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UNIVERSITY OF CALIFORNIA, SAN DIEGO

The Effects of Temporal Context on Preference in a Multiple Schedule with  
Alternating Concurrent-Chains and Simple Concurrent Schedule Components

A Dissertation submitted in partial satisfaction of the  
Requirements for the degree Doctor of Philosophy

in

Psychology

by

Paul John Romanowich

Committee in charge:

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Professor John Wixted

2007

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Chair

University of California, San Diego

2007

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## FIELDS OF STUDY

Major Field: Experimental Analysis of Behavior

Choice and Conditioned Reinforcement.  
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Delay-Reduction Theory  
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Applied Behavior Analysis  
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## ABSTRACT OF THE DISSERTATION

The Effects of Temporal Context on Preference in a Multiple Schedule with Alternating  
Concurrent-Chains and Simple Concurrent Schedule Components

by

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Doctor of Philosophy in Psychology

University of California, San Diego, 2007

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The present set of experiments tested the influence of events outside of the concurrent-chains procedure on choice proportions and other behavioral measures within the procedure. Context effects on the initial link relative response rates (i.e., choice proportions) were not found in each experiment. However, when a choice proportion context effect was found, the results generally indicated that choice proportions increased as a function of increasing rates of reinforcement in the context. This result is not predicted by the three currently popular quantitative theories of choice. However, because the effects found were relatively weak the current theories of choice do not require modification. It was further shown that reinforcement in the context must be response-dependent to have an impact on choice proportions. However, increases in

initial and terminal link response rates as a function of increases in contextual reinforcement were found in conditions with both response-independent and dependent reinforcement. It appeared that the modulation of initial link response rates was due in large part to reinforcement rates in the context. In general, choice may not need to be conceptualized as a process independent of external factors. Just as other behavioral theories such as contrast and the quantitative law of effect have acknowledged and synthesized the impact of distal events on proximal behavior, general theories of choice may need to do the same if the results from some of the current experiments can be replicated.

## I. INTRODUCTION

### A. Concurrent Schedules

Choice has been a popular topic in behavior analysis since the formulation of concurrent schedules of reinforcement (Ferster and Skinner, 1957). In a concurrent schedule of reinforcement, two or more independent schedules of reinforcement are available simultaneously. Responding on either schedule will result in primary reinforcement. Thus, it is up to the organism on how to distribute responding between the alternatives most effectively. Research on concurrent schedules of reinforcement has yielded one of the most popular quantitative descriptions of choice, known as the matching law (Herrnstein, 1961). Simply stated, an organism's relative response rate will be proportional to obtained relative reinforcement rates (for review, see Williams, 1988). The matching law can be mathematically written as:

$$\frac{R_1}{R_1 + R_2} = \frac{r_1}{r_1 + r_2} \quad (1)$$

where  $R$  is the rate of responding to one of the two alternative schedules of reinforcement and  $r$  is the obtained rate of reinforcement from each alternative. However, one weakness with studying choice using concurrent schedules of reinforcement is the inability to rule out how response rates produced by each individual schedule affect choice (Fantino and Logan, 1979). For example, an organism that responds on a concurrent fixed ratio (FR) 25 variable interval (VI) 15 second schedule of reinforcement will best be served to respond at a high rate on the FR schedule, because increased response rates result directly in increased rates of

reinforcement. On a VI schedule only one response is necessary to obtain reinforcement; the first response after the interval has timed out. Increasing response rates on a VI schedule has a minimal effect on reinforcement rates. Thus, to obtain the most reinforcements per unit time, the organism should respond almost exclusively on the FR schedule, while occasionally responding to the VI schedule (about every 15 s). The response rates produced on the schedules confound any attempt to obtain a reliable measure of preference from the organism.

#### B. The Concurrent-Chains Procedure

One way choice has been separated from response rates has been by using the concurrent-chains procedure, first developed by Autor (1960, 1969). In a standard concurrent-chains procedure (see Figure 1) subjects choose between two identical and independent VI schedules that operate in the initial links, or choice phase. When either of these schedules is set up for a reinforcer, the next response to that schedule terminates both initial link stimuli and provides access to one additional discriminative stimulus in the terminal link, or outcome phase. The terminal link operates on an independent schedule of reinforcement that terminates in primary reinforcement. Each initial link stimulus is correlated with a unique, mutually exclusive terminal link stimulus. Thus, the initial link schedule that is not selected is blacked out and no longer operable until the initial link is reinstated after primary reinforcement. Choice, in a concurrent chains procedure, is measured by the proportion of responses emitted during the initial links. The more an organism responds to one of the initial links, the more it is said that the organism prefers the terminal link associated with it.

Early studies on choice using the concurrent-chains procedure provided evidence for a description of behavioral allocation in accord with the matching law (Chung and Herrnstein, 1967; Herrnstein, 1964b) where relative response rates during the initial links matched relative reinforcement rates produced by the terminal links. However, a study by Fantino (1969) provided strong evidence that manipulating the absolute duration of the initial links can systematically affect relative response rates in the initial links. This result has also been replicated by manipulating the absolute duration of the terminal links (Duncan and Fantino, 1970; MacEwen, 1972; Omino, 1993; Williams and Fantino, 1978). The matching law, as proposed by Herrnstein (1970) could not adequately deal with these results.

### C. Delay-Reduction Theory

Fantino (1969) attempted to quantify his results in what has been termed the delay reduction theory (DRT). DRT is expressed in the following equation:

$$\frac{R_L}{R_L + R_R} = \frac{T - t_{2L}}{(T - t_{2L}) + (T - t_{2R})}, \text{ (when } t_{2L} < T, t_{2R} > T)$$

$$(2)$$

$$= 1 \text{ (when } t_{2L} < T, t_{2R} > T)$$

$$= 0 \text{ (when } t_{2L} > T, t_{2R} < T)$$

where  $R_L$  and  $R_R$  are the responses emitted to the left and right terminal links, respectively.  $T$  is the average overall time to primary reinforcement from the beginning of the initial links, and  $t_{2L}$  and  $t_{2R}$  are the average times for the left and right terminal links. This formulation of concurrent-chains behavior states that the value of

a terminal link stimulus as a conditioned reinforcer is determined by the reduction in time to primary reinforcement, relative to the onset of the initial links (Fantino, 1969).

The initial success of Fantino's (1969) quantification of concurrent-chain performance encouraged other researchers to attempt to quantify the extant choice data. Each researcher emphasized a particular aspect of the conditioned reinforcement process. Davison (1987) compared three such quantitative models of concurrent-chain performance against 10 data sets to see how well each accounted for the available data. Each model was chosen either because of a lack of free parameters, or because the required parameters could be closely estimated (Davison, 1987). The models included Squires and Fantino's (1971) updated DRT model, which incorporates a term for unequal initial link schedules; a model by Killeen (1982), which includes overall reinforcer rate and exponentially decaying effects of delayed reinforcers; and a model by Davison and Temple (1973), based more closely on a matching law approach to choice. Overall, each model accounted for less than 70% of the variance in the data sets, which by most accounts was not very substantial. Davison (1987) concluded that, "from this exercise...60-70% of the data variance in any set of data succumbs to almost any rational model- a rational model being one that, in general, makes correct ordinal predictions" (p. 234).

#### D. The Contextual Choice Model

This pessimism evidently did not deter other researchers from attempting to quantitatively describe behavior in concurrent-chain procedures. Grace (1994) introduced the contextual choice model (CCM) of concurrent-chain responding which generalizes to the matching law and includes within session context effects. More



specifically, these context effects refer to relative initial- and terminal-link lengths (Grace, 1994). Mathematically, CCM is expressed as follows:

$$\frac{R_L}{R_R} = b \left( \frac{t_{1R}}{t_{1L}} \right)^{a_1} \left( \frac{t_{2R}}{t_{2L}} \right)^{a_2 \left( \frac{T_i}{T_t} \right)}, \quad (3)$$

where  $R_L$  and  $R_R$  are the response to the left and right alternatives, respectively,  $b$  is a bias term,  $t_{1R}$  and  $t_{1L}$  are the mean initial link intervals for each alternative,  $t_{2R}$  and  $t_{2L}$  are the mean terminal link delays for each alternative,  $a_1$  and  $a_2$  are sensitivity parameters, and  $T_i$  and  $T_t$  are the overall average initial- and terminal-link durations, respectively (Grace, 1994).

CCM makes similar predictions to DRT in that varying the mean initial or terminal link durations will have an overall effect on relative initial link response rates. This sensitivity to initial and terminal link durations is expressed in terms  $a_1$  and  $a_2$ , respectively. Terminal link sensitivity, or  $a_2$ , has been found to increase as mean terminal link duration increases relative to mean initial link durations (MacEwen, 1972; Williams and Fantino, 1978). Conversely, as mean terminal link duration decreases relative to mean initial link duration,  $a_2$  decreases (Fantino, 1969; Fantino and Davison, 1983).

Grace (1994) went on to fit the data from 19 published studies using the concurrent-chain procedure to CCM. These studies fit the additional criteria of having at least four data points available per subject, using time-based terminal link schedules with equal reinforcement magnitudes, and reporting obtained preference measures with a range of at least 12.5%. Results indicated that CCM fit the data quite well; over 90% of the variance in the data was accounted for by the model. On the other hand,

the updated version of DRT (Squires and Fantino, 1971) that took unequal initial links into consideration, only accounted for 54% of the variance from the same data set. Accordingly, the models from Davison and Temple (1973) and Killeen (1982) accounted for only 55 and 51% of the variance, respectively. However, Grace (1994) did note that, "...CCM should be expected to account for more variance because it contains more free parameters" (p. 121).

#### E. The Hyperbolic Value-Added Model

Another theory of concurrent-chains performance was offered by Mazur (2001). His model builds on the idea that as a reinforcer becomes more temporally distant, the value of that reinforcer decreases or decays according to a hyperbolic function. In Mazur's (2001) hyperbolic value added (HVA) model, value is conceptualized by the hyperbolic-decay model with the following equation:

$$V = \frac{A}{(1 + KD)} \quad (4)$$

"...where V represents value of a reinforcer after some delay, D. A represents the amount of a reinforcer if it were available immediately and K is a parameter that determines how quickly value decreases with an increasing delay. (p.97)"

HVA makes the following assumptions about concurrent-chain performance: "(a) the value of each terminal link depends on the time from the onset of that link to primary reinforcement, (b) the value of the initial links depends on the time from the onset of the initial links to primary reinforcement, and (c) choice proportions are based

on the amount of value added when a terminal link is entered.” (p. 103)

Mathematically, HVA can be expressed as follows:

$$\frac{R_1}{R_2} = b \left( \frac{r_{i1}}{r_{i2}} \right)^{a_i} \left( \frac{V_{t1} - a_t V_i}{V_{t2} - a_t V_i} \right) V_{t1} > a_i V_i, \quad V_{t2} > a_t V_i, \quad (5)$$

As with both DRT and CCM,  $R_1$  and  $R_2$  on the left side of the equation represent the response rates of the two initial link choices. Similar to CCM, the  $b$  term represents bias and the  $a_i$  exponent represents sensitivity to the initial link schedules. The ratio of initial link reinforcement rates are expressed in the  $r_{i1}$  and  $r_{i2}$  terms. The  $a_i$  term is analogous to CCM’s  $a_2$  term to represent terminal link sensitivity.  $V_{t1}$  and  $V_{t2}$  represent the value of the two terminal link options, while  $V_i$  represents the value of the initial links.

Similar to DRT, when the values of the initial links decrease (an increase in the mean duration) the ratio of value terms becomes less extreme. This translates to the response ratio on the left side of the equation coming closer to a value of 0.5, or indifference. Increasing the value of the terminal links has the opposite effect; preference becomes more extreme.

Mazur (2001) analyzed all three models (DRT, CCM, and HVA) of concurrent-chain choice using the same 19 studies as in Grace (1994). However, unlike Grace, Mazur manipulated the number of free parameters to test whether more variance would be accounted for with their inclusion. Like before, Grace’s (1994) CCM accounted for 91% of the variance with the same data sets. With between 2 and 4 free parameters added, DRT now accounted for 83% of the variance, as opposed to 54% without. HVA was shown to account for 89% of the variance. Thus, all models

did an adequate job of describing the variance in the data sets when the number of free parameters was equated between the models.

#### F. Conceptual Distinctions

In general, all three models of choice attempt to account for an increase in preference for the shorter terminal link when the duration or value of the terminal links are large relative to the duration or value of the initial links (and also the converse). Also, when the initial links are removed, all three models reduce to strict matching. Therefore, the overall quantitative predictions between the models are quite similar, although they are achieved by slightly different theoretical assumptions. The distinctions between models can be subtle (see Mazur, 2001, 2006 for examples) and in general all three models are more similar than different. However, to better understand why a choice is made in each case, the core assumptions of each model will be briefly compared and contrasted.

In DRT, choice is a function of a comparison between two or more conditioned reinforcers (terminal links) that are each associated with a delay to primary reinforcement. The alternative that has the greatest *relative* decrease in delay to primary reinforcement will have the greatest value, and as a consequence will be chosen more often. The comparison that makes the delay relative is between the overall time to reinforcement ( $T$ , in equation 2) and the beginning of the terminal links ( $t_{2L}$  and  $t_{2R}$ ). That is, relative to the overall time you normally spend waiting for reinforcement, how long must you now wait in the terminal links?

There is no assumption about relative delays to reinforcement in the CCM. Instead, the value of the terminal links is determined by the ratio of the average time

spent in the initial and terminal links ( $T_i$  and  $T_t$  in equation 3) along with the rate of reinforcement in both the initial and terminal links ( $t_1$  and  $t_2$ ). However, the strongest effect of the ratio  $T_i/T_t$  is on the terminal link schedules, for which the ratio is an exponent. Conceptually, what is responsible for the value of the terminal links is different between DRT and CCM. For DRT, the key variable is relative delay-reduction. For CCM, the key variable is the rate of reinforcement in the terminal link modulated by the average time spent in both the initial and terminal links. Also, in determining preference the rate of reinforcement in the initial links modulates the value of the terminal links in CCM. In DRT, the role of the initial links is important only insofar as it changes  $T$ . Thus, the initial links have no direct effects on preference in DRT.

Like DRT, HVA assumes that the delay to reinforcement is an important determinant of value (equation 4), and thus, choosing between two options with different values. However, in HVA the comparison between the value of the initial and terminal links ( $V_t - V_i$  in equation 5) does not take into account an average value ( $T$  in equation 2). In HVA the comparison is more local than that of DRT, similar to CCM. Also, like CCM, the initial links modulate choice independent of the terminal links in HVA. Lastly, when entering the terminal links an increase in value occurs. It is the terminal link that has the most value added that is preferred and chosen more often.

Of the three models described only Grace (1994) states that the variables that effect initial link choice only occur within the confines of the concurrent-chain procedure. Both Fantino (1969) and Mazur (2001) implicitly agree with this notion by Grace, as no free parameters have been established to account for variables outside of

the initial and terminal link components in either model. The variables accounted for and tested will be briefly summarized next. Following that, variables not explicitly accounted for will be described in larger theoretical terms, stemming from other conceptions of behavior modification.

#### G. Internal Manipulations

Some of the more salient variables that could be manipulated within the concurrent-chains procedure include the access to other primary reinforcement either independent or dependent on an organisms responding. Fantino and Dunn (1983) showed that when a third response-dependent (VI) option was added to the terminal link of a normal two-key concurrent-chain procedure initial link response proportions varied. When the third option was sufficiently rich in reinforcements, choice proportions became more extreme for the shorter terminal link. The opposite result occurred when the added VI schedule was sufficiently low in reinforcement rate. Thus, the added VI schedule functioned as either an increase or decrease in the relative time to food in the terminal link. A similar result was demonstrated by Jacob and Fantino (1988) who varied response-dependent reinforcement rates in the initial links of a concurrent-chains procedure.

More recently, Mazur (2003) manipulated response-independent reinforcer presentations during the initial links of a standard concurrent-chains procedure. The response-independent reinforcer was either presented immediately, after a 30-s delay or not at all after a 30-s delay. The timing of these reinforcers was maintained on a variable time (VT) schedule. When the response-independent reinforcer was immediate, choice proportions became more extreme in the direction of the shorter

terminal link. No change in choice proportions occurred with the response-independent reinforcer delayed 30-s. A decrease in preference for the initial link correlated with the shorter terminal link occurred when no food was presented after the response-independent 30-s delay. Thus, the added reinforcement can shorten the average time to reinforcement (immediate response-independent reinforcement), or lengthen the overall time to food (no food after 30-s delay). Either way, the added reinforcement (or time) affects preference in a way consistent with simply shortening or lengthening the initial links relative to the terminal links (Fantino, 1969; MacEwen, 1972; Williams and Fantino, 1978).

#### H. External Manipulations

Researchers have also examined ways in which the variables outside the concurrent-chain procedure affect choice proportions. Goldshmidt, Lattal, and Fantino (1998) manipulated the length and type of stimulus presented during the inter-trial interval (ITI) and availability of food between concurrent-chain presentations. The ITIs were either signaled by the houselight present during the concurrent-chains procedure (Experiment 1), the stimulus associated with the richer terminal link (Experiment 2), or the stimuli associated with the initial links (Experiment 3). Additional response-independent food was presented on a variable schedule during the ITI in Experiment 4. Each of the 4 experiments failed to show any effect of stimulus presentation or reinforcement on initial link preference. The authors concluded that the concurrent-chains procedure is best viewed in a local context as opposed to a global context. This local contextual view would not need to take the ITI and other variables outside the procedure into consideration during tests of preference.

Additional support for a local contextual view of the concurrent-chains procedure was presented by a series of experiments by Williams and Fantino (1996). In these experiments, a response-dependent pre-choice period was implemented, which was functionally equivalent to an ITI. No food was presented in this pre-choice period. Results showed that this length of the ITI had no significant impact on choice proportions in the initial links.

However, a study by Gentry and Marr (1980) provided results which may indirectly lend support to the notion of context influencing choice. In this study, equal concurrent VI 60-sec schedules of reinforcement led to either a short delay, or a longer delay to reinforcement. The longer delay was always four times longer than the short delay. Following reinforcement, an ITI operated that equated the overall time between reinforcements for both schedules. That is, if the short key had a 4-sec delay to reinforcement and the long key had a 16-sec delay to reinforcement, then the ITI after reinforcement would be 16-sec and 4-sec for the short and long keys, respectively. This differential ITI duration could be considered a context, as it was changed depending both on which key was reinforced and how long the short delay was. Results were consistent with DRT until the short delay was greater than 8-sec (see their Figure 5). After this point, relative response rates for the short delay key began to decline, which is the opposite prediction of DRT (CCM and HVA, also). Thus, at longer overall delays between reinforcement choice became more indifferent, even though the absolute difference between the delays was increasing. All three of the birds tested in these conditions showed this effect (see their Figure 1). Thus, it is



plausible that increasing the average ITI could have an influence on choice, consistent with a global contextual view.

### I. Context as an Independent Variable

Context has been used as an independent variable for many different behavioral preparations. Context can be defined as the location, temporal, and/or specific environmental features in which a behavior can occur. Context can operate either concurrently or historically with a behavior. In the associative learning literature, Balsam and Tomie (1985) have pointed out that “all basic learning phenomena that have been studied (excitation, inhibition, extinction, discrimination learning), have been shown to be modulated by contextual manipulations.” (p.9) Whereas, associative learning preparations are quite explicit in their manipulation of either the physical (i.e., stimulus properties of the experimental chamber) or temporal (extra presentations of the conditioned stimulus - CS or unconditioned stimulus - US in the ITI) parameters during an experiment, operant preparations have by-in-large neglected to systematically explore context as a mediating variable in behavior. One exception is the phenomenon of behavioral contrast.

In a multiple schedule, two independent schedules of reinforcement, each with a unique discriminative stimulus alternate in a regular sequence. Reynolds (1961) used a multiple (*mult*) VI 3-min VI 3-min schedule in the classic demonstration of behavioral contrast. When one of the schedules was changed to extinction, a profound increase in response rate (*positive contrast*) was observed in the unchanged VI component. This demonstrated that the rate of reinforcement in one of the schedules was systematically related to the response rate of the other schedule, even though there

was no formal contingency programmed between the two schedules of reinforcement. The opposite result was also demonstrated; as one of the VI schedules provided reinforcement more often, the rate of responding to the unchanged component subsequently decreased (*negative contrast*). In terms of context, changing the rate of reinforcement (and corresponding rate of responding) of one schedule served as the background to the unchanged component of the multiple schedule. Although there has been a fair amount of research on how behavioral contrast occurs (see Williams, 2002 for a review), there is still no consensus as to why it occurs.

In a multiple schedule the organism has no explicit choice between the two schedules of reinforcement, because the contingencies controlling schedule presentation are independent. However, Herrnstein (1970, 1974) proposed that any operant behavior can be conceived of as choice behavior. Even though all of the reinforcers controlling behavior may not be programmed by the experimenter, or even intuitively obvious, there is always more than one option available when behavior is occurring, even if the alternative behavior is not behaving at all. Herrnstein (1970) modified Equation 1 to account for changing absolute response rates with alternative sources of reinforcement as the context. This equation is called the quantitative law of effect and it is written as:

$$B_1 = \frac{k(R_1)}{(R_1 + R_e)} \quad (6)$$

where the absolute rate of responses ( $B_1$ ) is a function of the rate of reinforcement produced from response option 1 ( $R_1$ ) multiplied by the total behavioral output ( $k$ )

relative to the rate of reinforcement from response option 1 and all other sources of reinforcement ( $R_e$ ). The constant  $k$  is empirically defined and sets the upper limit on the rate of responding produced by  $R_1$  (McDowell, 1986).

deVilliers (1977) has illustrated the generality of the quantitative law of effect in describing a wide variety of operant situations. In terms of behavioral contrast, when the rate of reinforcement in the changed schedule is decreased,  $R_e$  decreases, which increases the relative influence of  $R_1$  on  $B_1$ . The opposite is also predicted; as the rate of reinforcement increases on the changed schedule,  $R_e$  increases, which decreases the relative influence of  $R_1$  on  $B_1$ . Unfortunately, the concept of  $R_e$  is ambiguous to a fault. It is unclear whether the extraneous reinforcement need be available concurrently, successively, or both to be effective on  $B_1$ . Also, equation 6 has not been shown to have predictive power over choice situations like that found in Fantino (1969).

#### J. Current Experiments

From the data currently available, choice in the concurrent chains procedure is thought to be operating within a local context. As described above, none of the three main quantitative theories of choice includes a variable to account for changes in temporal parameters outside of the initial or terminal links. However, there is reason to believe that variables outside of the concurrent chains procedure could influence either response rates, choice proportions, or both. The phenomenon of behavioral contrast is well described and the quantitative law of effect owes its descriptive power to classifying reinforcement not contingent on a certain behavior as influencing the rate at which that behavior is produced.

One variable that has not been investigated is whether placing response-dependent schedules between presentations of a concurrent-chain procedure would have an effect on choice proportions, response rate, or both. The study by Goldshmidt et al. (1998) only used response-independent food presentations and found no evidence for a context effect. Likewise the response-dependent ITI in Williams and Fantino (1996) failed to effect choice proportions. However, it is reasonable to believe this type of manipulation would have an effect on response rates because the situation would be functionally equivalent to a multiple schedule of reinforcement. Thus, increasing the rate of reinforcement in the context, while holding the rate of reinforcement in the concurrent chains procedure constant, should decrease the response rates in the concurrent chains procedure. However, it is unclear which component (either the initial link or terminal link) would be affected relatively more, or whether the choice proportion would be affected by this response rate change.

