8-1991

Effects of Differential Force Requirements on Choice Behavior Under Concurrent-Chain Schedules

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EFFECTS OF DIFFERENTIAL FORCE REQUIREMENTS ON CHOICE BEHAVIOR UNDER CONCURRENT-CHAIN SCHEDULES

by

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A Dissertation
Submitted to the
Faculty of The Graduate College
in partial fulfillment of the
requirements for the
Degree of Doctor of Philosophy
Department of Psychology

Western Michigan University
Kalamazoo, Michigan
August 1991

Order Number 9135926

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Western Michigan University, 1991

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ACKNOWLEDGEMENTS

I would like the thank the members of my dissertation committee, Drs. Galen Alessi, Jack Michael, Wayne Fuqua, and Mike Bahr, for their guidance and encouragement on this project. I would also like to thank Jack Michael, and Laurel Grotzinger of The Graduate College, for the generous financial support provided throughout my education at Western Michigan University. Special thanks go to Mark Nickel and David Trimble for their help in running the animals in Experiments 2 and 3. Finally, I would like to thank my wife Ann for her unending encouragement throughout my graduate studies and my two boys, Nathanael and Jonathan, for gentling all rats used in this study.

Randal D. Reynolds

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INTRODUCTION

Background: Concurrent Chains

A chain schedule consists of two or more schedules of reinforcement sequentially presented and each associated with different stimuli, but only the last schedule in the sequence provides unconditioned reinforcement (Ferster & Skinner, 1957). The simultaneous presentation of two or more chain schedules is referred to as a concurrent-chain procedure. A diagrammatic representation of this procedure is shown in Figure 1. As typically employed, the concurrent-chain schedule involves regular alternations between two stimulus conditions, the initial-link (*choice* phase) and the terminal-link (*outcome* phase) schedules. The initial links are composed of two variable-interval (VI) schedules presented concurrently and each associated with a particular operandum. A response on either schedule occasionally produces a stimulus change correlated with one of two mutually exclusive terminal-link schedules. When the requirements of the terminal-link schedule are met, food is presented, after which the initial links are reinstated.

The concurrent-chain procedure was initially introduced for studying conditioned reinforcement (Autor, 1960, 1969). However, since its introduction it has been most extensively employed as a choice procedure. Choice, as a dependent variable, is quantified as the ratio of responses allocated to each initial-link VI schedule. The independent variable generally consists of manipulating factors in the two terminal-link schedules. Variables that have been investigated using this procedure include the

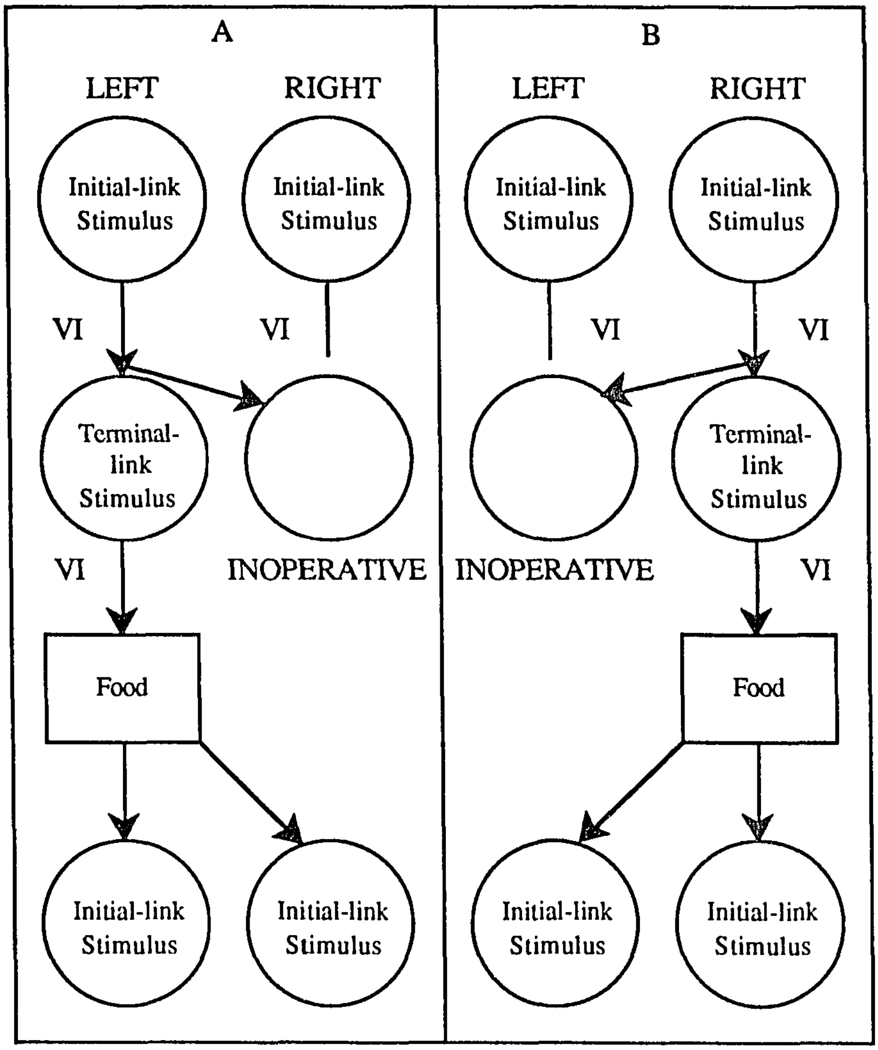

Figure 1. A Schematic Diagram of the Concurrent-Chain Procedure. Panel A Represents the Sequence of Events that Occur When an Initial-Link Response on the Left Operandum Produces a Stimulus Change Correlated with the Terminal-Link Condition. Panel B Represents a Similar Sequence of Events, but for the Right Operandum. (Adapted From Fantino, 1969a.)

immediacy of unconditioned reinforcement (e.g., Hursh & Fantino, 1973), number of reinforcements (e.g., Fantino & Herrnstein, 1968; Squires & Fantino, 1971), schedule preference (e.g., Davison, Alsop & Denison, 1988), magnitude of unconditioned reinforcement (e.g., Schwartz, 1969; Ten Eyck, 1970), and response topography (Starin, 1989a).

Advantages

The introduction of the concurrent-chains as a choice procedure provides several important advantages over the more traditional choice paradigms such as discrete-trial procedures and simple concurrent schedules. The principle advantage of concurrent-chain schedules, relative to discrete-trial choice procedures[1], is that they allow for the parametric investigation of the independent variable. This point may be illustrated by considering an early study that investigated the effects of delays to reinforcement on choice behavior using a discrete-trial procedure (Logan, 1952). In this study two levers were present; a single response on either lever produced food, but only after a short delay. The delay to reinforcement for one lever was 1 s, whereas the delay associated with the other lever was 5 s. The results showed that the rats exclusively chose the shorter delay lever. These same data would presumably be obtained with other delay parameters, as long as the delay values assigned to both levers were discriminably different. However, had VI schedules been employed in the choice phase of this study, effectively making it a concurrent-chain procedure, the independent variable could have been varied over a wide range of values before

[1]With the discrete-trial procedure a single response in the choice phase produces the outcome phase. Note that if the VI schedules in the initial link of a concurrent-chain procedure are assigned a value of 0, this procedure effectively becomes a type of discrete trial choice procedure. As such it is subject to the same disadvantages associated with the discrete-trial procedure.

exclusivity would be found. In other words, with VI schedules in the choice phase, the first response on the 1-s delay lever would generally not produce the outcome phase. As the VI timer on this lever is running, the rat will occasionally change over to the 5-s delay lever where a response will sometimes produce the outcome phase. Therefore, the employment of VI schedules in the initial link reduces the likelihood of finding exclusivity in the choice phase.

A related advantage of the concurrent-chain procedure is that the number of entries into the terminal-link generally remains close to the number scheduled by the experimenter, even though large preferences are shown for one terminal-link alternative (Fantino, 1977, p. 328; but see Davison & Temple, 1973). This advantage is again related to the nature of VI schedules as employed in the choice phase. For example, if the initial-link VI schedules are both assigned a value of 60 s, high response rates will produce 1 terminal-link entry on the average of every 60 s while in the initial link. However, because only 1 response is required with a VI schedule to produce reinforcement, extremely low response rates will also produce 1 terminal-link entry on the average of every 60 s. Therefore obtained and scheduled entries into the terminal link remain close despite marked discrepancies in initial-link response rates. This feature of the concurrent-chain procedure is important because it insures that the independent variable is not confounded with changes in rates of entry into the terminal-link. In contrast, these two variables are necessarily confounded using a discrete trial procedure because a preference for one alternative, even if it were not an exclusive preference, necessarily produces a discrepancy between obtained and scheduled terminal-link entries.

The third advantage may be discussed relative to simple concurrent schedules[2]. Concurrent-chain procedures remain a viable choice paradigm even when the choice outcome involves variables that *directly* affect response rate, such as schedules of reinforcement, response topography, response-force requirements and so on. The employment of simple concurrent schedules, the most widely used choice paradigm, to study this class of variables would be inappropriate because the direct effect of the independent variable is necessarily confounded with the measure of choice. For example, if response-force requirements are investigated using a simple concurrent procedure, choice, as measured by the relative rate of responding on each differentially weighted response operandum, is confounded with the direct effect of force requirements on responding. In other words, as response force increases, response rate decreases (e.g., Chung, 1965, exp. 1) and the choice measure is necessarily biased against the high force alternative. However, with the concurrent-chain procedure the effect of lever force on preference may be adequately assessed if lever force is varied in the outcome phase, but held constant in the choice phase.

Because of the advantages discussed above, concurrent-chain schedules may be used as a choice procedure to investigate a wide range of variables. However, the majority of research to date has focused on time related factors, such as rates of reinforcement and delays to reinforcement. With these variables the procedure has proven to be quite sensitive to changes in the independent variable (e.g., see Davison, 1987; and Fantino, 1977, 1981 for reviews). Changes in terminal-link delay ratios, for example, produce marked changes in initial-link response ratios. Interestingly enough, however, the choice ratios with the concurrent-chain procedure are somewhat

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[2]Simple concurrent schedules, as typically utilized in choice procedures, generally involve the simultaneous presentation of two VI schedules of reinforcement. This type of schedule may therefore be described as a special case of the concurrent-chain procedure where the terminal-link schedule values equal 0 s.

insensitive to other types of variables. For instance, studies have reported that response-rate ratios are indifferent to terminal-link response requirements (e.g., Davison, et al., 1988), or response topography (Starin, 1989a, 1989b). Taken together, these findings suggest either that certain nontime-based variables have little or no effect on choice behavior relative to time-base variables, or that the concurrent-chain procedure is less well suited for investigating nontime-based variables. These issues will be considered by first reviewing an extensive body of concurrent-chain literature pertaining to time-based variables. This discussion will be followed by a review of a much smaller body of literature pertaining to response-requirement variables. Finally, to anticipate the focus of the present study, research concerning the effects of response-force requirements on simply concurrent schedules will be briefly reviewed.

Sensitivity to Independent Variables

Time-Based Variables

Since the introduction of the concurrent-chain procedure, a large number of studies have focused upon the effects of delays to reinforcement on choice behavior. For example, two experiments by Autor (1960, 1969) investigated the relation between choice behavior in the initial link and *reinforcement density* in the terminal links. Reinforcement density was defined by Autor as either *rate* of reinforcement (reinforcements per unit time) or *probability* of reinforcement (reinforcements per response) in the terminal link. To investigate the former, Autor used either VI or differential-reinforcement-of-zero-responses (DRO) schedules in the terminal links; in the case of the latter, he used variable-ratio (VR) schedules in the terminal links. The initial links were always composed of VI 1-min schedules. In discussing the results

of both experiments, Autor noted that the relative response rate in the initial links nearly matched the relative reinforcement density in the terminal links. For example, the number of responses obtained on the left key was approximately twice the number allocated to the right key when the left key led to a terminal-link VI schedule that was one-half the value of the right key terminal link schedule.

Autor's study, however, left unanswered the question of whether reinforcement *rate* or *probability* was the critical variable in determining initial-link choice behavior. As Herrnstein (1964) noted, rate of reinforcement and probability of reinforcement generally covary with both VI and VR schedules of reinforcement. For example, an increase in a VR schedule value necessarily produces a decrease in reinforcements per response, but may also result in a decrease in reinforcements per unit time. Similarly, an increase in a VI schedule value necessarily produces a decrease in reinforcements per unit time, but may also result in a decrease in reinforcements per response. To determine which reinforcement measure (relative reinforcement rate or probability) best represented a change in relative response rate, Herrnstein employed a concurrent-chain procedure in which one terminal link was always composed of a VR schedule and the other composed of either a VR or VI schedule. The initial-link schedules were always VI 1-min. The basic design of the study assumed that, at a given reinforcement rate or probability, response rate will always be higher with a VR schedule relative to a VI schedule. With this design assumption met, Herrnstein found that variability in relative response rate in the initial links was better accounted for by relative reinforcement rate as compared to relative reinforcement probability. The following equation was therefore proposed as describing the data from both the Herrnstein and Autor (1960, 1969) studies:

$$\frac{B_L}{B_R} = \frac{\frac{1}{t_L}}{\frac{1}{t_R}}, \qquad (1)$$

where B_L and B_R represent the response rates in the left and right initial links, respectively, and t_L and t_R represent the average reinforcement delays[3] for the left and right terminal links[4].

Although equation 1 adequately describes the effects of reinforcement delays in the terminal link on initial-link choice behavior, it unfortunately implies that the duration of the initial-link schedules has no effect on choice. But, as Fantino (1969a) subsequently noted, it is intuitively reasonable to assume that less preference will be shown toward differentially high reinforcement rates in the terminal links with longer duration initial-link schedules. This effect was, in fact, experimentally demonstrated in Fantino's (1969a) study where the two terminal links always consisted of VI 30-s and VI 90-s schedules. The initial links were always equal, but were varied across conditions and consisted of either VI 40-s, VI 120-s, or VI 600-s schedules. Given these schedule parameters, equation 1 always predicts a choice ratio of 3.0 (i.e., [1/30] ÷ [1/90] = 3). However, the results from Fantino's study clearly showed that the choice ratio was indeed affected by the value of the initial-link schedules. That is, preference for the 30-s terminal link decreased with increased initial-link VI values. Fantino (1969a) thus proposed the following model to account for the deficiency of equation 1:

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[3]The reciprocals of t_L and t_R are the rates of reinforcement in the left and right terminal links, respectively.

[4]This equation, as proposed by Herrnstein (1964, 1970) was originally expressed in proportional terms:

$$\frac{B_L}{B_L + B_R} = \frac{\frac{1}{t_L}}{\frac{1}{t_L} + \frac{1}{t_R}}.$$

However, to facilitate the comparison of several types of equations, all equations in this paper will be expressed in ratio terms.

$$\frac{B_L}{B_R}\begin{cases} = \dfrac{T-t_L}{T-t_R} & \text{when } t_L < T, t_R < T, \\ = \infty & \text{when } t_L < T, t_R > T, \\ = 0 & \text{when } t_L > T, t_R < T, \end{cases} \tag{2}$$

where B and t remain the same as in equation 1, and T represents the average time to unconditioned reinforcement from the onset of the initial-link schedules[5]. This formula also predicts that if a given terminal link value is greater then the average time to unconditioned reinforcement, exclusive preference will be shown toward the other alternative. A subsequent study by Fantino (1969b) reported data that confirmed this latter prediction.

