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Pigeons' (*Columba livia*) Intertemporal Choice in Binary-Choice and Patch-Leaving Contexts

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Typical approaches to study self-control present subjects with a simultaneous choice between a larger-later (LL) reinforcer and a smaller-sooner (SS) reinforcer. In contrast, in patch-leaving tasks, subjects choose between staying at a patch for an SS (or LL) reinforcer and leaving for an LL (or SS) reinforcer. Previous studies show that blue jays, monkeys, humans, and rats prefer the SS reinforcer in binary-choice tasks, whereas the same subjects prefer the LL reinforcer in equivalent patch-leaving tasks. The current study systematically replicated this research using pigeons. Six pigeons responded in a binary-choice task and in two patch-leaving tasks in which staying led to an LL (Patch-L) or SS (Patch-S) reinforcer. Across conditions, the SS reinforcer delay varied from 5 to 55 s; the LL reinforcer delay was always 60 s. In binary-choice conditions, subjects preferred the SS reinforcer. In Patch-L and Patch-S conditions, subjects preferred the LL and SS reinforcer, respectively, reflecting a bias to stay at the patch. This bias persisted when the stay response was more effortful and when the delays to both reinforcers were equal. This may reflect a species-specific win-stay bias and the differential consequences of staying (which led to a stimulus signaling food) versus leaving (which led to a stimulus never associated with food). Thus, we propose a conditioned-reinforcement account of intertemporal choice in patch-leaving contexts. We suggest several avenues for further investigations of the mechanisms underlying intertemporal choice in different contexts and question the economic equivalence of the operant and patch-leaving procedures.

Keywords: intertemporal choice, self-control, patch leaving, win-stay bias, pigeon

Humans and nonhuman animals are often faced with intertemporal choice scenarios, in which they must weigh the costs of waiting against the benefits of a larger (but delayed) outcome. For example, a human might compare the long-term benefits of waking up early to exercise with the immediate gratification of sleeping in; a foraging animal must decide whether to travel to a patch that may yield a larger prey item in the future or to continue depleting their current patch. Under such conditions, organisms may exhibit self-control, defined as choosing the larger-later (LL) outcome, or they may behave impulsively and forego the benefits of the larger delayed outcome in favor of the smaller-sooner (SS) outcome (G. W. Ainslie, 1974; see Odum, 2011; Odum et al., 2020, for reviews). In general, organisms prefer the LL reinforcer when the delays to both reinforcers are longer overall, and the SS reinforcer at shorter delays (e.g., G. W. Ainslie & Herrnstein, 1981; Green & Estle, 2003; Green et al., 1981, 1994; Kirby & Herrnstein, 1995; Rachlin & Green, 1972). This reversal in preference from the self-controlled to the impulsive choice is thought to reflect the impact of delays on subjective reinforcer value: While the subjective value of an LL reinforcer is higher than that of an SS reinforcer when both reinforcers are delayed, their subjective values decrease over time and eventually reverse, resulting in greater impulsivity at shorter delays. Such delay discounting appears to be relatively ubiquitous across species (Odum et al., 2020; Vanderveldt et al., 2016) and may play a role in addiction (e.g., gambling, substance abuse, smoking; Bickel et al., 2012, 2019; Daugherty & Brase, 2010; Rung et al., 2019; Stein & Madden, 2013; Strickland et al., 2021) and in risky or deviant behavior (e.g., Arantes et al., 2013; Mishra & Lalumière, 2017; Weinsztok et al., 2021). Thus, elucidating the mechanisms that underlie intertemporal decision making has important implications across a range of domains (e.g., physical and mental health, finance, academic or workplace performance).

Studies examining the variables that impact intertemporal choice patterns have often focused on reinforcer delays and magnitudes (see

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Rung & Madden, 2018, for an overview). Because self-control is generally greater when reinforcer delays are longer, manipulations that increase the time to reinforcer delivery can increase self-control. For example, preference for the LL reinforcer is stronger when a common delay is added to the SS and LL alternatives, or when a larger number of responses is required in order to choose an alternative (G. W. Ainslie & Herrnstein, 1981; Fortes et al., 2015; Huskinson & Anderson, 2013; Mazur, 2012; Siegel & Rachlin, 1995). Likewise, when subjects can "precommit" to the LL alternative, thereby removing the opportunity to switch to the SS alternative later on, self-control is stronger (Rachlin & Green, 1972; Siegel & Rachlin, 1995). Greater exposure to reinforcer delays, or gradually (rather than suddenly) introducing delayed reinforcers (e.g., systematically increasing the LL delay), can also help increase self-control (Logue & Mazur, 1981; Mazur & Logue, 1978; Schweitzer & Sulzer-Azaroff, 1988). Manipulations that target reinforcer magnitude also impact self-control: Preference for the LL alternative is stronger when it is larger in size (e.g., $1,000 rather than $100; Grace et al., 2012; Green et al., 2013; Johnson & Bickel, 2002; Weatherly & Terrell, 2014) and when choice in the current trial determines the outcome in a subsequent number of trials too (reward bundling; e.g., choosing the LL alternative means that the next three trials will also deliver the LL reinforcer; G. Ainslie & Monterosso, 2003; Kirby & Guastello, 2001).

One procedural variable that has received considerably less attention in the intertemporal choice literature is the overall structure of the choice task itself. The standard procedure for studying intertemporal choice involves presenting subjects with two simultaneously available alternatives, one that leads to an SS reinforcer and the other to an LL reinforcer. Some evidence suggests that patterns of choice differ in such a binary-choice procedure compared with when the choice is presented within a sequential-choice framework. Figure 1A and 1B depicts examples of these two different procedures (Stephens & Anderson, 2001). In Figure 1A, choice of the SS alternative leads to two reinforcer deliveries after a delay of 5, 30, or 55 s, and choice of the LL alternative leads to four reinforcer deliveries after a delay of 60 s. The reinforcer delivery is followed by an intertrial interval (ITI) which may be fixed in length (as in Figure 1A) or vary between trials such that the total duration of a trial is always the same.[1] In Figure 1B (the "Patch-L" procedure), subjects' visit to a "patch" is followed by two reinforcer deliveries after 5, 30, or 55 s (i.e., the SS reinforcer), after which subjects choose between staying at or leaving the patch. If subjects choose to stay, they obtain another two reinforcers after a delay of 60 s minus the length of the first delay (i.e., 55, 30, or 5 s, respectively); hence, staying results in a total of four reinforcers after a total delay of 60 s—much like choosing the LL alternative in the binary-choice procedure. In contrast, if subjects choose to leave, the consequences are similar to choosing the SS alternative.

Stephens and Anderson (2001) were the first to compare intertemporal choice in the binary-choice and Patch-L tasks (Figure 1A and 1B). In their experiment, blue jays chose between two food pellets delivered after 5 or 50 s (SS reinforcer) and four pellets delivered after 60 or 90 s (LL reinforcer). The ITI lasted for either 30, 60, or 90 s in different conditions. Compared with the binary-choice task, blue jays more strongly preferred the LL reinforcer, particularly when the SS delay was longer, and choice appeared to shift toward the LL alternative more readily as the ITI duration increased in the Patch-L task. In replications of this study, Carter et al. (2015) found that people also preferred the LL alternative more strongly in the Patch-L task than in its binary-choice equivalent (but see also Seinstra et al., 2018, for no differences between tasks in humans), and Carter and Redish (2016) showed that rats tolerated longer delays to the larger reinforcer (implying greater self-control) in the Patch-L task compared with the binary-choice task. Thus, despite the purported economic equivalence between the binary-choice and Patch-L tasks, blue jays, rats, and humans appear to behave differently in the two tasks.

Although Stephens and Anderson (2001) suggested that the binary-choice and Patch-L tasks are economically equivalent, the contingencies at the choice point (i.e., the point at which subjects choose an alternative) differ between tasks. Most obviously, whereas subjects choose between two (SS) and four (LL) reinforcers in the binary-choice task, they effectively choose between two (leave) and two (stay) reinforcers in the Patch-L task (see Figure 1A and 1B). Stephens and McLinn (2003) arranged another patch-leaving task, the "Patch-S" variant (Figure 1C), in which the contingencies at the choice point were the same as in the binary-choice task. In the Patch-S task, blue jays first obtained the LL reinforcer, and then chose between staying for the SS reinforcer or leaving to end the trial (equivalent to choosing the LL reinforcer). To ensure that the delay to the LL reinforcer equaled 60 s, the ITI formed part of the 60-s delay. Thus, at the choice point, subjects chose between two reinforcer deliveries after a shorter delay and four reinforcers after a 60-s delay. Despite arranging the same contingencies at the choice point, subjects were much more self-controlled in the Patch-S task than the binary-choice task. Additionally, in support of the view that choice in the Patch-S task was controlled by total reinforcer delays, varying the relative lengths of the ITI and first delay while holding their combined duration (60 s) constant did not alter preference for the LL reinforcer. Collectively, these findings suggest that subjects make better choices—in the sense that they prefer the alternative that maximizes reinforcement—in patch-leaving tasks compared with binary-choice tasks (the patch effect; T. C. Blanchard & Hayden, 2015; Hayden, 2016; Stephens & Dunlap, 2009). This suggestion depends on the assumption that the procedures are economically equivalent (an assumption we will return to later on).