The following experiments attempt to demonstrate a context effect on choice in the concurrent chains procedure. In each of the experiments, the parameters of the concurrent chains procedure are held constant while the rate of reinforcement outside of the procedure is systematically varied. In Experiment 2 the inter-block interval (IBI) is systematically increased. In Experiment 3 and 4 the order of presentation of the context and concurrent chains procedure and duration of the IBI is manipulated. In Experiment 5 the context response option is changed to either a physically distinct location relative to the concurrent-chains procedure, or scheduled as response-independent, in an attempt to replicate the findings by Goldshmidt et al. (1998).

## II. EXPERIMENTS

### A. Experiment 1: Multiple Concurrent-Chains, Simple Concurrent Schedules

#### Method

**Subjects.** Four White Carneaux pigeons (*Columbia livia*) served as subjects (361, 524, 520, and 364). All birds had an extensive prior history participating in operant conditioning experiments. Birds were maintained at approximately 80% of their free-feeding body weights and given supplemental feeding only if their weight reached 75% of their free-feeding body weight. Birds weighing more than 85% were withheld from experimental testing until their weight was below 85% of their free-feeding weight. Nutrient enriched-water and grit were freely available in the home cage that was located in a colony room with a regular 12:12 day/night cycle. Testing sessions were typically conducted six days a week at approximately the same time each day.

**Apparatus.** The experimental chambers were 30.5-cm long, 24.1-cm wide, and 29.2-cm high. Three plastic response keys, each approximately 2.5-cm in diameter were mounted on the front wall, 22-cm above the stainless steel grid floor. A force of 15 grams of pressure was required to operate each key, and produced audible feedback when contact with the microswitch was made. Visual stimuli were projected onto each key by an IEE 12-bulb projector mounted behind the front wall. A pellet receptacle measuring 5.1-cm wide and 5.1-cm high, and approximately 11-cm above the grid floor directly below the center key provided access to 45-mg pellets. During reinforcement, all stimuli were turned off except a 100 mA house light mounted on the back wall 27-cm above the grid floor. Each chamber was housed in a sound and light-

attenuating wooden box that contained a small ventilation fan which doubled as a white-noise stimulus. A Windows®-based computer in an adjacent room used MED-PC® software to control stimuli and record operant key-peck responses.

**Procedure.** Each session began with either a block of concurrent-chains schedules or a block of simple concurrent schedules ( $p = 0.5$ ). A block consisted of 4 consecutive trials, each ending in reinforcement. After the 4<sup>th</sup> trial, a block consisting of the schedules not previously experienced began. After the 2<sup>nd</sup> block, schedules regularly alternated until either 48 reinforcements or 60 min elapsed. For example, if a session began with a concurrent-chains schedule, the first 4 trials would be concurrent-chains, while trials 5 through 8 would be simple concurrent schedules. Trials 9 through 12 would be concurrent-chains, etc...

*Concurrent Chains.* The standard concurrent-chains procedure is shown in Figure 1. The initial-link schedules were identical VI 60 s schedules of reinforcement differentially signaled by a horizontal and vertical white bar on the left and right stimulus keys, respectively. A change-over delay (COD) of 2 s was in effect during the initial-links; i.e., a minimum of 2 s had to elapse between a response to one initial link and the completion of the other initial link. Completion of the left (vertical) initial-link led to a green stimulus, while completion of the right (horizontal) initial-link led to a red stimulus. The alternative key not chosen became dark and inoperative. Terminal-link schedules were VI 15 s and VI 45 s counterbalanced within and between subjects. Completion of the terminal-link schedule was reinforced by three 45 mg pigeon pellets. After a 1 s delay the next schedule began.

*Simple Concurrent.* The simple concurrent procedure operated with identical VI schedules present. The left and right keys were both illuminated white. A COD of 2 s was in effect throughout the procedure. Schedule values could either be VI 40 s, 120 s, or 360 s, between conditions. Table 1 shows the order of schedule presentations for the simple concurrent schedules along with trials to stability, mean reinforcements obtained, initial link relative responses rates, concurrent schedule relative response rates and initial, terminal and variable interval response rates for each bird. All data presented in Table 1 are based on data that have met the stability criteria (discussed below). All VI-schedule distributions in both the concurrent chains and simple concurrent procedure consisted of Fleschler and Hoffman (1962) progressions of 15 values. Schedule values were selected randomly from a list without replacement. Once all schedule values were used, the values again became available for selection in a new, random order.

*Stability Criteria.* A condition was changed when stability in the initial-link response (choice) proportion was reached. Choice proportions were calculated by dividing the number of responses on the initial link that led to the shorter terminal link (VI 15 s) by the total number of responses in the initial-link. Stability was then determined by dividing the choice proportions of the last 9 sessions into three blocks of three and taking the average of each block. If the average of each block was no greater or less than 5% of either of the other blocks, and if there was no upward or downward trend, the condition was changed. Each condition was in effect for a minimum of 20 sessions. If stability data was below 0.50 (showing a preference for the longer terminal link), the data was thrown out and that condition was replicated

after the pigeon had reached stability in the other conditions. Eight such conditions were thrown-out and subsequently replicated.

*T-values.* In DRT the average time to reinforcement is represented by “T.” In the concurrent chains procedure used throughout this experiment, T is equal to half of the average time spent in the initial-links (30 s; as both schedules are operating concurrently) plus the average time spent in the terminal-links (30 s), which is 60 s. In the simple concurrent procedure, T is equal to one-half of the time for each schedule, or 20, 60, and 180 s for the *conc VI* 40, 120 and 360 s schedules, respectively. Therefore, the average time to reinforcement can either be three times faster (*conc VI* 40 s), three times slower (*conc VI* 360 s), or equal (*conc VI* 120 s) to the average time to reinforcement in the concurrent chains schedule.

## Results and Discussion

The overall results from Experiment 1 indicated no context effect on choice proportions between subjects. A slight increase in terminal link response rates as a function of decreasing rates of reinforcement in the context were observed, but was not statistically significant. Specific behavioral measurements are described in more detail below.

Figure 2 shows the average choice proportion across all 4 birds and the mean of all birds as a function of the T-value in the simple concurrent procedure. The standard error above the mean is represented by a vertical line for each average value. The mean data (bottom left graph) shows that there were no significant differences between any of the experimental (context) conditions, or between the baseline and the experimental conditions as calculated by a one-way ANOVA. Obtained mean choice



proportions were 0.69, 0.69, and 0.66 for the experimental conditions with T-values of 20, 60, and 180, respectively. The mean choice proportion in the baseline condition was 0.69. Within subjects data is much more variable than that shown in mean data. Statistical analysis of individual data was not possible, because  $n = 1$  in each case. Mean numerical values for each condition are represented in Table 1.

Choice proportions were also collapsed across contexts and compared to baselines choice proportions. A *t*-test showed no difference between context and baseline choice proportions.

The simple concurrent schedules were meant to add a reinforcement context onto the concurrent chains procedure. However, the concurrent schedules could also act as a measure of bias for either side key. Figure 3 shows the mean relative response rate towards the left key as a function of each of the three T-values along with individual data. A one-way ANOVA showed no significant difference between relative response rates for any of the three context conditions in the mean data (bottom left). The mean relative response rates toward the left key were 0.48, 0.55 and 0.52 for conditions with T-values of 20, 60 and 180, respectively. Overall, mean relative response rates in the concurrent schedules were not substantially biased to either the left or right key, with rates around 0.50 in each condition.

In behavioral contrast, when the reinforcement rate of one component of a multiple schedule is either increased or decreased, a subsequent decrease or increase in response rate in the unaltered component is observed, respectively. In this experiment, the unaltered component was the concurrent chains schedule, while the simple concurrent schedules would either increase (VI 40 s), decrease (VI 360 s) or stay the

same (VI 120 s) in terms of reinforcement rate. Figure 4 shows response rates during the initial link as a function of experimental conditions for the mean and individual subjects. A one-way ANOVA showed no significant differences between conditions. Individual data is somewhat more variable, with a slight increasing trend in pigeons 361 and 524 and no consistent effect in 520 or 364. Figure 5 shows response rates during the terminal link as a function of experimental conditions for the mean and individual subjects. A one-way ANOVA revealed no statistically significant differences between response rates in the terminal links between conditions. However, there were some noteworthy trends that conform to general patterns of response rates observed in experiments on behavioral contrast. All pigeons showed an increase in terminal link response rates above baseline levels for at least one of the experimental conditions. As shown in Table 1, terminal link response rates during baseline conditions were generally at the low end of the range in each of the four birds. During the experimental conditions, response rates when the T-value was 180 were higher than when the T-value was either 20 or 60 (there did not appear to be as large of a difference between these two conditions). Thus, in general, terminal link response rates increased as a context was added (above baseline levels), and the highest rates of responding were observed in the context with the lowest reinforcement rate. This qualitative result is consistent with accounts of positive behavioral contrast and that of DRT (Fantino, 1982; O'Daly, Meyer & Fantino, 2005).

It was expected that response rates in the simple concurrent schedules would decrease as reinforcement decreased (Catania, 1963; Ferster and Skinner, 1957). Figure 6 shows mean and individual subject's response rate as a function of the T-

value. A one-way ANOVA showed no significant differences between conditions. However, there appeared to be a decline in response rates during the *conc* VI 360-s VI 360-s context relative to the other two simple concurrent schedules. Again, individual data was more variable, with pigeon 361 showing an increase in response rate as a function of a decreasing rate of reinforcement in the concurrent schedules.

Although there were no statistical significant differences between conditions in Experiment 1, the increase in terminal link response rates showed that an interaction may have been occurring. The next set of experiments attempted to clarify the nature of the interaction between the context and behavior in the concurrent-chains procedure by temporally separating the context from the concurrent-chains procedure (Experiments 2-4) and keeping the order of blocks of trials constant (Experiment 3 & 4).

## B. Experiment 2: Varying the IBI

### Method

**Subjects.** Four White Carneaux pigeons (*Columbia livia*) served as subjects (408, 281, 880, and 333). All birds had an extensive prior history participating in operant conditioning experiments. Birds were maintained at approximately 80% of their free-feeding body weights and given supplemental feeding only if their weight reached 75% of their free-feeding body weight. Birds weighing more than 85% were withheld from experimental testing until their weight was below 85% of their free-feeding weight. Nutrient enriched-water and grit were freely available in the home cage that was located in a colony room with a regular 12:12 day/night cycle. Testing

sessions were typically conducted six days a week at approximately the same time each day.

**Apparatus.** The experimental chambers were 30.5-cm long, 24.1-cm wide, and 29.2-cm high. Three plastic response keys, each approximately 2.5-cm in diameter were mounted on the front wall, 22-cm above the stainless steel grid floor. A force of 15 grams of pressure was required to operate each key, and produced audible feedback when contact with the microswitch was made. Visual stimuli were projected onto each key by an IEE 12-bulb projector mounted behind the front wall. A pellet receptacle measuring 5.1-cm wide and 5.1-cm high, and approximately 11-cm above the grid floor directly below the center key provided access to 45-mg pellets. During reinforcement, all stimuli were turned off except a 100 mA house light mounted on the back wall 27-cm above the grid floor. Each chamber was housed in a sound and light-attenuating wooden box that contained a small ventilation fan which doubled as a white-noise stimulus. A Windows®-based computer in an adjacent room used MED-PC® software to control stimuli and record operant key-peck responses.

**Procedure.** The same general procedure as Experiment 1 was used. However, in addition to manipulating the simple concurrent schedules, the time between successive blocks of trials was also manipulated. Sessions began with either a block of the simple concurrent schedules or concurrent chains schedules ( $p = 0.5$ ). The next block of schedules would be whichever type of schedule did not start the session. An IBI began immediately after both blocks of simple concurrent and concurrent chains schedules finished (i.e., 8 primary reinforcers). The IBI could either be 1 s (same as in Experiment 1), 30 s or 60 s. After the IBI, the same sequence of schedules repeated in

the same order throughout the remainder of the session. Stability criteria and VI schedule values were identical to those used in Experiment 1. If stability data was below 0.50 for the richer terminal link, the data was thrown out and that condition was replicated after the pigeon had reached stability in the other conditions. Six conditions met this criterion and were replicated.

## Results and Discussion

Overall, Choice proportions were an increasing function of an increasingly rich context at the shortest and longest IBI values. Also, initial link response rates were an increasing function of an increasing IBI, independent of context. Conversely, terminal link response rates were a decreasing function of an increasing IBI.

Table 2 shows the order of presentation of conditions and results for each of the 4 pigeons used in the experiment. Pigeon 281 developed a right key bias and thus became insensitive to the time to reinforcement in the terminal link schedules midway through the experiment. This biased data was dropped from the analysis. Table 3 shows the results of each 3 X 3 ANOVA (Context X Inter-Block Interval) run for the mean data across five different behavioral measures. There was a high amount of individual variability across subjects, similar to Experiment 1. Therefore, only the most salient trends will be discussed below.

Figure 7 shows the choice proportion as a function of the IBI and rate of reinforcement in the context for each of the 4 pigeons and the aggregate data. Mean data showed a main effect for context on choice proportions that was approaching significance. As a group, at IBI values of 1- and 60-s the choice proportions increased with increased rates of reinforcement in the context. Neither a main effect for IBI nor

an interaction was found in the mean data. Individually, when the IBI was increased to 60-s there appeared to be a separation in choice proportions between contexts, with choice proportions the highest with the richest context and lowest with the poorest contexts. Only pigeon 880 failed to show this trend.

Figure 8 shows the simple concurrent relative response rate as a function of the IBI and rate of reinforcement in the context for each pigeon and the mean data. Data were generally consistent with that in Experiment 1, with relative response rates around 0.5. However, there was a slight trend at an IBI of 1-s whereby rates were generally around 0.4 during the concurrent VI 40-s condition and then progressively increased as the simple concurrent schedules decreased in reinforcement rates. Pigeon 281's (top right graph) right key bias is apparent even before the remainder of its' experimental sessions were terminated.

Figure 9 shows initial link response rates as a function of the IBI and rate of reinforcement in the context for each of the 4 pigeons and the averaged data. Table 3 shows a main effect for IBI on initial link response rates that approached statistical significance, whereby initial link response rates increased with an increased IBI. Individually, Figure 9 shows that pigeons 408 (top left) and 333 (bottom right) followed this general pattern of behavior. Little to no change in response rate was found in pigeon 281 or 880. In pigeon 333 there was a clear interaction between context and IBI; as the IBI increased the initial link response rate in the richest context increased and a difference between the richest and poorest context increased.

Terminal link response rates as a function of the IBI and rate of reinforcement in the context are illustrated in Figure 10 for each pigeon and mean data. A significant

main effect for IBI was found in the mean data (bottom left panel and Table 3). In general, terminal link response rates decreased as the IBI was lengthened. This effect was apparent and uniform in each pigeon except 880. Also, any response rate differences between contexts disappeared as the IBI was increased, at least for pigeons 408 and 333. There was not a pattern of increased terminal link response rates with decreased rates of reinforcement like those found in Experiment 1. However, the temporal separation by the IBI did seem to decrease any differences that may have existed at shorter IBI lengths, demonstrating the effectiveness of separating blocks of trials temporally.

Response rates as a function of the IBI and rate of reinforcement in the context during the simple concurrent schedules are shown in Figure 11 for each pigeon and the averaged data. There were no statistically significant main effects or interactions between IBI and context for the mean data. Like Experiment 1, it was expected that response rates in the simple concurrent schedules would decrease as a function of decreased reinforcement rates. This pattern can be observed only at an IBI of 1-s for subjects 408 and 281. Thus, in most conditions at increased IBI's, variability in response patterns became more evident.

The response rate data in both the initial and terminal links support the hypothesis that events outside of a concurrent-chains procedure impacts behavior inside the procedure. This finding is inconsistent with all of the current models of choice outlined in the introduction, because none of them predict a decrease in response rates (either in the initial or terminal link) with changes in the temporal spacing between trials. However, changing response rates do not necessarily mean that

the choice proportions will be affected. All three models have focused on the choice proportion as being the main independent variable of interest.

One finding was more problematic in terms of a general behavioral theory. The fact that response rates in the simple concurrent schedules didn't necessarily decrease with lowered reinforcement rates (Figure 11) suggests either a large interaction with the concurrent-chains schedule, insensitivity to the programmed schedules of reinforcement, or both. A lack of response rate differentiation during the simple concurrent schedules was also found in Experiment 1 (see Figure 6).

Experiments 3 and 4 attempted to clarify how an interaction between the concurrent-chains procedure and the context was modulated. For example, are there systematic and measurable differences if the concurrent-chains procedure always precedes the context (Experiment 3) and vice versa (Experiment 4)?

### C. Experiment 3 & 4: Varying the IBI and Order of Presentation

#### Method

**Subjects.** Eight White Carneaux pigeons (*Columbia livia*) served as subjects (Experiment 3: 881, 876, 882, 878; Experiment 4: 285, 417, 412, 413). All birds had an extensive prior history participating in operant conditioning experiments. Birds were maintained at approximately 80% of their free-feeding body weights and given supplemental feeding only if their weight reached 75% of their free-feeding body weight. Birds weighing more than 85% were withheld from experimental testing until their weight was below 85% of their free-feeding weight. Nutrient enriched-water and grit were freely available in the home cage that was located in a colony room with a



regular 12:12 day/night cycle. Testing sessions were typically conducted six days a week at approximately the same time each day.

**Apparatus.** The experimental chambers were 30.5-cm long, 24.1-cm wide, and 29.2-cm high. Three plastic response keys, each approximately 2.5-cm in diameter were mounted on the front wall, 22-cm above the stainless steel grid floor. A force of 15 grams of pressure was required to operate each key, and produced audible feedback when contact with the microswitch was made. Visual stimuli were projected onto each key by an IEE 12-bulb projector mounted behind the front wall. A pellet receptacle measuring 5.1-cm wide and 5.1-cm high, and approximately 11-cm above the grid floor directly below the center key provided access to 45-mg pellets. During reinforcement, all stimuli were turned off except a 100 mA house light mounted on the back wall 27-cm above the grid floor. Each chamber was housed in a sound and light-attenuating wooden box that contained a small ventilation fan which doubled as a white-noise stimulus. A Windows®-based computer in an adjacent room used MED-PC® software to control stimuli and record operant key-peck responses.

**Procedure.** The same procedure of varying both the simple concurrent schedule and IBI used in Experiment 2 was used in Experiment 3 and 4. However, the order of block presentation was differentiated between Experiments 3 and 4. Whereas Experiments 1 and 2 both began with either a concurrent chain or simple concurrent procedure randomly assigned to the first block, Experiment 3 always began with a block of the concurrent chains procedure. This was followed by a block of the simple concurrent procedure, then the IBI, with this regular alternation between types of schedules throughout the remainder of the session. Experiment 4 always began with a

block of the simple concurrent procedure, which was followed by a block of the concurrent chains procedure, then the IBI, and this regular alternation between types of schedules throughout the remainder of the session. Stability criteria and schedule values were identical to those used in Experiments 1 and 2. If stability data was below 0.50 for the richer terminal link, the data was thrown out and that condition was replicated after the pigeon had reached stability in the other conditions. Twelve conditions in Experiment 3 were replicated, while 10 were replicated in Experiment 4.

### Results and Discussion

*Experiment 3.* When sessions always began with a concurrent chains block of schedules choice proportions decreased with increasing IBI values. A similar trend was found in initial link response rates, although the effect was not significant. However, just like Experiment 2, terminal link response rates decreased as IBI values increased.

Table 4 shows the order of conditions for each subject along with obtained behavioral measures during stability. All mean data were analyzed using a 3 X 3 (Context X IBI) ANOVA, the results of which are listed in Table 5.

Figure 12 shows the choice proportions as a function of the IBI and rate of reinforcement in the context for each pigeon along with averaged data from Experiment 3. A 3 X 3 ANOVA showed no significant differences between contexts, or an interaction between the context and IBI. However, a main effect for IBI was statistically significant, as seen in Table 5. As the IBI increased initial link relative response rates decreased. This pattern can be seen in pigeons 881 and 882. It was also apparent that the choice proportions were well below those predicted by the three main

theories of choice (see Table 4, also). In fact, there were only 4 instances out of 44 possible chances that the initial link choice proportion was at or above 0.70. For comparison, there were 20 such instances (out of 40) in Experiment 2.

The relative response rates as a function of the IBI and rate of reinforcement in the context during the concurrent schedules are illustrated in Figure 13 for each pigeon and the mean. There were no statistically significant main effects or interactions for the mean data. Individual data was variable, similar to that found in Experiments 1 and 2.

Initial link response rates as a function of the IBI and rate of reinforcement in the context for each subject and the averaged data are shown in Figure 14. No statistically significant main effects or interactions were found after running a 3 X 3 ANOVA. There was a slight trend of decreasing response rates as a function of an increased IBI, but this effect was not statistically significant.

Figure 15 illustrates terminal link response rates as a function of the IBI and rate of reinforcement in the context for both individual subjects and the averaged data across conditions. There was a statistically significant main effect for the IBI, as shown in Table 5. The bottom left panel of Figure 15 shows that as the IBI was increased the rate of responding in the terminal links decreased. This pattern was evident to a greater or lesser extent in pigeons 876, 881 and 878. However, there was no indication of this pattern of behavior for pigeon 882. This was the same pattern of behavior shown in Experiment 2.

The response rate during the simple concurrent schedules as a function of the IBI and rate of reinforcement in the context for individual subjects and the group mean

is shown in Figure 16. A 3 X 3 ANOVA revealed no significant main effects or interactions for the mean data.

Relative to Experiment 2, subjects in Experiment 3 showed less of a difference in choice proportions across contexts. However, there was a significant difference between IBI's, with increased choice proportions as a function of decreased IBI's. To the extent that the manipulation of IBI's can be thought of as a change in context, this finding lends support to the view that factors outside the concurrent-chains procedure can affect variables within it. Also, response rates increased during the terminal links as a function of a decreased IBI, which was the one constant finding between Experiments 2 and 3. However, unlike Experiment 2, there was no statistically significant response rate change during the initial links as a function of the IBI.

*Experiment 4.* There were no statistically significant findings in Experiment 4. However, like Experiment 2, choice proportions appeared to increase as a function of an increased rate of reinforcement in the context. Unlike Experiment 2 and 3, there were no systematic changes in either the initial or terminal link response rates as a function of either the context or the IBI.

Table 6 shows the order of conditions for each of the 4 pigeons used in the experiment along with 5 behavioral measures taken during stability. Pigeon 285 died midway through the experiment due to an enlarged heart. Due to a malfunction in recording pigeon 417's baseline data were lost. All mean data were analyzed with a 3 X 3 (Context X IBI) ANOVA, the results of which are listed in Table 7. The same method of presenting and discussing the results used in Experiments 2 and 3 will be used in Experiment 4, with a general discussion to follow.

Figure 17 shows the choice proportion as a function of the IBI and context for each subject and the mean. There were no significant main effects or interactions between contexts and the IBI. However, a main effect for context is approaching significance, as shown in Table 7. The most evident trend was an increased choice proportion over increased rates of reinforcement in the context. This was the same trend shown by the subjects in Experiment 2. Similar to Experiment 3, there were only 7 occurrences out of 38 opportunities in which initial link relative response rates were at or above 0.70.

Figure 18 displays the simple concurrent relative response rate as a function of the IBI and context for each subject and group mean. There were neither statistically significant main effects nor an interaction between the context and IBI. There were no systematic trends in the data between individual subjects.