Recent modifications of Equation 2 have involved cases where the initial-link VI schedules are unequal. Equation 2 predicts indifference in choice behavior when terminal-link values are equal and initial-link VI values are unequal. However, data from several studies rendered this aspect of the formula untenable (e.g., Squires & Fantino, 1971). Most recently Fantino and Davison (1983) have proposed the addition of the square-root of unconditioned reinforcement rate on each alternative (r_L and r_R) to equation 2 as best representing the data, even when the initial-link schedules are unequal:

[5]The average time to unconditioned reinforcement (T) is calculated in a two alternative choice procedure by summing one-half the mean value of the two initial-link schedules plus one-half the combined value of the two terminal-link schedules.

$$\frac{B_L}{B_R}\begin{cases} = \dfrac{\sqrt{r_L}(T-t_L)}{\sqrt{r_R}(T-t_R)} & \text{when } t_L < T, t_R < T, \\ = \infty & \text{when } t_L < T, t_R > T, \\ = 0 & \text{when } t_L > T, t_R < T. \end{cases} \quad (3)$$

The above research forms the basis of Fantino's *delay reduction hypothesis* which predicts "that (1) organisms will choose the stimulus correlated with the greatest reduction in time to primary reinforcement and (2) preference will be greater the larger the difference in the delay reductions correlated with the chosen alternatives" (Fantino, 1977, p. 326).

Other Quantitative Models

Fantino's model is actually only one of a special class of concurrent-chain models (e.g., Davison & Temple, 1973; Herrnstein & Vaughan, 1980; Killeen, 1982). The models in this class are all similar in that they have no free parameters[6]. In reviewing these models Davison (1987) reported that although each seemed to have its particular areas of competence relative to the nature of the terminal-link schedule (e.g., VI, fixed-interval [FI] or fixed-delay [FD]), all models described most concurrent-chain data only moderately well, but some of the data was not accounted for by any of the models. Furthermore, Davison reported that between 10 and 20 alternative concurrent-chain models were also found to perform equally well. Based on these findings Davison suggested that these models, and any subsequently proposed

[6]Models that involve no free parameters may be contrasted to other models that involve parameters that are derived from the experimental data. These models will be discussed next.

models should be rigorously assessed with parametric variations in the independent variable so as eliminate poorer models.

An alternative class of models are those that involve free parameters. Among these models Baum and Rachlin's (1969) *generalized-matching equation* has been extensively examined in the area of simple concurrent schedules where it remains preeminent. This model states:

$$\log\left(\frac{B_L}{B_R}\right) = a \log\left(\frac{R_L}{R_R}\right) + \log c, \qquad (4)$$

where $\log(R_L/R_R)$ represents the reinforcement ratio. The parameter c represents response bias (Baum, 1974a) and the parameter a represents the sensitivity of the response ratio to changes in the reinforcement ratio[7]. This model has been extended to concurrent-chain performance by specifying initial-link , $\log(R_{L1}/R_{R1})$, and terminal-link, $\log(R_{L2}/R_{R2})$, reinforcement ratios:

$$\log\left(\frac{B_L}{B_R}\right) = a \log\left(\frac{R_{L1}}{R_{R1}}\right) + b \log\left(\frac{R_{L2}}{R_{R2}}\right) + \log c. \qquad (5)$$

In addition, the parameters a and b now represent the sensitivity of the response ratio to changes in the initial-link and terminal-link reinforcement ratio, respectively. This extension assumes, however, that changes in the reinforcement ratio of one link do not interact with the sensitivity parameter of the other link. That is, the generalized matching equation, as forwarded by Baum and Rachlin (1969), requires that

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[7]Baum and Rachlin (1969) noted that equation 1, if expressed in log ratio terms, is actually a special case of equation 4 where both a and c equal 1, thus suggesting perfect matching between the response ratio and the reinforcement ratio. Baum (1974a) argued, however, that the data rarely supported such a conclusion. The addition of the parameter c therefore adjusts the equation for deviations away from strict matching due to a response bias toward one particular alternative. Furthermore, the addition of the parameter a allows for adjustments due to differential sensitivity of the response ratio to variables such as rates of reinforcement, and so on. The values of these free parameters are actually derived from a least-square regression equation where c is the y-intercept of zero and a is the slope of the regression line.

parameters remain constant, not variable. This assumption is seemingly violated, however, by those studies previous reviewed that show an initial-link and terminal-link interaction (e.g., Fantino, 1969a, 1969b; Squires & Fantino, 1971). In terms of equation 5 these data would suggest that as the log(R_{1L}/R_{1R}) ratio is changed, parameter b is altered.

The failure of the generalized matching equation to describe the data from a large number of concurrent-chain studies may be due to one procedural difference between simple concurrent schedules and concurrent-chain schedules. As Davison (1987) noted, most simple concurrent schedules employ a change-over delay[8] (COD), which is rarely used with concurrent chains. However, several recent studies have shown that even with the imposition of a change-over delay in the initial-link of the concurrent-chain procedure, initial- and terminal-link schedule interactions are still observed (Alsop & Davison, 1988; Davison, 1983).

To date there remains "one combination of choice-affecting variables that is well described by the concatenated generalized matching law--reinforcer rate and response force (Hunter & Davison, 1982)" (Davison, 1988, p. 346). Whether this finding can be replicated with the concurrent-chain procedure is unknown.

Response-Requirement Variables

Terminal-link Response Rates

The sensitivity of initial-link choice behavior to time-based factors is in sharp contrast to another line of research which has shown choice behavior to be insensitive

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[8]A change-over delay is a procedure where a response on one alternative is not reinforced (given that reinforcement is scheduled for that alternative) if a specified time has not elapsed since the last response of the other alternative. This procedure is used to eliminate the problem of concurrent superstitions (Catania, 1966; Catania & Cutts, 1963).

to terminal-link response requirements. The first data to suggest this disparity was Herrnstein's (1964) study. As previously discussed, this study employed an experimental procedure that generated equal terminal-link reinforcement rates but unequal response rates, and vice versa. The finding that initial-link choice behavior was better described by changes in reinforcements per unit time (reinforcement rate) as compared to reinforcement per response (reinforcement probability) suggests that initial-link choice behavior may be insensitive to differential terminal-link response rates if reinforcement rates are equal. Subsequent studies directly investigating this issue have shown results that corroborate this deduction. However, under certain special conditions, several studies have shown sensitivity to terminal-link response requirements. These special conditions are apparently related to the nature of the schedule employed and method used to manipulate terminal-link response rates.

Fantino (1968), for instance, employed a differential-reinforcement-of-high-rate (DRL) or a differential-reinforcement-of-low-rate (DRH) schedule in one terminal link while the other terminal link always consisted of a simple FI schedule of reinforcement. The data from this study clearly showed an initial-link preference for the FI terminal link. In contrast, Killeen (1968) found that pigeons were indifferent given a choice between terminal-links involving simple VI and conjunctive variable-time (VT), DRO schedules[9], even though there were marked differences in response rates across the two terminal links. Neuringer (1969) also manipulated response rates in the terminal links of a concurrent chain procedure using both a blackout and a fixed-time procedure in one terminal link and a FI schedule in the other link. Although this study found that the blackout procedure slightly affected initial-link

[9]A conjunctive schedule provides reinforcement when the schedule requirements of two or more schedules are satisfied. In the Killeen (1969) study food was delivered when a 30 s variable timer had elapsed *and* when no response had occurred for 1.5 s.

response distributions, differential response rates in the terminal-link had no effect on preference.

These incongruous results were subsequently clarified in two experiments by Moore and Fantino (1975). In experiment 1 indifference was found given a choice between a terminal-link VT schedule and a tandem VT FR schedule[10]. In experiment 2, the terminal links consisted of fixed-time (FT) and a tandem FR FI schedule, and the pigeons showed a clear preference for the FT schedule. In reviewing these results, and the results of studies mentioned above, Moore and Fantino concluded:

> (1) when response contingencies, including required-rates, are imposed upon aperiodic schedules, in which there are no periods of (temporally) discriminated extinction (Killeen, 1968; Experiment I), then pigeons are indifferent to the contingencies; (2) when response contingencies may be satisfied on a periodic schedule without emitting responses during a period of (temporally) discriminated extinction (Neuringer, 1969), then pigeons are indifferent to the response contingencies; (3) however, when the response contingencies of a schedule must be satisfied early in the IRI [interreinforcement interval] of a periodic schedule, then pigeons typically prefer the alternate schedule. (p. 345)

The indifference observed with periodic schedules (2) was further investigated when Davison et al. (1988) asked whether the duration of the initial-link components had any effect on choice between response-dependent and independent outcomes. That is, all previous studies had used VI 60-s schedules in the initial links (except Neuringer [1969] who used VI 90 s), even though it could be argued that initial-link preference may be modulated by initial-link duration as it is toward differential terminal-link IRIs (e.g., Fantino, 1969a). However, data from the Davison et al. study showed indifference toward FT and FI terminal-link schedules even though initial-link schedules were varied from 15 to 180 s.

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[10]A tandem schedule consists of the sequential presentation of two or more schedules under constant stimulus conditions. Reinforcement occurs only after the terminal schedule requirements are satisfied.

Terminal-link Topographies

The finding of indifference toward response-independent and response-dependent schedules (e.g., Davison & Alsop, 1988; Neuringer, 1969) raises a related question of the effect of differential terminal-link effort on choice behavior. Although pigeons were indifferent toward response-rate requirements, except in the case of contingencies requiring responding early in a periodic schedule, this finding cannot be taken as evidence that the organism is indifferent toward differential effort requirements associated with each outcome. This conclusion is principally based on the assumption that, even with response-independent schedules, superstitious behavior is engendered--some of which may require a great deal of effort (Killeen, 1968). To date no research has directly addressed this issue using the concurrent-chain procedure. However, a related line of research involving different terminal-link topographies does provide a preliminary consideration of this issue. In one study, Starin (1989a) provided pigeons with a choice between terminal-link key pecking and treadling; a clear preference was shown toward the key-pecking outcome. However, because the birds pecked faster then they treadled, obtained reinforcement rates were higher in the key-pecking link relative to the treadling link. When this confound was corrected in a subsequent study (Starin, 1989b) the pigeons were indifferent toward the two outcomes. Even though force requirements were not explicitly manipulated in this study, the fact that treadling appeared to require greater effort relative to key pecking suggests that pigeons may also be insensitive to differential force requirements using this procedure.

Response Force Requirements

Even though the effects of differential force requirements have not been investigated using the concurrent-chain procedure, a number of other experimental

procedures have been used to study response-force requirements. Of particular interest here are the results of three studies that investigated the effects of force requirements using concurrent VI VI procedures.

In the earliest of these studies Chung (1965) described two such experiments. The first experiment employed a concurrent VI 1-min VI 1-min procedure with differential force requirements on two keys. Chung reported that higher response rates were always found with the low force key. The second experiment employed a concurrent VI 1-min VI 3-min schedule; force requirements on both keys were always equal, but varied across conditions. Chung found that preference for the VI 3-min schedule shifted as a function of changes in absolute force requirements, suggesting an *interaction* between reinforcement rate and key-force requirements. In other words, at 0.25 N force on both keys the relative response rate on the VI 3-min key was approximately 0.35, but with increases in the key force requirements the relative response rate on the 3-min key drifted lower.

Keehn (1981) systematically replicated Chung's (1965) first concurrent schedule experiment with rats. Keehn also found a change in response allocations with variations in lever force requirements, but unlike the previous study, Keehn's data showed evidence of behavioral contrast[11]. Keehn also examined his data in terms of a matching relationship between response-rate ratios and force ratios and concluded that "no simple relationship between effort on one bar and either response or reinforcement rate on the other bar emerged" (p. 168).

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[11]Data may be examined for behavioral contrast if the experiment involves several conditions where variables associated with one schedule are held constant while variables associated with the other schedule are varied. Both the Chung (1965) and Keehn (1981) studies involved such conditions. Given these experimental arrangements, behavioral contrast is defined as a change in response rate on the constant schedule as a function of changes on the varied schedule.

The most recent study to investigate the effects of response-force requirements on concurrent performance was reported by Hunter and Davison (1982). In this study VI schedule values and key force requirements were both varied across conditions. Like the previous studies, these conditions were arranged so that the data could be examined for behavioral contrast, and key force and reinforcement rate interactions. Consistent with the Chung (1965) study, Hunter and Davison reported that no behavioral contrast was observed. These authors also examined their data in terms of a matching relationship, and unlike the Keehn (1981) study, proposed the following matching equation as representative of the data:

$$\log\left(\frac{B_L}{B_R}\right) = a \log\left(\frac{R_L}{R_R}\right) + e \log\left(\frac{F_L}{F_R}\right) + \log c, \qquad (6)$$

where F and e represent the response force requirement and the sensitivity of the response ratio to changes in the force ratio, respectively. However, it should be noted that unlike the parameters of a, and b, in equation 4, e is a negative function because an increase in force produces a decrease in preference. Hunter and Davison's data also showed that response-force requirements and reinforcement rates were independent, unlike the data reported in Chung's (1965) study. This finding by Hunter and Davison was of some significance because an interaction between two parameters would make the generalized matching law inapplicable to this data.

Finally, Hunter and Davison (1982) observed that although response-allocation data were as statistically sensitive to changes in force requirements as changes in reinforcement rates, time-allocation data[12] were much less sensitive to force

[12]A time-allocation measure of choice provides an alternative method of quantifying the choice behavior. This measure is based on the amount of time that the organism spends on each alternative operandum. When each schedule of reinforcement is presented on spatially separate response operandum, as in the Hunter and Davison (1982) study, the time spent on each alternative is measured by a timer designated to each alternative. The timer for a particular operandum starts with the

requirements relative to reinforcement rates. They do not offer any reasons for this disparity, but a possible explanation will be discussed below.

Limitations of Concurrent Schedules

As straightforward as these three studies appear, the nature of the independent variable used in each raises several important considerations. The first involves the limitations of the simple concurrent procedure as a measure of preference between varied response-force requirements. This problem is highlighted by an experiment that investigated the effects of force on simple VI performance which demonstrated that response rates decreased with increased force requirements (Chung, 1965, exp. 1). Such results suggest that when the response-rate ratio is employed as the dependent measure of choice, the organism will necessarily show a preference for the low-force alternative. This difficulty is perhaps the basis of Hunter and Davison's (1982) observation that the response-allocation ratios were statistically more sensitive to changes in force requirements relative to time-allocation ratios. In other words, the incongruity between the time based and response based data is possibly accounted for by the fact that response-allocations are confounded by the *direct* effect of force on response rate.

