rico a pobre). Este efecto de rico a pobre sobre el ataque disminuyó o desapareció a medida que aumentó la duración del programa de intervalo fijo (es decir, el control sobre el ataque por el próximo tamaño del reforzador disminuyó con los aumentos en el intervalo entre reforzadores). Sin embargo, para todas las palomas y en todos los intervalos fijos, las pausas posteriores al reforzamiento fueron más largas durante las transiciones de rico a pobre. Estos datos (1) son consistentes con la noción de que los períodos posteriores al reforzamiento durante los programas intermitentes funcionan de manera aversiva y, por lo tanto, pueden precipitar un comportamiento agresivo, y (2) sugieren que las transiciones de rico a pobre pueden ser especialmente aversivas. Sin embargo, también indican que los efectos adversos de las transiciones de rico a pobre pueden diferir entre los programas de razón fija e intervalo fijo, y que las variables que controlan el ataque y la pausa pueden no ser isomorfas entre estos diferentes tipos de programas.

Palabras clave: agresión inducida por el programa, transiciones rico-pobre, pausa postreforzamiento, programas de intervalo fijo, palomas

By its nature, aggression is a form of social behavior. Although there may be exceptions (e.g., self-injury), it typically takes at least two individuals to fight. Numerous attempts have been made to define *aggression*, and much has been written about its many forms and functions, from both phylogenetic and ontogenetic perspectives (e.g., Bandura, 1976; Berkowitz, 1993; Buss, 1961). Much also has been written about the utility and validity of various laboratory models of aggression, including those that use nonhuman subjects (e.g., Blanchard & Blanchard, 2003; Mizcek, Weerts, Vivian, & Barros, 1995; Olivier & Young, 2002; Vitiello & Stoff, 1997). Issues associated with the definition of aggression and the validity of laboratory models aside, it is important to identify the conditions under which aggressive/agonistic/hostile behavior is likely. Although such behavior can occur under a variety of circumstances, it is clear that aversive and stressful conditions are among them (e.g., Veenema, 2002).

There is ample evidence that fixed-ratio (FR) and fixed-interval (FI) schedules can have aversive functions. For example, subjects will escape from stimuli associated with these intermittent reinforcement schedules (e.g., Appel, 1963; Azrin, 1961; Brown & Flory, 1972). Stimuli associated with these schedules, particularly ratio schedules, also can function as punishers (e.g., Thompson, 1965). Furthermore, a variety of species will engage in aggressive behavior during these schedules of positive reinforcement (see Looney & Cohen, 1982). For example, pigeons key pecking under FR and FI schedules will attack a conspecific (live, taxidermically prepared, or a visual representation), or an image of themselves in a mirror. Such *schedule-induced attack* has several noteworthy features, including: a) it can be vigorous and excessive, b) it occurs in individuals that do not otherwise attack (i.e., attack does not occur in the absence of the intermittent reinforcement schedule), c) it typically is confined to the period just after reinforcement presentation (i.e., during the postreinforcement pause), and d) it does not appear to be reinforced directly by the scheduled reinforcer (although see Killeen & Pellón, 2013).

Schedule-induced attack has been considered by some as an example of a more general class of schedule-induced, or *adjunctive*, activities. A number of theoretical formulations of schedule-induced behavior have been proposed (e.g., Falk, 1971, 1977; Killeen, Hanson, & Osborne, 1978; Killeen & Pellón, 2013; Staddon, 1977; Wetherington, 1982). Although these will not be discussed in detail here, it is worth noting that Falk (1971, 1977) proposed that schedule-induced activities were maintained by consequences which derive their reinforcing function as a result of intermittent scheduling of reinforcers for another class of activities. That is, the presence of an intermittent schedule of reinforcement for one operant activity serves a motivating function for those consequences that are available for other activities. Thus conceived, schedule-induced attack (and escape) could be considered behavior motivated by aversive functions of intermittent reinforcement. Experiments showing that access to a target conspecific can function as a reinforcer when intermittent schedules of food presentation are operating for a separate operant response are consistent with this formulation (e.g., Cherek, Thompson, & Heistad, 1973).

Evidence suggests that transitions from periods of reinforcement to periods of non-reinforcement, or from more favorable (richer) to less favorable (leaner) conditions of reinforcement (*negative incentive shifts*), function aversively. For example, under FR schedules, the period immediately after reinforcement, during which reinforcement is unavailable, produces a characteristic pause (the *postreinforcement pause*, or PRP), which increases as a function of the response requirement (e.g., Felton & Lyon, 1966; Powell, 1968). That is, under FR schedules, the period just after reinforcement functions as a signaled period of extinction. The PRP under FR schedules typically is longer following more favorable reinforcement conditions and in the presence of stimuli signaling less favorable reinforcement conditions (i.e., during rich-to-lean transitions). For example, Perone and Courtney (1992) exposed pigeons to multiple FR FR schedules in which each of two components arranged a different reinforcer magnitude (one smaller – the lean component; one larger – the rich component). Components alternated to generate four types of transitions between components: 1) both the past and current components provided the smaller reinforcer (lean-to-lean transitions), 2) the past component provided the smaller reinforcer and the current component provided the larger reinforcer (lean-to-rich transitions), 3) the past component provided the larger reinforcer and the current component provided the smaller reinforcer (rich-to-lean transitions), and 4) both the past and current components provided the larger reinforcer (rich-to-rich transitions). The PRPs were considerably longer during rich-to-lean transitions than during any other transition type. This effect appears to be both reliable and general; it has been shown with several species (e.g., pigeons, rats, monkeys, and humans), different manipulations of rich-to-lean conditions (e.g., ratio size, response effort, reinforcer delay), and different reinforcing stimuli (e.g., food, tokens, preferred activities) (Baron & Herpolsheimer, 1999; Brewer, Johnson, Stein, Schlund, & Williams, 2017; Galuska, Wade-Galuska, Woods, & Winger, 2007; Harris, Foster, Levine, & Temple, 2012; Jessel, Hanley, & Ghaemmaghami, 2016; Wade-Galuska, Perone, & Wirth, 2005; Williams, Saunders, & Perone, 2011; Young, Foster, & Bizo, 2017).