The mean initial link response rate as a function of the IBI and context for each subject and the mean for the group is shown in Figure 19. There was no statistically significant main effect or interaction between the context and IBI, as shown in Table 7.

Figure 20 shows the terminal link response rates as a function of the IBI and context for individual subjects as well as the mean in Experiment 4. As shown in Table 7, there were no statistically significant differences or interactions for the mean data. However, the similarity in the patterns of responding between the initial and terminal links is fairly well pronounced.

Figure 21 shows the response rates during the simple concurrent schedules as a function of the context and IBI for each subject and the mean. There were no

statistically significant main effects or interactions for this behavioral measure. Mean data was mostly undifferentiated across contexts and IBI's.

Experiment 4 had no statistically significant findings in terms of main effects or interactions, whereas Experiment 2 and 3 each had at least one. Unlike Experiment 2 and 3, the main effect of the IBI on the terminal link response rate was not significant. However, the main effect for context on choice proportions was much closer to statistical significance than in Experiment 3, and was similar in trend to Experiment 2.

Because of the similarity in procedures the mean results of Experiment 3 and 4 were compared. In terms of initial link choice proportion, there was not a significant difference between Experiment 3 and 4. There were also no significant differences between response rates in the initial link, terminal link, or concurrent schedule of reinforcement. Thus, the differences in procedures used did not significantly effect choice.

It could be argued that providing a context with the same availability of response options (i.e., only left and right keys) as the concurrent chains procedure may bias the situation in favor of generalization between the two types of procedures. Hence, any context effect found may simply be a matter of a failure to discriminate which type of trial is occurring at any one time. Experiment 5 sought to test this discrimination hypothesis by providing a context response option in a different physical position (i.e., the center key) than that of the concurrent chains procedure. Also, because rates of responding have appeared to be the strongest indicators of context effects so far, the context was arranged to be either response dependent or

independent. The response independent subjects also served as a partial replication of Goldshmidt et al. (1998), where no context effects were found.

#### D. Experiment 5: Varying the Context Requirement

##### Method

**Subjects.** Four White Carneaux pigeons (*Columbia livia*) served as subjects (276, 298, 297, 879). All birds had an extensive prior history participating in operant conditioning experiments. Birds were maintained at approximately 80% of their free-feeding body weights and given supplemental feeding only if their weight reached 75% of their free-feeding body weight. Birds weighing more than 85% were withheld from experimental testing until their weight was below 85% of their free-feeding weight. Nutrient enriched-water and grit were freely available in the home cage that was located in a colony room with a regular 12:12 day/night cycle. Testing sessions were typically conducted six days a week at approximately the same time each day.

**Apparatus.** The experimental chambers were 30.5-cm long, 24.1-cm wide, and 29.2-cm high. Three plastic response keys, each approximately 2.5-cm in diameter were mounted on the front wall, 22-cm above the stainless steel grid floor. A force of 15 grams of pressure was required to operate each key, and produced audible feedback when contact with the microswitch was made. Visual stimuli were projected onto each key by an IEE 12-bulb projector mounted behind the front wall. A pellet receptacle measuring 5.1-cm wide and 5.1-cm high, and approximately 11-cm above the grid floor directly below the center key provided access to 45-mg pellets. During reinforcement, all stimuli were turned off except a 100 mA house light mounted on the back wall 27-cm above the grid floor. Each chamber was housed in a sound and light-

attenuating wooden box that contained a small ventilation fan which doubled as a white-noise stimulus. A Windows®-based computer in an adjacent room used MED-PC® software to control stimuli and record operant key-peck responses.

**Procedure.** Each session began with a block of either concurrent-chains (as described in Experiment 1) schedules or a block of fixed (interval or time) schedules ( $p = 0.5$ ). A block consisted of 4 consecutive trials ending in reinforcement. After the 4<sup>th</sup> trial, a block of the other type of schedule began, after which the blocks of schedules alternated regularly until either 48 reinforcements or 60 min elapsed. For example, if a session began with a concurrent-chains schedule, the first 4 trials would be concurrent-chains, while trials 5 through 8 would be fixed schedules. Trials 9 through 12 would be concurrent-chains, etc...

*Fixed Schedules.* The fixed interval (FI) schedules operated by scheduling a reinforcer for the first response made on the center key after a certain amount of time had elapsed. Only the center key was illuminated white. Schedule values could either be FI 20 s, 60 s, or 180 s, between conditions. Table 8 shows the order of schedule presentations for the FI schedules along with terminal link values for the 2 birds run in this condition. Fixed time (FT) schedules were the same as FI schedules, except no response was required to obtain reinforcement after the interval had timed out. Therefore, instead of center key illumination, a white houselamp located on the rear wall was illuminated during each block of trials during the FT schedule. Similar to the FI condition, schedule values could either be FI 20 s, 60 s, or 180 s, between FT conditions. Table 8 shows the order of schedule presentations for the FT schedules along with terminal link values for the 2 birds run in the FT condition.



Stability criteria were identical to those used in Experiments 1 through 4. If stability data was below 0.50 for the richer terminal link, the data was thrown out and that condition was replicated after the pigeon had reached stability in the other conditions. Eleven conditions in Experiment 5 were replicated.

### Results and Discussion

Figure 22 shows the choice proportion as a function of fixed schedule value for the mean data and each subject. A *t*-test showed the difference between the initial link relative response rates between the type of response to not be statistically significant ( $t(1) = 3.60, p = 0.08$ ). However, as there were only 2 subjects in each condition, the effect appeared to be quite pronounced, with overall initial link relative response rates much higher and differentiated across contexts in the FI group relative to the FT group. Both pigeons in the FI group showed the same pattern of relative response rates across contexts; the highest choice proportions occurred in the contexts with the highest rates of reinforcement. Conversely, there was either the opposite type of change in choice proportions across conditions (pigeon 297), or no discernible pattern at all (pigeon 879). Thus, it appeared that the context only had a systematic affect on choice proportions when reinforcement during the context was response-dependent.

Figure 23 shows initial link response rates as a function of fixed schedule values for each individual subject as well as the mean data. There was no statistically significant difference between the two types of response requirements. In general, both pigeons in the FI group showed increased rates of responding during the initial link relative to baseline. Pigeons in the FT condition did not show an increase in initial link response rate, and in some cases (pigeon 297) showed a decrease.

Figure 24 shows terminal link response rates as a function of fixed schedule value for individual subjects and the mean data. There was no significant difference between terminal link response rates between the type of response requirements ( $t(1) = 3.91, p = 0.06$ ), although the difference is just below the threshold for significance. Terminal link response rates were higher in the FI condition relative to the FT condition. Pigeons 276 and 879 both showed the same undifferentiated response rates that they displayed in the initial links. Pigeon 298 also showed a similar pattern, with the highest rates during the FI 60-s condition.

The results of Experiment 5 lend support to the notion that a response during the context is necessary to have an impact on choice proportions during the concurrent chains procedure. Also, the data from the two subjects in the response-dependent condition appeared to be more systematic than any of the choice proportion context effects from the first 4 experiments. Thus, by moving the response option to different physical location than the choice options any generalization between procedures in the first 4 experiments seemed to have been minimized. The results of the choice proportions with the pigeons in the FT condition were consistent with the results found by Goldshmidt et al. (1998). It seems that adding response-dependent reinforcement in the context caused an excitation in responding, as response rates in both the initial and terminal links were higher for the 2 subjects in the FI condition. Initial link response rates were nearly identical between the 2 groups during baseline conditions (see Table 8).

### III. GENERAL DISCUSSION

The present set of experiments explored the effects of manipulating reinforcement rates outside of a choice situation (i.e., the context) on a measure of preference in a concurrent-chains procedure: initial link relative response rates (choice proportions). Other measures during the concurrent-chains procedure, such as initial and terminal link response rates, were measured as additional evidence for a context effect. There are no predictions from any of the currently popular quantitative theories of choice about manipulating reinforcement rates outside of the concurrent-chains procedure and the impact on behavior internal to the procedure. However, changes in the choice proportions, and/or the initial and terminal link response rates were found in some of the present experiments. Although these results were not altogether systematic, salient trends were found that suggest a relationship between events internal and external to the concurrent chains procedure. However, before modifying each model of choice, additional evidence is needed of a contextual effect. The literatures on choice and rates of responding in multiple schedules have not generally overlapped. Therefore, experimental effects on choice proportions and response rates in the concurrent chains procedure will be treated separately.

In Experiments 2, 4 and 5 decreasing the rate of reinforcement outside of the concurrent chains procedure decreased choice proportions relative to conditions with richer rates of reinforcement. In Experiment 3, increasing the IBI, which is functionally analogous to extinction, decreased choice proportions below baseline levels. Experiment 1 provided the only clear null result. Save for Experiment 1, these results share a common theme of having extended time without reinforcement causing

decreased preference for the shorter chain in the concurrent chain schedule. As mentioned earlier, the first quantitative model of choice assumed that the sole determinant of choice in a concurrent chains procedure was the ratio of time to reinforcement in the two terminal link schedules, regardless the length of the initial length schedules (Herrnstein, 1964). Fantino's (1969) delay-reduction theory was created from results to the contrary, thus establishing more distal contingencies as effective modifiers of the value of primary reinforcers. Therefore, results of this kind are not without precedent.

However, establishing that reinforcement rates outside of the concurrent chains procedure effects choice proportions brings with it other questions. First, how large is the effect? Although a context effect was visible in both Experiments 2 and 4, the results were just below statistical significance, as one of the four pigeons in each experiment appeared to be relatively insensitive to the change in contexts.

Second, and related to the first is how reliable is the effect? Experiment 1 had a clear null result, yet these were the only subjects to be studied in each context condition twice; once with the shorter terminal link on each side key. In at least two of the pigeons a side key bias was evident which, when the two stability points were averaged together, resulted in a weaker effect. This bias is shown in Figure 25. These sorts of side biases were prevalent throughout the experiments, leading to the data in many conditions being thrown out. Thus, perhaps a procedural artifact of not randomizing the presentation of the initial link stimuli contributed to the statistically insignificant context effects in some of the pigeons. It is also possible that presenting both procedures on the same response keys decreased the pigeons' ability to

discriminate between both components of the multiple schedule. Evidence for this interpretation was presented in Experiment 5.

Lastly, and most important for a science of behavior is the question of why the context effect occurs. Each of the three quantitative theories of choice outlined in the introduction has a different view on what the critical variables that control value are. The current experiments were not designed to test differences between the models. However, each of the three models was designed using results from the same concurrent-chains procedure. Therefore, it may be useful to look more closely at how that procedure operates.

The essence of a chain schedule is a response-dependent contingency between each of the links. Taking away this response contingency between the initial and terminal links reduces the procedure to a simple concurrent schedule. Therefore, choice proportions should match relative reinforcement rates. Goldshmidt et al. (1998) found that response-independent manipulations to the time between primary reinforcement and the next occurrence of the initial links were ineffective in changing choice proportions. However, the response-dependent manipulations of some of the current experiments were effective in changing choice proportions. Thus, it appears that only response-reinforcement contingencies in the context affect value in the initial links. Removing this contingency leaves value to depend solely on the temporal association with a distant primary reinforcer.

The literature on behavioral contrast in multiple schedules appears to be incompatible with some of the outcomes of the present experiments. One of the strongest findings in behavioral contrast is that a sustained contrast effect is primarily

due to the schedule *following* an unchanged component (Williams, 1979, 1981; Williams and Wixted, 1986). Thus, a change in reinforcement rate for an impending schedule creates a reliable contrast effect on the unchanged schedule, whereas changing the reinforcement rate for the preceding schedule generally does not (see Flaherty, 1996; Williams, 2002 for reviews). In behavioral contrast experiments with multiple schedules, rates of primary reinforcement are manipulated in one of the components. For the current experiments, a behavioral contrast interpretation can be applied most directly to terminal link response rates, as each terminal link leads directly to primary reinforcement.

In Experiment 1 the block of simple concurrent schedules followed the block of concurrent chains. Consistent with positive behavioral contrast, a small non-significant increase in terminal link response rate was observed in Figure 5. In Experiment 2 the block of concurrent chains was followed by either a block of simple concurrent schedules or an IBI. However, as rate of reinforcement decreased, terminal link response rates also decreased, which is inconsistent with behavioral contrast. In Experiments 3 and 4 the block of concurrent chains was followed by a block of simple concurrent schedules and an IBI, respectively. A non-significant decrease in terminal link response rates as reinforcement rate in the context decreased was observed in Experiment 3, while no trend was apparent in Experiment 4. Thus, the only statistically significant finding was inconsistent with the theory of behavioral contrast.

There are many theories, but no consensus on why behavioral contrast occurs in multiple schedules. A common variable in some theories of contrast and choice is that response rates are indicative of levels of value for the unchanged component. A

higher rate of responding means the schedule is more valuable than in previous conditions. However, there is evidence that value may have more than one cause, each of which may be more likely to control response rates in certain situations (Williams and McDevitt, 2001). Thus, it is difficult to know precisely how response rates correspond to value. Taken together, the increase in terminal link response rates during the relatively richer context seems to suggest a general arousal effect throughout the session.

In summary, the present experiments explored whether or not response-dependent reinforcement affected behavior during a temporally separate concurrent chains procedure. Some of the present experiments provided evidence in the affirmative. Specifically, choice proportions increased with relatively richer contexts and decreased with relatively poorer contexts. Further experiments should focus on the replicating the present findings and extending the generality of contexts effects on other choice procedures, such as the successive encounters procedure.

Table 1

Experiment 1. Programmed schedule values for the simple concurrent blocks along with the side the shorter terminal link in the concurrent chains procedure was presented on. Also listed are trials to stability, mean reinforcements earned, initial link and concurrent relative response rates, and initial link, terminal link and simple concurrent response rates (responses/second).

Pigeon	Concurrent Schedule	VI 15-s TL	Trials	S <sup>R+</sup> / Session	IL Relative	Concurrent	IL	TL	Concurrent
					Response Rate	Response Rate	Response Rate	Response Rate	Response Rate
361	VI 120-s VI 120-s	Right	144	48.0	0.61	0.52	0.36	1.79	1.74
	VI 360-s VI 360-s	Right	64	23.6	0.62	0.51	2.23	2.02	1.79
	VI 120-s VI 120-s	Left	47	39.4	0.62	0.49	2.00	2.34	2.24
	VI 40-s VI 40-s	Right	33	47.1	0.66	0.44	0.98	1.73	1.52
	Baseline	Left	78	39.3	0.94	-	0.94	1.51	-
	Baseline	Right	26	42.7	0.71	-	0.86	1.57	-
	VI 360-s VI 360-s	Left	62	23.1	0.57	0.65	1.40	2.70	2.19
VI 40-s VI 40-s	Left	32	47.4	0.70	0.47	1.66	2.22	1.47	
524	VI 40-s VI 40-s	Right	176	48.0	0.92	0.44	2.99	2.69	3.25
	VI 360-s VI 360-s	Left	45	27.9	0.53	0.31	3.78	2.60	2.28
	VI 120-s VI 120-s	Right	25	46.4	0.79	0.31	4.12	3.14	2.80
	VI 360-s VI 360-s	Right	65	27.7	0.76	0.44	3.12	2.37	1.75
	VI 120-s VI 120-s	Left	30	43.7	0.54	0.49	2.86	2.16	1.48
	VI 40-s VI 40-s	Left	32	47.6	0.66	0.32	3.01	2.11	1.77
	Baseline	Right	29	42.7	0.77	-	3.43	2.40	-
Baseline	Left	26	41.4	0.67	-	3.67	2.12	-	
520	VI 120-s VI 120-s	Right	85	46.7	0.53	0.54	1.16	2.90	2.27
	VI 360-s VI 360-s	Left	26	39.7	0.61	0.44	1.48	2.78	1.41
	VI 120-s VI 120-s	Left	68	40.9	0.77	0.71	1.22	1.64	1.14
	VI 40-s VI 40-s	Right	33	48.0	0.57	0.43	1.74	1.71	1.55
	VI 40-s VI 40-s	Left	21	48.0	0.54	0.45	1.04	1.54	1.43
	Baseline	Right	23	38.8	0.55	-	1.09	2.07	-
	Baseline	Left	32	41.2	0.64	-	0.73	1.64	-
VI 360-s VI 360-s	Right	53	21.3	0.51	0.64	1.06	2.46	0.96	
364	VI 360-s VI 360-s	Left	29	39.9	0.85	0.70	0.88	2.73	1.45
	VI 40-s VI 40-s	Left	20	48.0	0.82	0.74	1.08	3.04	4.04
	VI 120-s VI 120-s	Left	24	45.8	0.80	0.72	1.56	2.29	3.64
	Baseline	Right	41	43.9	0.73	-	1.53	2.25	-
	Baseline	Left	29	42.3	0.53	-	1.44	2.56	-
	VI 40-s VI 40-s	Right	54	46.9	0.67	0.57	1.70	2.41	1.82
	VI 360-s VI 360-s	Right	72	21.2	0.83	0.49	1.41	2.11	1.60
VI 120-s VI 120-s	Right	62	38.2	0.93	0.58	1.91	1.69	1.73	



Table 2

Experiment 2. Programmed schedule values for the simple concurrent blocks along with the side the shorter terminal link in the concurrent chains procedure was presented on. Also listed are trials to stability, mean reinforcements earned, initial link and concurrent relative response rates, and initial link, terminal link and simple concurrent response rates (responses/second).

Pigeon	Concurrent Schedule	IBI	VI 15-s		SR+/ Session	IL Relative	Concurrent		TL	Concurrent
			TL	Trials		Response Rate	Response Rate	Response Rate	Response Rate	
408	VI 40-s VI 40-s	1	Right	60	48.0	0.84	0.43	0.99	2.80	1.93
	VI 120-s VI 120-s	30	Left	25	47.8	0.68	0.53	1.06	1.14	0.75
	VI 360-s VI 360-s	1	Right	81	48.0	0.55	0.57	0.83	1.16	0.63
	VI 40-s VI 40-s	30	Left	40	46.4	0.74	0.46	1.41	1.32	1.21
	VI 120-s VI 120-s	1	Right	29	45.2	0.69	0.49	1.34	1.57	1.34
	VI 40-s VI 40-s	60	Right	29	47.9	0.92	0.50	1.51	1.18	0.99
	VI 360-s VI 360-s	30	Right	22	26.1	0.64	0.52	1.34	1.45	1.15
	VI 360-s VI 360-s	60	Left	55	19.9	0.66	0.57	1.28	1.08	1.11
	VI 120-s VI 120-s	60	Left	25	27.3	0.79	0.00	1.18	1.13	0.79
	Baseline	1	Left	30	41.9	0.83	-	1.10	1.78	-
Baseline	1	Right	44	46.1	0.86	-	1.01	1.75	-	
281	VI 120-s VI 120-s	1	Right	87	43.4	0.87	0.32	0.79	1.01	1.67
	VI 360-s VI 360-s	1	Right	21	48.0	0.68	0.46	1.20	1.35	0.94
	VI 120-s VI 120-s	60	Left	62	36.0	0.88	0.44	1.60	0.85	1.91
	VI 40-s VI 40-s	1	Right	27	48.0	0.85	0.24	1.65	1.44	2.20
	VI 360-s VI 360-s	60	Left	77	21.7	0.70	0.25	1.34	0.76	1.69
	VI 120-s VI 120-s	30	Right	53	42.8	0.87	0.18	1.43	0.70	1.12
	VI 360-s VI 360-s	30	Right	114	22.0	0.81	0.18	0.14	0.67	1.13
	VI 360-s VI 360-s	30	Right	46	46.0	0.61	0.65	1.18	0.98	0.59
880	VI 120-s VI 120-s	60	Left	52	44.3	0.67	0.67	1.33	0.85	0.67
	VI 40-s VI 40-s	30	Right	35	47.2	0.65	0.53	1.43	0.98	1.32
	VI 360-s VI 360-s	1	Left	63	22.6	0.76	0.49	1.49	1.15	1.59
	VI 120-s VI 120-s	30	Right	33	40.4	0.75	0.39	1.39	1.15	1.79
	VI 40-s VI 40-s	60	Left	21	45.2	0.59	0.49	1.39	0.95	1.47
	VI 360-s VI 360-s	60	Right	50	25.8	0.63	0.49	1.36	1.11	2.46
	VI 120-s VI 120-s	1	Left	20	42.3	0.54	0.45	1.32	1.33	2.19
	VI 40-s VI 40-s	1	Left	30	47.1	0.73	0.40	1.36	1.04	1.27
	Baseline	1	Left	33	42.3	0.85	-	1.26	1.36	-
	Baseline	1	Right	21	44.0	0.51	-	1.14	1.46	-
333	VI 120-s VI 120-s	1	Left	37	47.8	0.84	0.47	0.76	1.62	1.11
	VI 360-s VI 360-s	30	Right	47	31.4	0.81	0.50	1.61	1.19	1.42
	VI 120-s VI 120-s	30	Right	41	47.6	0.75	0.67	1.74	1.38	0.86
	VI 40-s VI 40-s	60	Right	28	47.6	0.85	0.54	2.78	1.43	2.06
	VI 120-s VI 120-s	60	Left	31	35.1	0.50	0.57	1.88	1.37	2.30
	VI 360-s VI 360-s	1	Right	22	27.2	0.54	0.47	2.15	2.41	2.69
	VI 40-s VI 40-s	30	Left	22	46.7	0.61	0.44	2.41	2.08	2.43
	VI 40-s VI 40-s	1	Right	25	46.1	0.60	0.41	1.78	1.92	2.09
	VI 360-s VI 360-s	60	Left	37	21.4	0.50	0.42	1.94	1.41	1.60
	Baseline	1	Right	22	40.4	0.67	-	1.92	1.88	-
Baseline	1	Left	23	33.3	0.56	-	1.14	1.52	-	

Table 3

Experiment 2. Results of 3 X 3 (Context X Inter-Block Interval) ANOVA's for mean data in Experiment 2. The 5 variables tested included the relative response rate in the initial link and simple concurrent schedules, and response rates in the initial, terminal and simple concurrent schedules. Probability values are considered significant below the 0.05 level.

Pigeon	Y Variable	Effect	F-ratio	Prob > F
MEAN	Initial Link Relative Rate	Main: Context	3.0412	0.0905
		Main: IBI	0.0104	n.s.
		Interaction	0.1537	n.s.
	Simple Concurrent Relative Rate	Main: Context	0.1912	n.s.
		Main: IBI	0.1049	n.s.
		Interaction	1.6339	n.s.
	Initial Link Response Rate	Main: Context	0.7249	n.s.
		Main: IBI	4.1335	0.0501
		Interaction	1.2340	n.s.
	Terminal Link Response Rate	Main: Context	1.1988	n.s.
		Main: IBI	7.9533	0.0081
		Interaction	0.1122	n.s.
	Simple Conc Response Rate	Main: Context	0.5898	n.s.
		Main: IBI	0.1152	n.s.
		Interaction	1.1719	n.s.

Table 4

Experiment 3. Programmed schedule values for the simple concurrent blocks along with the side the shorter terminal link in the concurrent chains procedure was presented on. Also listed are trials to stability, mean reinforcements earned, initial link and concurrent relative response rates, and initial link, terminal link and simple concurrent response rates (responses/second).