The second problem raised by the procedures employed by these studies involves the manipulation of force requirements via springs and counterweights on the response keys. Unfortunately, manipulating force requirements in this way not only changes the force requirements needed to close a microswitch, but necessarily alters

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first response on that alternative and stops with the first response on the other alternative. The total time spent on each alternative thus forms the basis of the time ratio (T_L/T_R) and this ratio may substitute for the response ratio (B_L/B_R) on the left side of equations 1, 2, 3, 4, 5 and 6. In fact some have argued (e.g., Baum & Rachlin, 1969) that time ratios actually provide the best measure of choice behavior.

the response definition. For example, all responses equal to or greater then 0.25 N are recorded in a condition requiring 0.25 N to close the microswitch. However, in a new condition requiring 0.50 N, only responses 0.50 N and greater are counted; responses less then 0.50 N, although they may still occur are no longer measured. This practice therefore confounds response definition with force requirements (Mintz, Samuels & Barber, 1976). All three studies reviewed above are confounded in this way, except perhaps the time-allocation measure employed in the Hunter & Davison (1982) study. Mintz et al. demonstrated that when this confound is eliminated from a response measure procedure with VI schedules, absolute response rates do not change as a function of increased force requirement, even though there are changes in percent of responses meeting a given criterion force requirement.

The employment of concurrent-chain schedules would potentially eliminate both problems associated with investigating force parameters. The first problem involving the confound between the measure of choice and the direct effect of force requirements on responding is eliminated if choice is measured in the initial links of the concurrent-chain schedule and force is manipulated in the terminal link. The second problem involving a confound between response definition and response force requirements is also eliminated if force requirements are held constant in the initial links and manipulated in the terminal links.

Focus of Study

The present study will investigate the effects of force requirements on choice behavior using concurrent-chain schedules. Concurrent-chains are well suited for investigating parameters such as response-force requirements, but as previously discussed, there is some question as to how sensitive concurrent-chain schedules are to nontime-based variables. However, if choice behavior is found to be sensitive to

force ratios, a secondary question becomes whether or not there is an interaction between initial-link reinforcement rates and terminal-link force ratios (Hunter & Davison, 1983). Again, this issue is of some importance because an interaction between these two parameters would be further evidence that the application of the generalized matching law to concurrent-chain schedules is inappropriate.

Experiment 1 of the present study will employ a conventional concurrent-chain procedure and will manipulate rates of reinforcements in the initial links and force values in both the initial and terminal links across experimental conditions. Experiment 2 will employ a nonindependent concurrent-chain procedure (Stubbs & Pliskoff, 1969) in some conditions and a modified concurrent-chain procedure in other conditions. The nonindependent procedure insures that programmed and obtained terminal-link entries remain equal. In contrast, the modified procedure employed in Experiment 2 will allow the VI timers in the initial links to run only when responding occurs on the lever associated with that schedule. Therefore the initial-link VI schedules will run sequentially as determined by the organism's behavior. In addition, the number of terminal-link entries will also be highly dependent upon initial-link lever preference. The sensitivity of initial-link choice ratios to manipulations in terminal-link force will then be compared across experimental procedures. Experiment 3 will replicate several of the conditions of Experiment 1, but will employ a nonindependent concurrent-chain procedure (Stubbs & Pliskoff, 1969).

All three experiments will employ a changeover delay in the initial links (Herrnstein, 1961). The addition of this procedure will facilitate comparisons with Hunter and Davison's (1982) study.

CHAPTER II

EXPERIMENT 1

Method

Subjects

Eight Hooded rats, maintained at 80% of their free-feeding body weights, served as subjects. All subjects were approximately 120 days old and experimentally naive at the beginning of the experiment. Between experimental sessions, rats were housed in individual cages with free access to water.

Apparatus

Four two-lever Lehigh Valley Electronics rat chambers, measuring 15 cm high, 13 cm wide, and 20 cm long, were individually housed within sound-attenuating boxes during experimental sessions. The levers in each chamber extended 2.5 cm from the wall and were located 10 cm from the floor, 1 cm from the side wall and 2 cm from a plexiglass barrier that separated the two levers. The plexiglass barrier extended 6 cm from the front of the chamber. A 3 cm aperture centered in the front panel and 4.5 cm above the floor provided access to a motor-operated dipper. The dipper was normally down. During reinforcement this dipper was raised for 5 s and delivered approximately 0.01 ml of a mixture containing 50% sweetened condensed milk and 50% water. Each chamber was also equipped with 2 lights located directly above each lever; in the rear panel were located a house light and a Sonalert tone device.

The lever mechanisms in each chamber were designed so as to allow changes of lever force during the experimental session. A diagram of the response lever is shown in Figure 2. The lever was constructed so that when it was depressed from inside the chamber, the bottom of a vertical metal shaft was displaced approximately 0.15 cm from the top of an electromagnet. The release of the lever allowed for the bottom of the shaft to rest on the electromagnet. The force required to depress the lever was modulated by the amount of current passed through the electromagnet. When the electromagnet was off, the lever was operated by approximately 0.20 N of force. A downward displacement of the lever of approximately 0.2 cm produced a click from both the operation of a microswitch and a relay attached to the side of the chamber nearest the operated lever.

Masking noise was provided by a Grason-Stadler White Noise Generator (Model 901B) through a speaker mounted on the side wall of the sound-attenuating box, and ventilation was provided by an exhaust fan. Data collection and experimental events were controlled by a PDP-8 minicomputer (Digital Equipment Corporation) with SUPERSKED software (State Systems, Kalamazoo, Michigan) in concert with electromechanical interfacing.

Procedure

Subjects were first trained to respond to the raised dipper. Milk was delivered on the average of every 60 s using a random time schedule. During this training condition a wire mesh barrier, placed over the levers, denied access to the two levers. At the end of three sessions all rats reliably licked the dipper when raised.

During the fourth session the wire mesh barrier was removed and continuous schedules of reinforcement were programmed on each lever. The fifth and

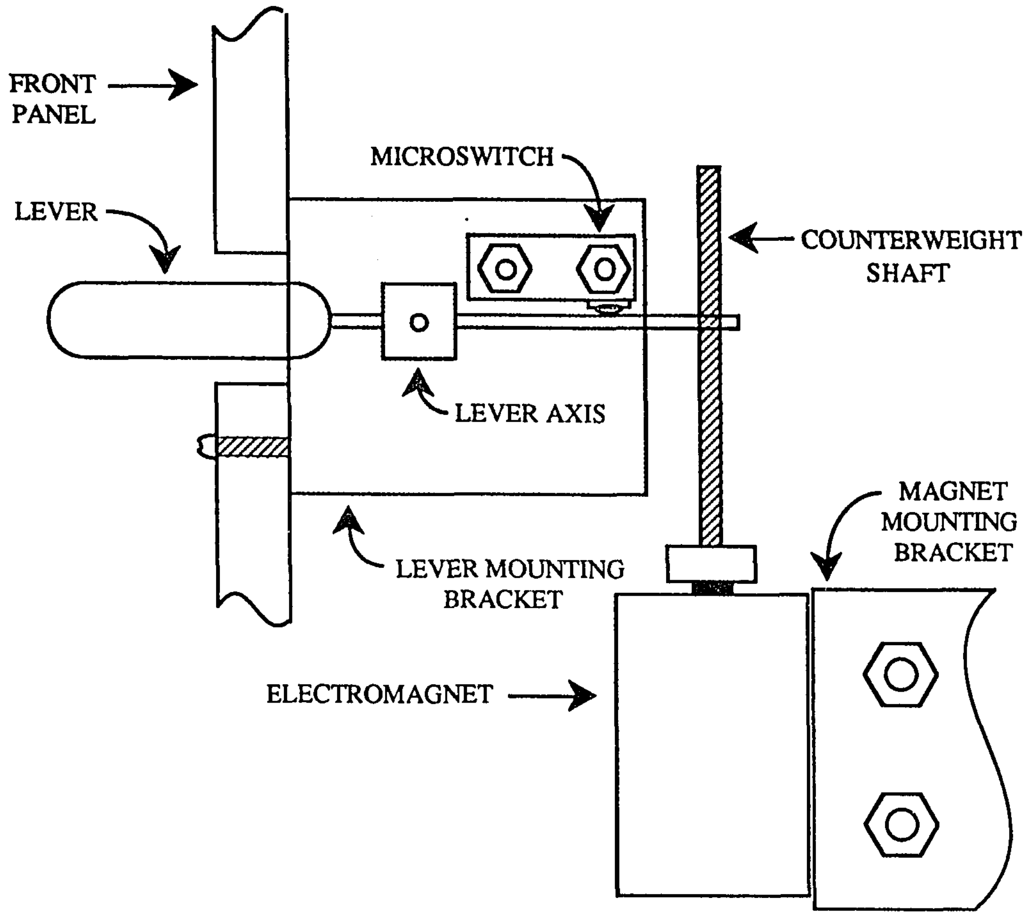

Figure 2. Schematic Diagram of the Response Lever. The Electromagnet Varied the Force Required to Operate the Lever During the Specified Link in the Concurrent-Chain Procedure.

subsequent training sessions involved the concurrent-chain procedure as described below, except that the VI values were gradually increased across sessions until experimental values had been obtained.

The concurrent-chain procedure is diagrammed in Figure 1 (Chapter 1); events that occur prior to food reinforcement on the left and right lever are represented in Part A and Part B, respectively. In the initial link, two lights over the levers were lighted, and two VI schedules were independently operated. If one VI schedule timed out, the other VI schedule continued to operate until it timed out or until a response on the other schedule occurred. A changeover delay (COD) of 1.5 s was employed in the initial link (Herrnstein, 1961). Therefore, a response on a timed-out VI schedule would produce the terminal-link stimulus only after 1.5 s had elapsed since the first response on that lever. The two terminal-link stimuli associated with the left and right levers were a red house light or a tone, counterbalanced across rats. Responses in the terminal link were followed by food on a VI 15-s schedule. At the termination of a 5-s food delivery period, new VI values were assigned to the initial and terminal links that had produced reinforcement (the other initial-link schedule retained whatever value it had prior to the terminal-link entry), and initial-link stimuli and VI schedules were reinstated. The session ended after 60 food deliveries.

All VI schedules were constructed using constant probability values (Catania & Reynolds, 1968). The 10 values of each VI schedule were selected in random order without replacement. However, the values for each terminal-link schedule were adjusted following each reinforcement to minimize the discrepancy between *programmed* and *obtained* VI values. This was done to insure that as response-force requirements in the terminal links were varied, rates of reinforcement in the terminal links remained constant. Specifically, following food reinforcement a new VI value for that terminal-link schedule was randomly selected and multiplied by an adjustment

factor that was calculated with the formula: Adjustment Factor = $[(a/b)(c/d)]$. The value of (a/b) was recalculated after each food delivery in a specific terminal link. This value was based on the total accumulated time in that link divided by the accumulated total of the preadjusted programmed VI values assigned to that link up to the time of recalculation. The value of (c/d) was recalculated after every five food deliveries in a specific link. This value was based on accumulated time in that link over the last five reinforcements divided by the accumulated total of the postadjusted programmed VI values assigned to that link over the last five reinforcements. Prior to the first food delivery on a given lever (a/b) equaled 1.0, and prior to the first five food deliveries on a given lever (c/d) equaled 1.0. This formula was selected among several similar formulas on the basis that it produced the least discrepancy between average programmed reinforcement rate and average obtained reinforcement rate.

The programmed VI values for initial-link schedules, and the initial-link and terminal-link force values are listed in Appendix A. The programmed VI values for the terminal schedules, prior to adjustment, were always 15 s. Experimental conditions were changed for each subject when stability was reached using the following criterion: a median of the relative number of responses on one lever (in the initial links) over five days must not be more then .05 different from the median of the preceding five days (Davison, 1972). When this criterion had been met five (not necessarily consecutive) times the next experimental condition was begun.

Results and Discussion

The data used in the analyses were means based on the last 5 sessions in each condition, unless otherwise specified. Overall time in the initial link, initial-link response rates, initial-link time allocations, terminal-link response rates and number of terminal-link entries are shown in Appendix B. It should be noted that although equal

numbers of terminal-link entries were programmed for all but two conditions, obtained terminal-link entries covaried with the manipulation of the independent variable. The implications of this problem will be discussed later.

The stability of performance to terminal-link force requirements was assessed with the replication of the 0.25 N /1.09 N force ratio in the initial-link VI 10 s VI 10 s and VI 30 s VI 30 s conditions. Preference was measured as relative response allocation (initial-link response rate on left lever divided by total initial-link response rate) and as relative time allocation (initial-link time on left lever divided by total time responding). There were no significant trends on a nonparametric test (Ferguson, 1965) over relative response or time allocation measures.

Adjusting VI Procedure

The adjusting VI procedure employed in this study was designed to minimize the discrepancy between the programmed and obtained terminal-link schedule values. As shown in Table 1, obtained terminal-link VI schedules were reasonably close to the programmed VI 15-s schedule.

Table 1

Effect of Terminal-Link Force on Terminal-Link Duration (Seconds)

	Force (Newtons)			
	0.25 *N* = 160	0.67 *N* = 160	1.09 *N* = 245	1.51 *N* = 160
Mean	15.12	15.04	15.13	15.19
SD	0.66	0.94	0.92	1.25

Note. Data in the 0.67, 1.09 and 1.51 cells are based on Conditions 2 - 8 and 11 - 17. Data in the 0.25 cell are based on Conditions 1 and 9. *N* = number of observations, *SD* = standard deviation.

There are no trends in mean terminal-link duration across force values, but a slight increase in standard deviations with increased force is suggested. This trend is explained if it is assumed that greater VI adjustments are needed with increased force values. Taken together, these data suggest that an important experimental design assumption has been met: Terminal-link force values were increased without producing a corresponding increase in terminal-link durations.

The distortion of the VI schedule by the adjustment procedure is examined in Figure 3. The programmed VI values are shown to produce a smooth, positively accelerated curve. The adjusted VI values show some deviation from the programmed VI 15-s values, but the distortion of the curve is minimal. Therefore, although the VI schedule was adjusted in the terminal link, it appears that it retained the essential characteristics of a constant probability VI schedule.

