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# Effects of unpredictable changes in initial-link duration on choice and timing

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ABSTRACT

Four pigeons responded in a concurrent-chains procedure in which terminal-link schedules were fixed-interval (FI) 10 s and FI 20 s. Across sessions, the location of the shorter terminal-link changed according to a pseudorandom binary sequence. Each session, the variable-interval initial-link schedule value was sampled from a uniform distribution that ranged from 0.01 to 30 s. On some terminal links, food was withheld to obtain measures of temporal control. Terminal-link delays determined choice (log initial-link response ratios) and timing (start and stop times on no-food trials) measures, which stabilized within the 1st half of each session. Preference for the shorter terminal-link delay was a monotonically decreasing function of initial-link duration. There was no evidence of control by initial-link durations from previous sessions.



## 1. Introduction

In typical concurrent-chains procedures (Herrnstein, 1964), subjects respond to two concurrently presented signaled options or ‘initial links’ that operate on variable interval (VI) schedules of reinforcement. Responding in initial links produces either of two mutually exclusive outcomes or ‘terminal links’ that end with food reinforcement after another delay has elapsed. Most concurrent-chains studies have used steady state designs in which the same schedules operate for many sessions. The usual result is that subjects respond more to the initial link preceding the terminal link associated with the relatively shorter delay to reinforcement (see Mazur, 2001, for review).

Preference in steady state concurrent chains, measured as the logarithm of the initial-link response ratio once behavior ceases changing systematically, can be affected by other temporal factors, including average duration of initial links. Longer absolute initial-link durations attenuate preference (Fantino, 1969; Mazur, 2005), a phenomenon known as the ‘initial-link effect.’ According to delay-reduction theory (Fantino, 1969), the conditioned reinforcement value of terminal links is determined by the reduction in delay to primary reinforcement, relative to the overall average time between initial-link onset and reinforcer delivery, signaled by onset of a terminal link.

To determine whether initial-link duration affects choice in transition, Berg and Grace (2006) investigated effects of relatively long (VI 24 s) and short (VI 8 s) initial-link schedules on preference and temporal acquisition using a successive-reversals design in which the location of the shorter of two terminal-link schedule values switched every 20 sessions. They replicated the initial-link effect of steady-state experiments: Response allocation was closer to indifference when the initial-link schedule was long. The magnitude of change in response allocation over the first three post-reversal sessions was greater when initial-link duration was short before the reversal and long after it, and smaller when initial-link duration was long before the reversal and short after it. Berg and Grace (2006) contended their results were consistent with the theoretical assumptions of delay reduction theory, since response allocation should be more resistant to change if the conditioned reinforcement value of both terminal links was greater when initial links were long (even though preference itself was less extreme).

Recent studies have shown that subjects’ response allocation adapts rapidly when terminal-link schedules change unpredictably across sessions (Grace et al., 2003; Grace and McLean, 2006; Kyonka and Grace, 2007). In one condition of Kyonka and Grace’s (2007) experiment, terminal-link schedule values were always FI 10 s and FI 20 s, but whether a peck to the left or right key produced the shorter terminal-link delay varied across sessions according to a pseudorandom binary sequence. Initial links always operated according to a VI 10 s schedule. One sixth of terminal links were “no-food” trials that ended after 60 s without reinforcement. Responding in no-food trials provided measures of temporal control (cf. Cheng and Westwood, 1993). Measures of choice and temporal control showed additional covariance beyond that attributable to terminal-link immediacy ratios, and performance stabilized approximately halfway through sessions with no evidence of influence of prior sessions. Similar research using rapid acquisition

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procedures has shown that response allocation can adapt to unpredictable changes in relative reinforcer rate (Schofield and Davison, 1997), magnitude (Maguire et al., 2007) and simultaneous manipulations of multiple reinforcer dimensions (Kyonka and Grace, 2008; Kyonka, 2008).

Christensen and Grace (2008) investigated effects of initial-link duration on preference when terminal-link schedules changed unpredictably each session. Pigeons were exposed to a rapid acquisition concurrent-chains procedure in which initial-link schedule value varied systematically between VI 0.01 s and VI 30 s across sessions according to an ascending–descending sequence. Response allocation adjusted to unpredictable changes in immediacy ratio and stabilized within the first half of sessions with no effect of previous sessions' immediacy ratios. Christensen and Grace noted several effects of changing initial-link duration across sessions. They observed an initial-link effect. However, it was bitonic: log response ratios became more extreme as programmed initial-link duration increased from 0.01 to 7.5 s, then decreased as initial-link duration increased to 30 s. They showed that an extension of Grace and McLean's (2006) decision model predicted the bitonic effect. They also found that preference was more extreme in the ascending than the descending part of the sequence. Christensen and Grace attributed the difference to "hysteresis," suggesting that preference established in previous sessions was carried over and influenced responding at the start of a new session.