One interpretation of the prolonged PRPs during rich-to-lean transitions is that the PRP functions as a form of escape (Everly, Holtyn, and Perone, 2014; Retzlaff, Parthum, Pitts, and Hughes, 2017). In their Experiment 2, for example, Everly et al. provided pigeons with opportunities to peck a second (stimulus-change) key which converted the multiple-schedule stimuli to a mixed-schedule stimulus (i.e., pecks to the stimulus-change key changed the stimulus signaling the upcoming reinforcer magnitude to one that was correlated with both reinforcer magnitudes). Pigeons were most likely to peck the stimulus-change key during rich-to-lean transitions. Retzlaff et al. found similar results in their Experiment 1, and extended these findings in Experiment 2 by providing pigeons with opportunities to peck a second, time-out, key which turned off the multiple-schedule stimuli and suspended the schedule contingencies (cf., Azrin, 1961). Retzlaff et al. found that self-imposed time outs occurred most often during rich-to-lean transitions (although they also occurred relatively frequently during lean-to-lean transitions).

The first paper in this two-paper sequence reported patterns of attack and pausing typical of FR schedules, but both attack and pausing were exaggerated in the presence of stimuli associated with rich-to-lean transitions (Williams, Hayashi, Brewer, Saunders, Fowler, & Pitts, 2019, *this issue*). Given that aversive conditions can precipitate aggression and lengthy PRPs, and that intermittent schedules of positive reinforcement can have aversive functions, it seems reasonable to conclude that the aversive properties of intermittent reinforcement are increased when there is an explicitly arranged, negative shift in reinforcement conditions – at least under multiple FR schedules.

Effects of rich-to-lean transitions primarily have been examined in the context of FR schedules. This makes sense given that the aversive characteristics of FR schedules, particularly those associated with the postreinforcement period, typically are attributed to the upcoming work requirement (e.g., Azrin, 1961; Griffiths & Thompson, 1973). The delay to the upcoming reinforcement also increases with increased FR requirements, which also may contribute to the aversive characteristics of FR schedules. Thus, a question arises as to whether or not the rich-to-lean effects reliably produced under FR schedules would occur in the context of other schedule arrangements (e.g., under fixed-interval, FI, schedules). Carlin (1998) examined pausing and escaping under multiple FI schedules that arranged different reinforcer magnitudes and/or different reinforcement rates. Carlin found the typical rich-to-lean effect described above with PRP, but not with escape (escape did not occur reliably). Thus, the data for pausing, but not escaping, were similar to those typically found with FR schedules. Recently published data showing that schedule-induced ethanol consumption in rats can be precipitated by rich-to-lean transitions under FR schedules of food presentation is consistent with this conclusion (Sawyer, Galuska, Cutright, & Hopper, 2019).

Although schedule-induced attack occurs reliably under FI schedules (e.g., Cherek & Heistad, 1971; Pitts & Malagodi, 1996), there is evidence to suggest that attacking occurs to a lesser extent under time-based than under response-based schedules, even when the inter-reinforcement interval is equated (Kupfer, Allen, & Malagodi, 2008). Together with Carlin's (1998) results, these data suggest that, although stimuli present during the postreinforcement periods under both FR and FI schedules can function aversively, there may some important differences in the nature of control by past and upcoming conditions under these two schedules. Thus, the purpose of the present study was to examine effects of rich-to-lean transitions on attack induced under FI schedules; effects of these transitions on the duration of the PRP also were assessed.

Method

Subjects

Three adult White Carneau pigeons (*Columba livia*) served as subjects. Two of the pigeons were female (7120 and 9978) and one was male (8534). Pigeons 7120 and 9978 had previous experience under FR schedules of food presentation with target pigeons present; Pigeon 8524 was experimentally naive. Each experimental pigeon was paired with another pigeon of the same sex that served as its target. All pigeons were housed individually with water and health grit continuously available. Experimental pigeons were maintained at approximately 80% of their free-feeding body weights by providing, as needed, supplemental mixed grain (Purina® Breeder) in the home cage after experimental sessions. Grain was available continuously for the target pigeons.

Apparatus

An experimental space (36 cm high by 38.5 cm wide by 36 cm deep) was enclosed in a light- and sound-attenuating chamber. The front and rear walls of the space were constructed of stainless steel, the right and left walls and the ceiling were made of drywall that was painted an opaque beige, and the floor was constructed of wire mesh. The front wall consisted of a BRS-Foringer two-key stimulus panel. The right key (3 cm in diameter) was located 7.5 cm from the right wall and 24 cm above the floor and could be transilluminated with colored lights or geometric figures by standard IEE 28-V 12-stimulus projectors. Pecks with a force of at least 0.19 N against this key were defined as responses. The left key (located 7.5 cm from the left wall and 24 cm from the floor) was dark and inoperative throughout the experiment. Two banks of house lights (28-VDC each), one located at the top edge of the front wall and one at the top edge of the rear wall, were mounted behind translucent barriers. An aperture (4.5 cm high by 5.5 cm wide), into which a food hopper could be raised, was centered on the front wall with the bottom edge 7.0 cm above the floor. Each food presentation consisted of raising the food hopper that contained Purina® mixed grain for 3 s, during which the house lights and key light were off and a 28-VDC white light illuminated the hopper.

The apparatus for restraining the target birds and for recording attack was similar to the one originally described by Azrin, Hutchinson, & Hake (1966) and nearly

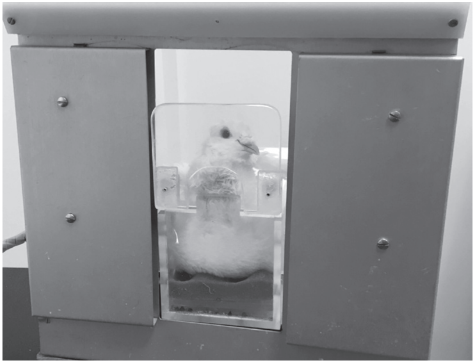

Figure 1. Photograph of the apparatus used for the target pigeon, taken from the perspective of the experimental pigeon. The entire unit was removed from the chamber for the photograph. The target pigeon was placed within a rectangular box that had one end facing the experimental space. The pigeon's head protruded through an opening on the top of the box closest to the chamber. The breast region was covered with a piece of synthetic while fur, and a Plexiglas® shield was mounted on the restraining box so that the pigeon's head and eyes were protected from contact by the experimental pigeon. The small opening in the shield provided access to the fur covered breast area. Pecks of sufficient force by the experimental pigeon to the shield and to the fur-covered breast area were recorded as attacks. See text (Apparatus) for additional details.

identical to the one described by Pitts and Malagodi (1996). The restraining unit was a rectangular box made of Plexiglas® mounted on a spring-loaded metal plate. The unit was positioned at the rear wall such that the front end faced the experimental space. Access to the target was provided through a 24 cm high by 11 cm wide rectangular opening in the rear wall. A microswitch was located under the metal plate such that displacements of the unit with a force exceeding 0.90 N activated the microswitch and were recorded as attacks. Visual observation of selected experimental sessions suggested that at this force requirement, most of the contacts by the experimental pigeons were recorded as attacks, but movements by the target pigeons were not.