Force and Terminal-Link Response Rates

The *direct* effect of terminal-link force on terminal-link response rates (Conditions 1 - 18 [1 - 19 for Rat 3]) is shown in Figure 4. These data clearly show decreased terminal-link response rates as a function of increased terminal-link lever force. Furthermore, this relationship appears to be unaffected by the size of the VI schedules employed in the initial links. However, the shape of this function is not consistent across rats. Rats 2, 5 and 6 show an almost linear decrement in response rate with increased force, whereas Rats 1,3 and 8 show a curvilinear function. In contrast, Rats 4 and 7 show a sharp decrease in response rate with exposure to the 0.67 N conditions, but this same low response rate is maintained across the higher lever force conditions. In general, however, these data are consistent with the findings of other studies that have investigated the direct effects of force on response

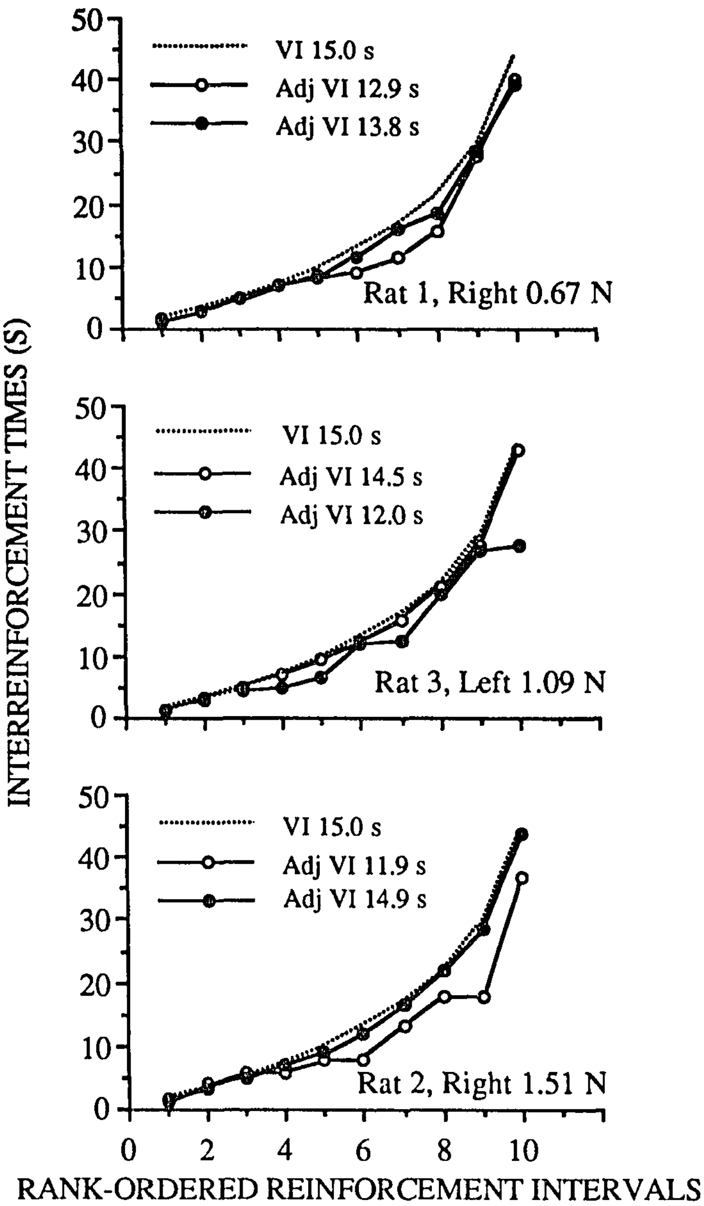

Figure 3. Representative Samples of Programmed and Adjusted Variable-Interval Interreinforcement Times, Rank Ordered Across 10 Reinforcement Intervals, for Force Values of 0.67, 1.09 and 1.51 N. The Closed Circles are the Last 10 Adjusted VI Values of the Session. The Open Circles are the Preceding 10 Adjusted VI Values in that Session.

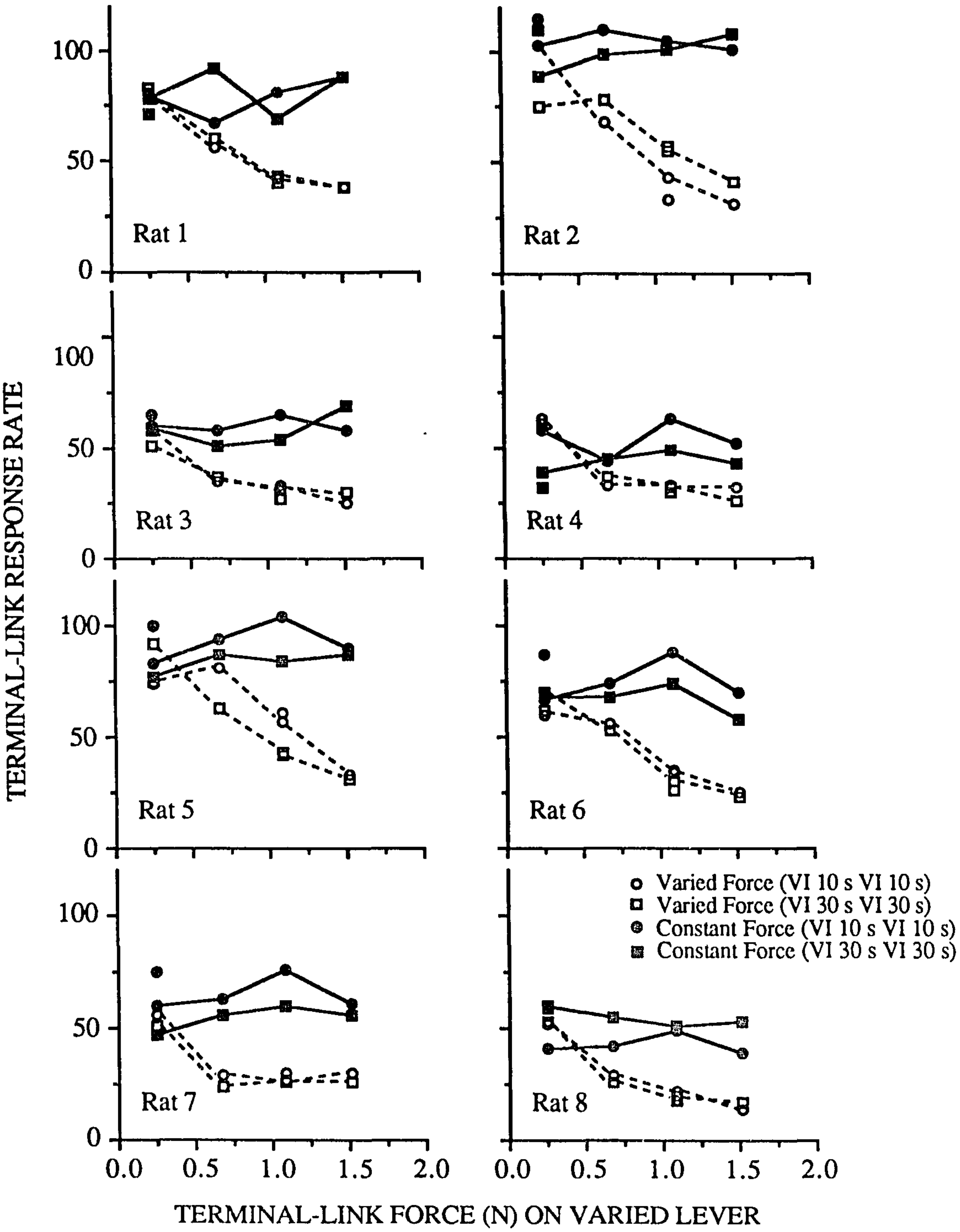

Figure 4. Terminal-Link Response Rate as a Function of Lever Force on the Constant (0.25 N) and Varied Lever When Initial-Link Schedules are VI 10-s VI 10-s or VI 30-s VI 30-s. Each Data Point is the Mean of Two Exposures to Each Condition. The Single Data Points are Replication Conditions.

rates: an increase in force requirements results in decreased response rates (e.g., Elsmore & Brownstein, 1968; Mintz, 1962; Mintz et al., 1976; Notterman & Mintz, 1965).

Response rates on the constant terminal-link 0.25 N lever show some variability, but there is no evidence of systematic changes as a function of force values employed on the alternative (varied force) terminal-link lever.

Response and Time Allocations

The results discussed in the sections above suggest that several important design assumptions were met. Specifically, terminal-link force was manipulated within ranges that directly affected terminal-link response rates without affecting terminal-link durations. Therefore, these data will be further examined in terms of the *indirect* effects of terminal-link force. Specifically, the experimental question to be addressed is the effect of terminal-link force on initial-link response and time measures.

This question will be first addressed by examining the effects of terminal-link force on initial-link absolute response rates. For comparative purposes, the effects of initial-link reinforcement rates and initial-link force values on initial-link response rates will also be considered.

Changes in initial-link response rate as a function of initial-link reinforcement rates, initial-link lever force and terminal-link lever force are shown in Figure 5. The data for all rats, except Rat 8, show higher response rates on the lever associated with the initial-link high reinforcement rate lever, a finding that is consistent with other concurrent-chain studies (e.g, Squires & Fantino, 1971). Similarly, initial-link force requirements also affected initial-link response rates. In contrast, however, initial-link response rates were relatively insensitive to the same terminal-link force requirements. Only Rats 3, 7, and 8 showed differential initial-link response rates as a function of

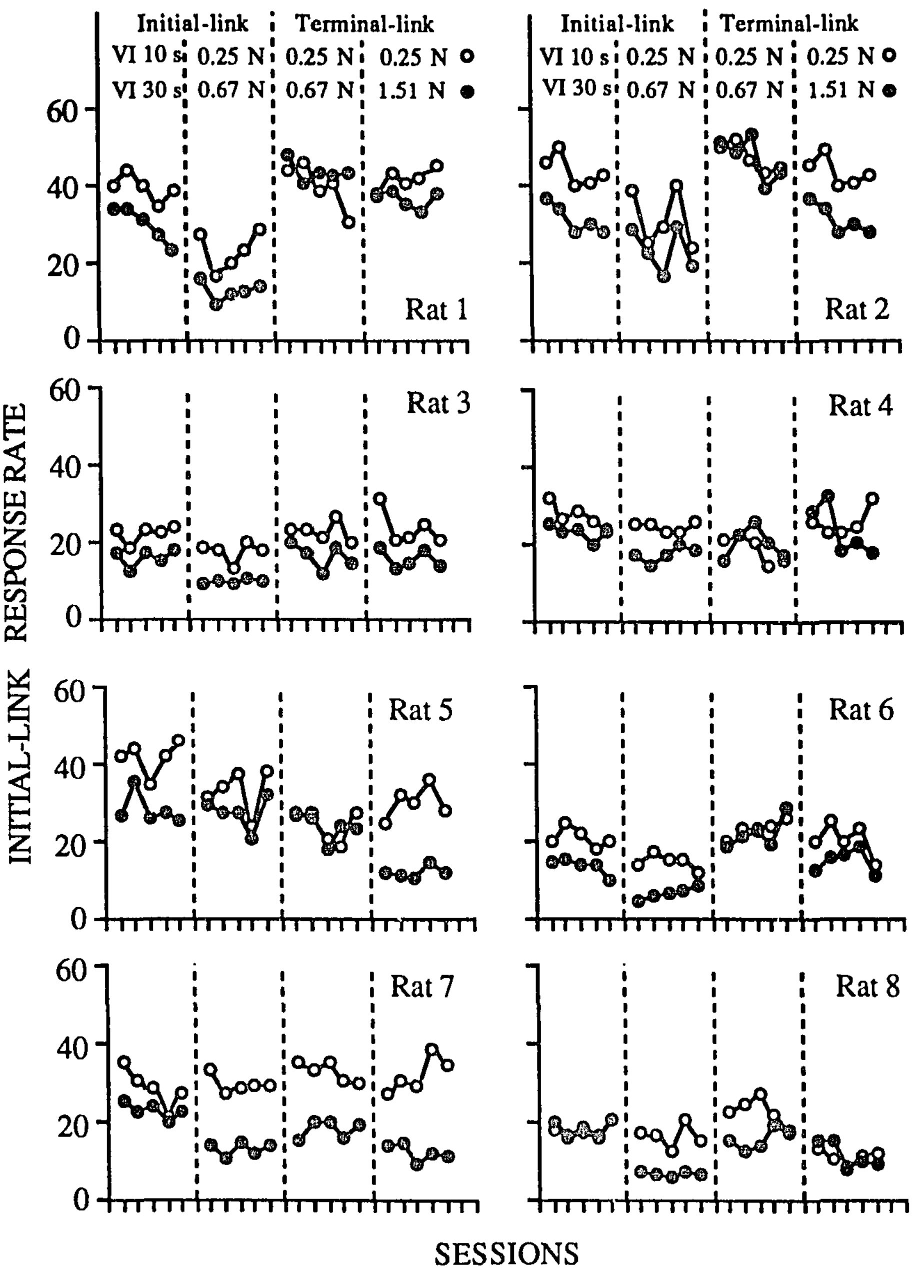

Figure 5. Initial-Link Response Rate as a Function of Four Types of Manipulations: Initial-Link Reinforcement Rate (VI 10 s VI 30 s), Initial-Link Lever Force (0.25 N 0.67 N), Terminal-Link Lever Force (0.25 N 0.67 N With Initial-Link VI 10-s VI 10-s schedules) and Terminal-Link Lever Force (0.25 N 1.51 N With Initial-Link VI 30-s VI 30-s). Each Data Point is the Mean of Two Exposures to Each Manipulation, Counterbalanced Across Levers. The Last Five Sessions in Each Condition are Displayed.

0.25 N/0.67 N terminal-link force requirements. Initial-link response rate sensitivity was found, however, with larger differential terminal-link force requirements (i.e., 0.25 N/1.51 N).

In general, therefore, absolute response-rate data suggest that the effect of force on initial-link response rates is dependent upon the link in which force parameters are manipulated; initial-link response rates are clearly more sensitive to initial-link force parameters. A similar conclusion is suggested by initial-link time measures, as investigated in Figure 6. Unlike the response-rate data, however, time-allocation measures were unexplainably insensitive to initial-link reinforcement rates.

The indirect effects of terminal-link force were also assessed through regression analyses. Terminal-link force ratios were regressed on initial-link response ratios (see Figure 7) and time ratios (see Figure 8). The regression equations in each panel show that the proportion of data variance accounted for by terminal-link force ratios is extremely low (below .75) for all regressions, except for Rat 3 (log response-ratio data) and Rat 7 (log response-ratio and log time-ratio data). Furthermore, none of the regression lines deviated significantly from 0, except the VI 10 s VI 10 s log response-ratio data for Rat 3 and 7 ($p < .01$; $F = 70.41$ and 153.00, respectively; Bonferroni F_B familywise alpha) and for the VI 10 s VI 10 s and VI 30 s VI 30 s log time ratio data for Rat 7 ($p < .01$; $F = 132.26$ and 128.00, respectively; Bonferroni F_B familywise alpha).

These analyses therefore show that variations in initial-link allocations are generally not accounted for by terminal-link force ratios. That is, variations in absolute response (Figure 5) and time (Figure 6) data were not strictly a function of terminal-link force parameters.