In the present experiment, both initial- and terminal-link schedule values changed pseudorandomly each session. Our primary goal was to determine what effects, if any, initial-link duration has on preference for the shorter delay to reinforcement and on measures of temporal control. In particular, we wanted to determine whether the effect of initial-link duration on response allocation would be bitonic and whether there would be any evidence of hysteresis. We were also interested in comparing the degree of control by log immediacy ratio in this experiment to those in which initial-link duration did not change.

## 2. Method

### 2.1. Subjects

Four pigeons of mixed breed and sex, numbered 111–114, were maintained at 85% *ad libitum* weight ±15 g through appropriate post-session feedings. Pigeons were housed individually in a vivarium with free access to water and grit, and a 12-h:12-h light:dark cycle plus windows providing natural light. All had experience with concurrent-chains procedures in which terminal-link delays changed unpredictably across sessions.

### 2.2. Apparatus

Four operant chambers (32 cm deep × 34 cm wide × 34 cm high) were enclosed in sound-attenuating boxes containing ventilation fans. Each chamber contained three keys 21 cm above the floor arranged in a row 10 cm apart, a houselight located above the center key, and a grain magazine with a 5 cm × 5.5 cm aperture that was centered 6 cm above the floor. The houselight provided general illumination at all times except during reinforcer delivery. The magazine, which was illuminated during reinforcement, contained wheat. A force of approximately 0.15 N was necessary to operate each key. Experimental events were controlled through a microcomputer and MED-PC® interface located in an adjacent room.

### 2.3. Procedure

Because all pigeons had previous experience, training began immediately in the concurrent-chains procedure. Prior to this experiment, pigeons had responded in a procedure similar to the present one in all respects except that the initial-link schedule was VI 10 s (Kyonka and Grace, 2007). Sessions ended after 72 initial- and terminal-link cycles or 70 min, whichever came first.

At the start of a cycle, side keys were lighted white to signal initial links. A terminal-link entry was assigned pseudorandomly to the left or right key with the constraint that in every block of 12 cycles, 6 were assigned to each key. If an interval selected from the initial-link schedule had timed out and it satisfied a 1-s changeover delay, a response to the preselected key produced a terminal-link entry.

The initial-link schedule did not begin timing until the pigeon first pecked either key. In this way, pausing after the completion of terminal links was excluded from initial-link time. The initial-link schedule contained 12 intervals sampled without replacement and constructed from an exponential progression (Fleshler and Hoffman, 1962). For each session, the initial-link schedule value was determined by sampling from a uniform distribution that ranged from 0.01 to 30 s.

Terminal-link entry was signaled by extinguishing the side keys and lighting the center key. The color of the center key depended on whether a left or right initial-link response had produced the terminal link (red—left, green—right). Terminal-link responses were reinforced with 3 s access to grain according to FI schedules, always FI 10 s and FI 20 s. The (left or right) location of each terminal-link delay varied across sessions according to a 31-step pseudorandom binary sequence similar to the one used by Hunter and Davison (1985), but stayed at a key location within a session. Of the six terminal-link entries that were scheduled in a block for each alternative, five food trials and one no-food trial were determined pseudorandomly. On food trials, after the scheduled interval elapsed, the first center-key response was reinforced. A 5-s limited hold was in effect, such that if a response was not made within 5 s after the FI schedule had elapsed, the terminal link ended and no reinforcement was delivered. On no-food trials, the center key was lighted for 60 s and no reinforcement was delivered. For both types of trials, after a terminal link ended the side keys were lighted white signaling the initial links and the beginning of the next cycle.

Measures of temporal control on individual no-food trials were obtained using the method of Cheng and Westwood (1993). Responses from individual no-food trials were sorted into 1-s bins. The time of occurrence of the first response from the first instance of three consecutive filled bins was designated the start time. The time of occurrence of the last response before three consecutive empty bins was designated the stop time.

Pigeons 111–113 received 160 and Pigeon 114 received 125 total sessions of training. Data included in these analyses are from the last 50 sessions of training for Pigeons 111, 112 and 114. However, after the first 50 sessions, responding for Pigeon 113 became erratic and thereafter it failed to complete sessions consistently. Thus, we analyzed data from the first 50 sessions for Pigeon 113. For all subjects, 10-session moving-average sensitivity to current-session immediacy ratios did not change systematically over the 50 included sessions.

## 3. Results

### 3.1. Obtained initial-link durations

Fig. 1 shows average overall time spent responding in the initial links for each subject and session, plotted as a function of programmed initial-link duration. Obtained initial-link duration was an increasing linear function of the programmed value. For three subjects, best-fitting regression lines accounted for over 87% of the variance. Obtained durations were more variable for Pigeon 113 than for the other subjects. For subsequent analyses reported below,