The patch effect is important because it suggests that reframing choices within a stay/leave framework may increase self-control and thereby reduce the potential negative consequences associated with impulsivity in humans (e.g., addiction; Carter et al., 2015). To explain the discrepancy between choice in binary-choice and patch-leaving tasks, some researchers suggest that natural selection has favored decision-making mechanisms that fare well in sequential-choice scenarios because these reflect animals' natural habitats. In contrast, the same mechanisms may fail to maximize reinforcement in binary-choice situations because such situations are dissimilar from those an animal experiences in the wild (T. C. Blanchard & Hayden, 2015; Fawcett et al., 2012; Hayden,

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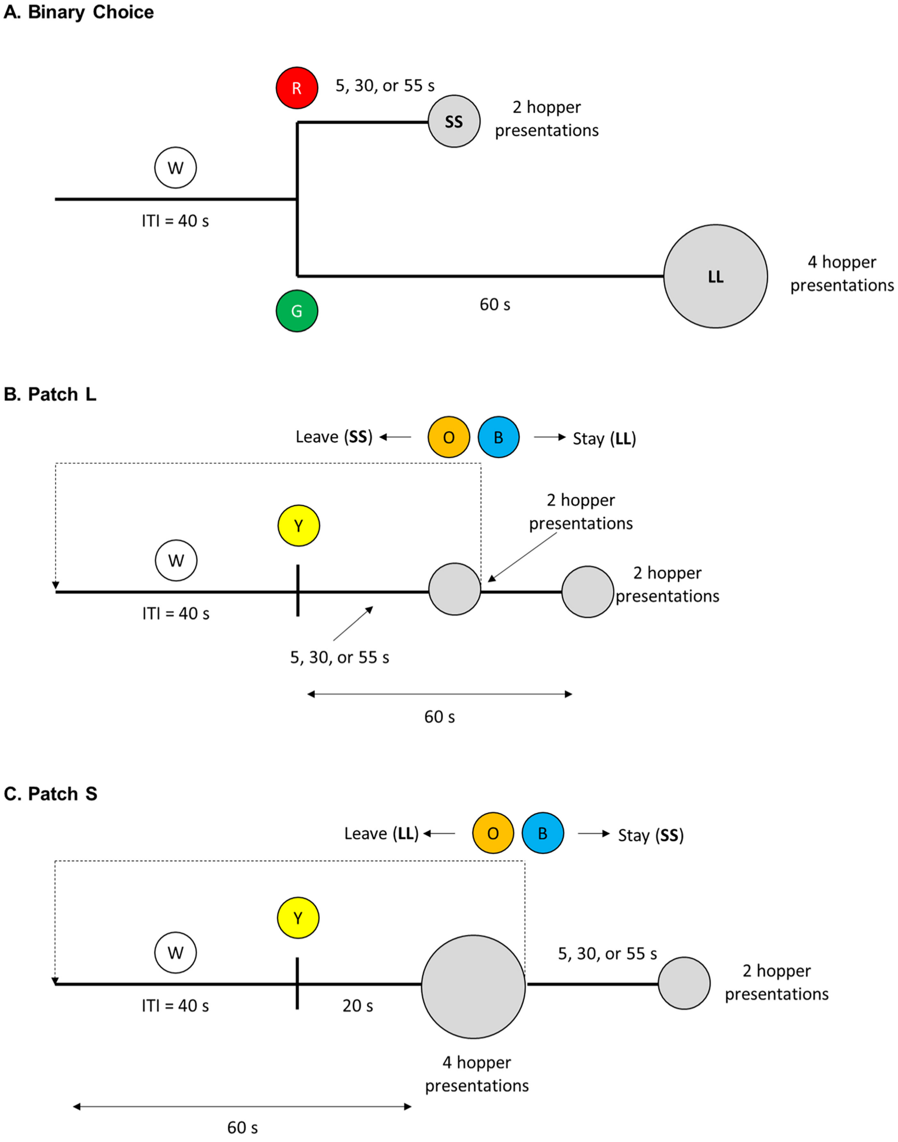
[1] Studies comparing intertemporal choice in the binary-choice and patch-leaving tasks depicted in Figure 1 arrange fixed-length ITIs. The current study, which replicated prior work in this area, also arranged fixed-length ITIs. The astute reader may notice that fixed-length ITIs mean that the choice maximizing reinforcement is not always the LL alternative. To remain consistent with the literature in this area, we will refer to the LL choice as "self-controlled" and the SS choice as "impulsive" here. We will return to the issue of ITI length and the definition of "self-control" in the Discussion section.

Figure 1

Trial Structure in the Binary-Choice (A), Patch-L (B), and Patch-S (C) Procedures



Note. In all panels, the SS reinforcer is two hopper presentations after 5, 30, or 55 s, and the LL reinforcer is four hopper presentations after 60 s. The responses corresponding to the SS and LL alternatives are labeled in the Patch-L and Patch-S diagrams. Labeled circles indicate key colors in the present experiment. W = white; R = red; SS = smaller-sooner; ITI = intertrial interval; G = green; LL = larger-later; O = orange; B = blue; Y = yellow. See the online article for the color version of this figure.

2016; Stephens, 2008; Stephens & Anderson, 2001; Stephens & Dunlap, 2009; Stephens & McLinn, 2003; Stevens & Stephens, 2010). However, the specific mechanism or decision rule is presently unclear (Stephens & Dunlap, 2009), and current intertemporal choice models—such as the popular hyperbolic discounting model, which predicts that the subjective value of a reinforcer declines with increasing delay to its receipt (Mazur, 1987)—fail to describe choice in both tasks (T. C. Blanchard & Hayden, 2015; Carter et al., 2015; Carter & Redish, 2016; see Hayden, 2016, for a brief review). Hence, some researchers have also considered the possibility that different decision-making mechanisms operate in the two procedures, giving rise to different patterns of behavior, although what those different mechanisms are also remains unclear (e.g., Carter et al., 2015). Nevertheless, regardless of whether the same or different mechanisms underlie choice in different intertemporal choice tasks, the implication of these perspectives is that behavior in one procedure (e.g., binary choice) does not necessarily predict how subjects will behave in other intertemporal choice scenarios (Hayden, 2016).

At present, research comparing intertemporal choice in binary-choice and patch-leaving tasks (Figure 1) is limited. Only four species (blue jays, rats, monkeys, and humans) have been tested, and only one of these (blue jays) in the Patch-S procedure. The dearth of research in this area means that the replicability and generality of the patch effect are currently not well established. More specifically, it is unclear to what extent previous findings reflect greater self-control per se in patch-leaving tasks versus other species-specific characteristics that may have influenced choice. Indeed, evolutionary or physiological differences have been shown to impact intertemporal choice (see Vanderveldt et al., 2016, for discussion); for example, species with higher metabolic rates (e.g., pigeons) choose more impulsively in the binary-choice procedure than those with lower metabolic rates (e.g., rats or humans; Tobin & Logue, 1994). Likewise, because patch-leaving tasks involve a decision to stay or leave, choice may reflect win-stay or win-shift biases. Blue jays, a food-caching species, store and retrieve food items from multiple locations (Brodin, 2005; Morris, 1962; Scarlett & Smith, 1991) and hence may be more likely to choose to leave the patch than non-food-caching species. As a result, blue jays' strong preference for the LL alternative in Stephens and Mclinn's (2003) Patch-S procedure may have reflected a win-shift bias, and such "self-control" may be less apparent in a different species. Growing evidence also demonstrates differences in sensitivity to reinforcer contingencies between species, resulting in some species (e.g., rats) choosing more optimally than others (e.g., pigeons) in identical procedures (e.g., Trujano & Orduña, 2015).

Therefore, greater self-control in patch-leaving tasks relative to binary-choice tasks may not necessarily be the rule across all species. To be sure, further investigations comparing intertemporal choice across these tasks in different species are required. To that end, in the present experiment we asked whether pigeons (*Columba livia*) would exhibit greater self-control in patch-leaving tasks than in binary-choice tasks. This is an important question because much of the research on intertemporal choice has used pigeons as subjects in the binary-choice task. Hence, our experiment provides insight into the extent to which knowledge gained from such research can be generalized to other intertemporal choice tasks. Additionally, pigeons have been consistently shown to choose more impulsively than other species (rats, humans, monkeys; Vanderveldt et al., 2016) in binary-choice procedures. Thus, the present experiment serves as a test of whether an apparently strongly impulsive species can demonstrate self-control in patch-leaving tasks.