Further data analyses found terminal-link entries to be a significant factor in explaining variations in initial-link choice measures. As alluded to earlier, a major

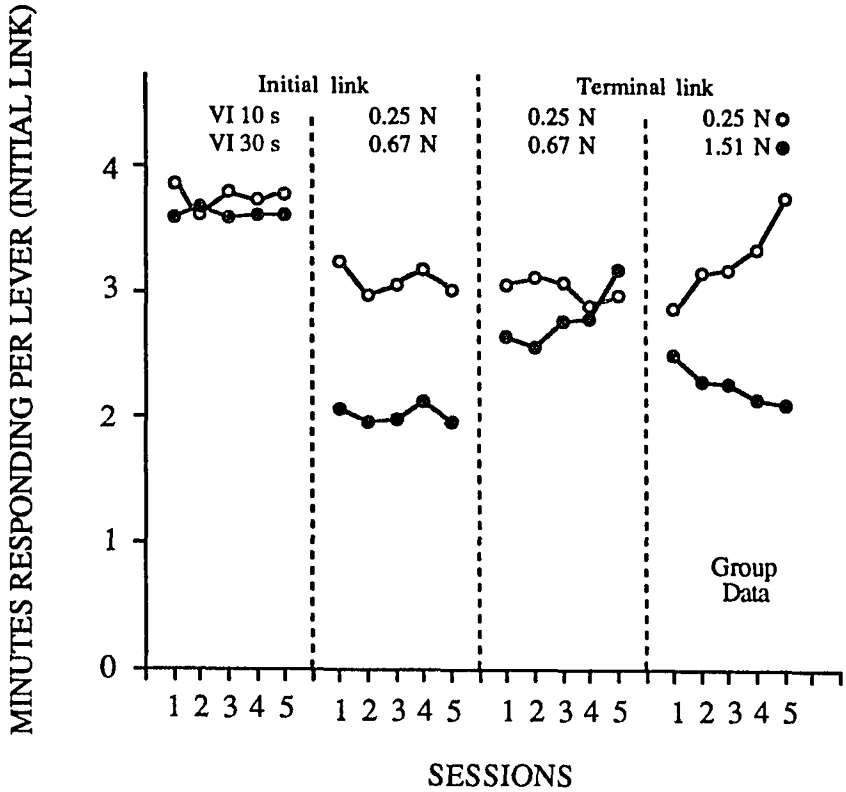

Figure 6. Minutes Responding Per Lever in the Initial Link, Averaged Across Two Exposures to Each of Four Manipulations: Initial-Link VI 10 s VI 30 s Schedules; Initial-Link 0.25 N/0.67 N, Terminal-Link 0.25 N/0.67 N (Initial-Link VI 10-s VI 10-s Conditions Only), and Terminal-Link 0.25 N/1.51 N Conditions (Initial-Link VI 10-s VI 10-s Conditions Only). Data From the Last Five Sessions of Each Condition are Shown.

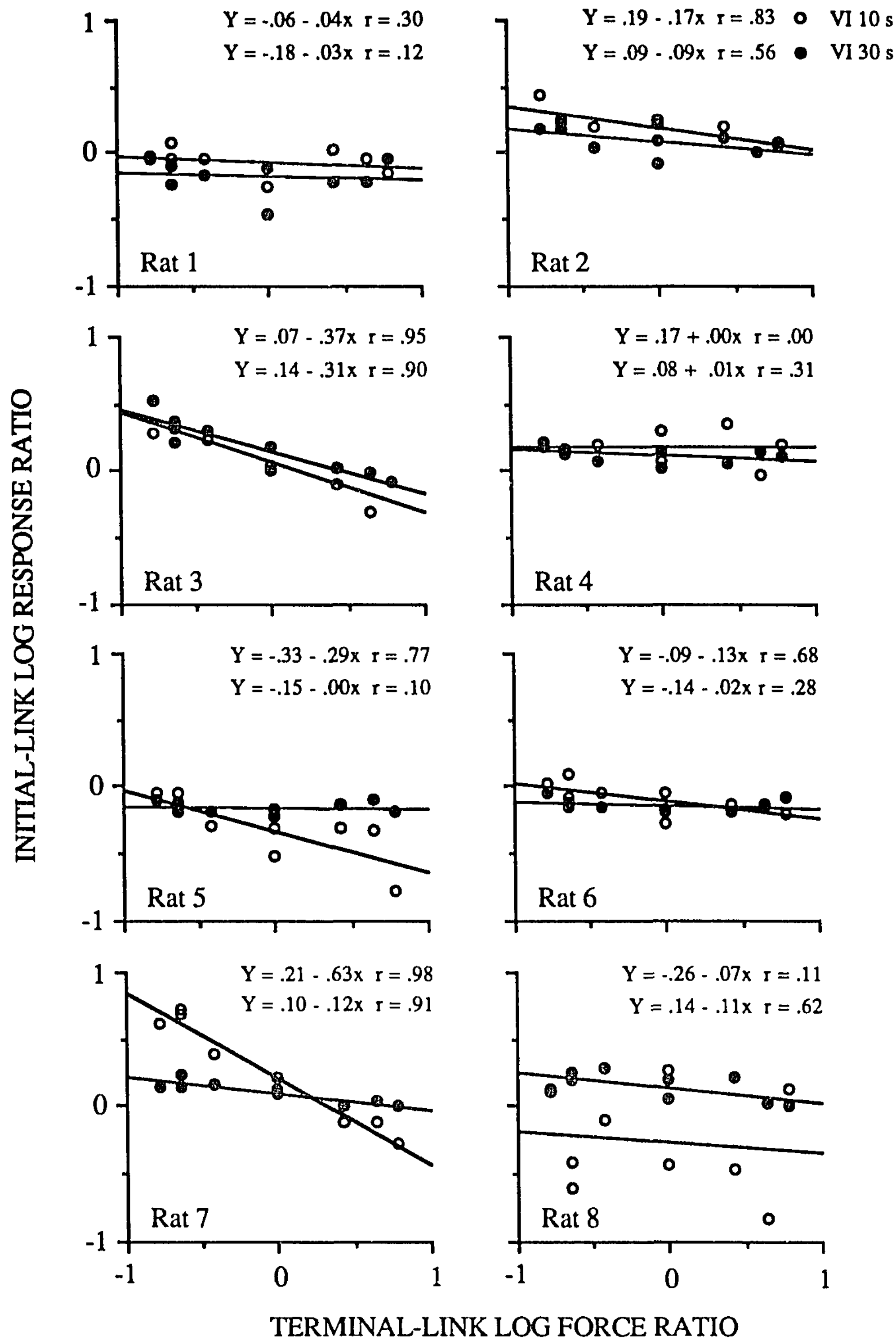

Figure 7. Initial-Link Log Response Ratio (Left Lever Over Right Lever) as a Function of Terminal-Link Log Force Ratio (Left Lever Over Right Lever). The Two Regression Lines and Regression Equations Shown For Each Subject. Correspond to Initial-Link VI 10-s VI 10-s (Open Circles) and Initial-Link VI 30-s VI 30-s Schedules (Closed Circles).

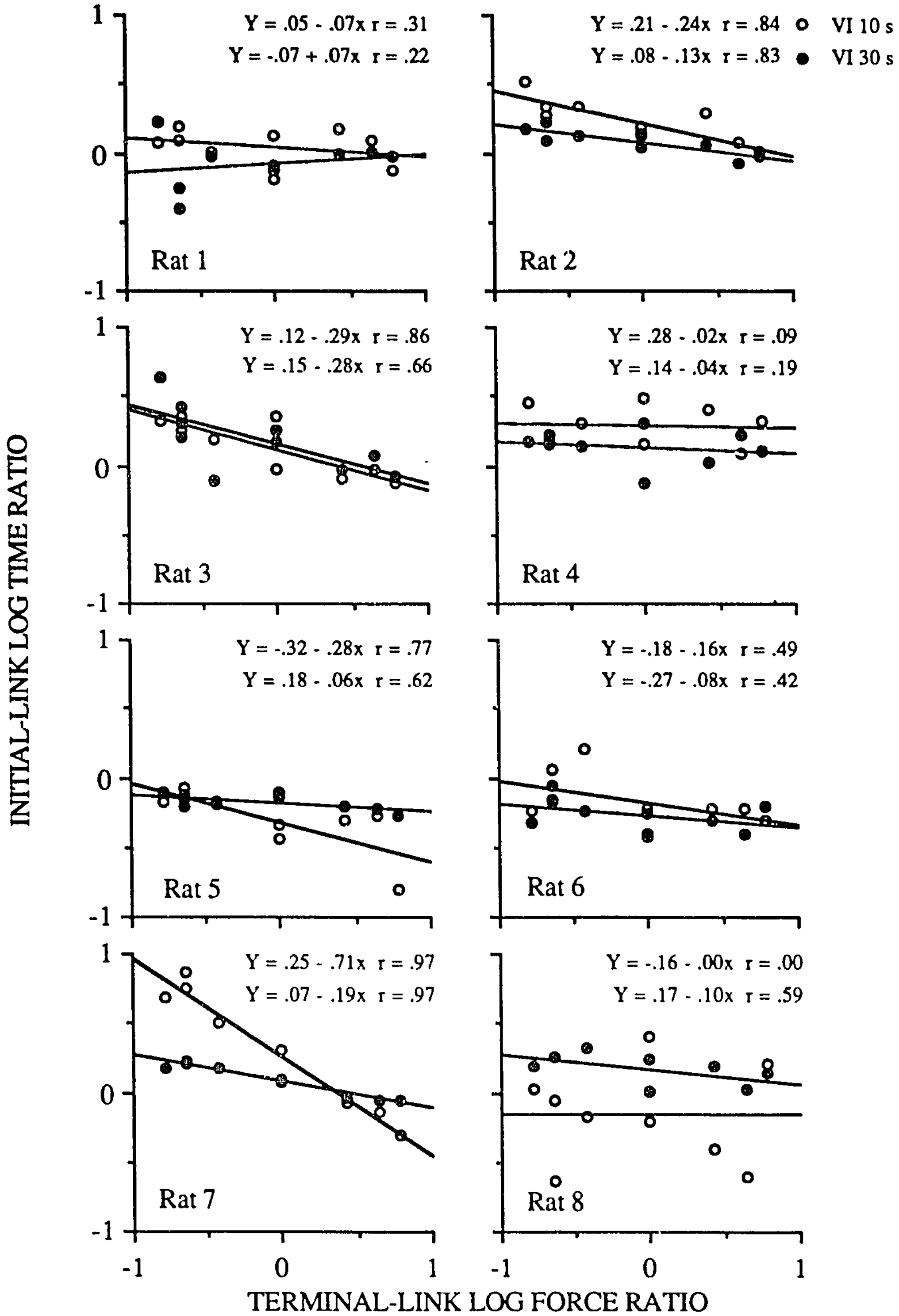

Figure 8. Initial Log Time Ratio (Left Lever Over Right Lever) as a Function of Terminal-Link Log Force Ratio (Left Lever Over Right Lever). The Two Regression Lines and Regression Equations Shown for Each Subject Correspond to Initial-link VI 10-s VI 10-s (Open Circles) and Initial-Link VI 30-s VI 30-s (Closed Circles) Schedules.

problem with the experimental procedure employed in this experiment was that obtained terminal-link entries covaried with the manipulation of the independent variable (see Appendix B). The effect of this covariation was assessed through multiple regression analysis carried out on both terminal-link entry ratios and terminal-link reinforcement ratios. The analyses found that variations in initial-link response ratios for 6 of the 8 rats were well described by terminal-link entry ratios (partial *F* ratios for terminal-link force ratios were all insignificant, but partial *F* ratios for terminal-link entry ratios were significant beyond the .01 level; Bonerroni F_B familywise alpha). Similar results were found with log time ratios for 4 of the 8 rats. These analyses therefore show that terminal-link force variables were confounded with terminal-link entries.

The problems created by covariation of terminal-link entries is further demonstrated in Experiment 2. The effects of terminal-link force on initial-link response rates were investigated using two variations of the concurrent-chain procedure employed in Experiment 1. Although one procedural variation eliminated terminal-link covariation, the other procedure, unfortunately, exacerbated the problem of covariation in terminal-link entries.

CHAPTER III

EXPERIMENT 2

Method

Subjects

Four Hooded rats, maintained at 80% of their free-feeding body weights, served as subjects. All subjects were approximately 120 days old and experimentally naive at the beginning of the experiment. Between experimental sessions, rats were housed in individual cages with free access to water.

Apparatus

The apparatus used in Experiment 1 was also employed in Experiment 2.

Procedure

The training procedure described in Experiment 1 was employed in Experiment 2. The experiment proper involved two types of concurrent-chain procedures. *Nonindependent* concurrent VI VI schedules (Stubbs & Pliskoff, 1969) were employed in the initial-links of one of the procedures. With the nonindependent concurrent procedure, the initial links consisted of only one VI schedule. When this VI schedule elapsed, the first response on the designated lever produced a terminal-link entry which was probabilistically ($p = .5$) assigned to either the left or right lever. This procedure ensured that the number of terminal-links entries for both the left and right levers were nearly equal at the end of the session.

The second concurrent-chain procedure employed *response-selected* VI VI schedules in the initial links (see Findley, 1958, p. 130). Although a VI schedule was associated with each lever in the initial links, these two schedules never operated concurrently after the first response of the session. That is, a response on one lever stopped the VI timer associated with the other lever; the next changeover response started the VI timer associated with the selected lever and simultaneously stopped the timer associated with the nonselected lever, and so on.

The sequence of experimental conditions, programmed VI values and terminal-link force requirements of Experiment 2 are listed in Table 2. All other

Table 2

Sequence of Experimental Conditions for Experiment 2

			Initial-link VI Schedule (s)		Terminal-link Force (N)		
Subject	Condition	Procedure	Left	Right	Left	Right	Sessions
9	1	N	5	5	0.25	0.67	15
	2	RS	5	5	0.25	0.67	25
	3	N	5	5	0.67	0.25	17
	4	RS	5	5	0.67	0.25	26
10	1	N	5	5	0.25	0.67	17
	2	RS	5	5	0.25	0.67	14
	3	N	5	5	0.67	0.25	14
	4	RS	5	5	0.67	0.25	26
11	1	N	5	5	0.67	0.25	18
	2	RS	5	5	0.67	0.25	27
	3	N	5	5	0.25	0.67	27
	4	RS	5	5	0.67	0.67	14
12	1	N	5	5	0.67	0.25	18
	2	RS	5	5	0.67	0.25	22
	3	N	5	5	0.25	0.67	15
	4	RS	5	5	0.67	0.67	19

Note. N = Nonindependent concurrent VI VI procedure, RS = Response-Selected VI VI procedure, s = seconds, N = Newtons.

procedural details of Experiment 1 were replicated in Experiment 2.

Results and Discussion

The data used in the analyses were means based on the last 5 sessions in each condition, unless otherwise specified. Overall time in the initial link, average time in terminal-link, initial-link response rates, initial-link time allocations, terminal-link response rates and number of terminal-link entries are shown in Table 3. As the summary data in this table suggest, the adjusting VI procedure employed in the terminal-link appeared to work reasonably well. The discrepancy between programmed terminal-link VI values and obtained VI values were minimal.

Table 3 also shows that terminal-link entries and force manipulations covaried with the response-selected procedure, but not with the nonindependent procedure. The difficulties that this problem imposes upon data analysis will be returned to later.

The *direct* effect of terminal-link force requirements on terminal-link response rates across the nonindependent (Conditions 1 and 3) and response-selected (Conditions 2 and 4) procedures are shown in Table 4.

As expected, response rates decreased with increased force requirements. Response rates shown in Table 4 are comparable to those obtained in Experiment 1 (Figure 4).