Figure 1 shows a photograph of a pigeon placed within the target-restraining unit, which has been removed from the chamber. The unit served as the entire rear wall of the experimental space and is shown from the perspective of the experimental pigeon. Each target pigeon was placed within the rectangular box with foam cushions positioned below it and to its rear. The top side of the box was a door which allowed placement of the target pigeon so that it was facing the experimental space. A small opening on the top of the rectangular box closest to the experimental space allowed for the extrusion of the target pigeon's head, neck, and upper breast. A bib, constructed of synthetic white fur, was attached to the target pigeon so that the exposed upper breast region was entirely covered. A Plexiglas® shield was mounted 3.0 cm in front of the target pigeon's face and in the same plane as the rear wall of the chamber. This shield had a semicircular opening with a 3.0 cm radius cut into it and was positioned so the fur-covered breast of the target pigeon was exposed through the opening, but its face and head were protected (see Figure 1). Contacts of sufficient force to either the breast region or the shield activated the microswitch while safeguarding against injury to the target pigeon; none of the target pigeons were injured during this study. Access to the target bird could be controlled by motor-driven sliding doors; the doors remained open throughout experimental sessions in which attack was measured.

Continuous white noise was present in the surrounding room to mask extraneous sounds, and a ventilation fan provided air circulation within the experimental space. Experimental events were programmed and data were recorded by a Windows®-controlled microcomputer using Med Associates® (Georgia, VT) software and interfacing equipment located in an adjoining room.

Procedure

Assessment of attacking prior to experimental training. Prior to any training, each experimental pigeon was placed in the chamber for a minimum of five, 1-hr pretraining sessions, during which the white house lights were illuminated, the doors to the restraining unit were open, the target pigeons were present, and attacks were recorded.

Preliminary training. Because of previous experience, 7120 and 9978 were placed directly on the experimental procedure (see below). Preliminary training for 8534 took place with the target pigeon absent and the doors to the restraining unit closed. After 8534 was trained to eat from the food hopper, key pecking was shaped by reinforcing successive approximations in the presence of a white key light and white house lights. After acquisition of key pecking, a chained FI FR 1 schedule was implemented. Under this schedule, the first key peck after 10 s had elapsed in the presence of a white key light and white house lights changed the key light to a white triangle on a black background and the next key peck produced food. After food presentation, the white key light and house lights reappeared and the cycle was repeated. These sessions ended following the 17th cycle. Over the next several sessions, the value of the FI initial link was increased to 4 min.

Experimental procedure. Each experimental pigeon was exposed to a two-component multiple schedule. Each component consisted of a chained FI FR 1 x *n* schedule of food presentation in which the first key peck after the FI had elapsed changed the color of the key light and the house lights, and each of the next *n* key pecks produced food. The components differed with respect to *n*, the number of reinforced key pecks in the terminal link of the chain and with respect to the stimuli present during the FI. In one component *n* was 1 (intervals that ended in the smaller reinforcer), whereas in the other component *n* was 8 (intervals that ended in the larger reinforcer). That is, for the smaller reinforcer the chain ended with single FR 1 schedule (i.e., one 3-s food presentation following a single peck); whereas, for the larger reinforcer the chain ended with 8 consecutive FR 1 schedules (eight 3-s food presentations, each following a single peck). For 8534 and 9978, the key light and house lights were green during intervals that ended in the smaller reinforcer and were red during intervals that ended in the larger reinforcer; for 7120 the stimuli correlated with upcoming reinforcer size were reversed. During the terminal links of both components, the key light was transilluminated with a black triangle on a white background and the house lights were white. Thus, each interval ended with delivery of either a small (lean) or a large (rich) reinforcer magnitude that was correlated with specific stimuli present during the interval. A changeover delay (COD) was arranged such that key pecks within 5 s of an attack could not initiate the final link of the chain or produce grain.

Each session consisted of 17 chained-schedule cycles; 8 or 9 of the intervals ended in the lean reinforcer and the other intervals ended in the rich reinforcer. The order of exposure to the lean and rich reinforcers in a given session was determined by selecting from a list of 12 different sequences. Six of the sequences arranged eight lean and nine rich reinforcers, the other six arranged nine lean and eight rich reinforcers. Each sequence was constructed with three features. First, the 16 intervals that followed the first interval contained 4 transitions of each type (lean-to-lean, intervals that followed and ended with the smaller reinforcer; lean-to-rich, intervals that followed the smaller reinforcer and ended with the larger reinforcer; rich-to-lean; and rich-to-rich). Second, a maximum of three intervals of a given reinforcer magnitude could occur consecutively. Third, each of the two interval types that could follow a particular interval type did so on exactly half of the occasions (e.g., only a lean-to-lean or a lean-to-rich transition could follow a lean-to-lean transition, and each did so on exactly half of the occasions). For each block of 12 consecutive sessions, sequences were drawn randomly from the list without replacement. Because of weight gain during the session, the number of chained-schedule cycles during each session for 7120 was reduced to 13, with 6 or 7 of each interval type (3 of each transition type). For 7120 and 9978, the initial FI value was 1 min, for 8534 the initial FI value was 4 min. After 12 sessions at these initial FI values, the target pigeons were introduced and the doors to the restraining unit were open for all remaining sessions.

Table 1
List of conditions, the number of sessions at each condition, and the order of exposure for each pigeon.

Pigeon/Condition	Order	Sessions
7120		
FI 1 min	**1**	**32**
FI 4 min	**2**	**20***
FI 8 min	**3**	**25***
8534		
FI 1 min	**2**	**32**
FI 4 min	**1**	**111**
FI 8 min	**3**	**46**
9978		
FI 1 min	**1**	**52**
FI 4 min	**3**	**20***
FI 8 min	**2**	**53**

Note. All subjects experienced at least 24 sessions under each procedure. However, asterisks denote conditions for which the exact number of sessions could not be determined because data from some of the early sessions were lost. For these conditions, the numbers listed indicate the number of sessions for which data were available.

Each experimental pigeon was exposed to three different FI initial-link schedule values (1, 4, and 8 min) across phases. The order of exposure to these values and the number of sessions at each value are shown in Table 1. Experimental conditions were changed after a minimum of 24 sessions and when attacks per reinforcer for each of the four interval types were considered stable for 10 consecutive sessions, as determined by visual inspection of daily plots. Sessions for 8534 were conducted 5 days per week; because of weight gain, sessions for 7120 and 9978 were conducted on Mondays, Wednesdays, and Fridays.

Results

For all pigeons, attack during the preliminary assessment (prior to training) was infrequent (data not shown). Typically, attacks occurred occasionally during the first one or two sessions, after which attacks were rare. For all pigeons, there were no attacks during the last five sessions of this condition.