The present experiment arranged a systematic replication of Stephens and McLinn (2003). Here, six pigeons responded in the binary-choice, Patch-L, and Patch-S procedures depicted in Figure 1. Unlike previous studies, in which subjects physically moved to and from the patch in the Patch-L and Patch-S procedures, our pigeons pecked a lit key to "visit" the patch, and then pecked "stay" or "leave" keys, each illuminated a different color, to stay or leave the patch. This made the response requirements in the patch-leaving tasks identical to the binary-choice procedure and closely resembles the response topographies in previous research on self-control. To examine the effects of reinforcer delay on choice, the delay to the SS reinforcer (which was two food deliveries) varied from 5 to 55 s across conditions, whereas the delay to the LL reinforcer (four reinforcer deliveries) remained fixed at 60 s. Overall, this procedure allowed us to assess the replicability and generality of the patch effect with a different species (pigeons) and operant response (pecking) than previous research.

Method

Standards for Transparency and Openness

We report how we determined our sample size, all data exclusions (if any), all manipulations, and all measures in the study. All data and analysis code for this study are available upon request from the corresponding author. The study's design and its analyses were not preregistered.

Subjects

Six pigeons, numbered 231–236, served as subjects. Pigeons were maintained at 85% ± 15 g of free-feeding body weight by supplementary feeding of mixed grain about 30 min after experimental sessions. Pigeons were housed in a colony room in a time-shifted environment (lights on at 12 a.m., off at 4 p.m. daily). Water and grit were freely available. All pigeons had previous experience in various operant experiments. Our sample size was based on previous research (e.g., Stephens & McLinn, 2003).

Apparatus

Experimental sessions were conducted in three experimental chambers, which were separate from the pigeons' home cages and were placed inside separate sound-attenuating and light-proof boxes. Each chamber measured 300 mm high, 250 mm wide, and 295 mm deep. A houselight, which was illuminated during experimental sessions, was mounted on the center-top of the left wall of each chamber. The operant response panel was mounted on the right wall, 190 mm above the cage floor, and contained one row of three MED-PC® ENV-131 response keys. Response keys were 25 mm in diameter and were centered 60 mm apart. The center key could be lit orange or white, and the left and right keys could be lit red, green, orange, yellow, or blue. Additionally, white vertical lines could be superimposed on each color on the left and right keys. Responses exceeding 0.1 N to illuminated keys were recorded. Below the response keys, centered on the wall and 40 mm above the floor, was a magazine aperture measuring 50 mm high, 70 mm wide, and 50 mm deep. A hopper filled with wheat was located behind the magazine aperture. When a reinforcer was delivered, the key lights were turned off, the hopper was raised for 4 s, and the magazine aperture was illuminated. A computer running MED-PC® IV software ran the experiment and recorded all experimental events.

Procedure

All procedures were conducted under Approval 2657, granted by the University of Auckland Animal Ethics Committee.

Because only three experimental chambers were available, the pigeons were split into two groups, one consisting of Pigeons 231–233 (Group 1) and the other consisting of Pigeons 234–236 (Group 2). Group 1 pigeons were tested first at about 12 p.m. each weekday, followed by Group 2 pigeons. Experimental sessions lasted for an hour or 50 trials, whichever occurred first.

Table 1 shows the order of conditions for each group of pigeons. Conditions lasted for 15 sessions each. In each condition, the pigeons chose between an SS and an LL reinforcer in either the binary-choice, Patch-L, or Patch-S procedure (see Figure 1). The SS reinforcer was two hopper presentations delivered after a delay of 5, 30, or 55 s. The LL reinforcer was always four hopper presentations delivered after a delay of 60 s. Successive hopper presentations were separated by a 1.5-s delay to allow the hopper to refill. Reinforcers were delivered following the first peck that occurred after the respective delay had elapsed (i.e., according to a fixed-interval schedule). All trials began with a 40-s ITI, during which the center key was lit white. Pecks to the center key were recorded, but had no consequence, during the ITI.

To ensure that the pigeons had experience with both alternatives, 40% of trials in each session—split evenly between the SS and LL (in the binary-choice procedure) or stay and leave (in the Patch-L and Patch-S procedures) alternatives—were forced-choice trials, in which only one alternative was presented. Pecks to this alternative produced the respective consequence, whereas pecks to the other alternative had no effect. The remaining trials were free-choice trials, in which both alternatives were available. Trial order was randomized, with the exception that the first four trials in each session were always forced-choice trials (two SS, two LL trials in random order).

Binary-Choice Conditions

All pigeons completed binary-choice conditions first (Conditions 1–3; Table 1). Figure 1A shows a typical trial. After the ITI, the center key was extinguished, and the left and right keys were illuminated (or just one key, in forced-choice trials) to signal the start of a trial. One key was lit red and the other was lit green, and the location of these colors was counterbalanced across trials. For Group 1 pigeons, red led to the SS reinforcer and green led to the LL reinforcer. The reverse was arranged for Group 2 pigeons. After a peck to one of the side keys, a white vertical line was superimposed on that key and the other key was extinguished, signaling the start of the delay associated with that alternative. Trials ended after the reinforcer delivery.

Patch-L Conditions

Group 1 pigeons completed Patch-L conditions in Conditions 4–6, whereas Group 2 pigeons completed Patch-L conditions in Conditions 7–9 (Table 1). Due to a programming error in Condition 4 for Group 1 pigeons, this condition was rerun in Condition 11, and data from Condition 4 for Group 1 pigeons were excluded from the experiment.

Figure 1B shows a typical trial in Patch-L conditions, in which the pigeons chose between staying or leaving a patch. Trials began with the left or right key (chosen randomly, with $p = .50$) lit yellow to represent the patch (hereafter, patch key). The pigeons "visited" the patch by pecking the patch key, after which a white vertical line was superimposed on that key to signal the start of the delay to the SS reinforcer. After the delivery of the SS reinforcer, both side keys were illuminated (or one side key, in forced-choice trials). For Group 1 pigeons, the patch key was lit orange and the other key was lit blue; the reverse was arranged for Group 2 pigeons. A peck to the patch key (i.e., orange for Group 1 pigeons, blue for Group 2 pigeons) constituted a "stay" response, whereas a peck to the other key constituted a "leave" response.

After a stay response, a white vertical line was superimposed on the patch key, signaling the start of a second delay. In free-choice trials, the other key remained lit during the delay; hence, the pigeons could choose to leave the patch at any time. The duration of the second delay varied between conditions, such that the total delay from the start of the patch visit to the second reinforcer delivery equaled 60 s (i.e., the second delay was 60 s minus the length of the first delay; see Figure 1B). For example, if the delay to the SS reinforcer was 5 s, then the second delay was 55 s. The second delay was followed by two hopper presentations. Thus, staying at the patch resulted in a total of four reinforcer deliveries over a total delay of 60 s. After a leave response, the side keys were extinguished and the trial ended.

Patch-S Conditions

Group 1 pigeons completed Patch-S conditions in Conditions 7–9, whereas Group 2 pigeons completed Patch-S conditions in Conditions 4–6 (Table 1). Patch-S conditions were similar to Patch-L conditions, except that the LL reinforcer was delivered first. Figure 1C shows a

Table 1
Sequence of Conditions

	Group 1 pigeons		Group 2 pigeons	
Condition	Procedure	SS delay (s)	Procedure	SS delay (s)
1	Binary choice	5	Binary choice	30
2	Binary choice	55	Binary choice	5
3	Binary choice	30	Binary choice	55
4	Patch-L	55[a]	Patch-S	30
5	Patch-L	5	Patch-S	55
6	Patch-L	30	Patch-S	5
7	Patch-S	5	Patch-L	30
8	Patch-S	55	Patch-L	5
9	Patch-S	30	Patch-L	55
10	Patch-S	60	Patch-S	60
11	Patch-L	55[a]		
12	Patch-S (half-incongruent)	30	Patch-S (half-incongruent)	30
13	Patch-S (half-incongruent)	5	Patch-S (half-incongruent)	5
14	Patch-S (half-incongruent)	55	Patch-S (half-incongruent)	55
15	Patch-S (half-incongruent)	60	Patch-S (half-incongruent)	60

Note. The order of conditions differed between groups of pigeons. "Half-incongruent" (Conditions 12–15) indicates that half of trials were congruent and the other half were incongruent. SS = smaller-sooner.
[a] Due to a programming error in Condition 4 for Group 1 pigeons, we reran this condition for Group 1 in Condition 11, and data from Condition 4 were excluded from the experiment.

typical Patch-S trial. The patch key was lit yellow, and a peck to this key was followed by the first delay and then the delivery of the LL reinforcer. The first delay was always 20 s long, such that the total delay from the start of the ITI to the first reinforcer delivery was 60 s. After the LL reinforcer, both side keys were illuminated (or one side key, in forced-choice trials) as in Patch-L conditions. A stay response was followed by the SS reinforcer delivery, whereas a leave response ended the trial. In addition to conditions in which the SS reinforcer delay was 5, 30, or 55 s, we also ran one condition (Condition 10) in which the delay to the SS reinforcer was 60 s (i.e., the delays to both reinforcers were equal).