Initial-link absolute response rates and absolute minutes responding as a function of differential terminal-link force requirements are shown in Figure 9. The left side of each panel displays the response-selected VI VI data (the mean of Conditions 2 and 4), whereas the right side of each panel displays the nonindependent VI VI data (the mean of Conditions 1 and 3). The response-selected data for each rat clearly shows higher initial-link response rates on the lever associated with the 0.25 N terminal-link force requirement. In contrast, initial-link response rates with the nonindependent concurrent VI VI procedure are comparatively insensitive to terminal-link force

Table 3

Summary of Results for Experiment 2

	Overall Time	Overall Time in Terminal Link		Initial-link Responses Per Minute		Initial-link Time Allocations		Terminal-link Responses Per Minute		Terminal-link Entries	
Condition	Initial Link	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
Rat 9											
1	18.97	0.254	0.262	8.56	7.88	5.40	3.80	60.23	33.71	30.0	30.0
2	15.20	0.256	0.306	15.74	7.75	11.58	2.29	52.35	30.66	40.6	19.6
3	18.48	0.256	0.258	7.74	9.94	4.25	6.44	40.38	55.80	30.0	30.2
4	10.88	0.254	0.254	12.82	14.92	4.50	6.23	50.90	80.18	29.2	31.2
Rat 10											
1	11.83	0.250	0.246	18.97	13.86	4.11	4.97	74.50	48.66	30.2	30.0
2	7.72	0.248	0.256	31.39	17.61	3.98	3.58	76.24	47.14	35.6	24.6
3	16.18	0.254	0.298	12.31	11.08	4.09	8.86	55.08	59.96	30.2	30.0
4	6.97	0.288	0.246	6.10	42.18	0.91	5.89	14.59	73.53	7.4	53.2
Rat 11											
1	12.86	0.250	0.250	15.74	12.86	4.29	5.64	31.22	73.83	30.2	30.0
2	7.31	0.270	0.252	17.74	24.54	2.74	4.51	47.01	51.07	23.6	36.6
3	11.83	0.250	0.248	22.50	13.53	6.40	3.46	94.06	36.21	30.2	30.0
4	6.09	0.246	0.294	50.88	8.64	5.26	0.51	101.22	36.17	53.6	6.8
Rat 12											
1	9.93	0.250	0.250	22.88	22.10	3.69	4.17	47.24	65.58	30.0	30.2
2	6.51	0.246	0.254	36.09	30.90	3.37	2.86	64.80	67.31	32.8	28.0
3	9.33	0.250	0.244	30.75	15.83	4.34	3.46	71.63	29.05	30.2	30.0
4	5.81	0.254	0.256	67.44	24.60	3.83	1.88	104.74	33.22	42.8	18.0

Note. All time data are expressed in minutes.

Table 4

Effect of Terminal-Link Force on Terminal-Link Response Rate, Experiment 2

	Terminal-link Force	
Procedure	0.25 (N)	0.67 (N)
Nonindependent	68.60	40.19
Response Selected	75.83	40.56

Note. Group response rates are means of two exposures to each condition. N= Newtons.

requirements. Similar, but less pronounced, findings are shown in Figure 9 with the time allocation measure.

Unfortunately, however, terminal-link entry and terminal-link force requirement covariation associated with the response-selected VI VI procedure makes a direct comparison with the nonindependent procedure impossible. The slight differences in response rate shown for Rat 12 with the nonindependent procedure, for example, may be attributed to differential terminal-link force requirements. In contrast, the large variations in initial-link response rates observed with the response-selected procedure are not simply a function of terminal-link force requirements, but of an interaction between terminal-link force requirements and number of terminal-link entries.

The logic for utilizing the response-selected VI VI procedure was to maximize the sensitivity of initial-link response rates to terminal-link force requirements. With the typical concurrent-chain procedure, independent concurrent VI VI schedules are employed in the initial link (this type of procedure was employed in Experiment 1). The configuration of this procedure is such that initial-link response rates are generally sensitive to manipulations in terminal-link events (e.g., number of reinforcements, etc.). However, the initial-link response rate associated with each lever is not purely a function of the independent variable, but is at least partially determined by

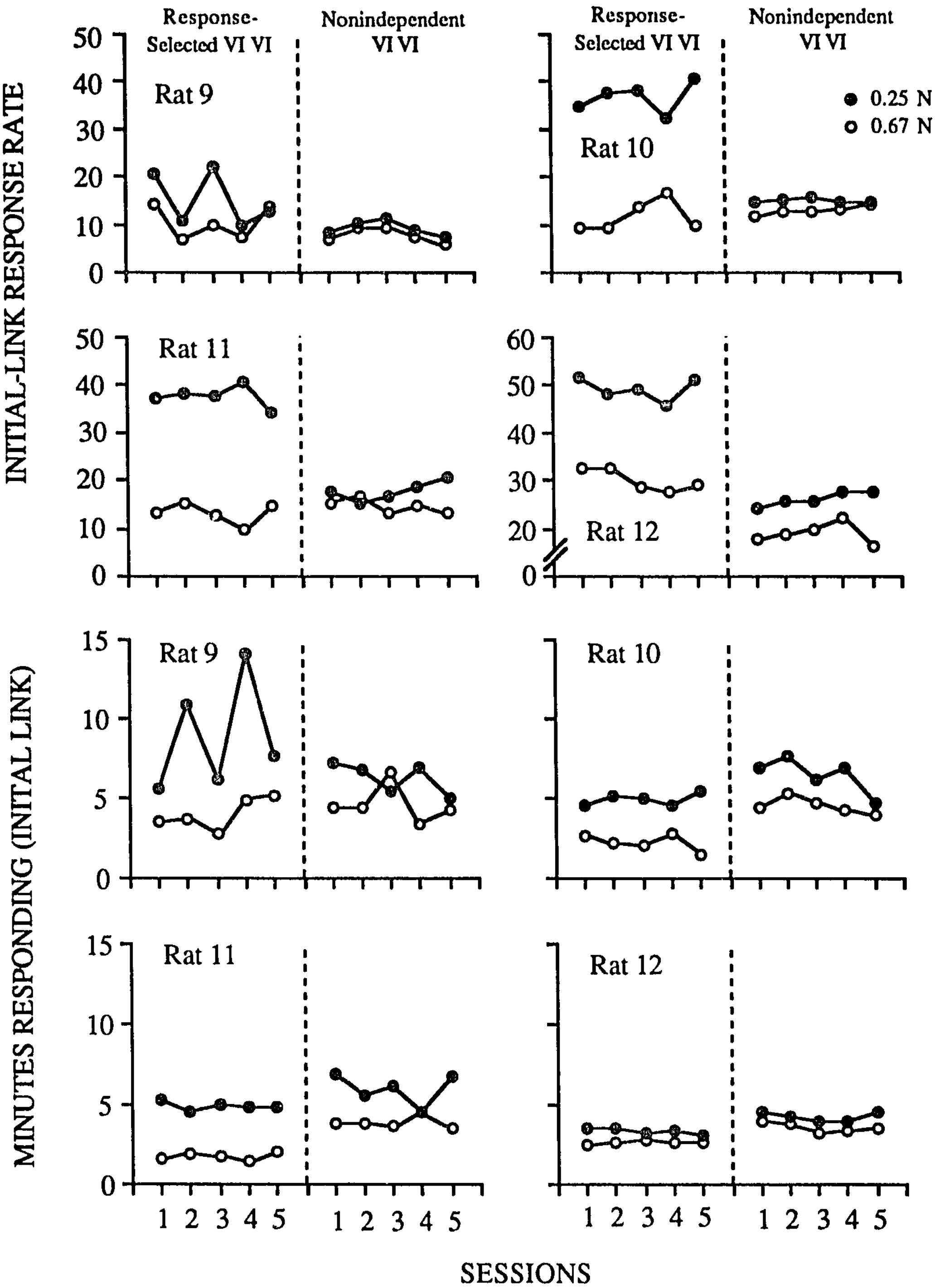

Figure 9. Initial-link Response Rate and Minutes Responding as a Function of Terminal-Link Force Requirements. The High and Low Force Values Were Differentially Associated With Both the Left and Right Lever Across Conditions. The Left Side of Each Panel Shows From the Initial-Link Response-Selected VI VI Procedure; the Right Side of Each Panel Shows From the Nonindependent Concurrent VI VI Procedure. Data From the Last Five Sessions of Each Condition are Shown.

concurrently running VI VI schedules. Findley (1958) demonstrated, for example, that when VI VI schedules are made to run successively rather concurrently, as with the response-selected procedure employed in the present experiment, the number of changeover responses decreased considerably. In other words, when VI VI schedules run successively, slight differences in reinforcement rates, force requirements, and so on, result in a strong preference for one alternative. The results from the response-selected procedure of Experiment 2 partially support this analysis. Large differences in initial-link response rates were obtained, but unfortunately the effects of terminal-link force on this dependent measure are confounded with covariation in terminal-link entries.

In conclusion, results of Experiment 1 and 2 show that the study of terminal-link force may be best accomplished with the nonindependent procedure. Furthermore, the results of Experiment 2 suggest that initial-link response rates are slightly sensitive to terminal-link force requirements. Experiment 3 will therefore further investigate initial-link sensitivity to much larger terminal-link force ratios with the nonindependent procedure.

CHAPTER IV

EXPERIMENT 3

Method

Subjects

Four Hooded rats, maintained at 80% of their free-feeding body weights, served as subjects. All subjects were approximately 120 days old and experimentally naive at the beginning of the experiment. Between experimental sessions, rats were housed in individual cages with free access to water.

Apparatus

The equipment used in Experiment 1 and 2 was employed in Experiment 3.

Procedure

The training procedure described in Experiment 1 was also employed in Experiment 3. The experiment proper employed a concurrent-chain procedure with nonindependent initial-link concurrent schedules, as described in Experiment 2. That is, the initial links consisted of a single VI schedule and entry into the terminal link was probabilistically (p = .5) assigned to either the left or right lever, in the manner of Stubbs and Pliskoff (1969). This procedure ensured that the number of terminal-link entries for both the left and right levers were nearly equal at the end of each session.

The programmed VI values and the response-force requirements for both initial- and terminal-links are listed in Table 5.

Table 5

Sequence of Conditions for Experiment 3

		Initial-link Schedule (s)		Terminal-link Schedule (s)		Initial-link Force (N)		Terminal-link Force (N)		
Subject	Cond	Left	Right	Left	Right	Left	Right	Left	Right	Session
13	1	5	5	15	15	0.20	0.20	0.25	0.25	14
	2	5	5	15	15	0.20	0.20	1.51	0.25	14
	3	5	5	15	15	0.20	0.20	0.25	1.51	19
	4	5	5	30	5	0.20	0.20	0.25	0.25	22
	5	5	5	5	30	0.20	0.20	0.25	0.25	14
	6	5	5	15	15	0.20	0.20	1.93	0.25	14
	7	5	5	15	15	0.20	0.20	0.25	1.93	15
	8	5	5	15	15	0.67	0.25	0.20	0.20	15
	9	5	5	15	15	0.25	0.67	0.20	0.20	17
14	1	5	5	15	15	0.20	0.20	0.25	0.25	14
	2	5	5	15	15	0.20	0.20	0.25	1.51	14
	3	5	5	15	15	0.20	0.20	1.51	0.25	26
	4	5	5	5	30	0.20	0.20	0.25	0.25	15
	5	5	5	30	5	0.20	0.20	0.25	0.25	22
	6	1	1	15	15	0.20	0.20	1.93	0.25	16
	7	1	1	15	15	0.20	0.20	0.25	1.93	14
	8	5	5	15	15	0.25	0.67	0.20	0.20	14
	9	5	5	15	15	0.67	0.25	0.20	0.20	16
15	1	5	5	15	15	0.20	0.20	0.25	0.25	14
	2	5	5	15	15	0.20	0.20	1.51	0.25	14
	3	5	5	15	15	0.20	0.20	0.25	1.51	17
	4	5	5	30	5	0.20	0.20	0.25	0.25	17
	5	5	5	5	30	0.20	0.20	0.25	0.25	14
	6	5	5	15	15	0.20	0.20	1.93	0.25	14
	7	5	5	15	15	0.20	0.20	0.25	1.93	15
	8	5	5	15	15	0.67	0.25	0.20	0.20	15
	9	5	5	15	15	0.25	0.67	0.20	0.20	14
16	1	5	5	15	15	0.20	0.20	0.25	0.25	17
	2	5	5	15	15	0.20	0.20	0.25	1.51	18
	3	5	5	15	15	0.20	0.20	1.51	0.25	15
	4	5	5	5	30	0.20	0.20	0.25	0.25	15
	5	5	5	30	5	0.20	0.20	0.25	0.25	16
	6	1	1	15	15	0.20	0.20	0.25	0.25	14
	7	1	1	15	15	0.20	0.20	0.25	0.25	18
	8	5	5	15	15	0.25	0.67	0.20	0.20	14
	9	5	5	15	15	0.67	0.25	0.20	0.20	15

Note. Initial- and terminal-link variable-interval (VI) schedule values are in seconds; initial- and terminal-link response-force requirements are in Newtons.

Results and Discussion

The data used in the analyses were means based on the last 5 sessions in each condition, unless otherwise specified. Overall time in the initial link, average time in terminal-link, initial-link response rates, initial-link time allocations, and terminal-link response rates and terminal-link entries are shown in Table 6. As the summary data in this table suggest, the adjusting VI procedure employed in the terminal-link appeared to work reasonably well. The discrepancy between programmed terminal-link VI values and obtained VI values was minimal. In addition, the terminal-link entry data show that the nonindependent initial-link procedure worked well at controlling terminal-link entry rates.

The effect of force on terminal-link response rates is shown in Table 7. Terminal-link response rates on the 0.25 N lever were higher then response rates on either the 1.51 N or 1.93 N lever. Response rates at 1.51 N are comparable to those obtained in Experiment 1, but the difference in rates between 1.51 N and 1.93 N force values is negligible. A notable exception to the means shown in Table 3 are the data for Rat 12 in Condition 3. Terminal-link responses rates on the 1.51 N lever averaged 76 responses per minute (see Table 5). Although this discrepancy suggests either equipment failure or experimenter error, this data was retained in the analyses presented below.