Pigeon	Concurrent Schedule	IBI	VI 15-s TL	Trials	SR+/ Session	Concurrent				
						IL Relative Response Rate	Relative Response Rate	IL Response Rate	TL Response Rate	Concurrent Response Rate
881	VI 120-s VI 120-s	1	Left	51	42.1	0.76	0.49	1.23	1.55	2.41
	VI 40-s VI 40-s	30	Right	28	47.1	0.54	0.48	1.43	1.10	1.51
	VI 360-s VI 360-s	1	Left	32	26.9	0.69	0.44	1.46	1.53	2.35
	VI 120-s VI 120-s	30	Right	37	39.6	0.59	0.47	1.68	1.29	1.90
	VI 360-s VI 360-s	30	Right	25	27.7	0.57	0.55	1.40	1.11	1.97
	VI 120-s VI 120-s	60	Left	37	35.8	0.56	0.67	1.26	0.91	1.44
	VI 360-s VI 360-s	60	Left	67	23.9	0.57	0.58	1.56	1.28	1.47
	VI 40-s VI 40-s	60	Left	38	46.4	0.60	0.52	1.37	0.97	0.98
	VI 40-s VI 40-s	1	Right	38	48.0	0.51	0.63	1.30	1.45	1.00
	Baseline	1	Right	31	47.8	0.87	-	1.53	1.43	-
Baseline	1	Left	27	36.2	0.56	-	1.47	2.22	-	
876	VI 40-s VI 40-s	1	Left	24	47.3	0.66	0.34	1.57	1.59	2.06
	VI 120-s VI 120-s	1	Right	42	42.1	0.53	0.35	2.52	2.33	1.98
	VI 40-s VI 40-s	60	Right	45	45.4	0.68	0.49	1.50	0.95	1.52
	VI 360-s VI 360-s	1	Right	65	26.3	0.52	0.61	2.22	1.90	2.56
	VI 40-s VI 40-s	30	Left	38	47.2	0.56	0.36	1.48	0.85	1.77
	VI 120-s VI 120-s	60	Right	48	37.0	0.59	0.33	1.72	0.94	2.15
	VI 360-s VI 360-s	30	Left	50	25.2	0.52	0.43	1.83	1.28	2.08
	VI 120-s VI 120-s	30	Left	21	43.3	0.52	0.40	1.95	1.31	2.50
	Baseline	1	Right	24	37.0	0.55	-	1.32	1.02	-
	VI 360-s VI 360-s	60	Left	22	25.6	0.52	0.47	1.26	0.74	1.87
Baseline	1	Left	32	39.6	0.67	-	0.96	0.86	-	
882	VI 40-s VI 40-s	60	Right	23	46.1	0.58	0.52	0.70	0.55	0.80
	VI 40-s VI 40-s	1	Right	25	45.3	0.63	0.51	0.33	0.53	0.47
	VI 120-s VI 120-s	60	Left	44	39.2	0.59	0.49	0.72	0.44	0.95
	VI 360-s VI 360-s	60	Right	38	22.2	0.61	0.44	0.79	0.53	1.04
	VI 360-s VI 360-s	30	Left	71	24.2	0.59	0.33	0.82	0.53	0.70
	VI 120-s VI 120-s	1	Right	28	40.8	0.54	0.32	0.97	0.56	0.88
	VI 40-s VI 40-s	30	Left	26	44.1	0.57	0.44	0.84	0.49	0.69
	VI 120-s VI 120-s	30	Left	51	37.3	0.61	0.41	0.69	0.55	0.85
	Baseline	1	Right	21	39.3	0.59	-	0.73	0.58	-
	Baseline	1	Left	29	38.7	0.54	-	0.80	0.56	-
VI 360-s VI 360-s	1	Left	122	26.3	0.64	0.46	0.56	0.56	0.72	
878	VI 40-s VI 40-s	30	Left	39	46.3	0.58	0.75	1.42	0.89	1.42
	VI 40-s VI 40-s	1	Left	39	46.1	0.69	0.76	0.97	0.76	0.88
	VI 40-s VI 40-s	60	Right	20	45.4	0.57	0.70	1.09	0.44	0.76
	VI 120-s VI 120-s	1	Right	23	41.4	0.54	0.53	1.35	0.87	1.04
	VI 120-s VI 120-s	30	Left	34	39.6	0.59	0.57	1.48	0.75	1.24
	VI 360-s VI 360-s	1	Left	24	22.2	0.59	0.62	1.27	0.83	1.07
	VI 360-s VI 360-s	30	Right	36	19.7	0.51	0.44	1.39	0.57	0.71
	VI 360-s VI 360-s	60	Left	56	23.6	0.53	0.49	1.00	0.44	0.65
	Baseline	1	Left	30	37.3	0.62	-	1.10	0.76	-
	VI 120-s VI 120-s	60	Right	40	36.6	0.72	0.48	1.20	0.57	0.72
Baseline	1	Right	23	42.9	0.74	-	0.75	0.63	-	

Table 5

Experiment 3. Results of 3 X 3 (Context X Inter-Block Interval) ANOVA's for mean data in Experiment 2. The 5 variables tested included the relative response rate in the initial link and simple concurrent schedules, and response rates in the initial, terminal and simple concurrent schedules. Probability values are considered significant below the 0.05 level.

Pigeon	Y Variable	Effect	F-ratio	Prob > F
MEAN	Initial Link Relative Rate	Main: Context	0.0001	n.s.
		Main: IBI	4.3911	0.0432
		Interaction	1.2504	n.s.
	Simple Concurrent Relative Rate	Main: Context	0.6267	n.s.
		Main: IBI	0.5303	n.s.
		Interaction	0.5814	n.s.
	Initial Link Response Rate	Main: Context	0.5797	n.s.
		Main: IBI	0.2499	n.s.
		Interaction	0.8170	n.s.
	Terminal Link Response Rate	Main: Context	0.1742	n.s.
		Main: IBI	7.0432	0.0118
		Interaction	0.1128	n.s.
	Simple Conc Response Rate	Main: Context	0.6542	n.s.
		Main: IBI	1.0627	n.s.
		Interaction	0.2828	n.s.

Table 6

Experiment 4. Programmed schedule values for the simple concurrent blocks along with the side the shorter terminal link in the concurrent chains procedure was presented on. Also listed are trials to stability, mean reinforcements earned, initial link and concurrent relative response rates, and initial link, terminal link and simple concurrent response rates (responses/second).

Pigeon	Concurrent Schedule		IBI	VI 15-s TL	Trials	SR+/ Session	Concurrent			Concurrent Response Rate	
							IL Response Rate	Relative Response Rate	IL Response Rate		
285	VI 120-s	VI 120-s	1	Left	22	40.3	0.61	0.42	1.41	1.58	2.21
	VI 40-s	VI 40-s	30	Right	27	48.0	0.61	0.60	1.63	1.45	2.38
	VI 360-s	VI 360-s	1	Left	30	22.8	0.59	0.51	1.58	1.83	2.44
	VI 120-s	VI 120-s	30	Right	30	42.3	0.67	0.47	1.83	1.43	2.62
	VI 40-s	VI 40-s	60	Left	38	46.6	0.58	0.57	1.69	1.34	2.28
	VI 120-s	VI 120-s	60	Left	20	38.0	0.54	0.52	1.59	1.42	2.22
	VI 40-s	VI 40-s	1	Right	39	39.1	0.76	0.58	0.68	0.93	1.11
	VI 40-s	VI 40-s	1	Left	20	47.9	0.56	0.42	1.54	1.92	2.31
	VI 120-s	VI 120-s	1	Right	82	43.4	0.58	0.36	2.05	1.82	3.05
	VI 360-s	VI 360-s	60	Left	54	20.4	0.54	0.50	2.08	1.44	2.82
	VI 40-s	VI 40-s	60	Right	21	44.0	0.62	0.39	2.79	2.02	2.21
	VI 40-s	VI 40-s	30	Left	24	47.8	0.58	0.40	3.31	2.16	2.11
417	VI 120-s	VI 120-s	60	Right	56	42.1	0.57	0.55	2.19	1.69	2.21
	VI 360-s	VI 360-s	30	Left	65	22.4	0.56	0.52	2.15	1.84	2.06
	VI 360-s	VI 360-s	1	Right	26	24.8	0.51	0.56	2.89	2.02	1.91
	VI 120-s	VI 120-s	30	Left	44	47.7	0.87	0.65	2.73	1.57	1.61
	Baseline		1	Right							
	Baseline		1	Left							
	VI 40-s	VI 40-s	60	Right	59	46.1	0.71	0.59	1.31	0.83	1.05
	VI 40-s	VI 40-s	1	Right	23	48.0	0.83	0.50	1.21	0.90	0.78
	VI 120-s	VI 120-s	60	Left	33	37.9	0.54	0.39	1.18	0.91	0.96
	VI 360-s	VI 360-s	60	Right	43	23.0	0.59	0.51	0.81	0.86	0.56
	VI 360-s	VI 360-s	30	Left	27	20.3	0.54	0.65	0.99	0.95	0.63
412	VI 120-s	VI 120-s	1	Right	55	40.0	0.83	0.53	1.45	0.80	0.81
	VI 360-s	VI 360-s	1	Left	53	21.0	0.62	0.39	0.95	1.07	0.91
	VI 120-s	VI 120-s	30	Left	40	43.2	0.60	0.52	1.82	1.36	1.32
	VI 40-s	VI 40-s	30	Left	20	47.7	0.51	0.60	2.05	1.53	1.49
	Baseline		1	Left	40	46.0	0.57	-	1.82	1.23	-
	Baseline		1	Right	49	44.8	0.50	-	1.64	1.44	-
	VI 40-s	VI 40-s	30	Left	29	47.4	0.61	0.50	1.46	1.10	1.56
	VI 40-s	VI 40-s	1	Right	23	47.8	0.51	0.45	1.66	1.72	1.79
	VI 120-s	VI 120-s	1	Right	27	37.7	0.54	0.47	1.31	0.96	1.60
	VI 120-s	VI 120-s	30	Left	32	40.6	0.52	0.52	0.82	0.84	1.74
	VI 360-s	VI 360-s	1	Left	21	21.3	0.62	0.68	1.16	1.06	1.11
413	VI 360-s	VI 360-s	60	Left	42	19.4	0.50	0.45	1.26	0.71	1.35
	Baseline		1	Right	24	40.6	0.54	-	0.83	0.85	-
	Baseline		1	Left	36	40.6	0.73	-	0.97	0.59	-
	VI 40-s	VI 40-s	60	Left	25	43.4	0.78	0.44	0.89	0.60	1.16
	VI 120-s	VI 120-s	60	Right	41	38.0	0.56	0.71	1.88	1.18	2.08
	VI 360-s	VI 360-s	30	Right	121	24.4	0.61	0.39	1.53	1.12	1.38

Table 7

Experiment 4. Results of 3 X 3 (Context X Inter-Block Interval) ANOVA's for mean data and individual subjects in Experiment 2. The 5 variables tested included the relative response rate in the initial link and simple concurrent schedules, and response rates in the initial, terminal and simple concurrent schedules. Probability values are considered significant below the 0.05 level.

Pigeon	Y Variable	Effect	F-ratio	Prob > F
MEAN	Initial Link Relative Rate	Main: Context	2.6386	0.1141
		Main: IBI	0.5049	n.s.
		Interaction	0.3638	n.s.
	Simple Concurrent Relative Rate	Main: Context	0.1048	n.s.
		Main: IBI	0.5369	n.s.
		Interaction	0.9374	n.s.
	Initial Link Response Rate	Main: Context	0.2144	n.s.
		Main: IBI	0.4065	n.s.
		Interaction	1.3176	n.s.
	Terminal Link Response Rate	Main: Context	0.0300	n.s.
		Main: IBI	0.6615	n.s.
		Interaction	1.4909	n.s.
	Simple Conc Response Rate	Main: Context	0.6619	n.s.
		Main: IBI	0.0178	n.s.
		Interaction	0.0454	n.s.

Table 8

Experiment 5. Programmed schedule values for the fixed interval (FI) or fixed time (FT) blocks along with the side the shorter terminal link in the concurrent chains procedure was presented on. Also listed are trials to stability, mean reinforcements earned, initial link and concurrent relative response rates, and initial link and terminal link response rates (responses/second).

Pigeon	FI/FT Schedule	VI 15-s TL	Trial	S <sup>R+</sup> /Session	IL Relative Response Rate	IL Response Rate	TL Response Rate
276	Baseline	Right	53	42.3	0.64	0.76	1.35
	FI 20-s	Left	63	47.7	0.87	0.88	1.09
	FI 60-s	Left	36	45.2	0.92	0.81	1.26
	FI 180-s	Left	28	26.0	0.67	0.66	1.11
	FI 60-s	Right	29	47.7	0.74	0.94	1.26
	FI 180-s	Right	29	32.0	0.92	1.05	1.17
	FI 20-s	Right	37	46.9	0.97	1.08	1.30
	Baseline	Left	77	43.2	0.58	0.60	1.22
298	FI 180-s	Left	33	28.0	0.65	1.40	2.27
	FI 20-s	Right	27	48.0	0.69	1.44	2.65
	FI 180-s	Right	25	27.6	0.53	2.13	3.31
	FI 20-s	Left	39	48.0	0.70	2.01	3.57
	FI 60-s	Left	48	48.0	0.63	1.90	3.88
	FI 60-s	Right	27	45.7	0.59	2.08	4.23
	Baseline	Right	48	45.3	0.65	1.22	2.67
	Baseline	Left	34	44.1	0.52	1.28	1.88
297	Baseline	Left	59	44.8	0.58	1.45	1.46
	FT 20-s	Left	73	48.0	0.60	1.35	1.49
	FT 180-s	Left	45	26.9	0.57	0.57	1.54
	FT 60-s	Left	78	45.3	0.62	1.07	1.54
	FT 180-s	Right	104	29.3	0.73	1.74	2.44
879	Baseline	Left	24	41.0	0.62	0.65	0.91
	FT 180-s	Left	20	26.3	0.61	0.84	1.27
	FT 60-s	Right	41	45.9	0.52	0.73	1.62
	FT 20-s	Left	49	46.7	0.65	0.64	1.13
	FT 180-s	Right	61	26.1	0.70	0.73	1.29
	FT 60-s	Left	26	46.6	0.57	0.72	1.06
	FT 20-s	Right	25	48.0	0.63	0.76	1.13
	Baseline	Right	32	43.2	0.78	0.68	0.91

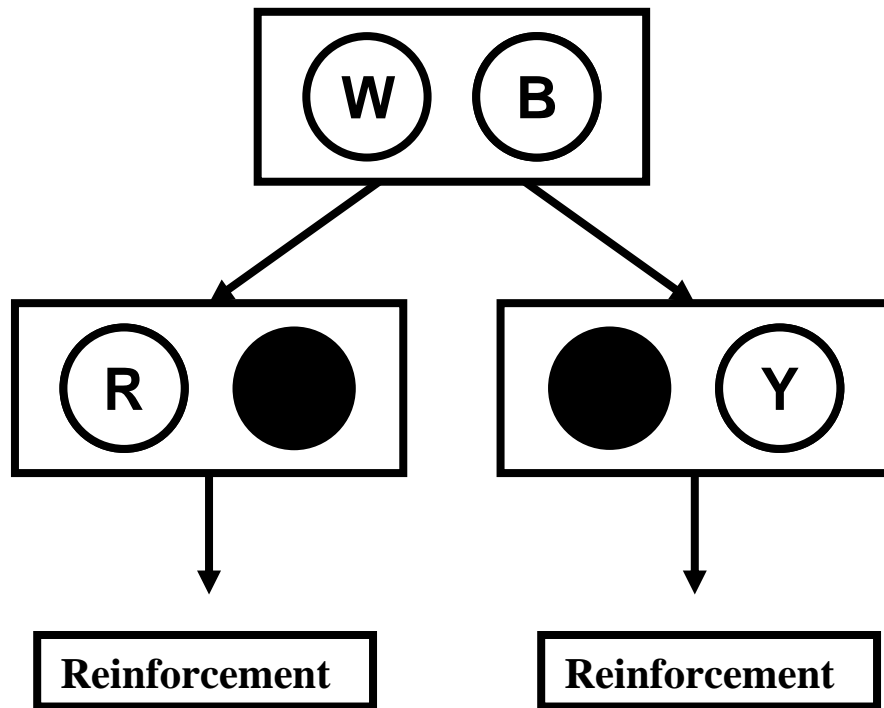


Figure 1

Schematic of standard concurrent-chains procedure. Top box represents initial link response options, with W = white key light and B = blue key light. Programmed schedules of reinforcement in the initial link are equal VI schedules. Bottom boxes represent mutually exclusive terminal link response options, where R = red key light and Y = yellow key light. Programmed schedules of reinforcement in the terminal links can be any type of schedule. Completion of either terminal link schedule ends in reinforcement, after which the initial links are reinstated. In each experiment in this dissertation the initial links were equal VI 60-s schedules of reinforcement and the terminal links were VI 15-s and VI 45-s schedules of reinforcement, counterbalanced on the left and right sides.



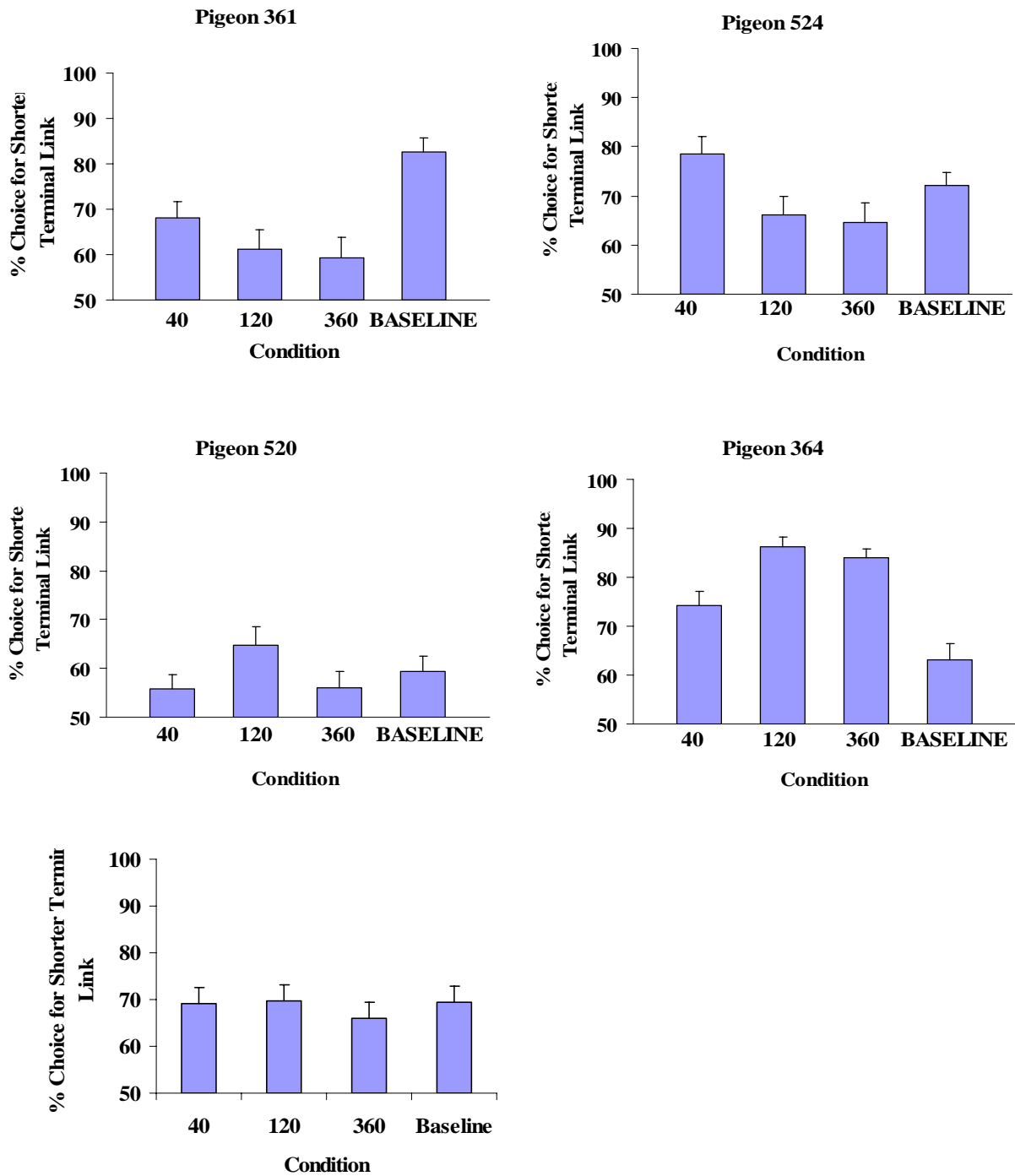


Figure 2

Experiment 1. Relative response rate for the initial link leading to the shorter (VI 15-s) terminal link schedule for each of the 4 subjects and the mean. Vertical bars represent the standard error.

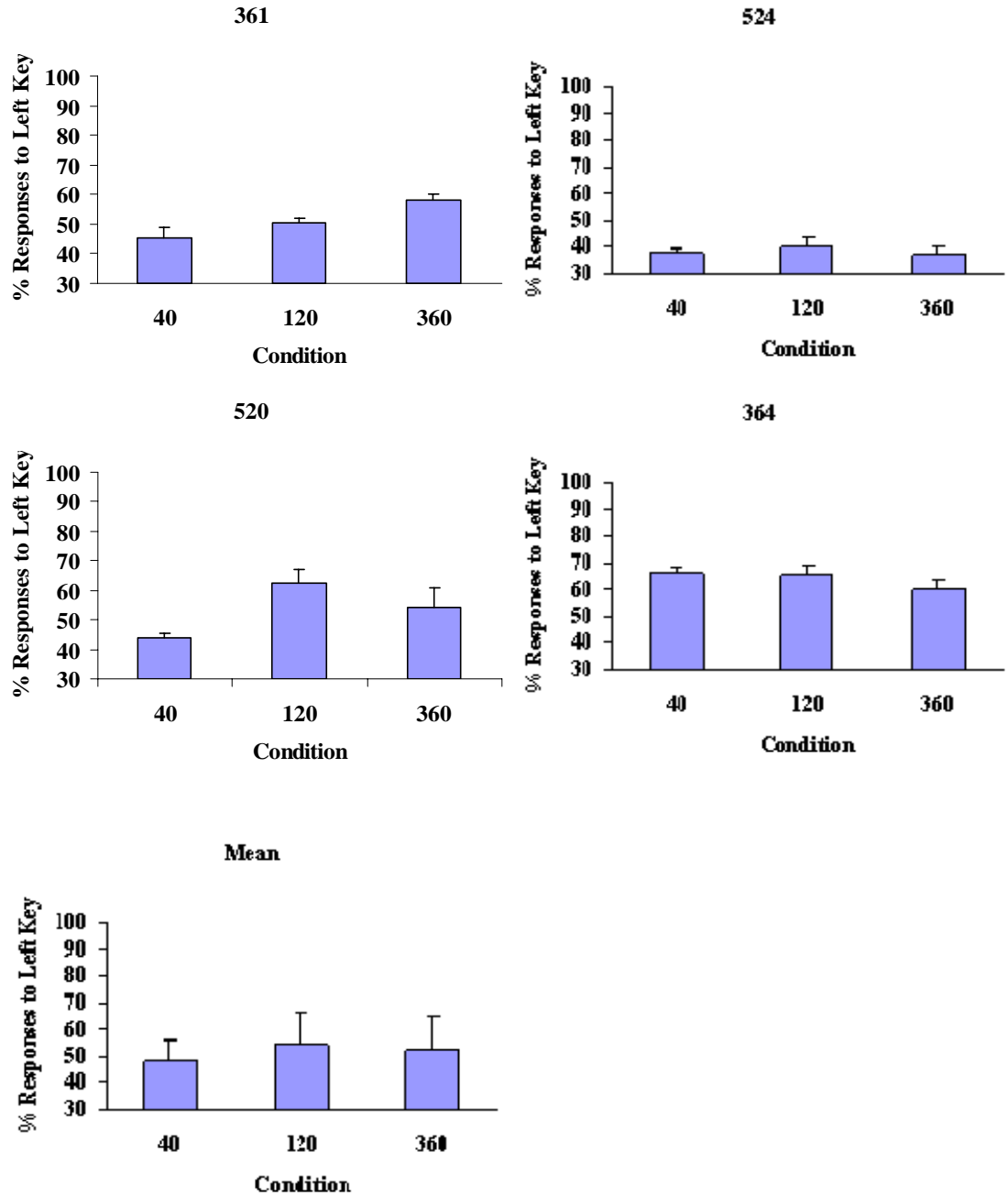


Figure 3

Experiment 1. Mean relative response rate for the left key during the simple concurrent schedule of reinforcement across 4 subjects for each condition. Vertical bars represent the standard error.