Additional Patch-S Conditions (Half-Incongruent Conditions)

To gain further insight into the variables controlling choice in Patch-S conditions, we ran four additional Patch-S conditions (Conditions 12–15). In these conditions, we varied the locations of the stay and leave alternatives. Half of the trials were congruent trials, in which the stay alternative was at the same location as the patch key (i.e., as in previous Patch-S conditions). The other half of the trials were incongruent trials, in which the stay alternative was on the other key. That is, after the LL reinforcer, the patch key was lit blue for Group 1 pigeons and orange for Group 2 pigeons, and a peck to the patch key now constituted a leave response. The other key became the patch key, and it was lit orange or blue for Group 1 or 2 pigeons, respectively, and a peck to this key constituted a stay response. Thus, in incongruent trials, the colors associated with the stay and leave alternatives remained unchanged from earlier conditions, but the pigeons had to switch to the other key in order to stay at the patch.

Data Analysis

For Pigeon 235 in Condition 8 (Patch-L condition, 5 s delay to SS reinforcer), data from the last two sessions were unavailable due to an equipment issue. For Pigeon 233 in Condition 10 (Patch-S condition, 60 s delay to SS reinforcer), data from the 11th session were unavailable due to an equipment issue. Besides this, data were available for all six pigeons in all other sessions and conditions. We assessed stability by visual inspection of daily choice data; choice stabilized quickly (see Figure 2), typically within the first five sessions of each condition.

Choice

Responses to the SS and LL alternatives (binary-choice conditions) or to the stay and leave alternatives (Patch-L and Patch-S conditions) in free-choice trials were aggregated together. Stay and leave responses in Patch-L conditions were recoded as LL and SS responses, respectively, because staying at the patch was equivalent to choosing the LL alternative and leaving was equivalent to choosing the SS alternative in these conditions (see Figure 1). The reverse was true for Patch-S conditions, hence, stay and leave responses were recoded as SS and LL responses, respectively, for Patch-S conditions. We then used these response counts to calculate the proportion of LL responses in each condition.

Response Latencies and Patch-Leaving Behavior

We calculated latencies to choose an alternative by subtracting the time at which the choice alternatives were illuminated from the time at which the first response was made. Because few responses of a particular type were made in some conditions (e.g., no leave responses were emitted in the Patch-S condition with a 5-s delay to the SS reinforcer), we analyzed response latencies in both free- and forced-choice trials, and combined data across pigeons for latency analyses.

In Patch-L and Patch-S conditions, the leave alternative remained illuminated during the second delay in free-choice trials. Hence, an initial stay response could later be followed by a leave response. Analyses of response latencies only considered the time to the first response; hence, any leave responses that occurred later were not included in latency analyses. Thus, to examine when the pigeons were most likely to leave the patch, we aggregated data from free-choice trials in which a leave response occurred, and (a) counted the number of stay responses (hereafter, stay visit length) that occurred before the leave response and (b) calculated the time between the onset of the choice alternatives and the leave response.

Response Patterns

To examine patterns of responding during delays to reinforcers, responses to the chosen alternative (SS or LL) in binary-choice conditions, or to the patch key in Patch-L and Patch-S conditions, were aggregated into 1-s time bins. We then divided the number of responses in each bin by the number of times that bin was reached and multiplied this value by 60 to yield responses per minute. Preliminary analyses indicated that response patterns were similar in free- and forced-choice trials; thus, we combined data from free-choice and forced-choice trials for analyses of response patterns. This was because some pigeons infrequently chose one alternative in free-choice trials (due to a strong preference for the other alternative). Hence, combining data from free- and forced-choice trials ensured that enough data were available for each pigeon to reliably compare response patterns across time.

Results

Stability

Figure 2 shows the mean proportion of LL responses across successive blocks of three sessions in binary-choice, Patch-L, and Patch-S conditions. The patterns shown in Figure 2 are generally representative of the individual-pigeon data, although there were differences in the strength of preference for an alternative between pigeons (e.g., some pigeons preferred the SS alternative more strongly than others). In general, choice changed within the first few blocks of each condition before stabilizing by about the last two blocks. When there were changes in choice in the last few blocks of a condition, these tended to be relatively unsystematic and were typically due to one pigeon (rather than to a systematic change across most or all pigeons). Additionally, the proportion of LL responses within a condition tended to remain above or below .50, indicating that preference for a particular alternative was relatively stable. Therefore, all further analyses used data from the last five sessions of each condition.[2]

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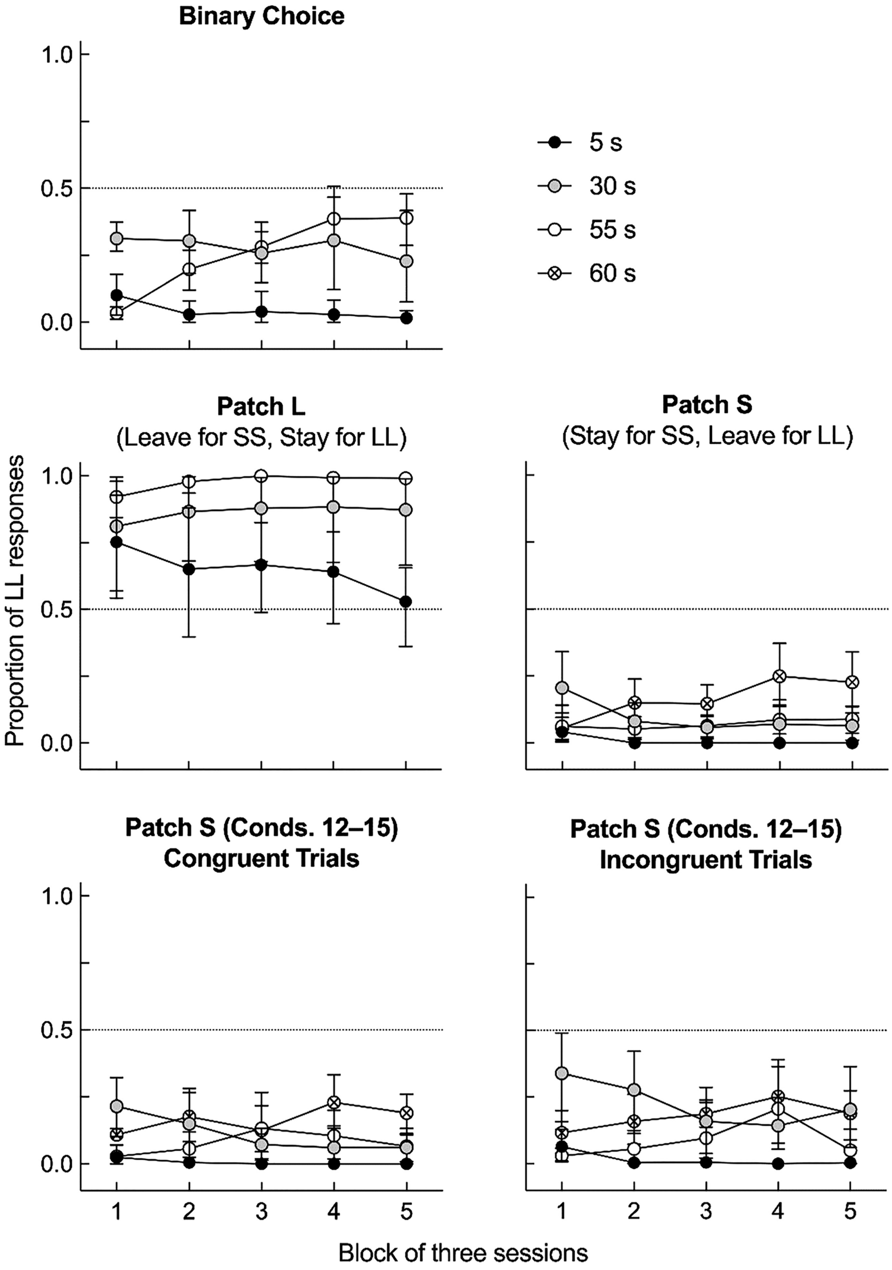
[2] Due to equipment issues, data from the last two sessions were unavailable for Pigeon 235 in Condition 8, and from the 11th session for Pigeon 233 in Condition 10. Because choice was stable across blocks in both these conditions (see Figure 2), we used the last five sessions with available data for steady-state analyses.

Figure 2
Mean Choice Across Blocks of Sessions



Note. Symbol shades/patterns represent the delay to the SS reinforcer −5 s (black), 30 s (gray), 55 s (solid white), and 60 s (white with a cross in the center). Data shown are averaged across pigeons, and error bars show bootstrapped 95% confidence intervals. SS = smaller-sooner; LL = larger-later; Conds. = conditions.