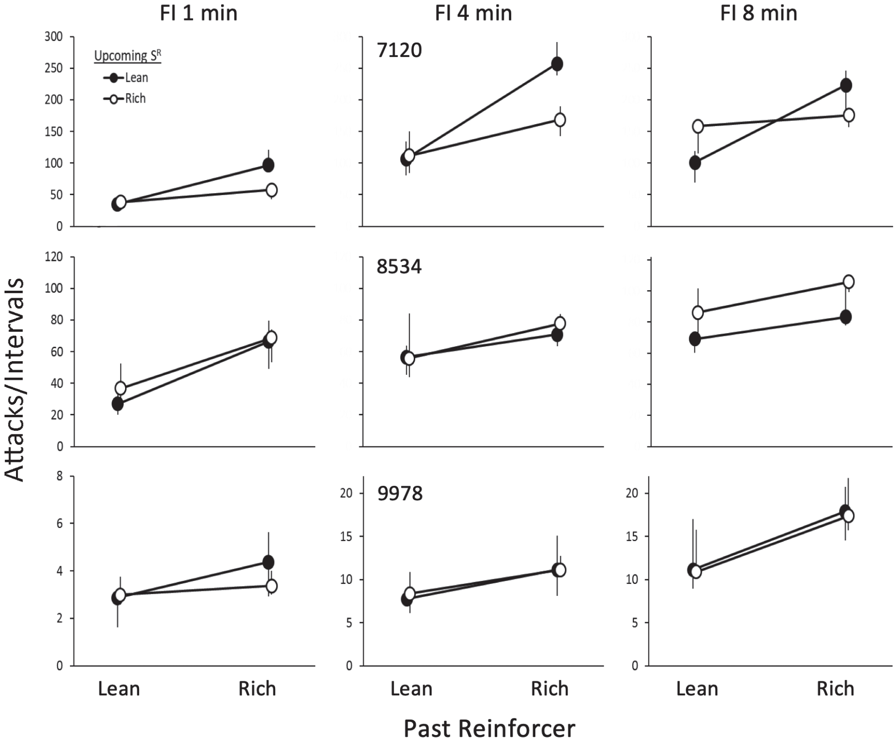

Figure 2. Attacks per interval for each pigeon during each transition across the different FIs. In each graph, attacks per interval are plotted as a function of the past reinforcer magnitude (Lean=Small; Rich=Large), with the upcoming reinforcer magnitude indicated by the different symbols (filled = lean; unfilled = rich). Data for each pigeon are presented in rows and data for each FI are presented in columns. Data points are medians from the last 10 sessions of each condition and error bars show interquartile ranges (the absence of an error bar indicates that the interquartile range fell within the area of the data point). Note the individualized y-axis ranges across pigeons. For each pigeon, except 9978, the y-axis range is consistent across the FIs; for 9978, the y-axis range at FI 1 min is reduced to illustrate the slightly elevated attack under the rich-to-lean transitions.

Figure 2 shows attacks per interval for each transition type; attacks per interval were obtained by dividing the total number of attacks generated by a given transition by the number of transitions of that type). In this figure, attacks per interval are plotted as a function of the past reinforcer magnitude (lean or rich) when the upcoming reinforcer magnitude was lean (filled circle) or rich (unfilled circles). For each pigeon (shown in rows), more attack occurred following rich reinforcers than following lean reinforcers. That is, there appeared to be a main effect of the past reinforcer magnitude; larger reinforcers produced more attack. For two pigeons (7120 and 9978), under at least one of the FIs, the effect of the past reinforcer magnitude was modulated by the size of the upcoming reinforcer such that attack was highest following a rich reinforcer and in the presence of a stimulus signaling a lean upcoming reinforcer. That is, under some conditions for these pigeons, attack was highest during rich-to-lean transitions. This rich-to-lean effect was modulated by the length of the FI. Increasing the FI tended to reduce the differential effect produced by rich-to-lean transitions. For 7120, a reliable rich-to-lean effect occurred at FI 1 min and FI 4 min. This effect was reduced somewhat at FI 8 min, mainly by an elevation of attacks per interval during lean-to-rich transitions relative to lean-to-lean transitions. For 9978, a small, but relatively reliable, rich-to-lean effect occurred at FI 1 min, which disappeared completely at FI 4 min and FI 8 min. Pigeon 8534 did not show a rich-to-lean effect at any of the FIs. At FI 1 and 4 min, attacking was controlled entirely by the past reinforcer magnitude. At FI 8 min, some control by the upcoming magnitude was evident, such that attacks per interval were higher during the stimulus signaling a larger upcoming magnitude (i.e., the unfilled circles are higher than the filled circles at both past reinforcer magnitudes).

Figure 3 shows PRPs (plotted as a proportion of the FI) under each transition type; PRP was defined as the time from the end of the reinforcer cycle to the first key peck of the interval. These data are displayed in the same manner as those in Figure 2. For all pigeons, to one degree or another, pausing was under joint control of the past and upcoming reinforcer magnitudes. Pauses usually were longest after the large reinforcer and in the presence of the stimulus signaling the small upcoming reinforcer (i.e., during the rich-to-lean transitions). There was a slight attenuation of this relation at FI 8 min; data points for the small past reinforcer tend to diverge slightly (pauses for the larger upcoming reinforcer were elevated) and data points for the large past reinforcer tend to converge. Pausing also was controlled by the FI; for the most part, PRPs for individual pigeons during each transition type were a relatively constant proportion of the FI.

Figure 4 shows within-interval distributions of attacking and key pecking for 7120 from a representative session under the FI 4-min condition; this pigeon showed a reliable rich-to-lean effect with attacks per interval under these conditions. This session was selected from the last 10 sessions of this condition in the following manner. First, all sessions with the same rank order of attacks per interval across the four transition types as the rank order of the medians were identified (in this case, from highest to lowest, the order was rich-to-lean, rich-to-rich, lean-to-rich,