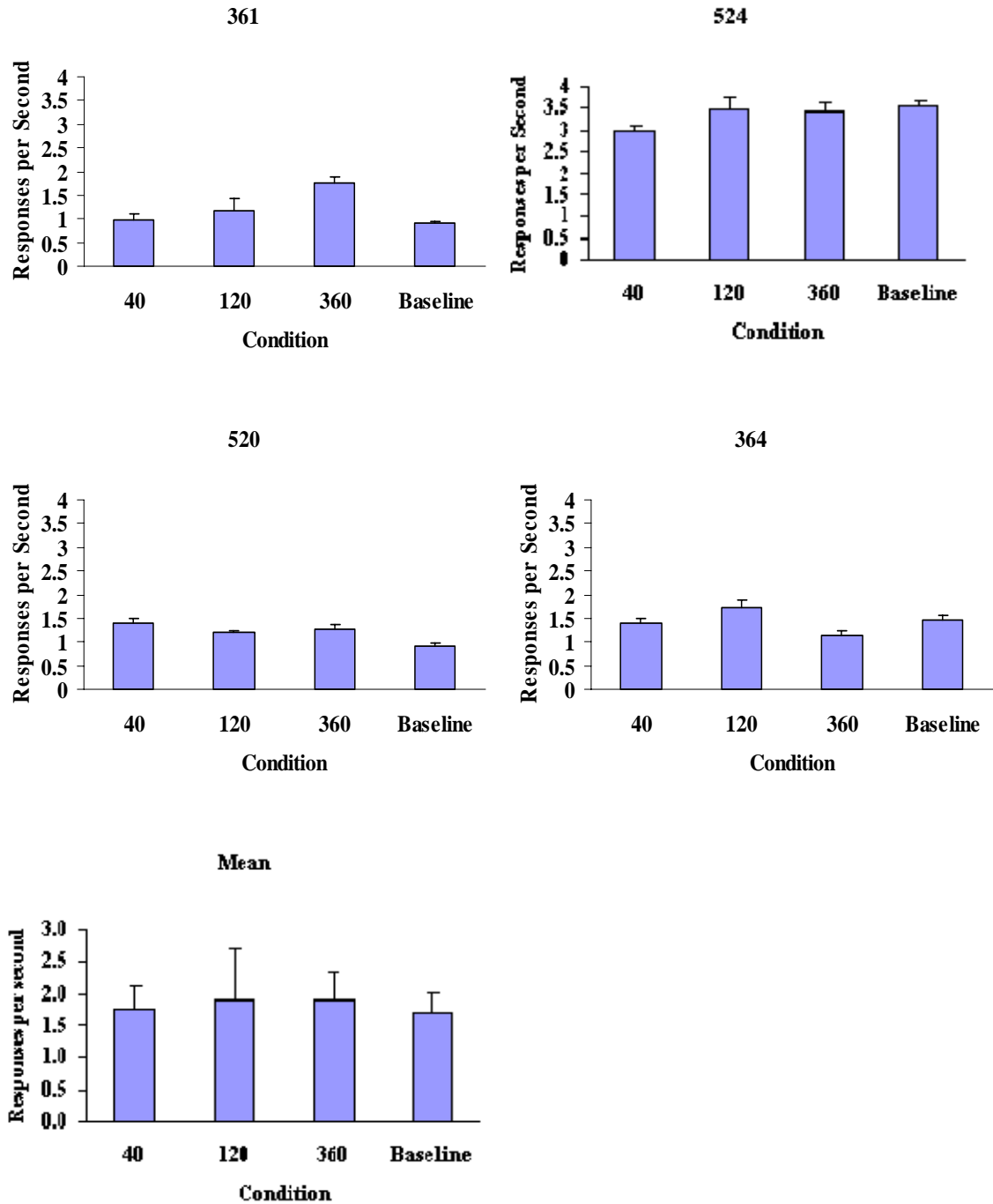


Figure 4

Experiment 1. Mean initial link response rate across 4 subjects for each condition. Vertical bars represent the standard error.

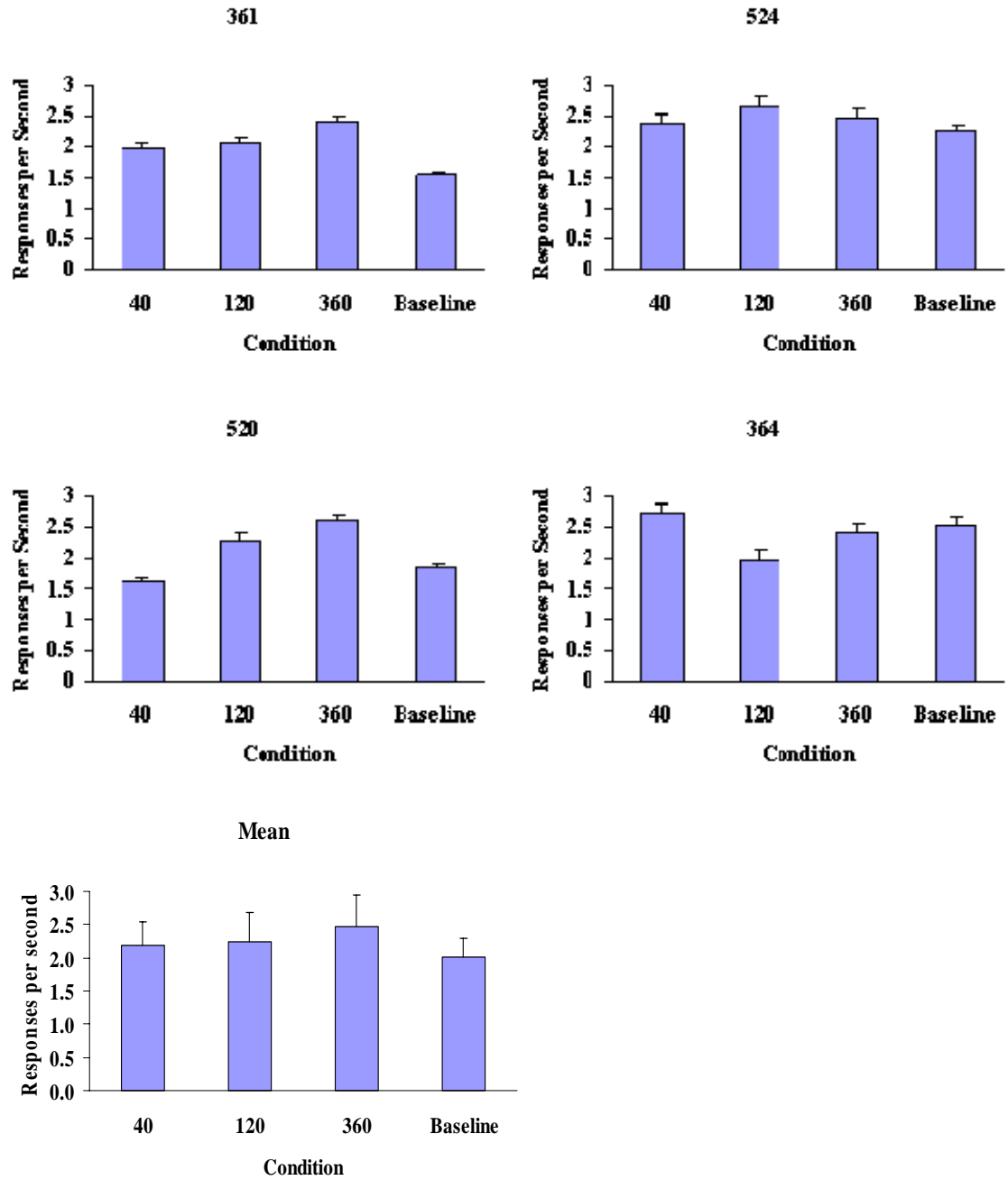


Figure 5

Experiment 1. Mean terminal link response rate across 4 subjects for each condition. Vertical bars represent the standard error.

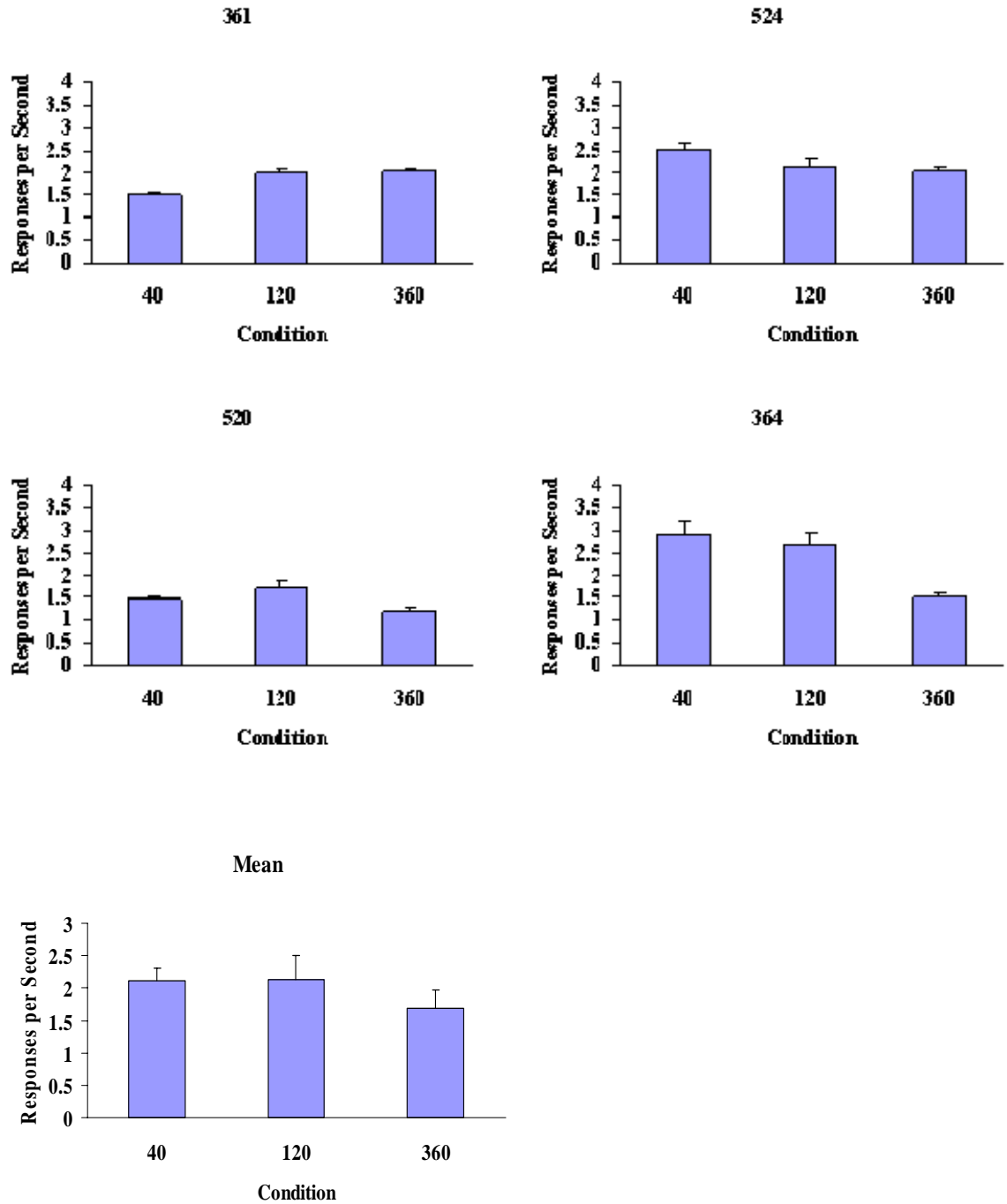


Figure 6

Experiment 1. Mean simple concurrent response rate across 4 subjects for each condition. Vertical bars represent the standard error.

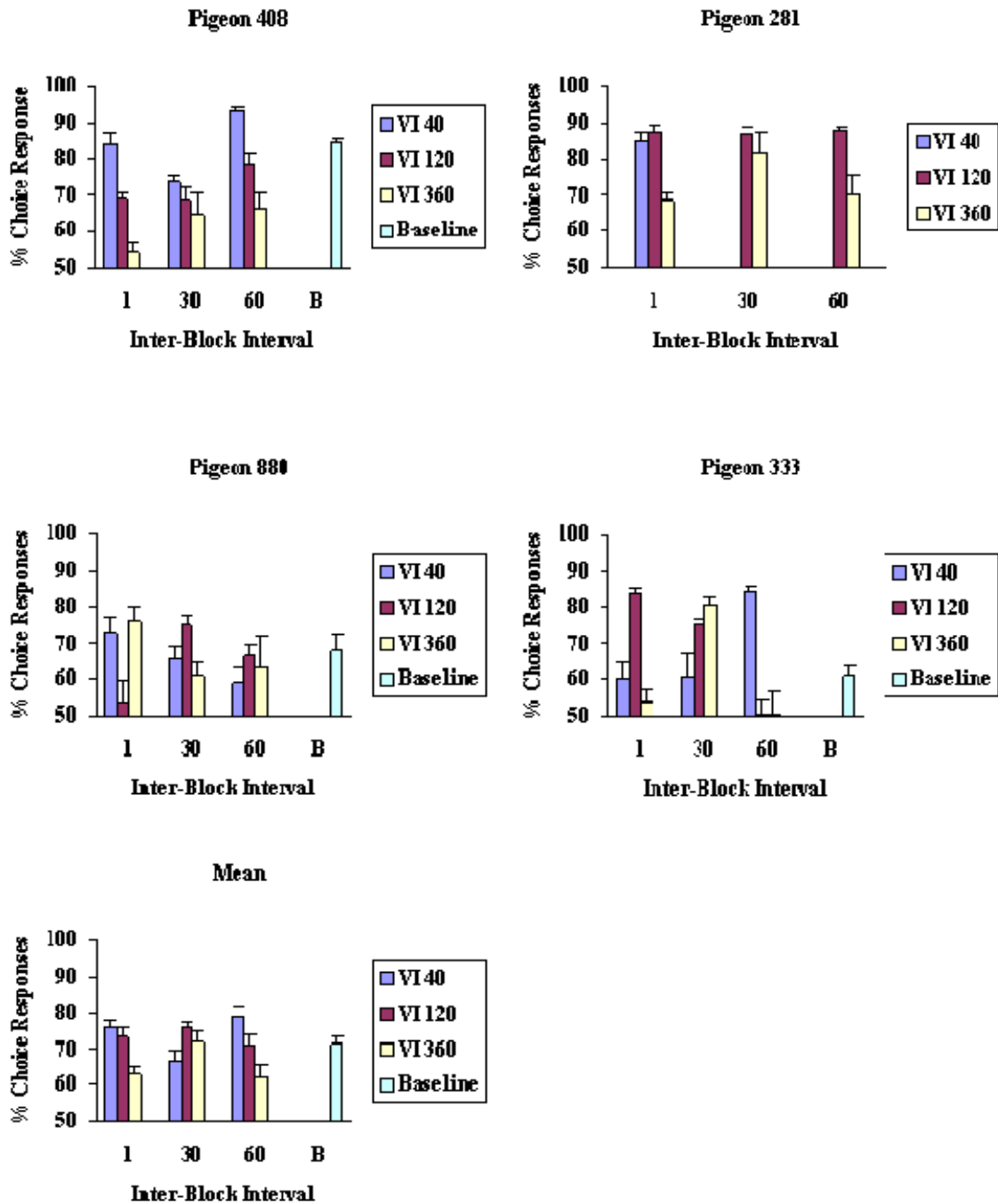


Figure 7

Experiment 2. Relative response rate for the initial link leading to the shorter (VI 15-s) terminal link schedule for each of the 4 subjects and the mean. Vertical bars represent the standard error.

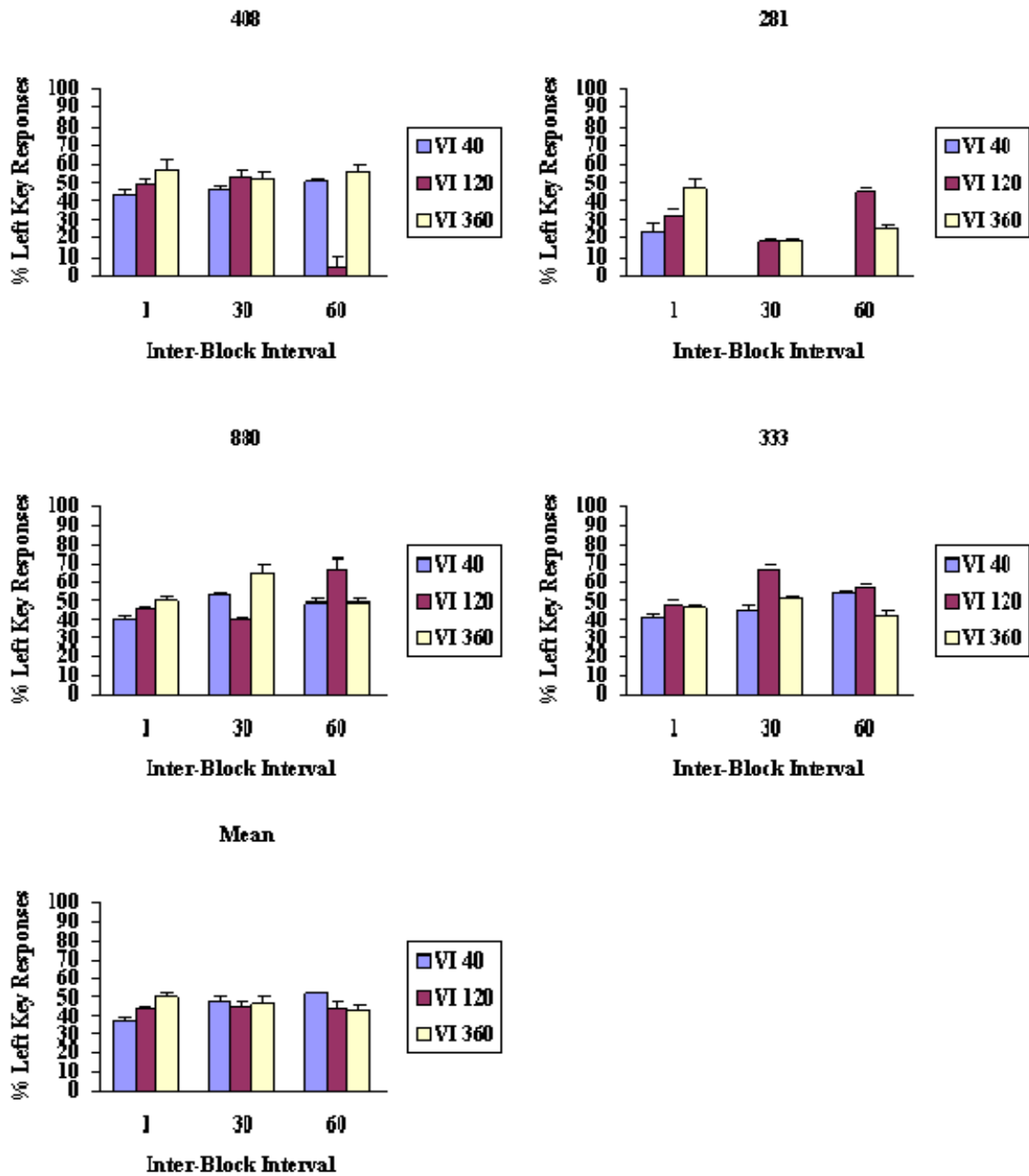


Figure 8

Experiment 2. Mean relative response rate for the left key during the simple concurrent schedule of reinforcement across 4 subjects for each condition. Vertical bars represent the standard error.

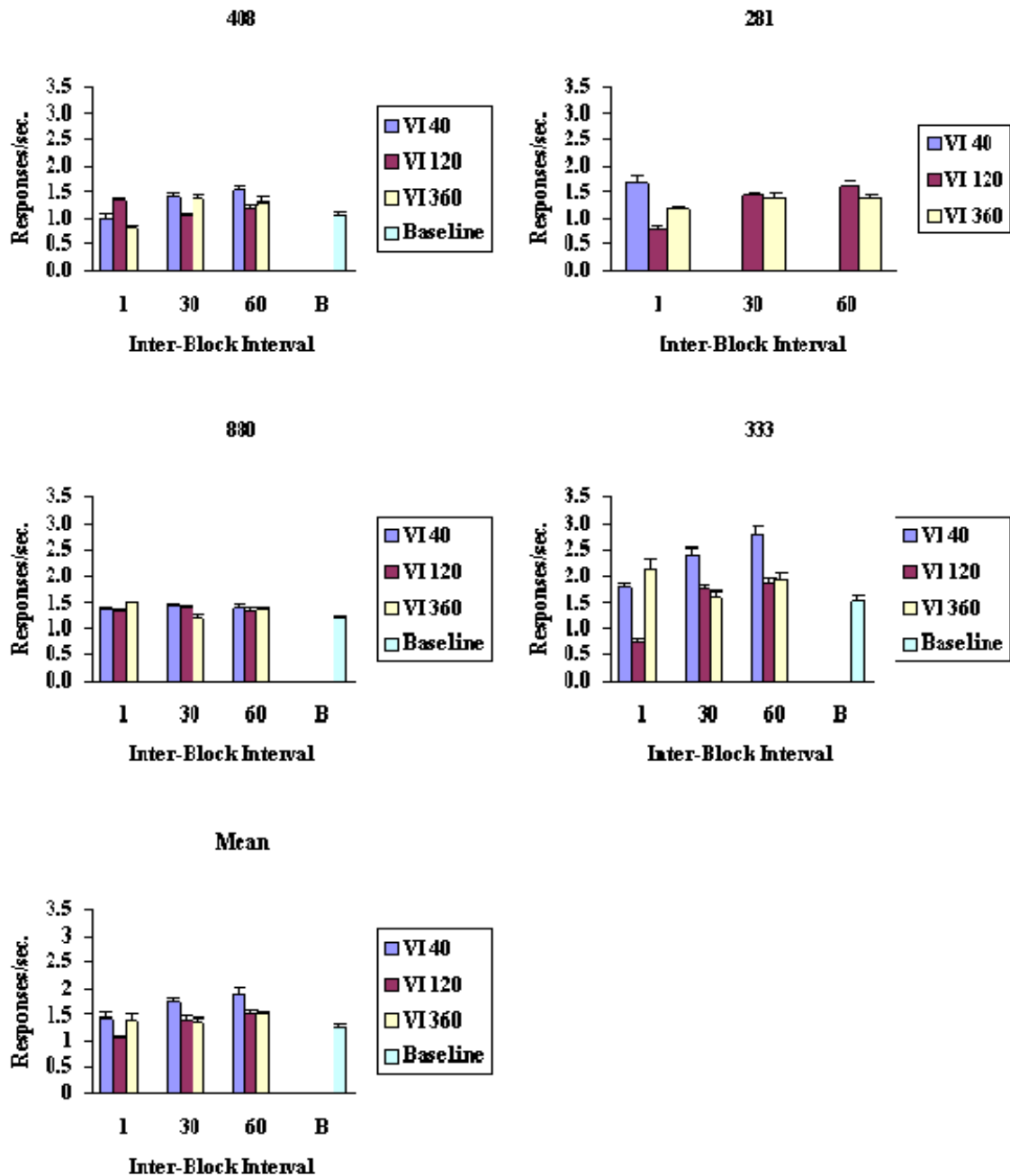


Figure 9

Experiment 2. Mean initial link response rate across 4 subjects for each condition. Vertical bars represent the standard error.