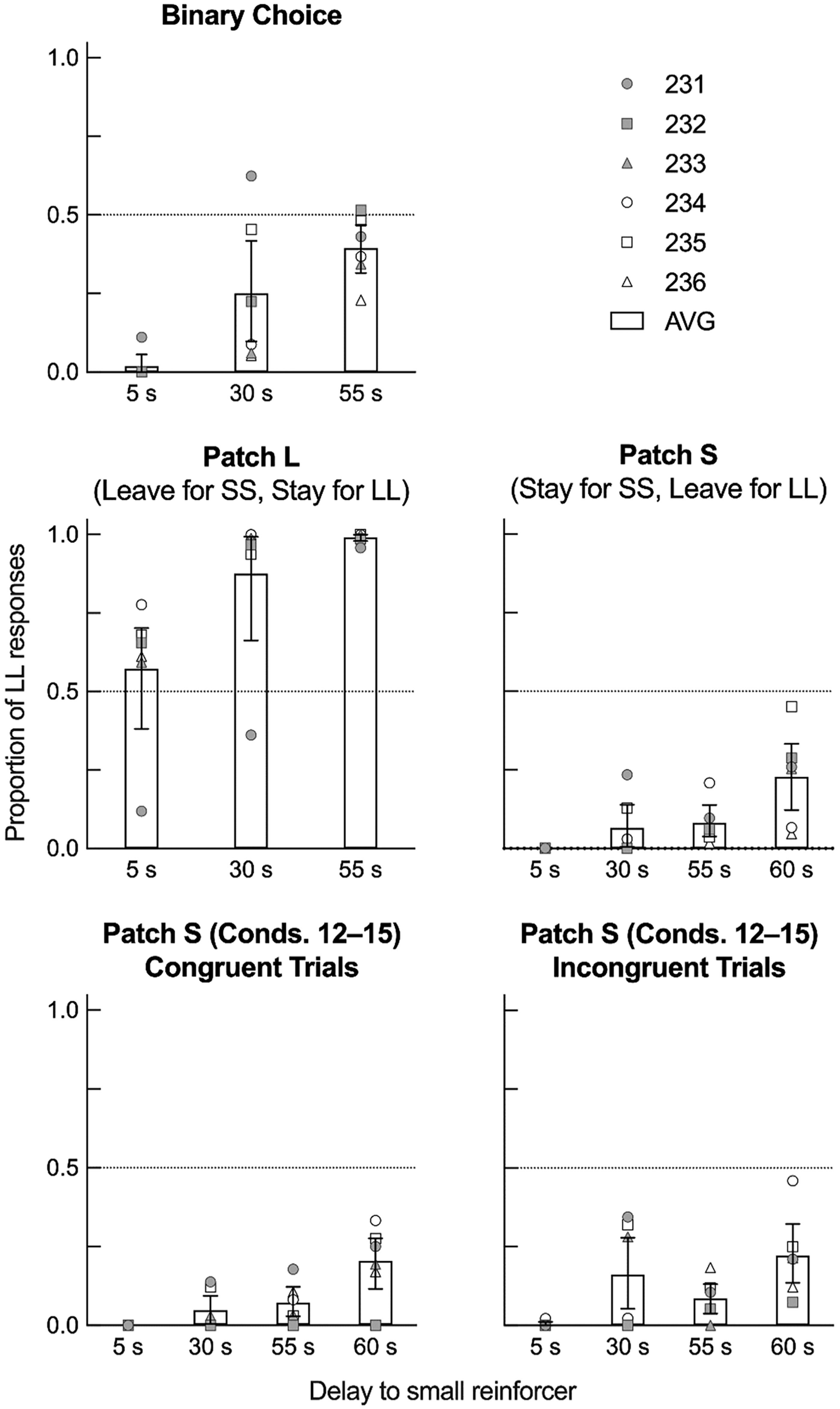
Steady-State Choice

Figure 3 shows individual (data points) and mean (bars) proportion of LL responses as a function of the delay to the SS reinforcer in the last five sessions of each condition. Preference varied depending on the procedure, and on the delay to the SS reinforcer. A repeated-measures ANOVA with procedure (binary-choice, Patch-L, Patch-S, Patch-S congruent trials, and Patch-S incongruent trials) and delay (5, 30, and 55 s) as within-subjects factors indicated significant main effects of procedure, $F(1.27, 6.32) = 55.36$, $p < .001$, $\eta_p^2 = .92$; delay, $F(1.27, 6.33) = 40.27$, $p < .001$, $\eta_p^2 = .89$; a significant Procedure × Delay interaction, $F(8, 40) = 8.74$, $p < .001$, $\eta_p^2 = .64$.

In binary-choice conditions, choice favored the SS alternative, and the strength of such preference depended on the delay to the

Figure 3

Steady-State Choice



Note. Symbols show data from individual pigeons, and error bars show the mean (± bootstrapped 95% confidence intervals). AVG = average; SS = smaller-sooner; LL = larger-later; Conds. = conditions.

SS reinforcer (Figure 3). Preference almost exclusively favored the SS alternative when the delay to the SS reinforcer was 5 s and became gradually less extreme—although still in favor of the SS alternative—as the delay increased. A one-tailed nonparametric trend test (Elliffe & Elliffe, 2019; Kendall, 1955) confirmed this trend in preference across delays ($\Sigma S = 14$, $p = .002$).

In Patch-L conditions, preference always favored the LL alternative (Figure 3), with one exception (Pigeon 231, for whom preference favored the SS alternative when the delay to the SS reinforcer was shorter). In contrast, preference strongly favored the SS alternative in Patch-S conditions. Despite these opposite preferences, choice shifted toward the LL alternative as the delay to the SS reinforcer increased in Patch-L and Patch-S conditions (one-tailed nonparametric trend tests: $\Sigma S = 16$ and 27 in Patch-L and Patch-S conditions respectively, both $p < .001$). This was also the case in Patch-S half-incongruent conditions (congruent trials: $\Sigma S = 26$, $p < .001$; incongruent trials: $\Sigma S = 19$, $p = .001$). The opposite preferences in Patch-L and Patch-S conditions indicate that the pigeons preferred to stay at the patch, regardless of whether this led to the LL (Patch-L conditions) or SS (Patch-S conditions) reinforcer, and regardless of whether the locations of the patch key and stay alternative were congruent or incongruent.

Response Latencies and Patch-Leaving Behavior

Figure 4 shows median (across pigeons) latencies to respond in free- and forced-choice trials. In binary-choice conditions, latencies were longer for the LL alternative than for the SS alternative, and SS-response latencies increased as the SS delay increased from 5 to 55 s. Similarly, in Patch-L and Patch-S conditions, latencies were generally longer when the reinforcer delay associated with the chosen alternative was longer. In forced-choice trials, latencies were longer when the available alternative was not the pigeons' preferred alternative; that is, latencies were longer in forced-choice trials with the LL alternative (binary-choice conditions) and when the pigeons were forced to leave the patch (Patch-L and Patch-S conditions).

The data shown in Figure 4 only consider the time to the first response in free-choice trials. In Patch-L and Patch-S conditions, the pigeons may have chosen to stay at the patch, and then later chosen to leave. To examine patch-leaving behavior more thoroughly, Figure 5 shows the frequency of stay visit lengths (the number of stay responses preceding a leave response) in free-choice trials in which a leave response was emitted. When a leave response occurred, it was most likely to occur immediately (i.e., almost all leave responses were not preceded by a stay response). Hence, although we also calculated the time between the onset of the choice alternatives and the leave response, these data are not presented here because they are much the same as the data shown in Figure 4. Thus, in summary, if the pigeons chose to stay at the patch, there were very few trials in which they later chose to leave.

Response Patterns

Finally, we examined patterns of responding during reinforcer delays. Figure 6 shows mean response rates (± 95% confidence intervals), expressed as a proportion of the maximum response rate, as a function of time since the start of the delay. Despite differences in preference for the SS and LL alternatives between binary-choice, Patch-L, and Patch-S conditions (Figure 3), response rates followed similar patterns in all conditions. Specifically, response rates increased throughout the reinforcer delay, reaching a maximum at about the time of the reinforcer delivery, and the response-rate increase was more rapid when the delay to the reinforcer was shorter.