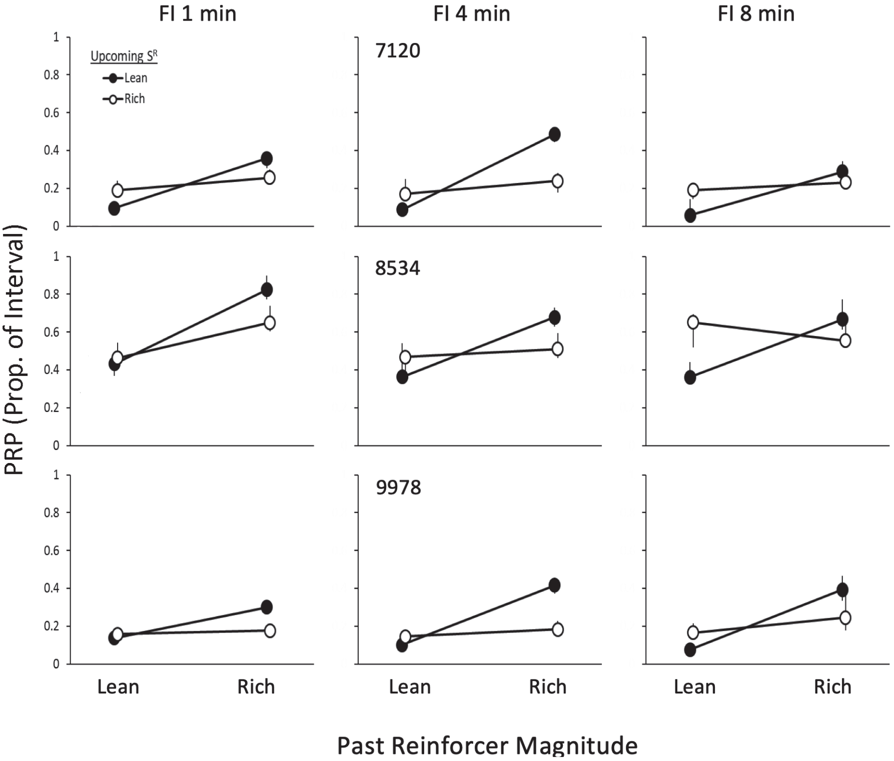

Figure 3. Postreinforcement pause duration, as a proportion of the FI, plotted as a function of the past reinforcer magnitude for individual pigeons across the different FIs. All other features of this figure are the same as in Figure 2.

and lean-to-lean). Second, from those, the session for which the smallest sum of the absolute values of the differences between the session data and the median data at each transition was selected. In Figure 4, attacks (darker lines) and key pecks (lighter lines) in 4-s bins across the interval are shown for each transition type (in different panels). Several features of these data are noteworthy. First, in all transitions, high levels of attack tended to occur during the period immediately after reinforcement. As the interval progressed attacking decreased, and key pecking was initiated and continued throughout the remainder of the interval. Second, higher levels of attack occurred following rich reinforcers (bottom panels) than following lean reinforcers (top panels). Third, in all transitions, attacking persisted beyond the initiation of key pecking. Indeed, although the likelihood of attack decreased across the inter-

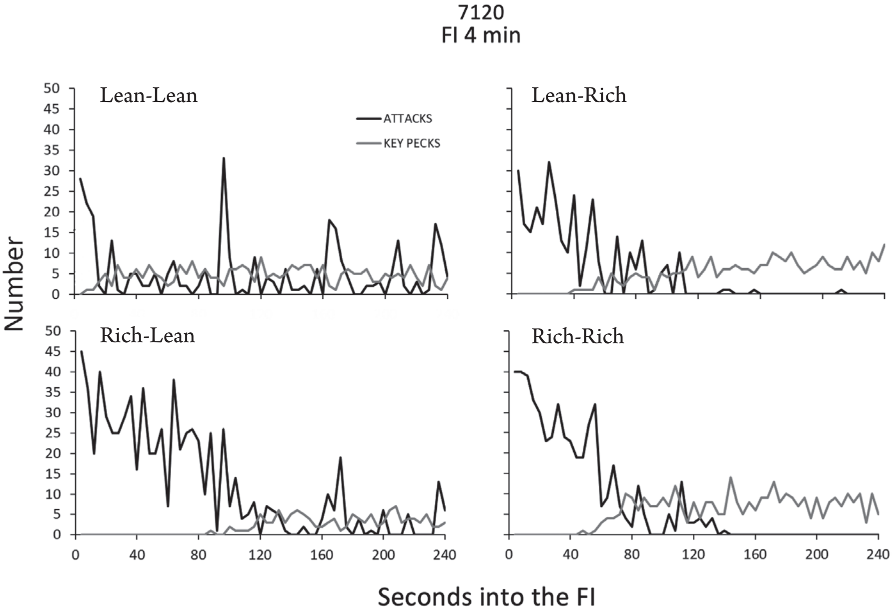

Figure 4. Number of attacks (darker lines) and number of key pecks (lighter lines) for 7120 across the FI (in 4-s bins). Data for each transition type are shown in a separate panel; see text for descriptions of the abbreviations used for the transition types. Data are from a single, representative, session from the FI 4-min condition (see description of this figure in Results for selection criteria).

val, attacking persisted to some degree throughout the interval when the upcoming reinforcer was small (during the lean-to-lean and rich-to-lean transitions, shown in the left-hand panels). Finally, high levels of attack persisted longer, and key pecking was initiated later, during the rich-to-lean transitions than during the other transition types. This persistence of attack far into the interval and the alternation of attack and key pecking was most prevalent for 7120, and occurred at all FI durations in this pigeon. This pattern also was observed with 8534 (primarily at FI 1 and FI 4), and to a much lesser extent with 9978 (data not shown). For 9978, attacking only occasionally occurred after the initiation of key pecking, and only did so at FI 1, and typically only during rich-to-lean transitions.

The degree to which attack persisted into the interval is illustrated in Figure 5. This figure shows the number of attacks across 10$^{\text{ths}}$ of the interval in each transition type during a representative session for each pigeon across all FI conditions (representative sessions were selected using the same criteria described above for