The first question asked of the data in Experiment 2 is the sensitivity of initial-link responses rates and time measures to terminal-link force parameters using a nonindependent initial-link procedure. This question will be first addressed by examining the effects of terminal-link force (Conditions 2 and 3) on initial-link absolute response rates. For comparative purposes, the effects of terminal-link reinforcement rates (Conditions 4 and 5) and initial-link force values (Conditions 8

Table 6

Summary of Results for Experiment 3

	Overall Time	Overall Time in Terminal Link		Initial-link Responses Per Minute		Initial-link Time Allocations		Terminal-link Responses Per Minute		Terminal-link Entries	
Condition	Initial Link	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
Rat 13											
1	15.25	0.254	0.250	10.47	10.47	6.12	5.06	51.24	73.45	30.2	30.0
2	13.02	0.246	0.250	12.20	12.60	5.82	4.99	30.84	70.71	30.0	30.0
3	13.54	0.250	0.252	12.00	10.64	6.72	3.39	61.25	24.31	30.0	30.0
4	12.24	0.498	0.080	11.96	26.66	2.23	8.04	51.21	95.50	30.0	30.2
5	13.02	0.080	0.498	15.66	12.28	6.86	3.43	76.20	36.18	30.0	30.0
6	10.57	0.250	0.250	17.07	19.55	3.34	5.21	20.73	74.75	30.0	30.0
7	11.36	0.250	0.250	11.75	12.30	4.58	2.92	64.65	23.08	30.0	30.0
8	15.94	0.250	0.250	7.66	8.01	2.56	8.06	71.39	91.32	30.0	30.0
9	17.64	0.252	0.250	7.60	8.64	8.13	4.35	57.09	83.85	30.0	30.0
Rat 14											
1	19.97	0.250	0.258	23.75	13.74	7.45	7.48	92.94	71.29	30.2	30.0
2	23.01	0.264	0.384	11.30	7.76	7.67	8.92	69.53	21.45	30.0	30.0
3	28.12	0.250	0.260	8.84	9.50	5.85	11.15	21.59	98.10	30.0	30.0
4	13.33	0.080	0.506	24.75	12.62	8.74	2.69	94.66	67.06	30.2	30.0
5	17.55	0.504	0.082	14.88	27.16	2.73	12.41	90.91	90.39	30.0	30.6
6	7.18	0.244	0.250	13.44	15.33	2.50	3.25	29.18	107.17	30.0	30.0
7	6.02	0.250	0.248	14.56	16.56	2.17	2.47	110.81	19.70	30.0	30.0
8	19.27	0.252	0.252	9.92	6.45	10.01	4.61	92.34	94.50	30.0	30.0
9	8.49	0.250	0.250	15.43	16.36	4.08	4.30	96.69	91.67	30.0	30.0

Note. All time data are expressed in minutes.

Table 6--Continued

Condition	Overall Time	Overall Time in Terminal Link		Initial-link Responses Per Minute		Initial-link Time Allocations		Terminal-link Responses Per Minute		Terminal-link Entries	
	Initial Link	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
Rat 15											
1	12.42	0.250	0.250	18.26	15.29	4.56	5.77	57.93	68.14	30.0	30.0
2	15.81	0.282	0.252	13.43	11.42	3.92	9.27	15.37	70.39	30.4	30.0
3	11.87	0.250	0.252	16.70	11.73	4.33	4.72	62.82	25.33	30.0	30.0
4	12.54	0.504	0.082	18.08	20.77	2.92	8.31	77.83	68.57	30.0	30.0
5	13.18	0.080	0.504	24.69	12.01	7.32	4.44	93.50	36.20	30.0	30.2
6	11.02	0.246	0.250	22.30	16.95	3.92	5.56	19.42	55.55	30.0	30.0
7	11.03	0.250	0.248	21.47	14.97	5.32	4.30	68.06	26.11	30.0	30.0
8	10.46	0.250	0.248	24.01	15.01	3.89	5.05	75.95	60.76	30.0	30.0
9	12.20	0.250	0.248	12.11	17.01	3.13	7.63	67.78	62.80	30.0	30.0
Rat 16											
1	14.54	0.258	0.246	12.94	12.38	6.00	5.22	51.72	67.67	30.4	30.0
2	14.53	0.256	0.300	13.31	9.99	7.76	3.56	65.38	9.45	30.0	30.4
3	12.66	0.248	0.248	18.29	15.00	6.60	3.82	76.62	54.71	30.0	30.2
4	14.16	0.080	0.500	26.82	10.32	10.54	2.36	91.48	42.17	30.4	30.0
5	12.02	0.498	0.080	14.24	20.40	4.25	5.85	37.28	92.09	30.0	30.2
6	7.04	0.252	0.252	14.99	13.25	3.42	2.14	87.40	22.89	29.8	30.2
7	6.72	0.246	0.248	13.45	13.41	2.38	2.41	19.66	63.07	30.0	30.0
8	13.89	0.248	0.248	14.59	6.86	7.67	2.24	84.72	77.25	30.0	30.0
9	13.74	0.250	0.248	8.27	10.04	3.35	6.24	56.07	48.40	30.0	30.0

Table 7

Effect of Terminal-Link Force on Terminal-Link Response Rate, Experiment 3

	Force in Newtons		
Conditions	0.25	1.51	1.93
2 and 3 $N = 4$	69.11	28.12	--
6 and 7 $N = 3$	80.17	--	23.04

Note. N = Number of subjects exposed to each Condition.

and 9) on initial-link response rates will also be considered as shown in Figure 10. Differential initial-link response rates, as a function of terminal-link reinforcement rates, are found for all subjects. Similar results are shown with the initial-link time allocation measure. These findings are congruent with other concurrent-chain studies that have investigated the effects of terminal-link reinforcement rates on concurrent-chain performance (see Davison, 1987; and Fantino, 1977, 1981 for reviews).

The data displayed in Figure 10 also suggest slight sensitivity in initial-link measures to initial-link force manipulations. In contrast, however, these data show complete insensitivity in initial-link response rates to differential terminal-link force requirements. The time allocation data for Rats 9 and 11, however, suggest slight sensitivity to terminal-link force requirements.

Indifference toward terminal-link force requirements raises a second question asked of the Experiment 3 data: Does initial-link duration affect sensitivity toward terminal-link force requirements? The logic of this analysis comes from Fantino's delay reduction hypothesis (Fantino, 1969a, 1969b) which predicts increased initial-link sensitivity to differential terminal-link reinforcement rates with decreased initial-link durations. A large body of research has confirmed this hypothesis with

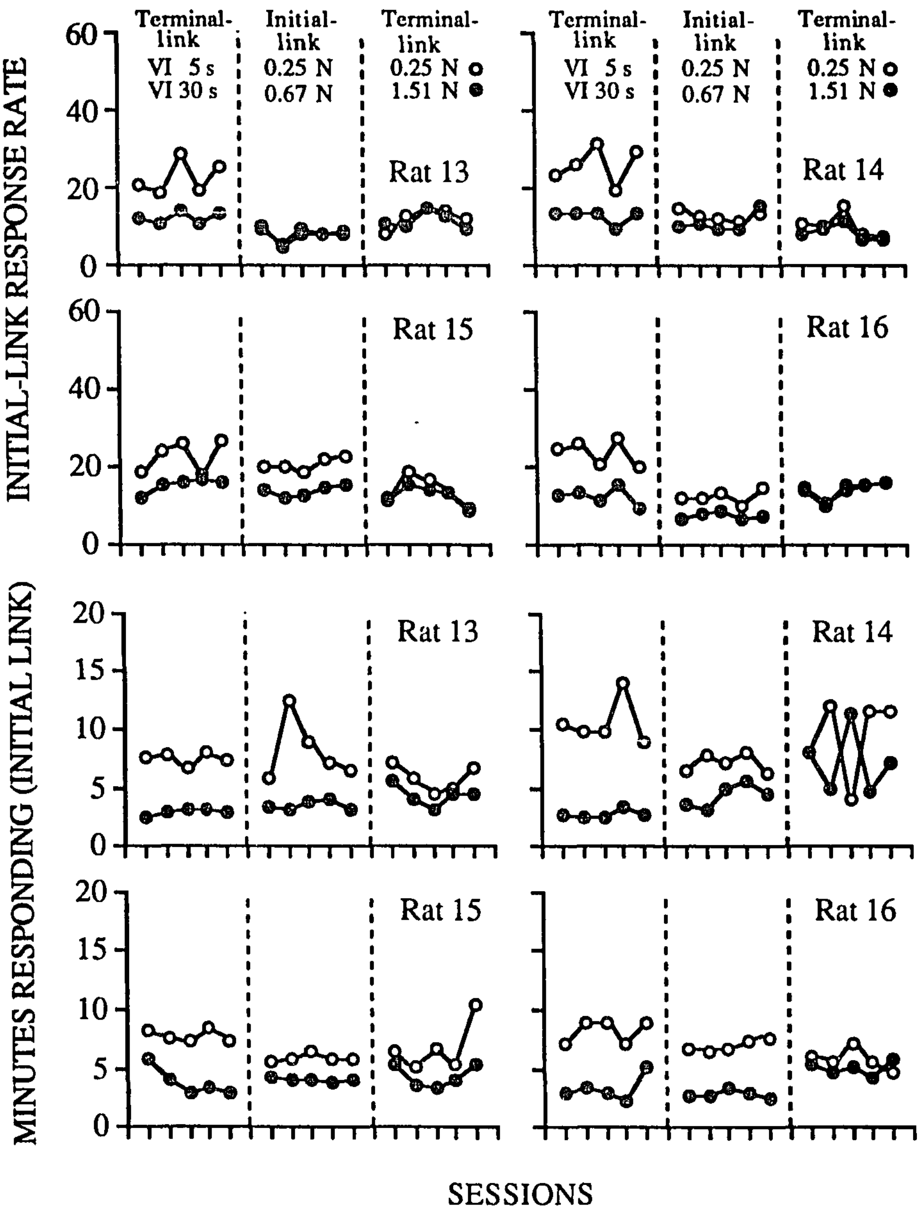

Figure 10. Initial-Link Response Rate as a Function of Three Types of Manipulations: Terminal-Link Reinforcement Rate (VI 5 s VI 30 s), Initial-Link Lever Force (0.25 N 0.67 N), and Terminal-Link Lever Force (0.25 N 1.51 N). Each Data Point is the Mean of Two Exposures to Each Manipulation, Counterbalanced Across Levers. The Last Five Sessions in Each Condition are Displayed.

reinforcement variables (see Chapter 1). The data for Rat 7, Experiment 1 (see Figure 9) also suggests the possibility of this type of interaction.

Figure 11 shows initial-link response rates and time responding as a function of terminal-link force requirements across different initial-link durations. The long duration initial-link conditions involved concurrent VI 5 s VI 5 s schedules (Conditions 2 and 3) and the short duration initial-link conditions involved concurrent VI 1 s VI 1 s schedules (Conditions 6 and 7) for Rats 14 and 16. The average time in the initial-link during the long duration conditions were a mean 24 s and 14 s for Rat 14 and 16, respectively. The average time in the initial-link during the short duration conditions was a mean of 7 s for both rats. Although initial-link durations were reduced slightly in the VI 1 s VI 1 s conditions, the data presented in Figure 11 do not suggest increased sensitivity toward terminal-link force values.

The effects of terminal-link force parameters were further examined through multiple regression analyses. Three factors were regressed on initial-link log response ratios and on log time ratios: log terminal-link reinforcement ratios (a), log initial-link force ratios (b) and log terminal-link force ratios (c). The results of these regressions are summarized in Table 8. These analyses show that preference measures were sensitive to reinforcement ratios, and, in some cases, initial-link force ratios. (Note that the coefficient for initial-link force ratios is negative because of the inverse relationship between the force and choice ratio.) However, in every case response and time measures were found insensitive to terminal-link force ratios.

In summary, the data from Experiment 3 support the conclusion that initial-link performance is insensitive to manipulations in terminal-link force requirements, but slightly sensitive to initial-link force manipulations. In addition, initial-link performance was found to be clearly sensitive to terminal-link reinforcement rates.

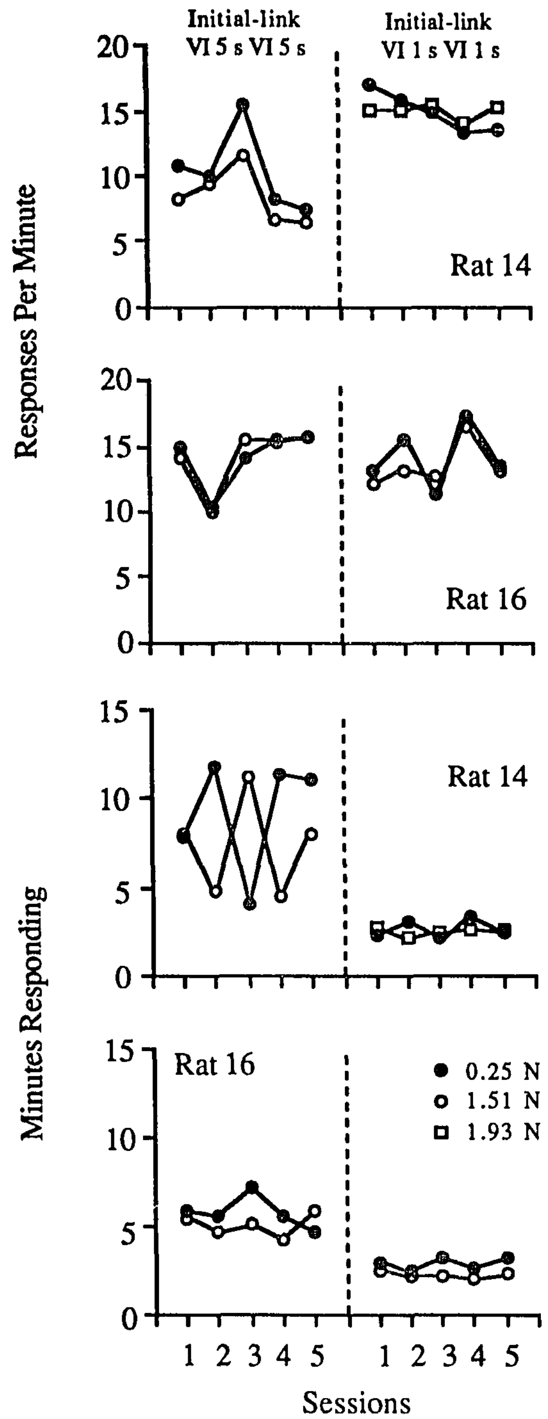

Figure 11. Initial-Link Response Rates and Minutes Responding as a Function of Terminal-Link Force When the Initial-Link Schedules Were Either VI 5 s VI 5 s or VI 1 s VI 1 s. Force Values Were Differentially Associated With Both the Left and Right Lever Across Conditions; Each Data Point Represents the Average Across Both Exposures. Data From the Last Five Sessions are Shown.

Table 8

Summary of Regression Analyses

Rat	*a*	*(SE)*	*b*	*(SE)*	*c*	*(SE)*	*log d*	*(SE)*	*MSE*	*VAC*	*N*
A. Response allocations											
13	.30**	.06	--	--	--	--	-.04	.02	.01	.80	9
14	.36†	.12	--	--	--	--	.04	.04	.02	.57	9
15	.23†	.05	-.41†	.09	--	--	.10	.02	.01	.87	9
16	.37**	.05	-.47**	.10	--	--	.09	.02	.01	.93	9
B. Time allocations											
13	.55†	.23	--	--	--	--	-.03	.06	.06	.45	9
14	.75*	.16	--	--	--	--	.01	.06	.03	.75	9
15	.64†	.14	--	--	--	--	-.14	.05	.03	.60	9
16	.52*	.10	-.94*	.19	--	--	.18	.04	.01	.96	9

Note. All nonsignificant coefficients were omitted. $d = y$ intercept; *SE* = standard error; *MSE* = mean square error, *VAC* = variance accounted for; *N* = number of data used for each regression.
*$p < .05$, Bonerroni F familywise alpha.
**$p < .01$, Bonerroni F familywise alpha.
†$p < .05$, per comparison alpha.