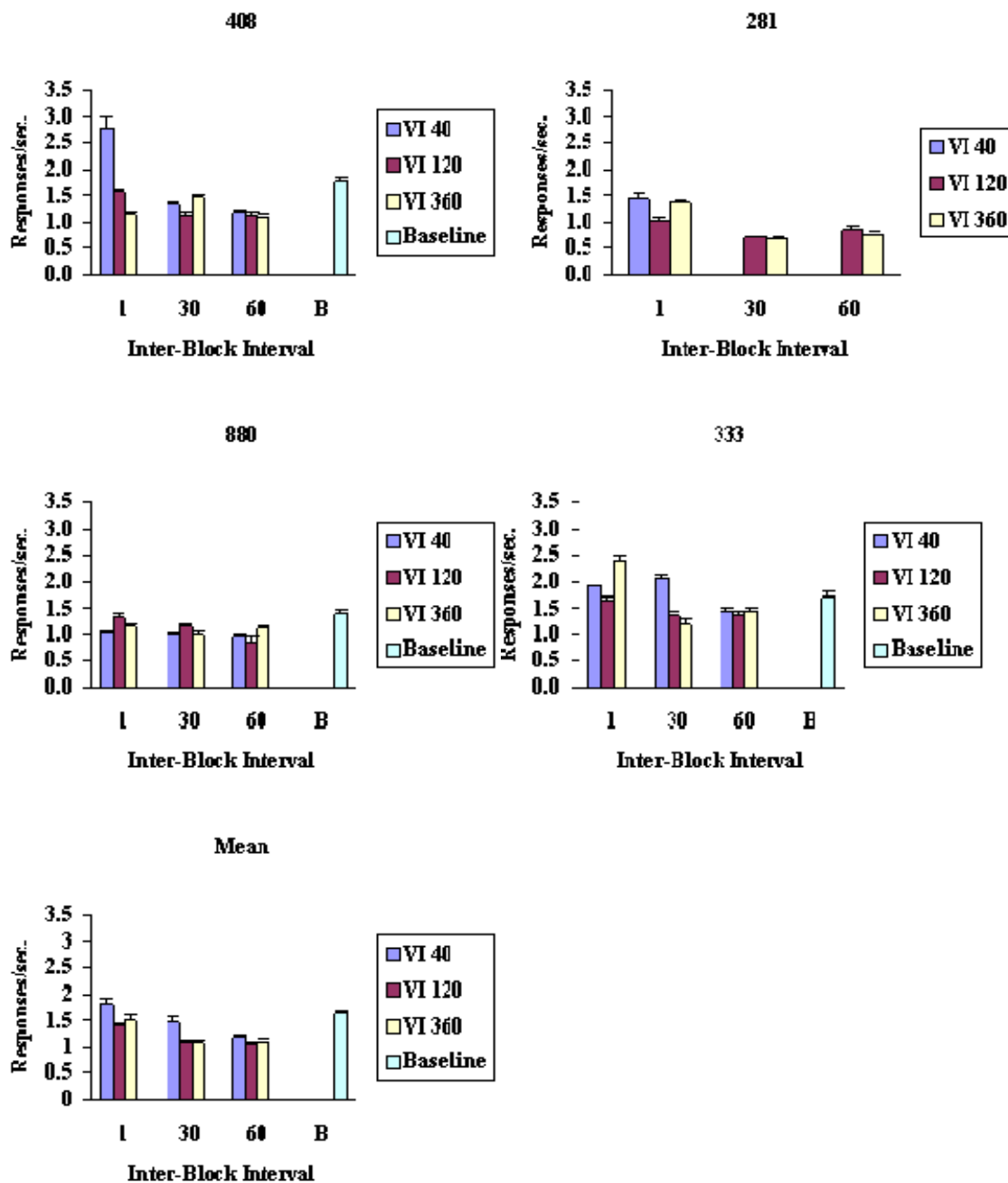


Figure 10

Experiment 2. Mean terminal link response rate across 4 subjects for each condition. Vertical bars represent the standard error.

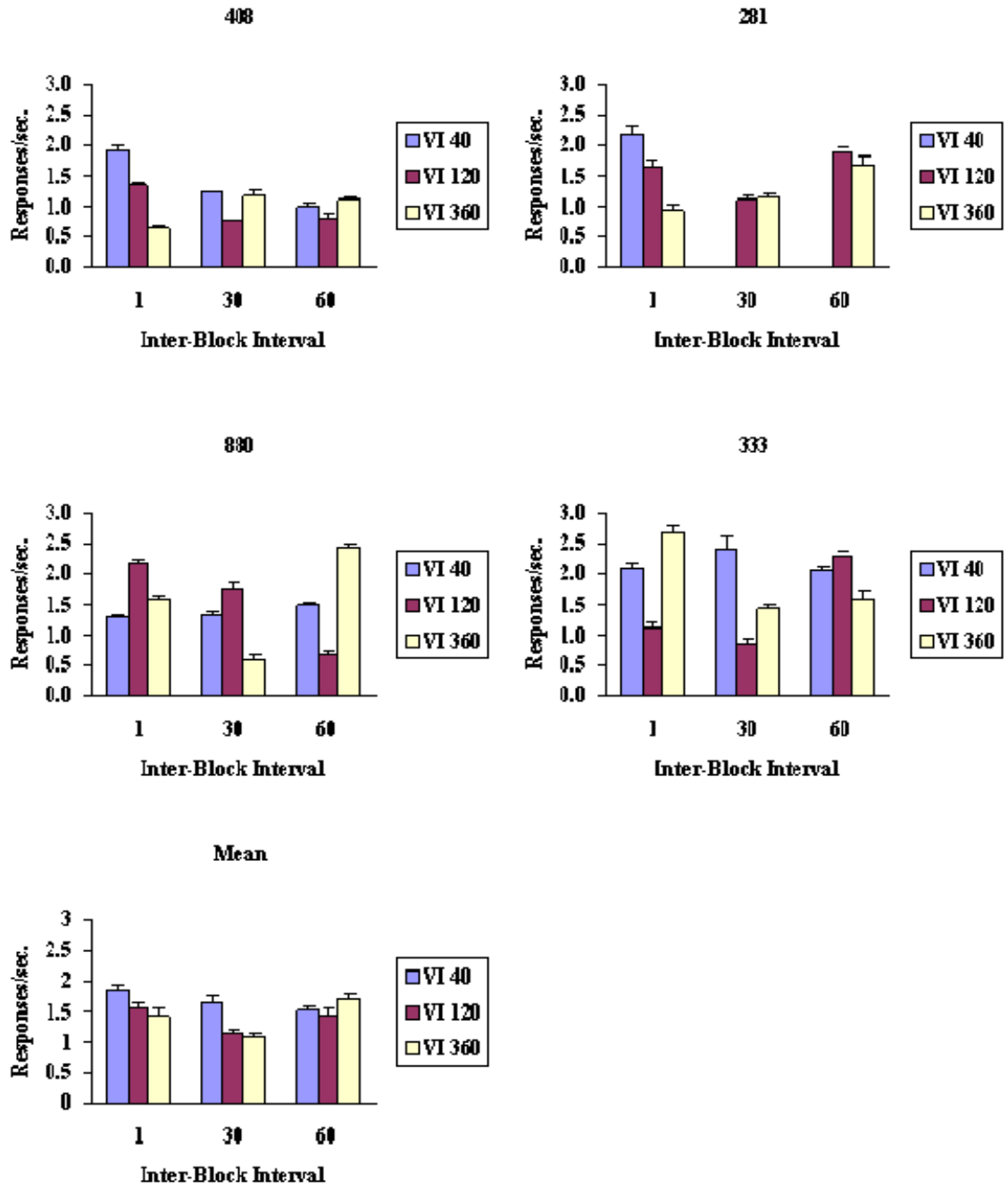


Figure 11

Experiment 2. Mean simple concurrent response rate across 4 subjects for each condition. Vertical bars represent the standard error.

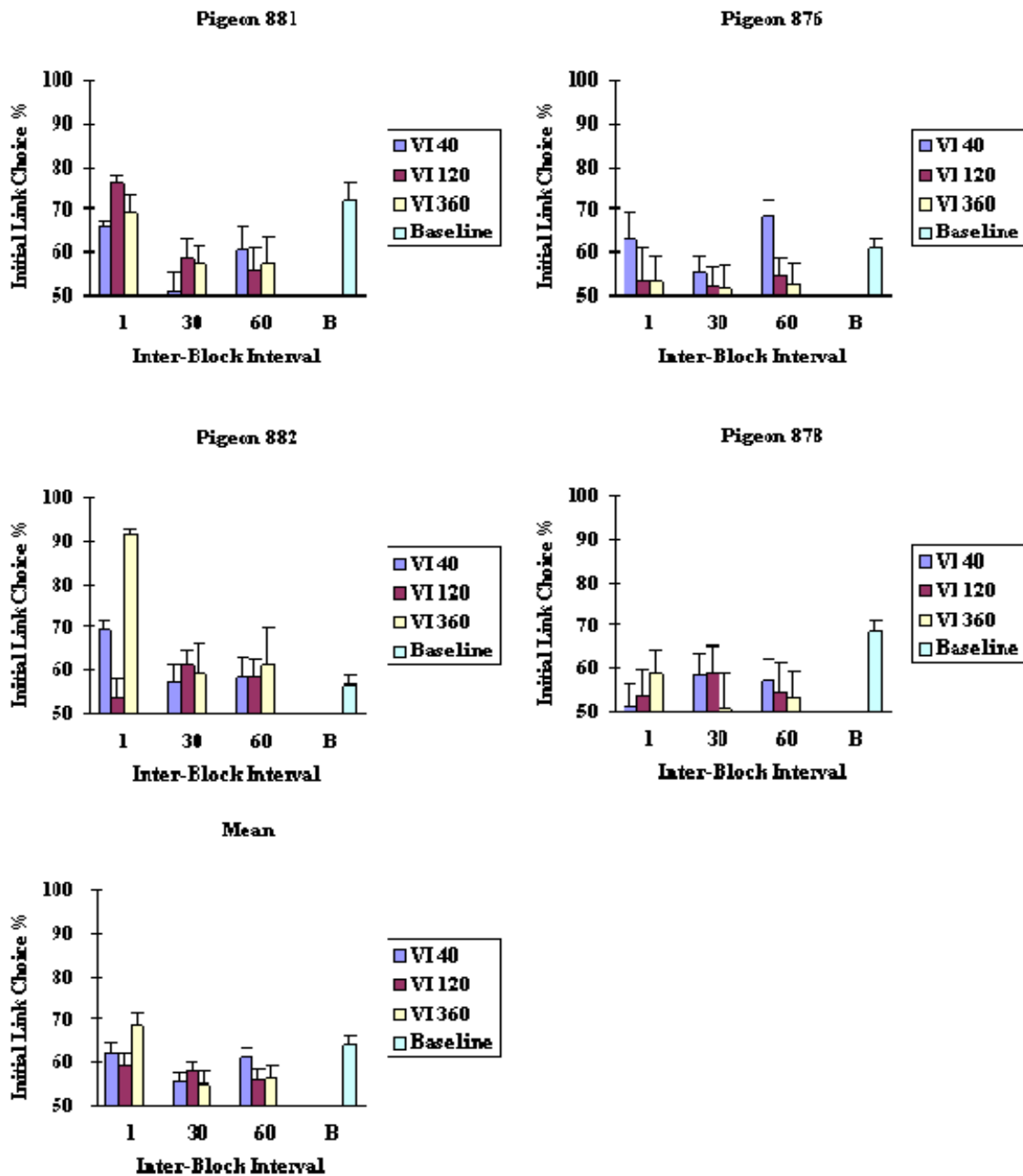


Figure 12

Experiment 3. Relative response rate for the initial link leading to the shorter (VI 15-s) terminal link schedule for each of the 4 subjects and the mean. Vertical bars represent the standard error.

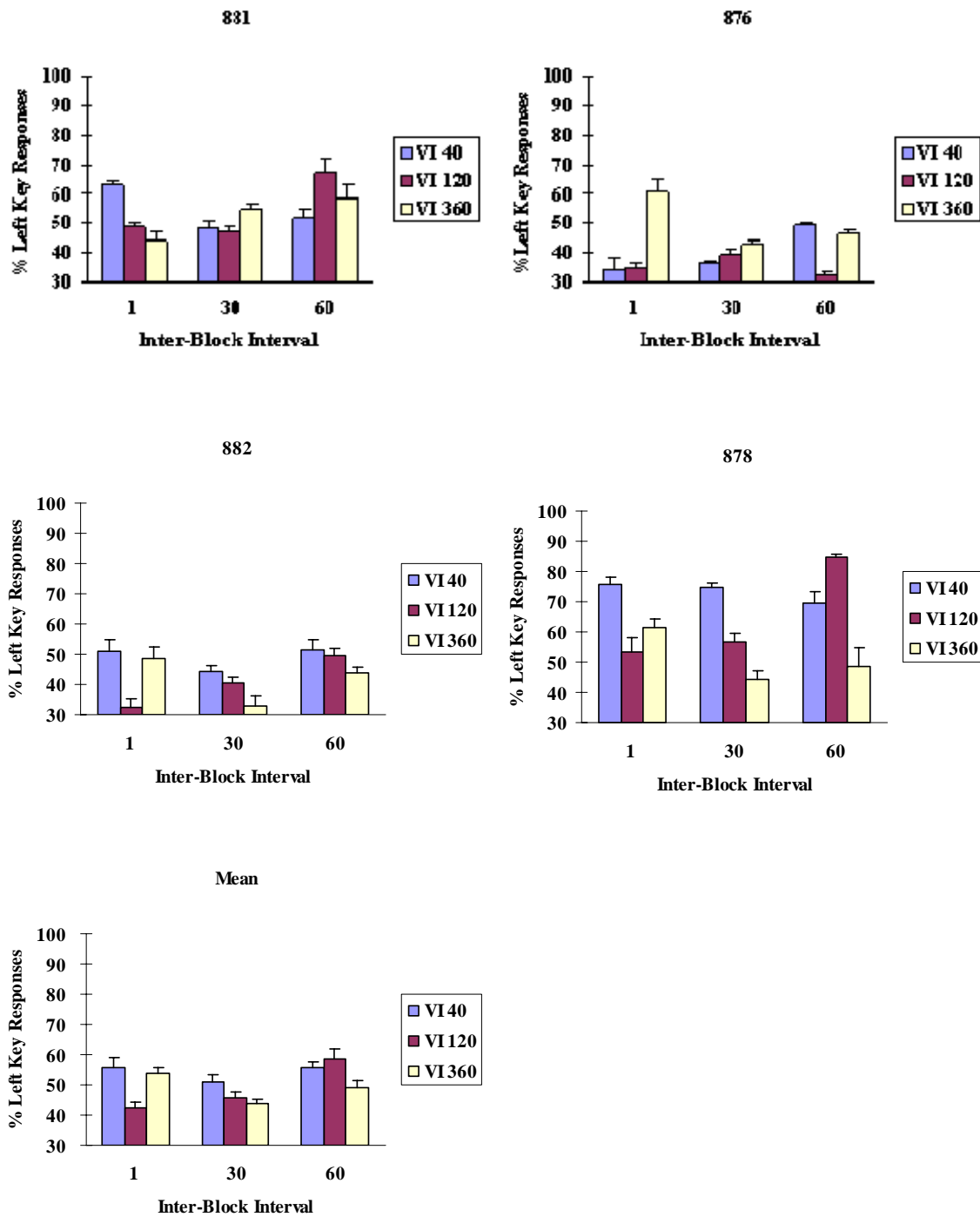


Figure 13

Experiment 3. Mean relative response rate for the left key during the simple concurrent schedule of reinforcement across 4 subjects for each condition. Vertical bars represent the standard error.

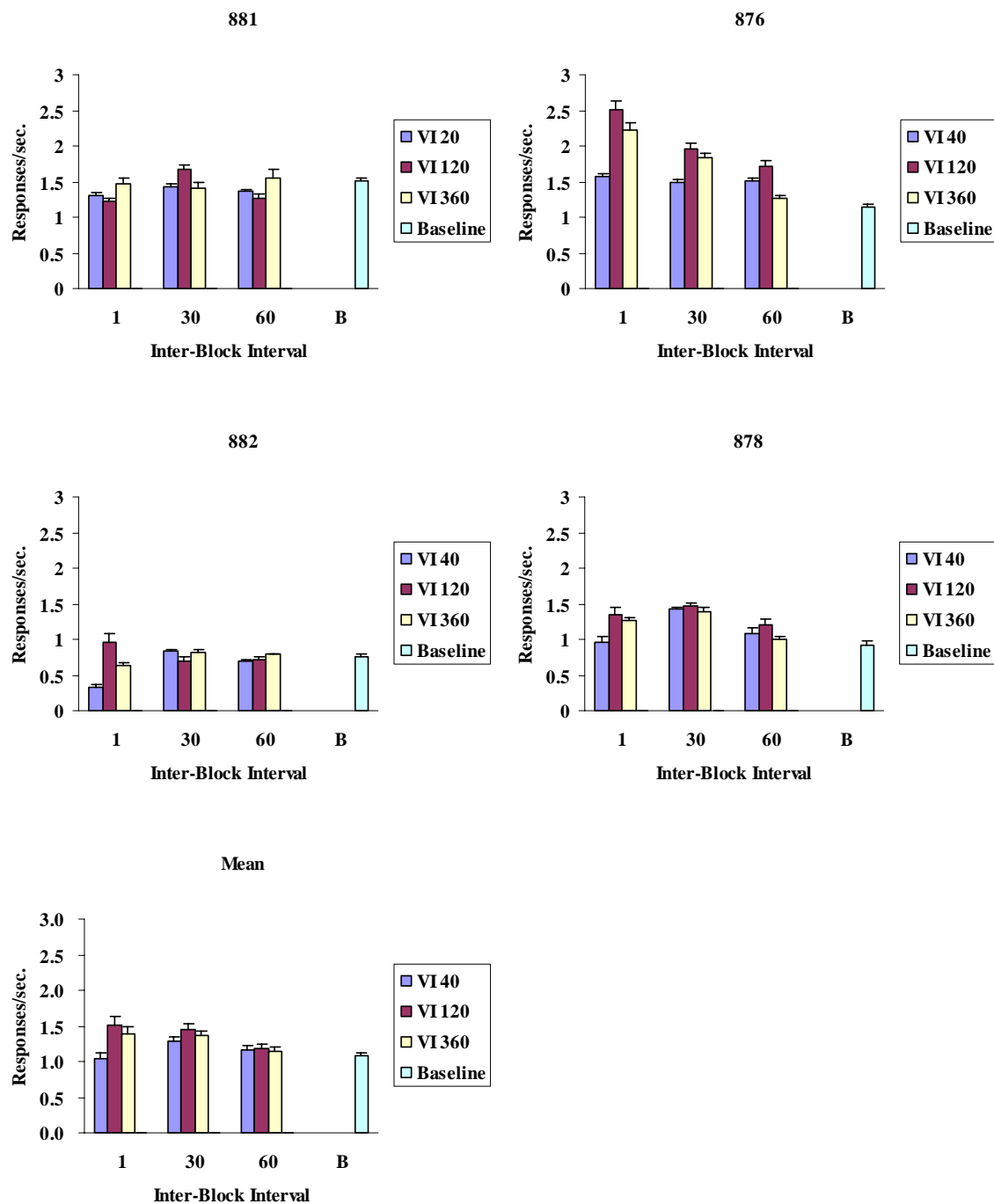


Figure 14

Experiment 3. Mean initial link response rate across 4 subjects for each condition. Vertical bars represent the standard error.

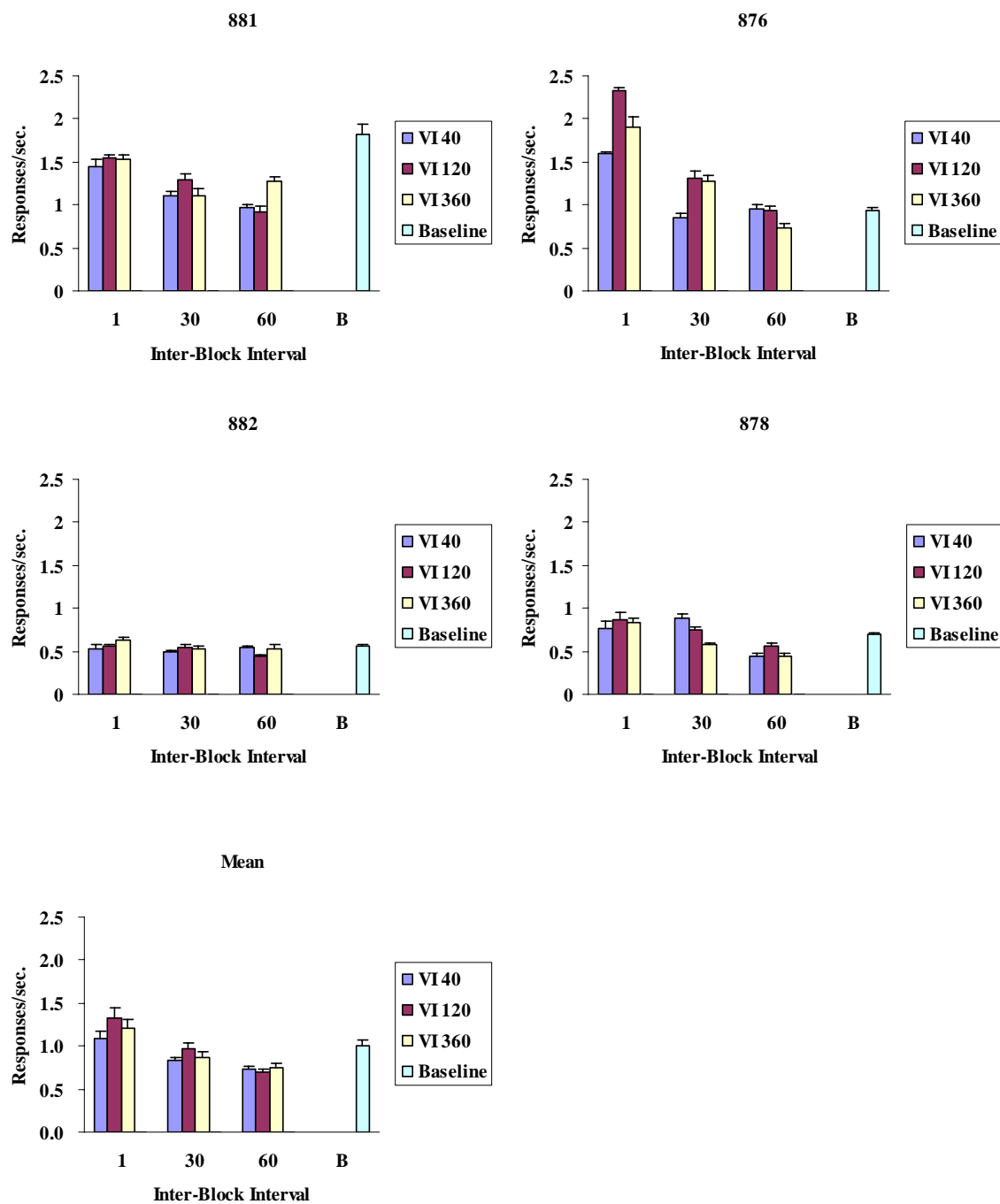


Figure 15

Experiment 3. Mean terminal link response rate across 4 subjects for each condition. Vertical bars represent the standard error.