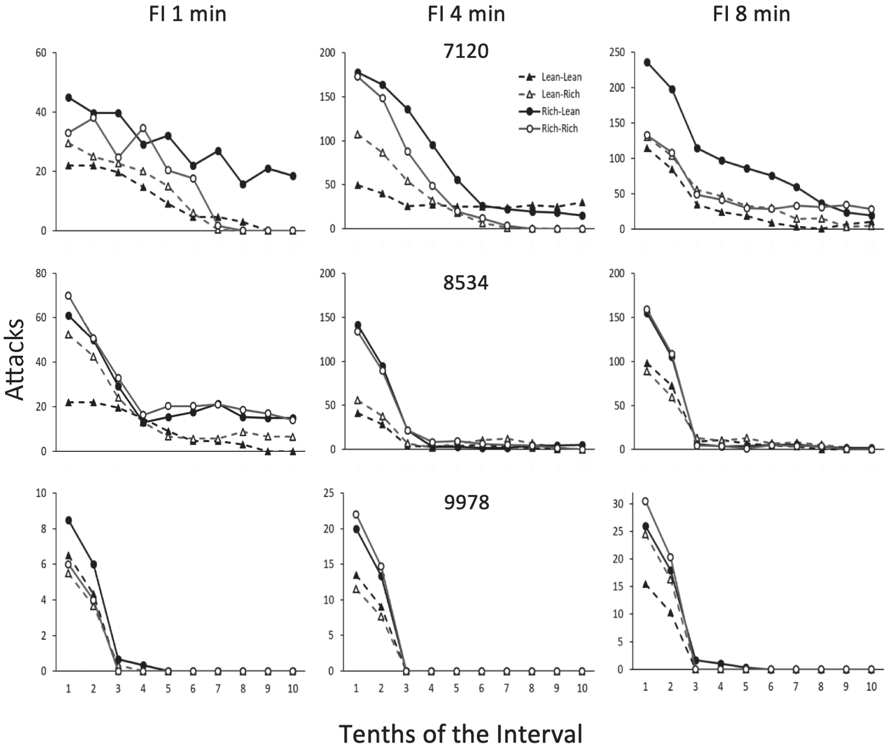

Figure 5. Number of attacks across successive tenths of the interval in individual pigeons for each transition type across the conditions of the experiment. Data in each panel are from a single, representative, session. Data from transitions with the lean (small) and rich (large) past reinforcers are shown by triangles/dashed lines and circles/solid lines, respectively; data from transitions with the lean and rich upcoming reinforcers are shown by the filled symbols/darker lines and unfilled symbols/lighter lines, respectively. Data points are moving averages; each point is the mean of the indicated and the immediately adjacent bin(s). The overall layout of this figure is similar that used in Figures 1 and 2.

Figure 4). Each transition type is indicated by a unique symbol/line combination. Values are moving averages; each point is the mean of the indicated bin and the two immediately adjacent bins (values at 1 and 10 are means of the first and last two bins, respectively). Data from transitions with lean past reinforcers are indicated by triangles/dashed lines and transitions with rich past reinforcers are indicated by circles/solid lines; data from transitions with lean upcoming reinforcers are indicated by filled symbols/darker lines and transitions with rich upcoming reinforcers are indicated by unfilled symbols/lighter lines. As with Figure 4, this figure illustrates that attack was most prevalent during the period just after reinforcement for all pigeons, and that postreinforcement attack was higher following rich (larger) than following lean (smaller) reinforcers (circles/solid lines vs. triangles/dashed lines). This figure also shows that attack decreased across the interval, but that in some cases it persisted well into the interval (e.g., 7120, all FIs; 8534, FI 1). For 7120, although attack immediately after food presentation was highest during rich-to-lean transition at all FIs, it also persisted longer into the interval during these transitions than during the other transition types. To some extent, this also was the case for 9978 at FI 1 min, during which a rich-to-lean effect with attack also was obtained.

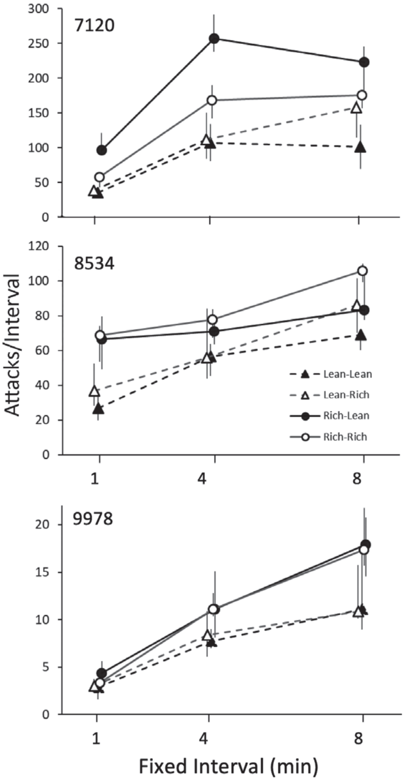

Figure 6. Attacks per interval as a function of FI for individual pigeons under each of the 4 types of transitions. Each type of transition is indicated by a different symbol/line combination, which are the same as in Figure 5. Data points are medians from the last 10 sessions of each condition and error bars show interquartile ranges (the absence of an error bar indicates that the interquartile range fell within the area of the data point). Note the individualized y-axis ranges across pigeons.

Figure 6 shows attacks per interval for each transition type as a function of FI. These data are the same as those shown in Figure 2, but plotted differently to reveal the effect of the FI. In general, attacks per interval were an increasing function of the FI duration, for all of the transition types. A possible exception to this was with 7120, in which there was a slight decrease in attacks per interval at FI 8 min for the lean-to-lean and rich-to-lean transitions. This figure also illustrates the higher levels attack following rich reinforcers (circles) than following lean reinforcer (triangles).

Table 2 shows key peck rates for each transition in individual pigeons. For each FI, the top number is the overall key peck rate and the bottom number is the run rate (key pecks per minute after the first response of the interval). For all pigeons,

Table 2

Key pecks per minute for each pigeon under each condition of the experiment.

Pigeon/ Condition	Lean-Lean	Lean-Rich	Rich-Lean	Rich-Rich
7120				
FI 1 min	**46.9 (39.7-54.4)**	**57.2 (53.0-62.1)**	**21.6 (16.0-25.8)**	**51.0 (46.4-52.2)**
	51.3 (45.6-60.8)	**71.5 (65.6-77.4)**	**34.2 (26.2-39.0)**	**67.0 (61.5-70.4)**
FI 4 min	**20.7 (16.4-27.5)**	**25.8 (17.0-31.3)**	**6.1 (5.4-7.1)**	**27.4 (25.6-28-6)**
	21.9 (18.3-29.5)	**30.1 (26.3-37.3)**	**12.2 (11.0-13.1)**	**35.9 (34.5-37.6)**
FI 8 min	**19.4 (15.1-21.7)**	**20.3 (18.5-24.2)**	**9.4 (8.9-11.6)**	**18.1 (15.1-21.6)**
	20.4 (18.4-22.8)	**27.9 (24.1-29.1)**	**13.6 (13.0-15.3)**	**24.2 (19.5-28.3)**
8534				
FI 1 min	**30.5 (25.2-33.5)**	**31.5 (26.4-33.6)**	**10.2 (7.8-11.7)**	**22.9 (18.8-28.5)**
	57.6 (47.7-59.2)	**58.4 (53.1-63.5)**	**53.5 (42.4-69.9)**	**70.2 (58.3-71.9)**
FI 4 min	**27.4 (25.1-31.1)**	**23.2 (20.3-24.5)**	**16.6 (11.3-18.3)**	**27.1 (22.4-28.6)**
	51.4 (45.9-56.3)	**43.8 (35.9-52.2)**	**53.4 (49.3-56.0)**	**54.6 (50.8-59.6)**
FI 8 min	**26.5 (20.7-30.7)**	**13.6 (9.9-16.8)**	**17.2 (13.8-20.5)**	**17.3 (13.7-22.2)**
	42.9 (39.5-44.3)	**33.5 (27.9-45.9)**	**55.7 (50.1-64.2)**	**44.6 (38.5-47.3)**
9978				
FI 1 min	**136.7 (133.4-145.4)**	**141.3 (138.2-146.3)**	**106.5 (98.2-110.1)**	**135.9 (132.8-137.2)**
	161.8 (153.5-165.8)	**171.7 (167.0-174.3)**	**154.7 (148.3-157.4)**	**164.4 (162.2-169.3)**
FI 4 min	**115.9 (99.2-124.5)**	**57.0 (53.0-64.7)**	**59.5 (49.5-69.0)**	**64.9 (62.2-73.5)**
	133.2 (112.0-141.5)	**64.9 (62.0-76.4)**	**101.2 (88.4-113.5)**	**91.2 (76.0-93.9)**
FI 8 min	**73.2 (51.9-84.4)**	**54.6 (46.9-55.2)**	**49.1 (30.2-52.3)**	**60.9 (57.7-64.8)**
	82.6 (57.0-90.0)	**62.6 (57.8-68.3)**	**76.6 (51.3-89.0)**	**87.7 (77.5-94.2)**