Discussion

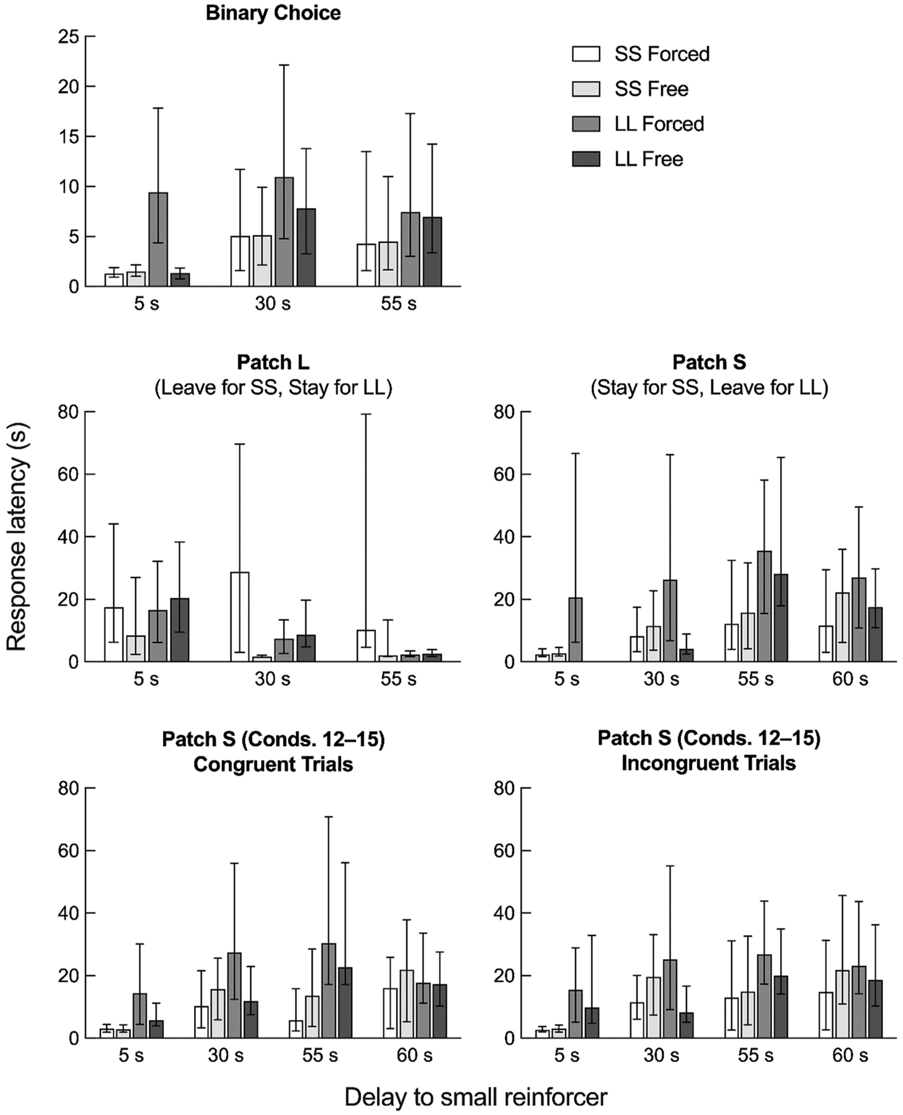
The present experiment compared pigeons' choice in the commonly used binary-choice self-control procedure, in which subjects choose between simultaneously available SS and LL alternatives, with choice in patch-leaving procedures, in which they choose between staying or leaving a patch (Figure 1). In the current Patch-L conditions, staying at the patch was equivalent to choosing the LL reinforcer and leaving the patch was equivalent to choosing the SS reinforcer, whereas the reverse was arranged in Patch-S conditions (see also Stephens & McLinn, 2003). Our main finding was that pigeons' choice differed between procedures (Figure 3): In binary-choice conditions, choice favored the SS alternative, whereas choice favored the LL and SS alternatives, respectively, in Patch-L and Patch-S conditions. The opposite preferences in Patch-L and Patch-S conditions reflected a strong bias to stay at the patch, and this bias persisted even when the locations of the stay alternative and patch key were incongruent, and when the delays to the SS and LL reinforcers were equal. These findings add to the evidence suggesting that choice in the operant procedure may not necessarily predict choice in other intertemporal choice procedures.

Much of the research comparing intertemporal choice between procedures has aimed to identify the rule(s) that govern choice across contexts. At present, no single rule appears to account for behavior in the binary-choice and patch-leaving tasks. The hyperbolic discounting model (Mazur, 1987) describes choice in the binary-choice procedure relatively well, but it cannot account for choice in patch-leaving tasks (T. C. Blanchard & Hayden, 2015; Carter & Redish, 2016; Stephens & Anderson, 2001). Stephens and Anderson (2001) proposed a "short-term rate" rule, which predicts that subjects choose based on the relative amount (A)-to-delay (D) ratios (i.e., A/D). In the binary-choice task, only the reinforcer delays are considered, resulting in impulsivity. In contrast, the ITI forms part of the reinforcer delays in the patch-leaving tasks (see Figure 1), and so subjects consider both the reinforcer delays and the ITI, resulting in self-control. However, support for this rule in both operant and patch-leaving tasks is limited; although Seinstra et al. (2018) found that the short-term rule accounted for choice in both tasks, others have found otherwise (e.g., Carter et al., 2015; Carter & Redish, 2016; Stephens & McLinn, 2003). Thus, most studies—including the present study—have found that subjects behave differently in different intertemporal choice contexts, and these behavioral differences are currently not captured by a single rule. Furthermore, our pigeons preferred the smaller reinforcer even when the delays to the SS and LL reinforcers were both 60 s in Patch-S conditions (Figure 3), suggesting that choice in patch-leaving tasks may not depend solely on reinforcer amounts and delays. This suggests that any common rule describing choice in intertemporal choice contexts should consider variables other than reinforcer amounts and delays.

Previous research has focused on comparing the binary-choice procedure with the Patch-L procedure. Such studies have found greater self-control and sensitivity to changes in reinforcer delays in the Patch-L task, leading to the conclusion that organisms behave

Figure 4

Median Response Latencies in Forced-Choice and Free-Choice Trials



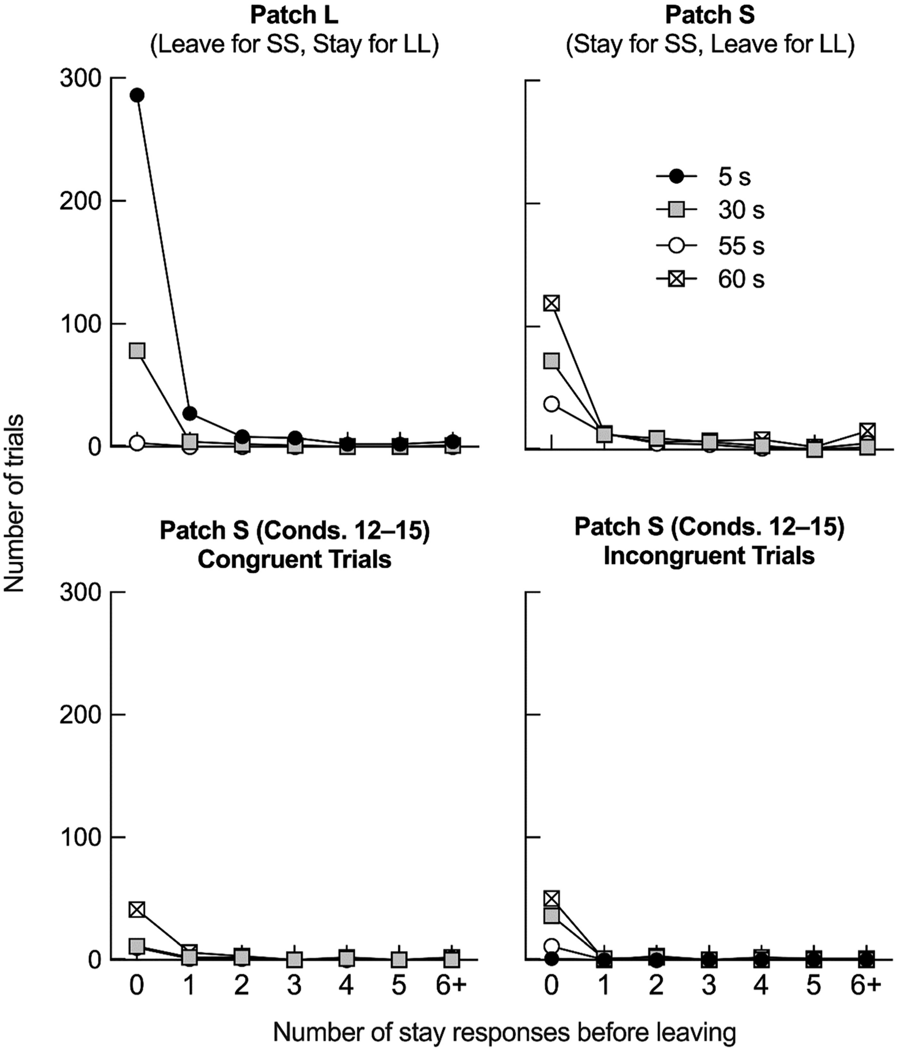
Note. Median latencies were calculated using data from all pigeons. Error bars show the interquartile range. SS = smaller-sooner; LL = larger-later; Conds. = conditions.

more optimally in patch-leaving tasks because such tasks better reflect intertemporal choice scenarios in natural environments (e.g., Carter et al., 2015; Carter & Redish, 2016; Stephens & Anderson, 2001; Stephens & Dunlap, 2009). Our findings call this conclusion into question—although our pigeons were indeed more self-controlled in Patch-L conditions compared with the binary-choice procedure, they were much less self-controlled in Patch-S conditions (Figure 3). Additionally, changes in the delay to the SS reinforcer had similar effects on choice in the binary-choice and Patch-L conditions, and smaller effects in Patch-S conditions, implying that temporal sensitivity was similar across procedures. Thus, it is not necessarily the case that organisms will behave more optimally in patch-leaving tasks. The present study highlights the importance of varying the contingencies arranged in patch-leaving tasks, in order to identify those conditions under which subjects behave more optimally versus those under which they do not.