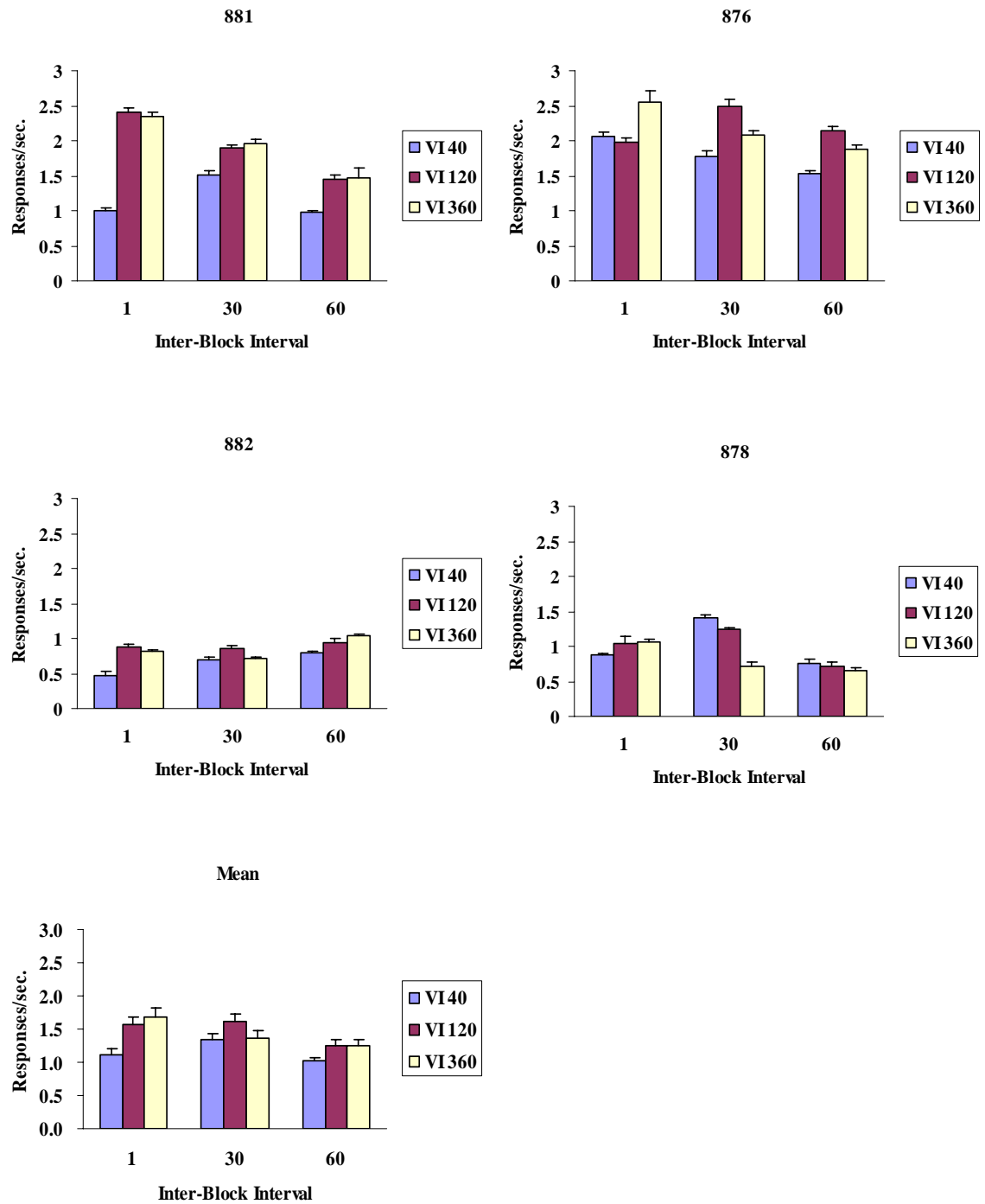


Figure 16

Experiment 3. Mean simple concurrent response rate across 4 subjects for each condition. Vertical bars represent the standard error.

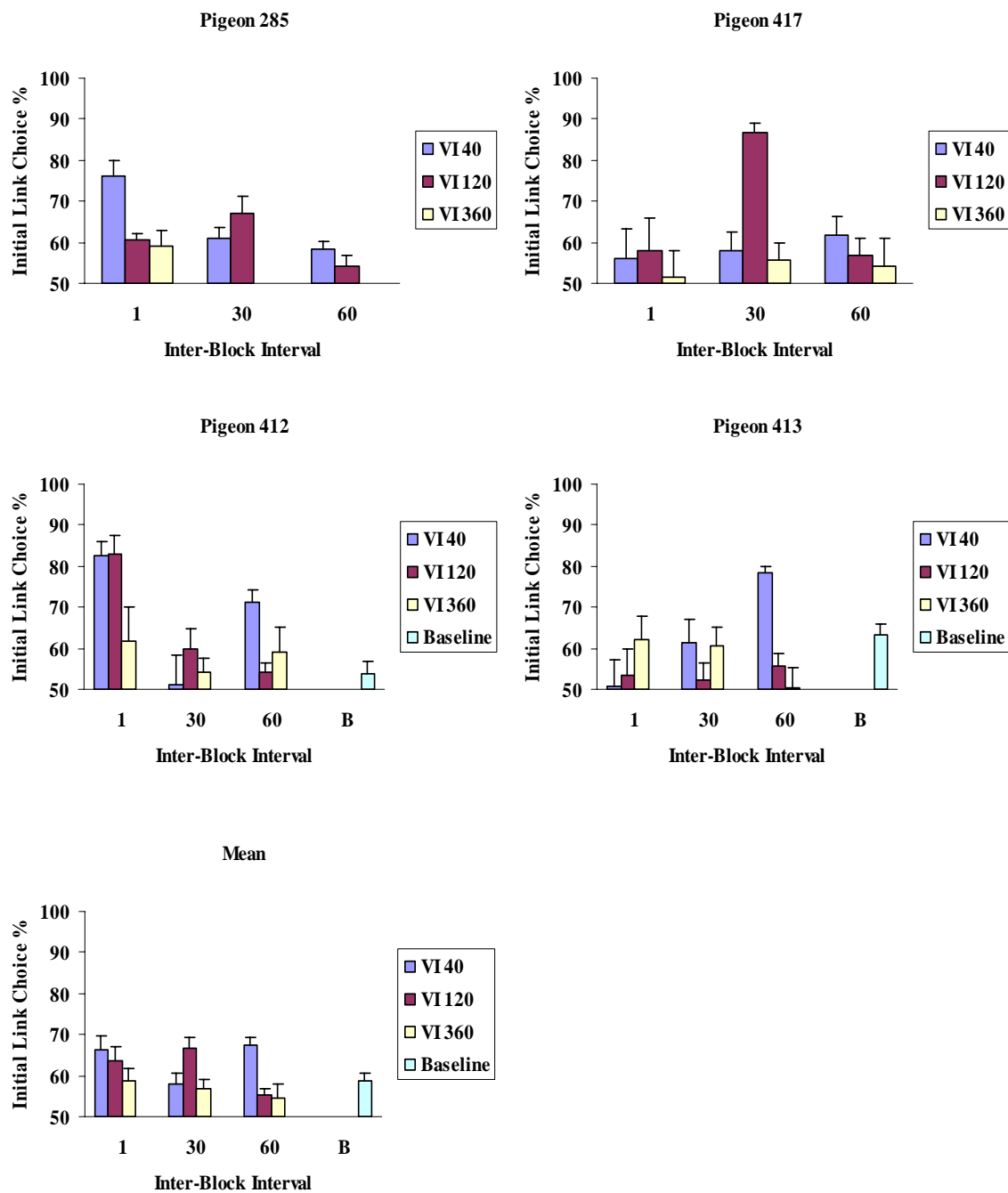


Figure 17

Experiment 4. Relative response rate for the initial link leading to the shorter (VI 15-s) terminal link schedule for each of the 4 subjects and the mean. Vertical bars represent the standard error.



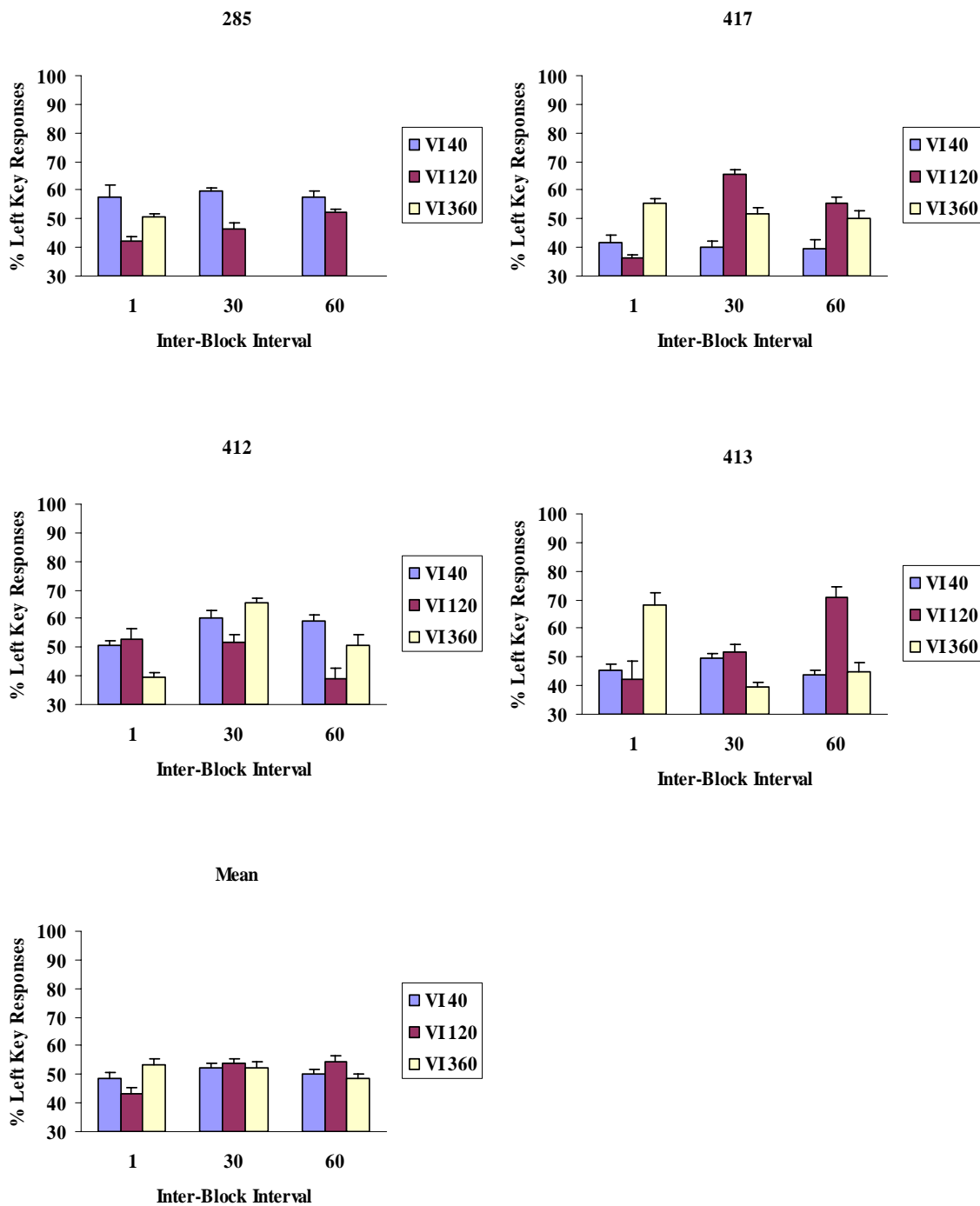


Figure 18

Experiment 4. Mean relative response rate for the left key during the simple concurrent schedule of reinforcement across 4 subjects for each condition. Vertical bars represent the standard error.

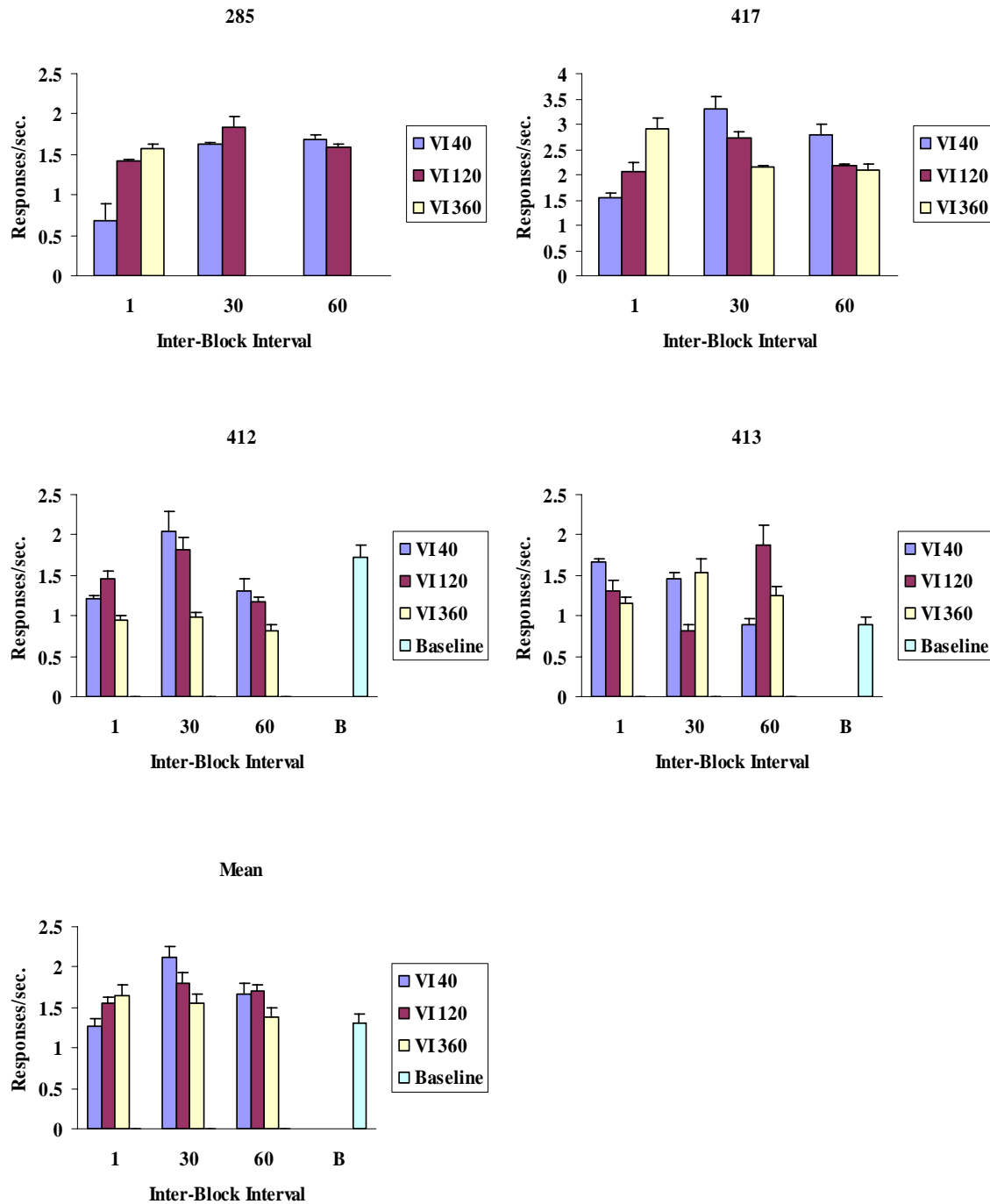


Figure 19

Experiment 4. Mean initial link response rate across 4 subjects for each condition. Vertical bars represent the standard error.

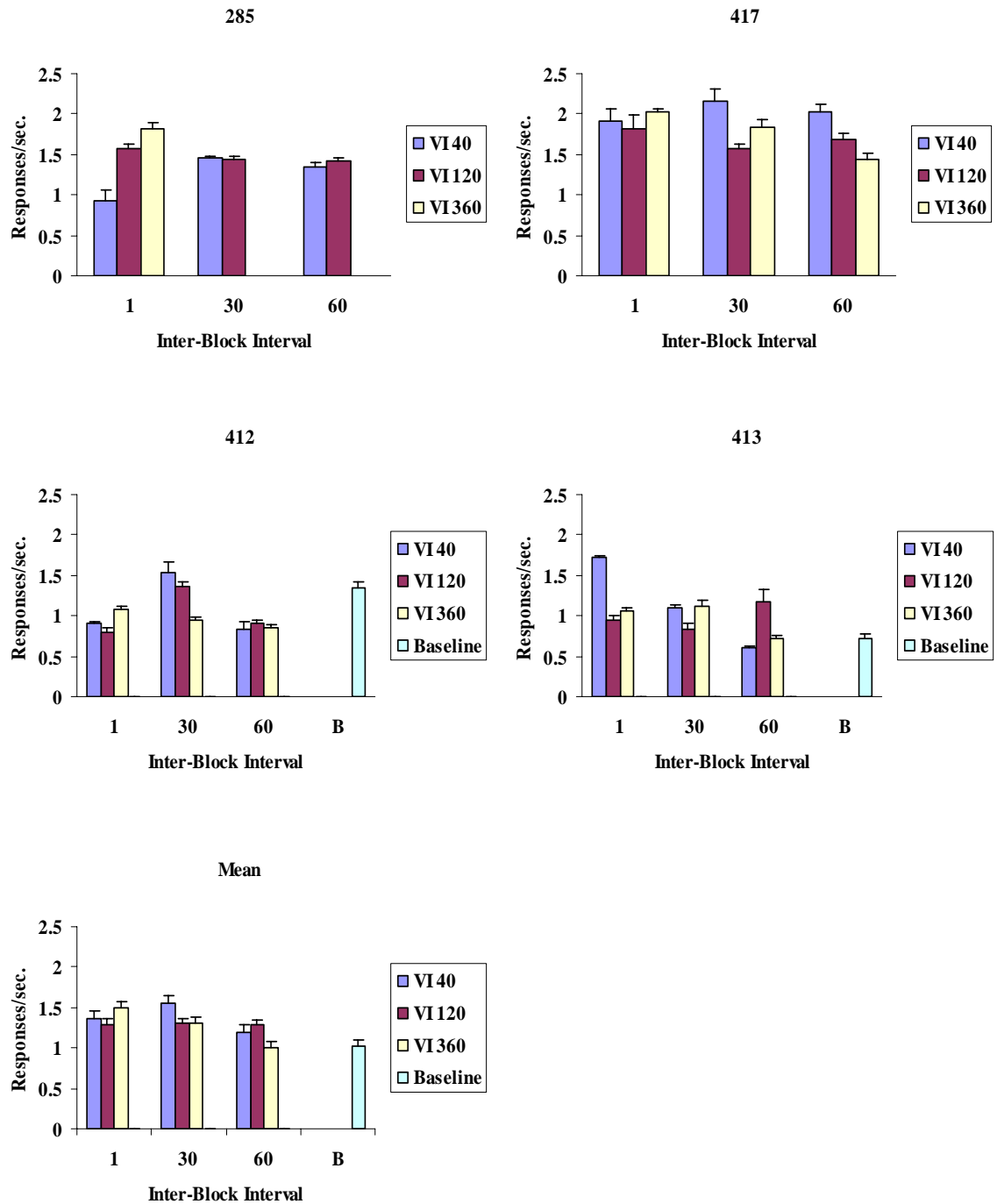


Figure 20

Experiment 4. Mean terminal link response rate across 4 subjects for each condition. Vertical bars represent the standard error.

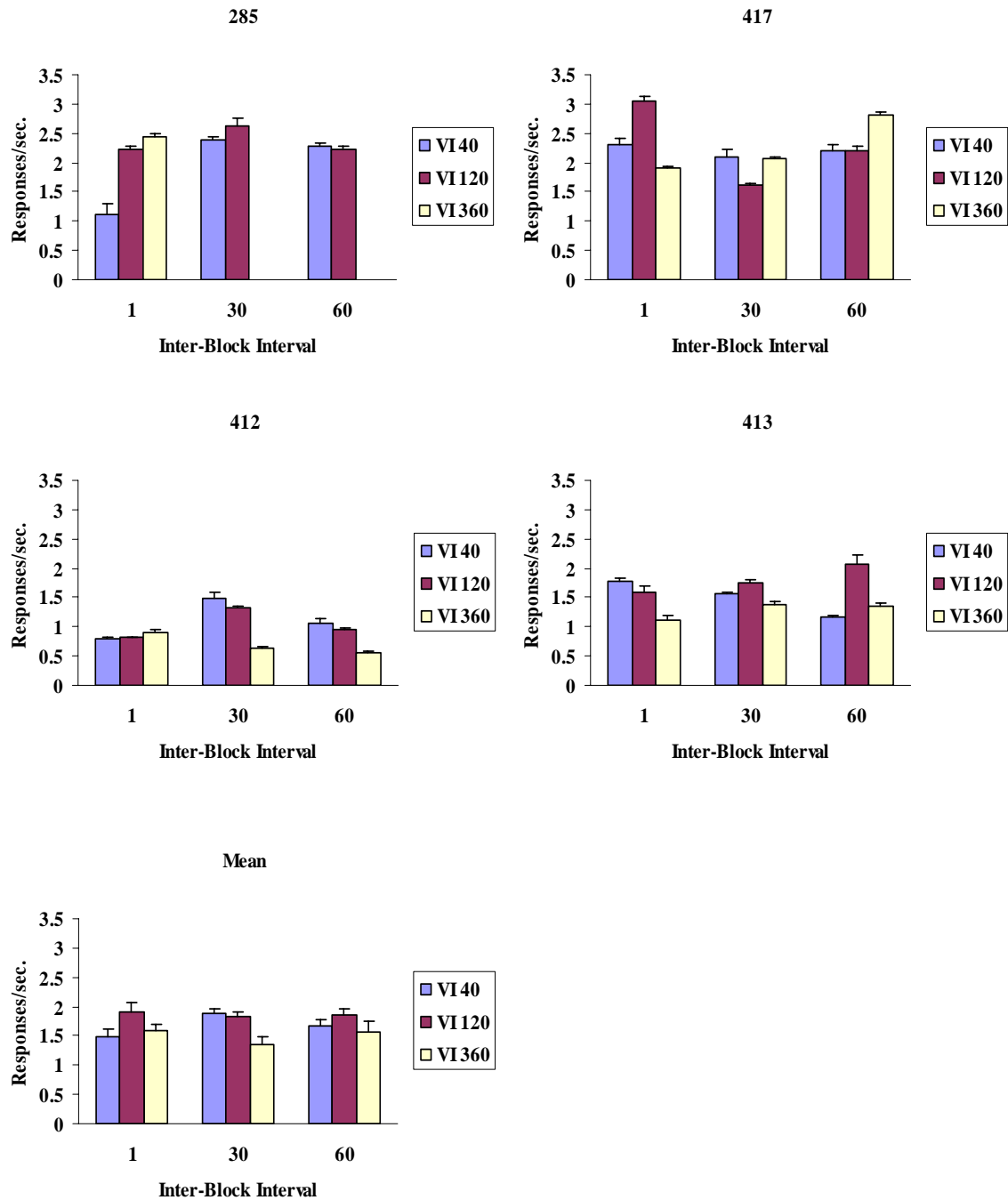


Figure 21

Experiment 4. Mean simple concurrent response rate across 4 subjects for each condition. Vertical bars represent the standard error.