Note. For each condition, the top number is the overall key peck rate and the bottom number is the run rate (key pecks per minute after the first response of the interval). Values are medians from the last 10 sessions of each condition and numbers in parentheses are interquartile ranges).

overall rates tended to be lower during the rich-to-lean transitions than the other transitions; this occurred in 7 of the 9 such transitions (8534 at FI 8 min and 9978 at FI 4 min were the exceptions). Comparisons of the data for overall rate in Table 1 with the data for PRP in Figure 3 indicate that the lower overall rates during the rich-to-lean transitions largely were the result of the longer PRPs during these transitions. For 7120, run rates (key pecks per minute after the first response of the interval) also were lower during the rich-to-lean transitions; but this was not the case with the other two pigeons.

Discussion

For all pigeons, FI schedules of food presentation induced attack. Some investigators have emphasized the excessive nature of schedule-induced (adjunctive) responses, including attack (Cohen & Looney, 1982; Falk, 1977). For two of the three pigeons (7120 and 8534), levels of attack could be described as excessive (although relative to the absence of attack during the pretraining assessment, it might be argued that any attack could be considered excessive). For all pigeons, attacks per reinforcer were higher following the rich reinforcer than following the lean reinforcer. One pigeon (7120) showed rich-to-lean effects on attack at all FIs, particularly at FI 1 and FI 4; the highest levels of attack occurred following the rich reinforcer and in the presence of the stimulus signaling the lean upcoming reinforcer. Pigeon 9978 also showed evidence of a rich-to-lean effect on attack at FI 1 min, but this effect disappeared at the longer FIs. For the most part, with all transitions, attacks per reinforcer increased monotonically as a function of the FI duration. Finally, to one degree or another, all pigeons showed rich-to-lean effects with PRP at all FIs; PRPs typically were longest during the rich-to-lean transitions.

The present findings are consistent with previous reports that FI schedules, and their correlated stimuli, can have aversive functions (e.g., Brown & Flory, 1972; Richards & Rilling, 1972) and, thus, induce aggressive behavior in much the same way as do other aversive stimuli (e.g., shock, a physical blow, extinction; Azrin, Hake, & Hutchinson, 1965; Azrin et al., 1966; Ulrich & Azrin, 1962). Furthermore, the present findings that attacks per reinforcer were more frequent after larger (rich) than after smaller (lean) reinforcers replicates those previously reported by Pitts and Malagodi (1996). Together, these data suggest that the aversive, attack-inducing, functions of postreinforcer stimuli (i.e., of the withdrawal of reinforcement) under FI schedules is enhanced by transitions from larger reinforcers (i.e., transitions from richer conditions).

Some of the present findings also suggest that the aversive, attack-inducing function of the postreinforcer period under FI schedules can be modulated by stimuli associated with upcoming reinforcer conditions in a manner similar to that previously reported with FR schedules (Everly et al., 2014; Retzlaff et al., 2017; Williams et al., 2019). A rich-to-lean effect on attack in the present experiment occurred for 7120 (at all FIs) and 9978 (at FI 1 min). This effect, however, did not occur for 8534. Furthermore, the rich-to-lean effect decreased (7120) or disappeared (9978) as a function of the FI duration. These data indicate that control over attack by the upcoming reinforcer magnitude decreased as function of its fixed temporal distance from the postreinforcement period. Under ratio schedules this temporal distance is free to vary with overall response rate. Under FI schedules, however, only a single response is required for reinforcement so the work requirement is free to vary.

The present data raise two, somewhat interrelated, issues regarding control over schedule-induced aggression by interactions between past and upcoming reinforcer magnitudes in the context of rich-to-lean conditions. The first issue concerns the nature of control by rich-to-lean conditions and potential differences in control by rich-to-lean transitions under FI versus FR schedules. Although attack typically was most prevalent during the period immediately following food presentation, in several cases (e.g., 7120 at all FIs and 8534 at FI 1 min), it persisted well into the interval, beyond the PRP, despite the contingency preventing food presentation within 5 s of attacking. Thus, in these cases, pigeons sometimes alternated between periods of attacking and key pecking (e.g., Figure 4). The persistence of attack further into the interval tended to occur during transitions with the higher overall levels of attack (e.g., during rich-to-lean transitions for 7120 and for 9978 at FI 1, and following larger reinforcer presentations for 8534; see Figure 5). This persistence, however, does not account entirely for the higher levels of attack during these transitions, as attack in these transitions already was elevated early during the postreinforcement period relative to the other transitions (see Figure 5).

The persistence of attack into the interval in the present experiment is similar to that reported previously under FI schedules (e.g., Cherek & Heistad, 1971) and is in contrast to the typical pattern of attack under FR schedules. Under FR schedules, attack usually is confined exclusively to the PRP (e.g., Gentry, 1968). This is not surprising given the nature of control over the required response under FR and FI schedules – attacking (and indeed, pausing) reduces the rate of reinforcement under FR, but not under FI, schedules. Whether or not this illustrates different sources of control over attack is unclear. The data reported by Kupfer et al. (2008) showing higher levels of attack under FR than under response-independent (matched-time) schedules suggest that an upcoming work requirement functions aversively, over and above that created simply by a discriminable period of nonreinforcement. Indeed, stimuli signaling that a large upcoming work requirement will produce a relatively small reinforcer may be particularly aversive (e.g., Williams et al., 2011).