Besides the current experiment, only one other study has compared choice in the binary-choice, Patch-L, and Patch-S procedures (Stephens & McLinn, 2003). In contrast to the present results, Stephens and McLinn (2003) found that blue jays' preference for the LL alternative was strongest in Patch-S conditions, whereas preference was similar—and tended to favor the SS alternative—in both binary-choice and Patch-L conditions. Furthermore, unlike our pigeons, Stephens and McLinn's blue jays did not display a bias to stay at the patch. Given the limited research in this area, it is unclear why our results differed from Stephens and McLinn's. There were, however, two notable procedural differences between the studies. First, Stephens and McLinn's blue jays physically

Figure 5

Number of Trials in Which a Leave Response Was Preceded by 0 to 6+ Stay Responses



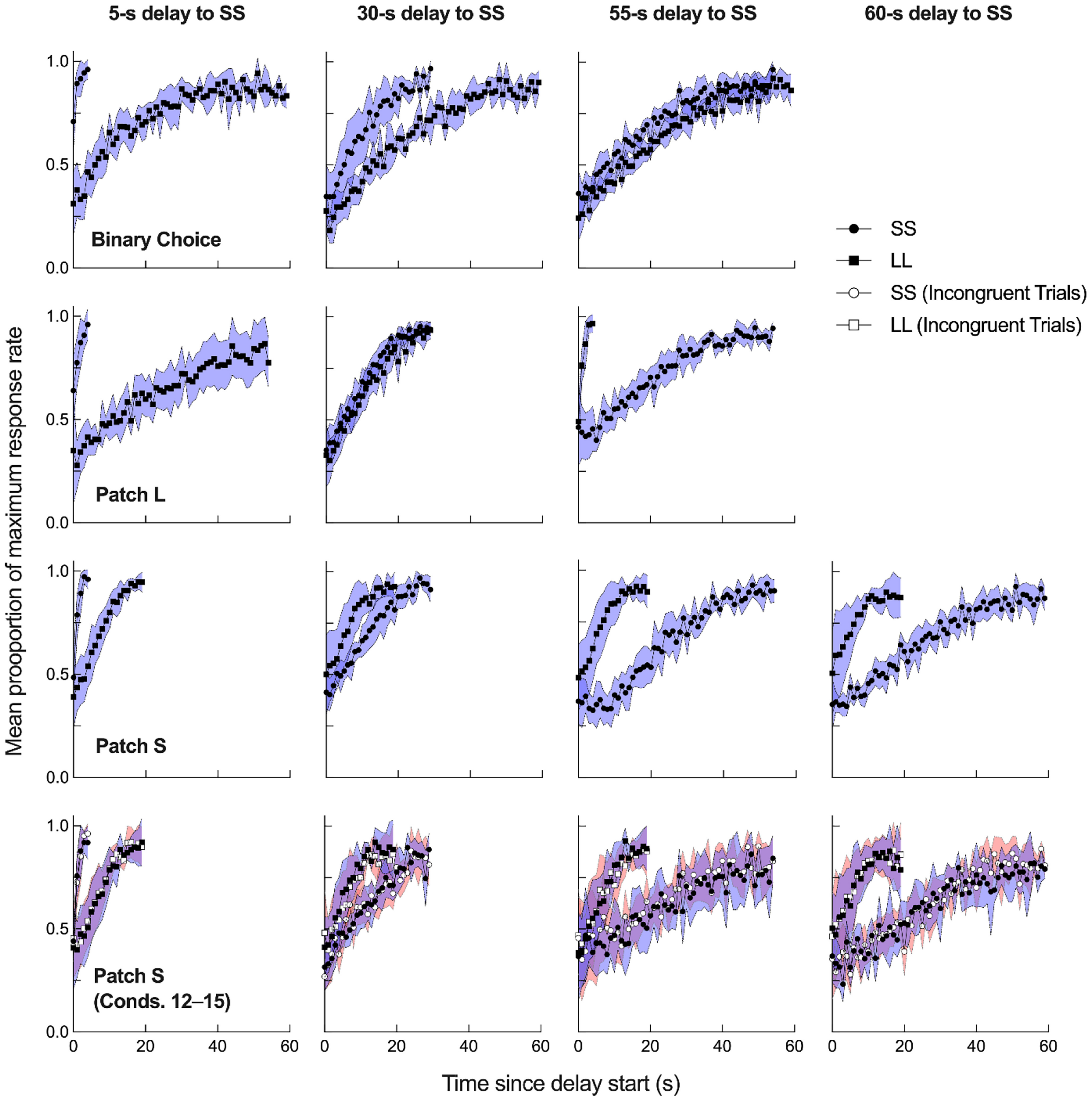
Note. Data are summed across all pigeons. Visit lengths longer than five responses are grouped together. SS = smaller-sooner; LL = larger-later; Conds. = conditions.

moved to and from the patch, whereas our pigeons pecked "stay" or "leave" keys. It seems unlikely that this difference contributed to differences in results; indeed, Carter et al. (2015) compared key-press responses and physical movement in binary-choice and patch-leaving tasks with humans, and found that patterns of intertemporal choice were similar with both topographies. Nevertheless, other research does suggest increased sensitivity to contingencies when response effort is higher (e.g., Aparicio, 2001; Baum, 1982; Kirshenbaum et al., 2000); hence, perhaps Stephens and McLinn's blue jays were more sensitive to reinforcer amounts and delays because the overall response effort was greater, compared with our pigeons.

The second procedural difference is that we arranged an open economy, in which pigeons completed one 1-hr session on weekdays and received supplementary food postsession, whereas Stephens and McLinn (2003) arranged a closed economy, in which blue jays completed sessions for 8 hr daily and obtained all (or almost all) of their food for responding during sessions. These economies can produce different behavioral patterns; for example, the number of responses that subjects will make in order to obtain a reinforcer is much higher in closed than in open economies (e.g., Carroll et al., 2000; Collier et al., 1972; Zeiler, 1999). Some evidence also suggests that subjects choose more suboptimally (e.g., by preferring an alternative with a longer delay to reinforcement) when sessions are shorter in length than when they are longer (e.g., Plowright & Shettleworth, 1991). In contrast, other studies have found little consistent effect of session length on choice (e.g., Lafiette & Fantino, 1989; Shettleworth & Plowright, 1989), and—of greater relevance to the present study—little difference in concurrent choice (e.g., Baum, 1972; Graft et al., 1977; Hursh, 1978; Lafiette & Fantino, 1989) or self-control in the binary-choice procedure (e.g., Logue et al., 1988) between open and closed economies. Based on the latter findings,

Figure 6

Mean Response Patterns During Reinforcer Delays



Note. Response rates are expressed as the mean (averaged across pigeons) proportion of maximum response rates. Response rates are shown separately for the delay to the SS (circles) and LL (squares) reinforcer. Note that the duration of delays in Patch-L and Patch-S conditions varied because of the trial structure (see Figure 1). The shaded areas show 95% confidence intervals. SS = smaller-sooner; LL = larger-later. See the online article for the color version of this figure.

and on the fact that our pigeons were not consistently more (or less) impulsive than Stephens and McLinn's blue jays across all conditions, the type of economy probably contributed little, if at all, to the differences between our and Stephens and McLinn's results. Differences in results between our study and Stephens and McLinn (2003) may instead reflect species differences. Blue jays cache food items for later consumption, and tend to cache individual items in different locations, resulting in many individual food stores scattered across a large area (Brodin, 2005; Morris, 1962; Scarlett & Smith, 1991). Hence, blue jays may not exhibit strong biases to stay at one location looking for food. On the other hand, pigeons are a non-food-caching species, and previous research suggests that they exhibit win-stay biases, even when food is more likely at a different location (e.g., Bond et al., 1981; Boutros et al., 2011; Cowie et al., 2011, 2017; Randall & Zentall, 1997). Such a bias may be adaptive in light of the typical pigeon diet—finding one grain of wheat is a likely indicator that more wheat is available nearby (Bond et al., 1981). Such species differences may explain why our pigeons strongly preferred to stay at the patch, whereas Stephens and McLinn's blue jays did not. Further research comparing these species is needed to determine the extent to which species differences contributed.

In addition to a predisposition to stay at the patch, our pigeons' strong preference to stay may also reflect control by the immediate consequences following stay and leave responses: After a stay response, the side keys remained illuminated and food was delivered after a delay, whereas after a leave response, the side keys were extinguished and the center key was lit white to signal the ITI. In other words, a stay response was followed by the continued illumination of a stimulus associated with food, while a leave response was followed by the illumination of a stimulus signaling a 40-s period of no food. Previous research has shown that subjects prefer alternatives that produce stimuli previously correlated with reinforcers (hereafter, "S+" stimuli) compared with alternatives that produce stimuli signaling the absence of reinforcers (hereafter, "S−" stimuli), even if both alternatives provide the same overall rate of food (e.g., Sears et al., 2022). Likewise, subjects will emit responses that delay the presentation of an S− stimulus (e.g., Pietras & Hackenberg, 2000) or will avoid emitting a response that occasionally produces an S− stimulus (e.g., Bland et al., 2018; R. Blanchard, 1975; Mulvaney et al., 1974), even if such responding has no bearing on obtained reinforcer rates. Such a conditioned-reinforcement account can parsimoniously account for choice in our Patch-L and Patch-S conditions: Our pigeons may have preferred to stay because this kept the stimulus associated with food illuminated, and also postponed the presentation of the no-food (ITI) stimulus. In support of this, response latencies to leave the patch were longer than latencies to stay, even when only one alternative was illuminated in forced-choice trials (Figure 4), suggesting that the contingencies associated with leaving were aversive.