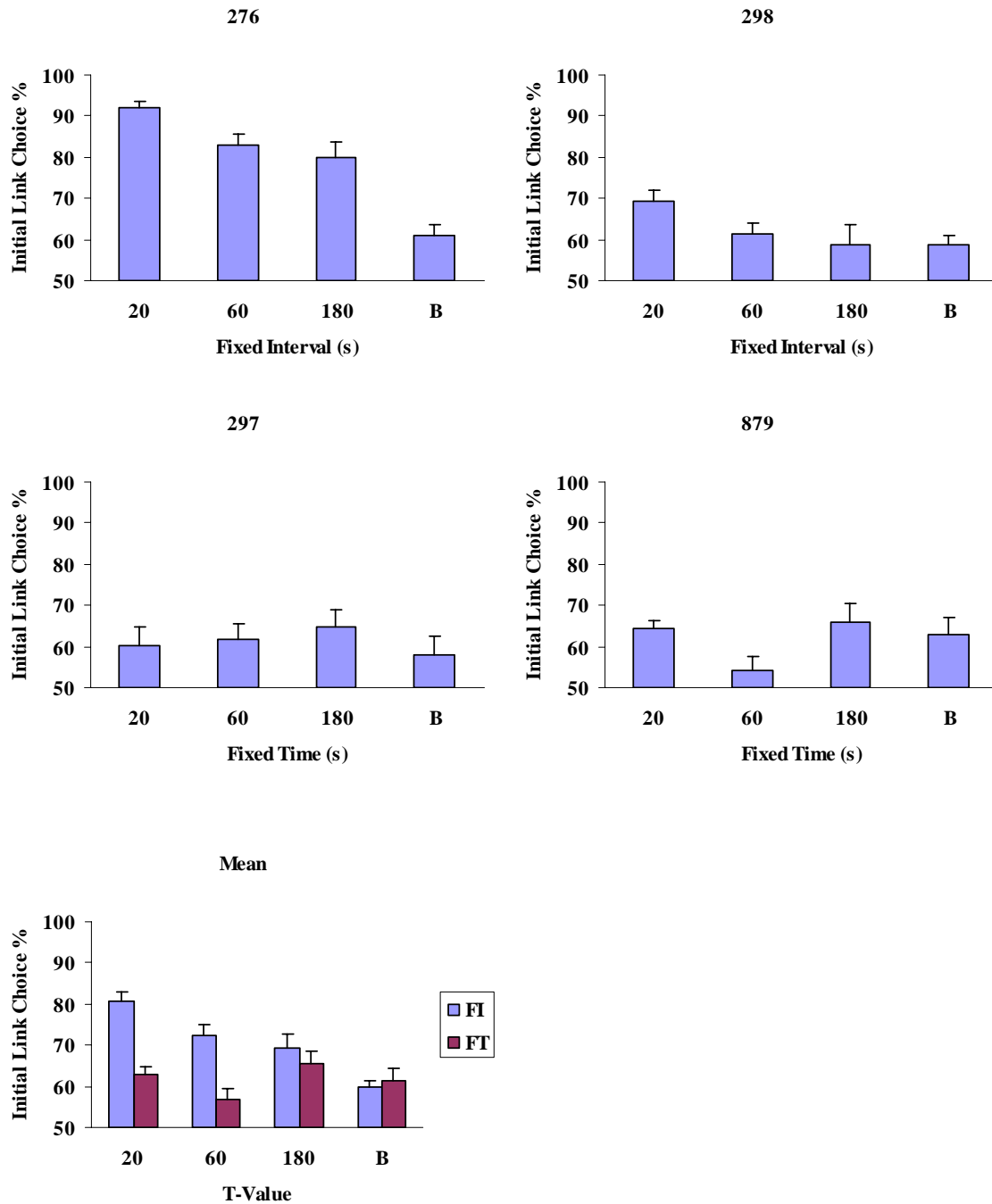


Figure 22

Experiment 5. Relative response rate for the initial link leading to the shorter (VI 15-s) terminal link schedule for each of the 4 subjects and the mean. Vertical bars represent the standard error.

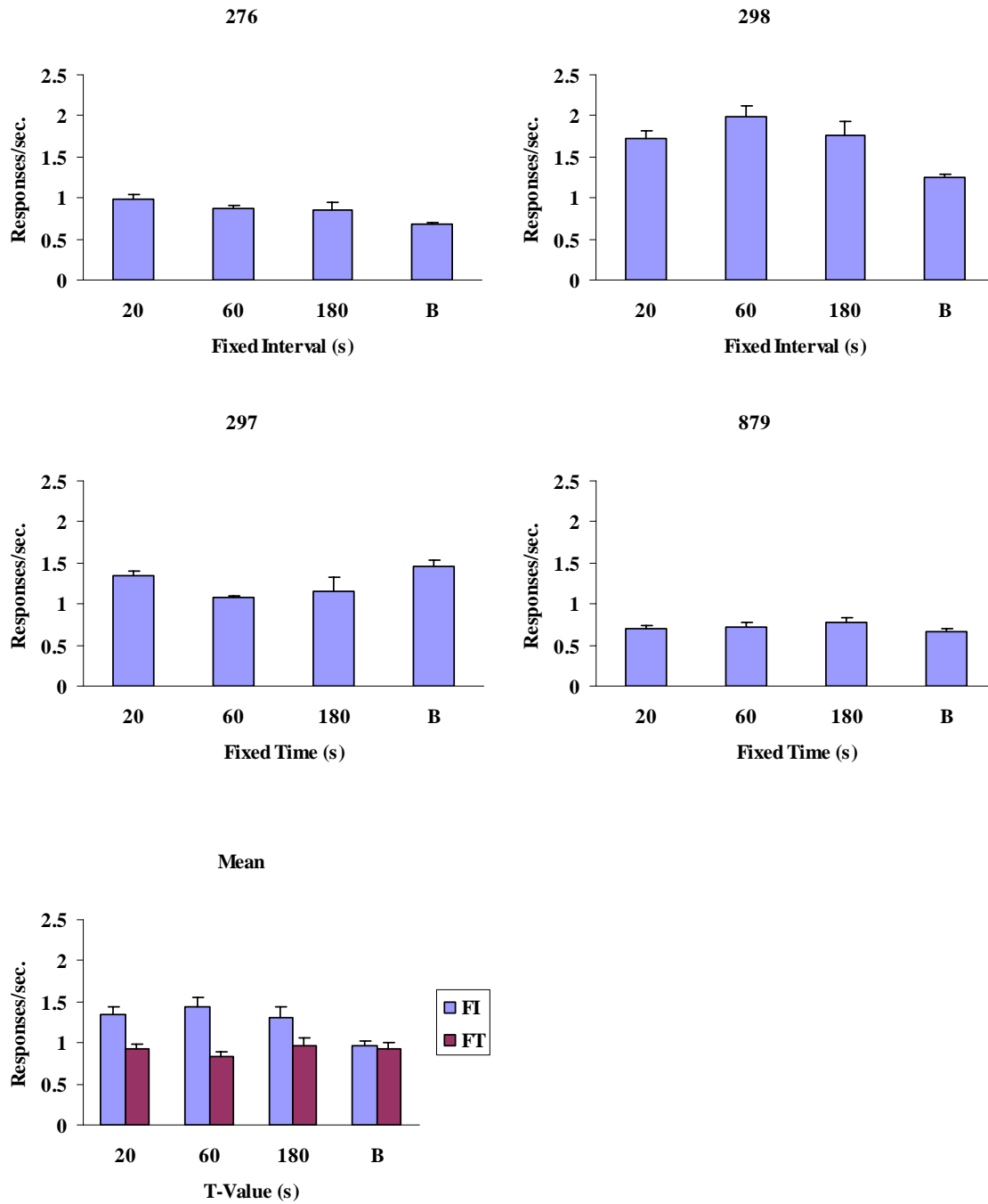


Figure 23

Experiment 5. Mean initial link response rate across 4 subjects for each condition. Vertical bars represent the standard error.

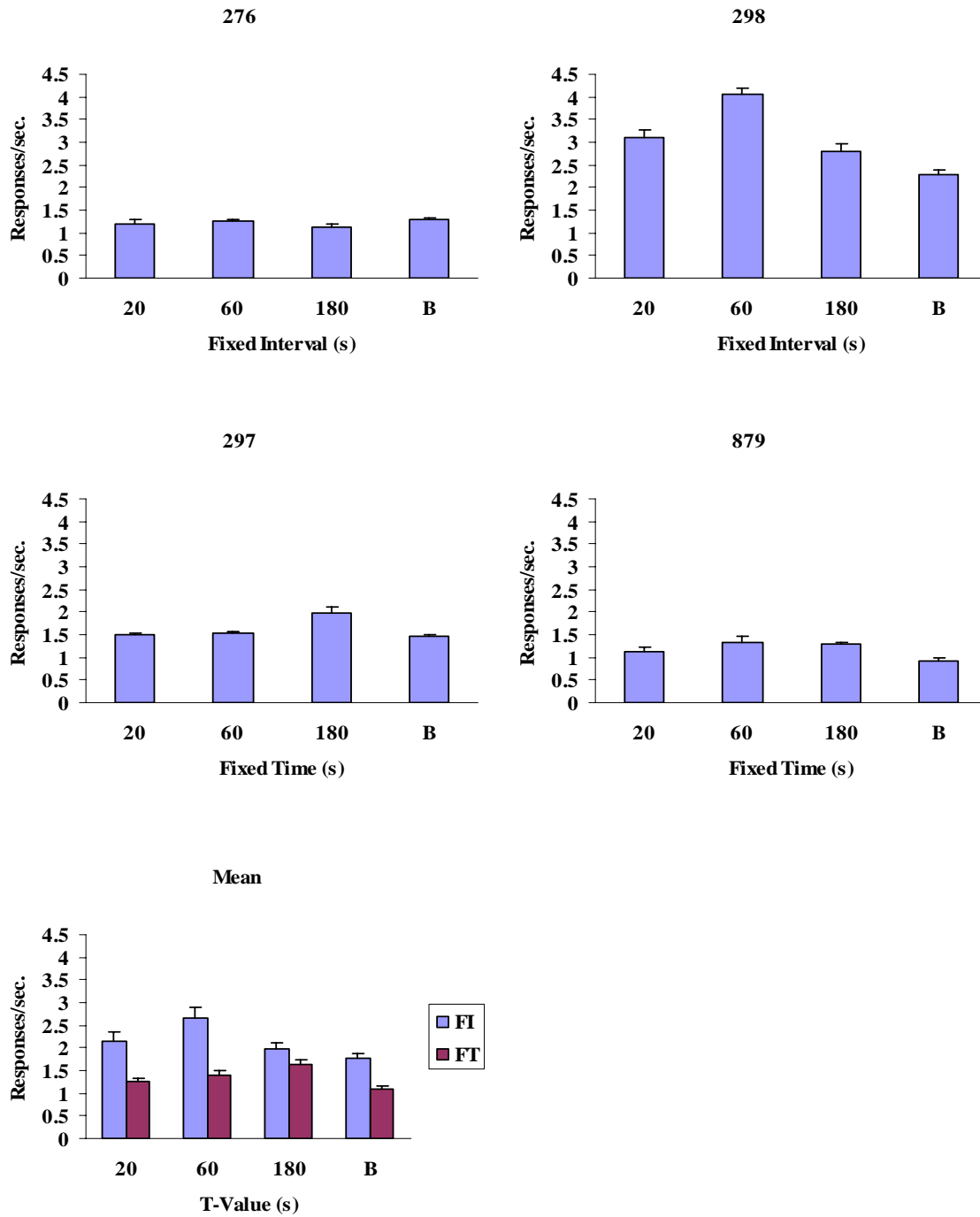


Figure 24

Experiment 5. Mean terminal link response rate across 4 subjects for each condition. Vertical bars represent the standard error.

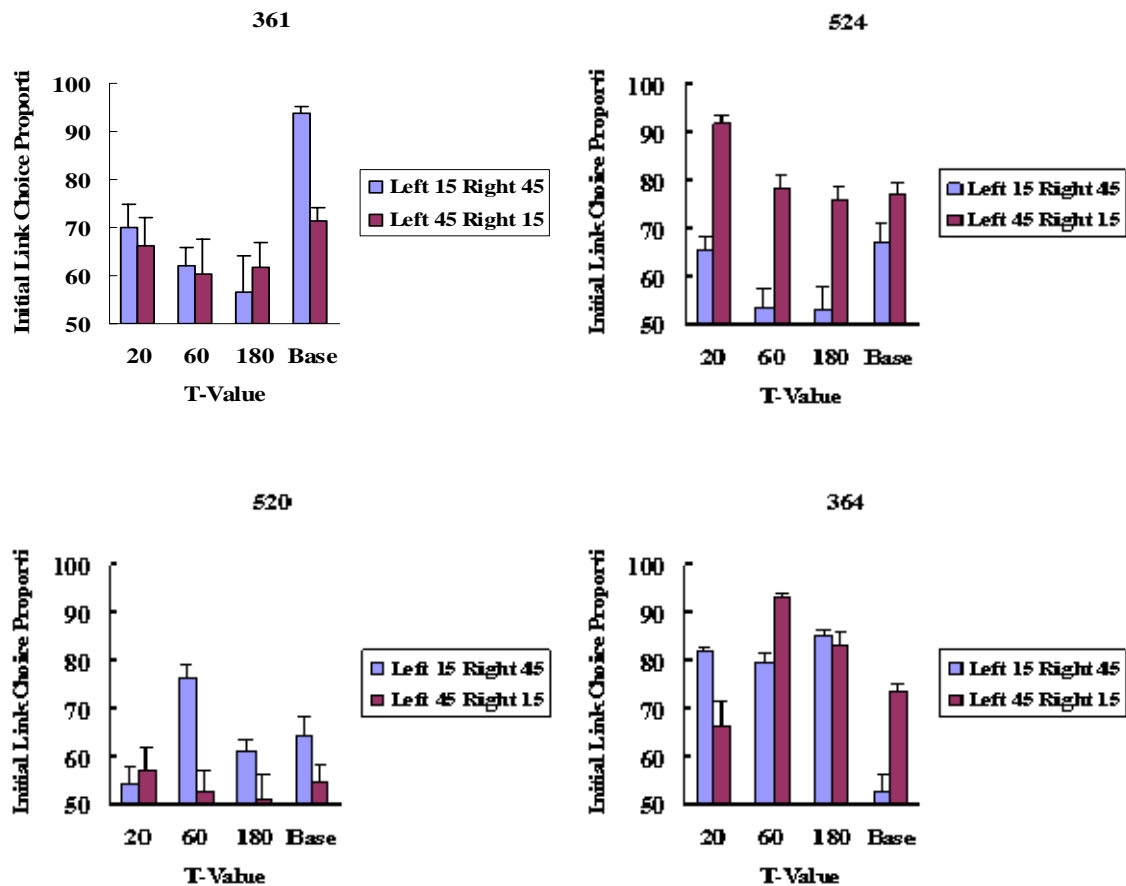


Figure 25

Experiment 1: Relative response rate for the initial link leading to the shorter (VI 15-s) terminal link schedule for each of the 4 subjects for the initial determination and replication. Vertical bars represent one standard deviation.



## REFERENCES

- Autor, S. M. (1960). *The strength of conditioned reinforcers as a function of frequency and probability of reinforcement*. Unpublished doctoral dissertation, Harvard University.
- Autor, S. M. (1969). The strength of conditioned reinforcers as a function of probability and reinforcement. In D. P. Hendry (Ed.), *Conditioned reinforcement* (pp. 127-162). Homewood, IL: Dorsey Press.
- Balsam, P. D. & Tomie, A. (1985). *Context and Learning*. Hillsdale, NJ: Erlbaum.
- Catania, C. A. (1963). Concurrent performances: reinforcement interaction and response independence. *Journal of the Experimental Analysis of Behavior*, 6, 253-263.
- Chung, S. H., & Herrnstein, R. J. (1967). Choice and delay of reinforcement. *Journal of the Experimental Analysis of Behavior*, 10, 67-74.
- Davison, M. C. (1987). The analysis of concurrent-chain performance. In M. L. Commons, J. E. Mazur, J. A. Nevin, & H. Rachlin (Eds.), *Quantitative analysis of behavior: Vol. 5. The effect of delay and of intervening events on reinforcement value* (pp. 225-241). Hillsdale, NJ: Erlbaum.
- Davison, M. C., & Temple, W. (1973). Preference for fixed-interval schedules: An alternative model. *Journal of the Experimental Analysis of Behavior*, 20, 393-403.
- deVilliers, P. (1977). Choice in concurrent schedules and a quantitative formulation of the law of effect. In W. K. Honig & J. E. R. Staddon (Eds.), *Handbook of operant behavior* (pp. 233-287). Englewood Cliffs, NJ: Prentice-Hall.
- Duncan, B., & Fantino, E. (1970). Choice for periodic schedules of reinforcement. *Journal of the Experimental Analysis of Behavior*, 14, 73-86.
- Fantino, E. (1969). Choice and rate of reinforcement. *Journal of the Experimental Analysis of Behavior*, 12, 723-730.
- Fantino, E. (1982). Effect of initial-link length on responding in terminal link. *Behaviour Analysis Letters*, 2, 65-70.
- Fantino, E., & Davison, M. (1983). Choice: Some quantitative relations. *Journal of the Experimental Analysis of Behavior*, 40, 1-13.

- Fantino, E. & Dunn, R. (1983). The delay-reduction hypothesis: Extension to three-alternative choice. *Journal of Experimental Psychology: Animal Behavior Processes*, 9, 132-146.
- Fantino, E., & Logan, C. A. (1979). *The experimental analysis of behavior: A biological approach*. San Francisco: Freeman Press.
- Ferster, C. B. & Skinner, B. F. (1957). *Schedules of reinforcement*. New York: Appelton-Century-Crofts.
- Flaherty, C. F. (1996). *Incentive relativity*. Cambridge: Cambridge University Press.
- Flescher, M. & Hoffman, H. S. (1962). A progression for generating variable-interval schedules. *Journal of the Experimental Analysis of Behavior*, 5, 529-530.
- Gentry, C. D. & Marr, M. J. (1980). Choice and reinforcement delay. *Journal of the Experimental Analysis of Behavior*, 33, 27-37.
- Gibbon, J. (1977). Scalar expectancy theory and Weber's law in animal timing. *Psychological Review*, 84, 279-325.
- Gibbon, J. (1995). Dynamic of time matching: Arousal makes better seem worse. *Psychonomic Bulletin & Review*, 2, 208-215.
- Goldshmidt, J. N., Lattal, K. M., & Fantino, E. (1998). Context effects on choice. *Journal of the Experimental Analysis of Behavior*, 70, 301-230.
- Grace, R. C. (1994). A contextual model of concurrent-chains choice. *Journal of the Experimental Analysis of Behavior*, 61, 113-129.
- Herrnstein, R. J. (1961). Relative and absolute strength of response as a function of frequency of reinforcement. *Journal of the Experimental Analysis of Behavior*, 4, 267-272.
- Herrnstein, R. J. (1964b). Secondary reinforcement and rate of primary reinforcement. *Journal of the Experimental Analysis of Behavior*, 7, 27-36.
- Herrnstein, R. J. (1970). On the law of effect. *Journal of the Experimental Analysis of Behavior*, 13, 243-266.
- Herrnstein, R. J. (1974). Formal properties of the matching law. *Journal of the Experimental Analysis of Behavior*, 21, 159-164.
- Jacob, T. C. & Fantino, E. (1988). Effects of reinforcement context on choice. *Journal of the Experimental Analysis of Behavior*, 49, 367-381.

- Killeen, P. (1982). Incentive theory: II. Models for choice. *Journal of the Experimental Analysis of Behavior*, 38, 217-232.
- MacEwen, D. (1972). The effects of terminal-link fixed-interval and variable-interval schedules on responding under concurrent-chained schedules. *Journal of the Experimental Analysis of Behavior*, 18, 253-261.
- Mazur, J. E. (2001). Hyperbolic value addition and general models of animal choice. *Psychological Review*, 108 (1) , 96-112.
- Mazur, J. E. (2003). Effects of free-food deliveries and delays on choice under concurrent-chains schedules. *Behavioural Processes*, 64, 251-260.
- Mazur, J. E. (2006). Mathematical models and the experimental analysis of behavior. *Journal of the Experimental Analysis of Behavior*, 85, 275-291.
- McDowell, (1986). On the falsifiability of matching theory. *Journal of the Experimental Analysis of Behavior*, 45, 63-74.
- O'Daly, M., Meyer, S. & Fantino, E. (2005). Value of conditioned reinforcers as a function of temporal context. *Learning and Motivation*, 36, 42-59.
- Omino, T. (1993). A quantitative analysis of sensitivity to the conditioned-reinforcing --value of terminal link stimuli in a concurrent-chains schedule. *Journal of the Experimental Analysis of Behavior*, 60, 587-594.
- Reynolds, G. S. (1961). Behavioral contrast. *Journal of the Experimental Analysis of Behavior*, 4, 57-71.
- Squires, N., & Fantino, E. (1971). A model for choice in simple concurrent and concurrent-chains schedules. *Journal of the Experimental Analysis of Behavior*, 15, 27-38.
- Williams, B. A. (1979). Contrast, component duration, and the following schedule of reinforcement. *Journal of Experimental Psychology: Animal Behavior Processes*, 5, 379-396.
- Williams, B. A. (1981). The following schedule of reinforcement as a fundamental determinant of steady state contrast in multiple schedules. *Journal of the Experimental Analysis of Behavior*, 35, 293-310.
- Williams, B. A. (1988). Reinforcement, choice, and response strength. In R. C. Atkinson, R. J. Herrnstein, G. Lindzey, & R. D. Luce (Eds.), *Stevens' handbook of experimental psychology: Vol. 2. Learning and cognition* (2<sup>nd</sup> ed., pp. 167-244). New York: Wiley.

- Williams, B. A. (2002). Behavioral contrast redux. *Animal Learning & Behavior*, 30 (1), 1-20.
- Williams, B. A., & Fantino, E. (1978). Effects on choice of reinforcement delay and conditioned reinforcement. *Journal of the Experimental Analysis of Behavior*, 29, 77-86.
- Williams, B. A., & McDevitt, M. A. (2001). Competing sources of stimulus value in anticipatory contrast. *Animal Learning and Behavior*, 29, 302-310.
- Williams, B. A., & Wixted, J. T. (1986). An equation for behavioral contrast. *Journal of the Experimental Analysis of Behavior*, 45, 47-62.
- Williams, W. A., & Fantino, E. (1996). Response-dependent prechoice effects on foraging-related choice. *Journal of the Experimental Analysis of Behavior*, 65, 619-641.