It is possible that control by number of responses also played a role in the current results. Both 7120 and 9978, who showed a rich-to-lean effect with attack, each had a history with FR schedules (although not in the context of a multiple schedule with differing reinforcer amounts); whereas 8534, who did not show a rich-to-lean effect, was experimentally naïve. This interpretation of the present results is weakened somewhat by the fact that, of the three pigeons, 9978 had the highest response rates (i.e., the most responses per reinforcer), but the fewest attacks per reinforcer. Furthermore, as noted above, attacking tended to persist into the interval under those conditions under which it was already high during the postreinforcement period. Thus, although discriminable upcoming work requirements under FR schedules may be especially aversive, particularly following relatively rich conditions, FR and FI schedules are similar in that they both arrange discriminable postreinforcement periods during which reinforcement is unavailable (e.g., Ferster & Skinner, 1957).

The second issue raised by the present data concerns the relation between the PRP and attack (and other measures of *aversiveness*, e.g., escape). Relatively consistent rich-to-lean effects occurred with the PRP in all pigeons at all FIs, even under conditions that did not produce rich-to-lean effects on attack. Thus, although the PRP was controlled by the temporal properties of the FI schedule (as illustrated in Figure 3), this control was modulated by the past and upcoming reinforcer magnitude in a manner similar to that typically obtained with FR schedules (e.g., Perone & Courtney, 1992). Carlin (1998) reported similar rich-to-lean effects on the PRP under FI schedules. Thus, it appears that the past and upcoming reinforcers can impact the PRP similarly under both FR and FI schedules. Some evidence suggests, however, that even under FR schedules, rich-to-lean effects on PRP may not simply reflect aversive functions of the postreinforcer periods (i.e., the PRP may be more than simply a form of escape). For example, Retzlaff et al. (2017) found that although pigeons self-imposed time-out periods (i.e., escaped) during rich-to-lean transitions more often than during any other type of transition, extended pausing occurred prior to initiating time-outs; that is, during rich-to-lean transitions, pigeons paused for an extended period, then escaped. Furthermore, using FR schedules that arranged the different transitions between large and small reinforcers, Langford, Pitts, and Hughes (2019) provided pigeons with a choice between transition-correlated (multiple-schedule) or transition-uncorrelated (mixed-schedule) stimuli. During selected transitions, both multiple- and mixed-schedule stimuli were presented, and a selection of one of the stimuli turned off the other and initiated the FR, which was completed in the presence of the selected stimulus. Under these conditions, pigeons were highly likely to choose the mixed-schedule stimulus during rich-to-lean transitions (i.e., they avoided completing the ratio in the presence of the multiple-schedule stimulus). The latency to select the mixed-schedule stimulus, however, was similar to the PRP typically obtained during rich-to-lean transitions under the multiple-schedule. That is, the pigeons paused then selected the mixed-schedule stimulus, rather than first selecting the mixed-schedule stimulus and then pausing. Finally, Carlin (1998) reported typical rich-to-lean effects on PRP as a function of reinforcement magnitude under FI schedules in pigeons. When provided the opportunity to escape, however, the pigeons rarely did so in any of the transitions. Taken together, the present data and those reviewed above suggest that variables controlling the PRP and those controlling other measures typically thought to reflect aversive aspects of intermittent schedules (e.g., escape, attack) may overlap, but are not isomorphic.

For all pigeons, attacks per interval typically increased monotonically as a function of the FI. This effect occurred for all of the transition types, with the possible exception of the lean-to-lean and rich-to-lean transitions for 7120. Although there has been considerable debate as to the fundamental relation between inter-reinforcement interval and schedule-induced behavior (e.g., Falk, 1971, 1977; Killeen et al., 1978; Staddon, 1977), a common finding is a bitonic (increasing then decreasing) relation, particularly under time-based schedules. It is important to note, however, that the particular form of the function obtained is highly dependent on the particular method used to measure schedule-induced activity (see Allen, Sicignano, Webbe, & Malagodi, 1981). For example, had the data in Figure 6 been presented as a rate of attack (e.g., attacks per minute), rather than attacks per interval, the functions would have been bitonic, as a result of an increase in the denominator as the FI increased. It also is important to note, however, that presenting the present data as rate of attack would not have altered the relative levels of attack across the different transition types at any given FI.

A few limitations in the present experiment must be acknowledged. Although the FI conditions were studied in different orders across the subjects, a relocation of the laboratory necessitated termination of the experiment before the pigeons could be re-exposed to one or more of the FI conditions. Also, rich-to-lean effects were obtained with two of the three pigeons (7120 and 9978, but not 8534), and these effects diminished or disappeared as a function of the FI. Therefore, an examination of FIs of less than 1 min in 8534 might have revealed rich-to-lean effects.

Finally, the approach taken here is consistent with the notion that behavior labeled *social* is fundamentally similar to nonsocial behavior (e.g., Skinner, 1953; see also Ackerman & Lattal, 2019, *this issue*). In this view, although social behavior involves interaction with other organisms and, thus, the actions of those others must be considered, an account of social behavior does not require reference to new types of controlling variables. The present experiment attempted to identify variables that control aggression against another organism, and, as such, these data are relevant to social behavior. As Skinner (1957) noted, however, when controlling variables involve the actions of others, the dynamics involved is such that the resulting behavior patterns may display complexities not typically present in nonsocial behavior. Whether this reflects quantitative or qualitative differences (or both) between social and nonsocial behavior is unclear, but it could be argued that the type of aggressive behavior studied here is, at best, only distantly related to the types of social aggression illustrated in human interactions (but see Chichinadze, Chichinadze, & Lazarashvili, 2011). Contingencies associated with attack itself were not directly manipulated in this experiment and, thus, effects of variables on scheduled-induced behavior that could be considered essentially social (e.g., the reactions of the aggressee; see Sakuma & Moriyama, 2019, *this issue*) remain to be characterized fully. As noted by Williams et al. (2019), however, attacks toward a mirror were less robust than is typical with live targets (also see Cohen & Looney, 1973; Looney, Cohen, & Yoburn, 1976). This could be a function of the lack of defensive responding shown by live targets. Nevertheless, in their comparative review, Frederiksen and Peterson (1977) noted that the characteristics of schedule-induced aggression, and the effects of a variety of parametric manipulations, are remarkably similar in human and nonhuman studies. Furthermore, Williams (2015) noted that a variety of behavior problems (including aggression) in individuals with autism occur during transitional periods, particularly those associated with rich-to-lean conditions. Perhaps the data presented here, along with those from other studies of schedule-induced aggression, are not so distantly related to human social behavior after all.

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