What is presently unclear is whether the same conditioned-reinforcement account can explain Stephens and McLinn's (2003) findings. Unlike our pigeons, Stephens and McLinn's blue jays appeared not to display a strong avoidance of the ITI stimulus. In fact, in direct contrast to the present results, their blue jays preferred to leave the patch in Patch-S conditions. Although this appears inconsistent with our conditioned-reinforcement explanation, it is important to note that differences in how the ITI was initiated may have contributed. Specifically, whereas a leave response initiated the ITI in the present experiment, Stephens and McLinn's blue jays initiated the ITI by hopping onto a rear perch only after leaving the patch. As a result, a leave response was not immediately followed by the presentation of the no-food ITI stimulus in Stephens and McLinn's experiment. Thus, although their jays appeared not to avoid leaving the patch, they may have avoided initiating the ITI (by delaying the hop onto the rear perch). Stephens and McLinn did not report response latencies, and hence it is presently unclear to what extent their jays may have avoided the ITI stimulus. Additionally, the stimulus signaling the ITI was positioned behind the rear perch in Stephens and McLinn, meaning the blue jays could have easily oriented away from the ITI stimulus and toward the choice alternatives during the ITI. In comparison, such "escape" (Terrace, 1971) from the no-food stimulus was harder for pigeons in the present experiment, because the ITI stimulus was presented in between the choice alternatives.

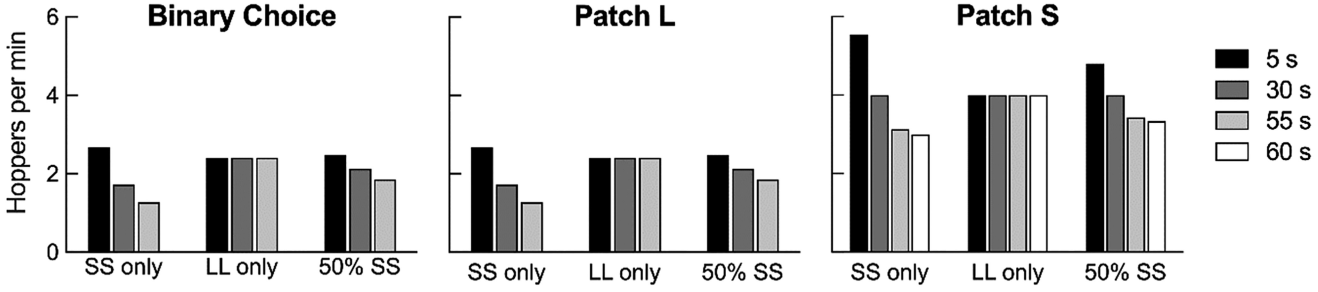
Thus, as the discussion above illustrates, the variables controlling choice in the operant versus patch-leaving self-control procedures remain unclear, and there is a dearth of research in this area. The present study is only the second to compare intertemporal choice in the binary-choice, Patch-L, and Patch-S procedures, and our study is the first to do so using pigeons, and key-peck responses instead of physical movement in the patch-leaving tasks. Thus, our study produces many fruitful avenues for future research. Several of the explanations that we have proposed can be tested empirically, for example, by varying the response requirements or response efforts for staying and leaving the patch, by comparing the same subjects' intertemporal choice in open and closed economies, and by taking a comparative approach to explore similarities and differences in intertemporal choice between species. Furthermore, to test our conditioned-reinforcement explanation, future studies could analyze response latencies or orienting behavior during the ITI, remove the stimulus during the ITI, or manipulate correlations between stimuli and reinforcers (e.g., by arranging a proportion of trials in which a reinforcer is delivered during the ITI).

The argument that subjects behave more optimally in patch-leaving tasks than the operant procedure rests on the assumption that the ITI forms part of the reinforcer delay in the former, but not the latter (Stephens & Anderson, 2001). This assumption is based on findings suggesting that the post-reinforcer delay has little impact on choice in the operant self-control procedure (e.g., Logue et al., 1985; Mazur, 1989; Mazur et al., 1985). However, studies comparing the binary-choice and patch-leaving procedures arrange a fixed-length ITI (e.g., 40 s, as in the present experiment), and hence choosing the SS reinforcer in the binary-choice procedure actually maximizes obtained reinforcement because the trial length is overall shorter than choosing the LL reinforcer. To illustrate, Figure 7 shows reinforcer rates (as hopper presentations per min) for choosing the SS or LL alternative in the present experiment: When the delay to the SS reinforcer was shorter, choosing this alternative resulted in a higher overall reinforcer rate—and hence this was the optimal choice, despite being labeled as "impulsive" by definition—in binary-choice, Patch-L, and Patch-S conditions. Even choosing the SS alternative in half of trials results in a higher overall reinforcer rate than exclusive choice of the LL alternative at shorter SS delays. In contrast, self-control studies in the operant literature add a post-reinforcer "buffer" delay to the SS reinforcer in order to equate the SS and LL trial lengths (Odum, 2011). This begs the question: How will subjects behave if trial lengths are equal regardless of whether subjects stay or leave in the patch-leaving procedure (e.g., by adding a buffer delay after a "leave" response)? Answering this question will help to elucidate how the ITI and reinforcer delays may jointly contribute to intertemporal choice in binary-choice and patch-leaving contexts.

Finally, and most importantly, the expectation that subjects will behave similarly across procedures rests on the assumption that the operant and patch-leaving tasks are economically equivalent (Stephens & Anderson, 2001). We believe that this assumption is unfounded. Figure 7 demonstrates this clearly by showing reinforcer rates associated with exclusive choice of the SS alternative, exclusive choice of the LL alternative, or choice of each alternative in

Figure 7

Reinforcer Rates Based on Exclusive Choice of the SS or LL Alternative, or Choice of Each Alternative in 50% of Trials, for Each Condition



Note. "SS only" and "LL only" show reinforcer rates for exclusive choice of the SS or LL alternative. "50% SS" shows reinforcer rates when each alternative is chosen in half of trials. SS = smaller-sooner; LL = larger-later.

50% of trials. Although reinforcer rates are indeed equivalent in the binary-choice and Patch-L procedures, this is not true of the Patch-S procedure. In the latter, the SS and LL alternatives are not mutually exclusive, because subjects can obtain both the SS and the LL reinforcer (i.e., a total of six hopper presentations in the present experiment) within a single trial. Additionally, trials are much shorter overall in the Patch-S procedure because the ITI forms part of the first delay. Thus, although the contingencies may appear identical at first glance in the binary-choice and Patch-S procedure—in the sense that subjects choose between one alternative leading to two reinforcer deliveries after a short delay and another alternative leading to four reinforcer deliveries after 60 s (see Figure 1A and 1C)—analysis of reinforcer rates make it clear that these procedures are not economically equivalent.

Furthermore, even though reinforcer rates are equal in the binary-choice and Patch-L procedures, the differences in behavior between procedures suggest that subjects do not discriminate such economic equivalence. In the Patch-L procedure (Figure 1B), economic equivalence implies that subjects essentially sum the first and second reinforcer amounts and delays. It seems more plausible—and more parsimonious—to suggest that our pigeons chose to stay for two reinforcers after a delay of 55, 30, or 5 s (60 s minus the SS delay of 5, 30, or 55 s respectively), or to leave for two reinforcers after a delay of 45, 75, or 95 s (40-s ITI plus the SS delay). The implication is that the Patch-L procedure may not measure "self-control" or "impulsivity" as it is typically defined, because the choice is not necessarily between an SS and an LL reinforcer; here, it was between two equal-sized reinforcers that differed only in delay. Our response-rate pattern analyses (Figure 6) tentatively support this suggestion, as responding during the second delay was controlled by the duration of that delay (i.e., the length of the first delay had no effect on responding during the second delay). Therefore, although comparisons between the binary-choice, Patch-L, and Patch-S procedures may help to elucidate the variables controlling intertemporal choice in different contexts, the expectation that subjects will behave similarly across these procedures is questionable.

In summary, we investigated pigeons' intertemporal choice in binary-choice and patch-leaving tasks. Our most notable finding was that pigeons always preferred to stay at the patch—regardless of whether this led to the SS or LL reinforcer, and even when the reinforcer delays for staying and leaving were equal—in patch-leaving tasks. We suggest that this reflects a species-specific win-stay bias, as well as the differential consequences for staying (the continued presentation of an S+ stimulus) versus leaving (the presentation of an S− stimulus during the ITI). Taken together, our study, along with previous research in this area, highlights the complex nature of intertemporal choice, and suggests that further cross-species investigations that manipulate a range of procedural variables are needed to identify the mechanisms underlying self-control in different environmental contexts.

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