CHAPTER V

GENERAL DISCUSSION

A large body of concurrent-chain research shows that initial-link preference measures are sensitive to changes in initial- and terminal-link reinforcement rates (e.g., Davison, 1987; Fantino, 1977; 1981). In contrast, a considerably smaller body of research suggests that choice measures are relatively insensitive to response-requirement factors (e.g., Killeen, 1968; Starin, 1989b). Results from Experiments 1, 2 and 3 are in general agreement with both lines of research: Initial-link preference measures were found to be sensitive to reinforcement variables, but comparatively insensitive to response-force variables.

Although data from Experiments 1 and 2 appeared to show sensitivity to differential terminal-link force requirements, analyses in both experiments suggest that this sensitivity was largely an artifact of covariation in terminal-link entries. When terminal-link entries are procedurally controlled, as in Experiment 3, the results suggest that initial-link measures are relatively insensitive to terminal-link force manipulations.

The insensitivity of choice measures to force variables, as demonstrated in the present study, is ostensibly inconsistent with results from simple concurrent schedule studies (e.g, Chung, 1965; Hunter & Davison, 1982; Keehn, 1981). These incongruous results are possibly explained by several factors.

As discussed in Chapter 1, the assessment of the effects of force variables on choice behavior with simple concurrent schedules is arguably confounded by the

direct effects of force on response rates. However, as noted in Chapter 1, this confound is effectively eliminated with the concurrent-chain procedure when choice is measured in the initial link and force is manipulated in the terminal link. Therefore, the results of the present study appear to support the conclusion that the differential effects of force on choice behavior observed with simple concurrent schedules may be purely an artifact of the direct effect of force on response rates.

Further support for this argument comes from the finding that initial-link force manipulations did result in differential initial-link response rates (e.g., Rats 15 and 16, Experiment 3). Procedurally this manipulation is similar to the assessment of force with simple concurrent schedules because the choice measure is contaminated by the direct effects of force on response rate.

The time allocation data from the present study, however, do not support the argument that observed variations in initial-link response rates are simply an artifact of the direct effects of force on response rates. Changes in time-allocation measures, as a function of manipulated initial-link force ratios, are not, in any simple way, confounded by the direct effects of force. This argument is understood by first considering the way in which the time-allocation measure is derived. Each changeover response starts and stops a timer differentially associated with each lever. Time on the left lever, for example, is recorded by a timer that is started by the first response on the left lever and stopped by the next response on the right lever. The ratio of times associated with the left and right lever at the end of the session is the time allocation measure. Changes in the time-allocation measure are therefore not necessarily correlated with a response-allocation measure. For example, if the *response*-allocation measure shows a preference for the low force alternative, but this measure is really simply an artifact of the direct effects of force on response rates, then the *time*-allocation measure should show indifference or even a preference for the high force lever, but certainly not a preference for the low force lever. Therefore, it

may be assumed that an observed preference for the low force alternative with the time-allocation measure, as in Experiment 3, suggests some sensitivity to force factors. It also suggests that there may be other factors that account for the general insensitivity to terminal-link force requirements with the procedures employed in this study.

The assessment of the indirect effects of force on choice behavior with the concurrent-chain procedure involves several complexities. The delay reduction hypothesis suggests, for example, that initial-link responding is maintained by stimulus changes correlated with reductions in time to unconditioned reinforcement. But it is logical to assume that initial- and terminal-link force requirements also affect the reinforcing effectiveness of stimuli associated with the initial-link. Assume, for example, that the animal has a choice between high force and low force terminal-link alternative, and all other factors are equal. It is reasonable to assume that the initial-link lever associated with the low force terminal-link alternative will engender higher response rates because the stimulus changes associated with this lever are repeatedly correlated with a decrease in average time to unconditioned reinforcement and only a slight increase in force. In contrast, stimulus changes associated with the other lever are correlated with the same reduction in average time to unconditioned reinforcement, but a larger increase in response effort. Therefore, stimuli correlated with the low force lever should be more effective as conditioned reinforcement relative to the stimuli correlated with the high force lever.

However, this same logic suggests that the relative effect of terminal-link force is dependent upon the duration of initial-link and terminal-link durations. As the delay reduction hypothesis states, the relative effectiveness of initial-link stimulus changes are a function of the initial-link duration relative to the average terminal-link duration. Initial-link stimulus changes correlated with large time reductions are highly reinforcing, whereas stimulus changes correlated with modest time reductions are

comparatively less reinforcing. The differential effect of terminal-link force requirements, should therefore, be a function of how reinforcing it is getting into the terminal-link. If differential force requirements are associated with each terminal-link entry, the effect on choice may be considerable if terminal-link entries are correlated with only slight reductions in average time to unconditioned reinforcement. The data for Rat 7, Experiment 1, partially support this analysis. As shown in Figure 9, the slopes of the two regression lines are quite different, with the greatest slope associated with the longer initial-link schedules. A test for the homogeneity of the regression lines (Huitema,1980) found this difference to be significant ($p = .01$; $F = 89.50$, $N =$ 18 conditions, $J = 2$ groups and $C = 1$ covariate; Bonferroni F_B familywise alpha). In general, therefore, it is possible that longer terminal-link durations, relative to the initial-link duration, engendered greater sensitivity to the differential effects of terminal-link force.

The effects of initial-link force may similarly be a function of the initial-link duration relative to the average terminal-link duration (i.e., longer terminal-link durations, relative to the initial-link duration, engender greater sensitivity to the differential effects of initial-link force). However, it is also possible that initial-link sensitivity to different initial-link force is simply a function of total average time to unconditioned reinforcement (i.e., greater sensitivity differential initial-link force requirements is found with increased total average time to unconditioned reinforcement). In terms of the present study, it is possible that average total time to unconditioned reinforcement was sufficient for initial-link measures to be sensitive to different initial-link force requirements, but terminal-link durations short enough that initial-link measures were insensitive to terminal-link force requirements.

The size of VI schedules may, therefore, be a critical factor in assessing the effects of force on choice behavior. Unfortunately, the VI schedules employed in this

study were, for various reasons[13], unusually short. Had larger initial- and terminal-links schedules been employed, greater sensitivity to force parameters may have been demonstrated. It should also be noted that an additional advantage of larger initial-link schedules is that terminal-link covariation with force manipulations would have been reduced (Fantino, 1977, p. 327-328, but see Davison & Temple, 1973).

A final issue concerns quantitative models of choice. A number of quantitative models have been proposed to describe concurrent-chain behavior, but none of these models include factors that related to response effort. Unfortunately, the results of the present study provide no additional information for a refinement of these models in terms of the effects of force on choice behavior.

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[13]Previous studies with the experimental chambers employed in this study have demonstrated that schedules larger then VI 30 s do not reliably maintain initial-link responding. There are two factors that possibly explain this poor schedule performance: (1) small reinforcement magnitude (reinforcement consists of the delivery of 0.01 ml of sweetened condensed milk), and (2) high response effort/awkwardness (response levers were located 10 cm from the floor).

APPENDICES

Appendix A

Sequence of Experimental Conditions for Experiment 1

Table 9

Sequence of Experimental Conditions for Experiment 1

		Initial-link VI Schedule (s)		Initial-link Force (N)		Terminal-link Force (N)		
Subject	Condition	Left	Right	Left	Right	Left	Right	Sessions
1	1	30	30	0.20	0.20	0.25	0.25	14
	2	30	30	0.20	0.20	0.25	.067	19
	3	30	30	0.20	0.20	0.67	0.25	14
	4	30	30	0.20	0.20	0.25	1.51	17
	5	30	30	0.20	0.20	1.51	.025	16
	6	30	30	0.20	0.20	0.25	1.09	16
	7	30	30	0.20	0.20	1.09	0.25	15
	8	30	30	0.20	0.20	0.25	1.09	18
	9	30	30	0.20	0.20	0.25	0.25	14
	10	10	10	0.20	0.20	0.25	0.25	15
	11	10	10	0.20	0.20	0.25	1.51	23
	12	10	10	0.20	0.20	1.51	0.25	17
	13	10	10	0.20	0.20	0.25	1.09	15
	14	10	10	0.20	0.20	1.09	0.25	14
	15	10	10	0.20	0.20	0.25	1.09	14
	16	10	10	0.20	0.20	0.67	0.25	14
	17	10	10	0.20	0.20	0.25	0.67	16
	18	10	10	0.20	0.20	0.25	0.25	19
	19	10	30	0.20	0.20	0.25	0.25	14
	20	30	10	0.20	0.20	0.25	0.25	17
	21	10	10	0.20	0.20	1.09	1.09	21
	22	10	10	0.20	0.20	1.51	1.51	14
	23	10	10	0.25	0.67	0.20	0.20	20
	24	10	10	0.67	0.25	0.20	0.20	23

Table 9--Continued

Subject	Condition	Initial-link VI Schedule (s) Left	Initial-link VI Schedule (s) Right	Initial-link Force (N) Left	Initial-link Force (N) Right	Terminal-link Force (N) Left	Terminal-link Force (N) Right	Sessions
2	1	30	30	0.20	0.20	0.25	0.25	23
	2	30	30	0.20	0.20	0.25	1.09	16
	3	30	30	0.20	0.20	1.09	0.25	19
	4	30	30	0.20	0.20	0.25	0.67	15
	5	30	30	0.20	0.20	0.67	0.25	14
	6	30	30	0.20	0.20	0.25	1.51	18
	7	30	30	0.20	0.20	1.51	0.25	15
	8	30	30	0.20	0.20	0.25	1,09	16
	9	30	30	0.20	0.20	0.25	0.25	14
	10	10	10	0.20	0.20	0.25	0.25	15
	11	10	10	0.20	0.20	0.25	0.67	15
	12	10	10	0.20	0.20	0.67	0.25	16
	13	10	10	0.20	0.20	0.25	1.09	15
	14	10	10	0.20	0.20	1.09	0.25	19
	15	10	10	0.20	0.20	0.25	1.51	14
	16	10	10	0.20	0.20	1.51	0.25	15
	17	10	10	0.20	0.20	0.25	1.09	15
	18	10	10	0.20	0.20	0.25	0.25	18
	19	30	10	0.20	0.20	0.25	0.25	19
	20	10	30	0.20	0.20	0.25	0.25	18
	21	30	30	0.20	0.20	1.51	1.51	14
	22	30	30	0.20	0.20	1.09	1.09	14
	23	10	10	0.25	0.67	0.20	0.20	17
	24	10	10	0.67	0.25	0.20	0.20	19

Table 9--Continued

		Initial-link VI Schedule (s)		Initial-link Force (N)		Terminal-link Force (N)		
Subject	Condition	Left	Right	Left	Right	Left	Right	Sessions
3	1	30	30	0.20	0.20	.25	0.25	18
	2	30	30	0.20	0.20	1.51	0.25	15
	3	30	30	0.20	0.20	0.25	1.51	16
	4	30	30	0.20	0.20	1.09	0.25	21
	5	30	30	0.20	0.20	0.25	1.09	16
	6	30	30	0.20	0.20	0.67	0.25	16
	7	30	30	0.20	0.20	0.25	0.67	23
	8	30	30	0.20	0.20	0.25	1.09	15
	9	30	30	0.20	0.20	0.25	0.25	19
	10	10	10	0.20	0.20	0.25	0.25	21
	11	10	10	0.20	0.20	0.25	1.09	17
	12	10	10	0.20	0.20	0.25	1.09	14
	13	10	10	0.20	0.20	1.09	0.25	16
	14	10	10	0.20	0.20	0.25	1.09	14
	15	10	10	0.20	0.20	1.51	0.25	16
	16	10	10	0.20	0.20	0.25	151	14
	17	10	10	0.20	0.20	0.67	0.25	17
	18	10	10	0.20	0.20	0.25	0.67	17
	19	10	10	0.20	0.20	0.25	0.25	17
	20	10	30	0.20	0.20	0.25	0.25	17
	21	30	10	0.20	0.20	0.25	0.25	17
	22	10	10	0.25	0.67	0.20	0.20	19
	23	10	10	0.67	0.25	0.20	0.20	17

Table 9--Continued

		Initial-link VI Schedule (s)		Initial-link Force (N)		Terminal-link Force (N)		
Subject	Condition	Left	Right	Left	Right	Left	Right	Sessions
4	1	30	30	0.20	0.20	0.25	0.25	15
	2	30	30	0.20	0.20	0.25	1.51	20
	3	30	30	0.20	0.20	1.51	0.25	14
	4	30	30	0.20	0.20	1.09	0.25	27
	5	30	30	0.20	0.20	0.25	1.09	14
	6	30	30	0.20	0.20	0.67	0.25	14
	7	30	30	0.20	0.20	0.25	0.67	16
	8	30	30	0.20	0.20	0.25	1.09	14
	9	30	30	0.20	0.20	0.25	0.25	18
	10	10	10	0.20	0.20	0.25	0.25	27
	11	10	10	0.20	0.20	0.25	1.09	14
	12	10	10	0.20	0.20	1.09	0.25	14
	13	10	10	0.20	0.20	0.25	1.09	19
	14	10	10	0.20	0.20	0.67	0.25	18
	15	10	10	0.20	0.20	0.25	0.67	17
	16	10	10	0.20	0.20	1.51	0.25	17
	17	10	10	0.20	0.20	0.25	1.51	27
	18	10	10	0.20	0.20	0.25	0.25	16
	19	10	30	0.20	0.20	0.25	0.25	20
	20	30	10	0.20	0.20	0.25	0.25	17
	21	10	10	0.25	0.67	0.20	0.20	14

Table 9--Continued

Subject	Condition	Initial-link VI Schedule (s) Left	Initial-link VI Schedule (s) Right	Initial-link Force (N) Left	Initial-link Force (N) Right	Terminal-link Force (N) Left	Terminal-link Force (N) Right	Sessions
5	1	10	10	0.20	0.20	0.25	0.25	20
	2	10	10	0.20	0.20	0.25	1.51	15
	3	10	10	0.20	0.20	1.51	0.25	17
	4	10	10	0.20	0.20	0.25	1.09	25
	5	10	10	0.20	0.20	1.09	0.25	20
	6	10	10	0.20	0.20	0.25	1.09	15
	7	10	10	0.20	0.20	0.67	0.25	17
	8	10	10	0.20	0.20	0.25	0.67	17
	9	10	10	0.20	0.20	0.25	0.25	18
	10	30	30	0.20	0.20	0.25	0.25	21
	11	30	30	0.25	0.20	0.25	0.67	14
	12	30	30	0.20	0.20	0.67	0.25	14
	13	30	30	0.20	0.20	0.25	1.51	14
	14	30	30	0.20	0.20	1.51	0.25	14
	15	30	30	0.20	0.20	0.25	1.09	17
	16	30	30	0.20	0.20	1.09	0.25	14
	17	30	30	0.20	0.20	0.25	1.09	20
	18	30	30	0.20	0.20	0.25	0.25	18
	19	10	30	0.20	0.20	0.25	0.25	20
	20	30	10	0.20	0.20	0.25	0.25	15
	21	10	10	0.25	0.67	0.20	0.20	19
	22	10	10	0.67	0.25	0.20	0.20	22

Table 9--Continued

Subject	Condition	Initial-link VI Schedule (s) Left	Initial-link VI Schedule (s) Right	Initial-link Force (N) Left	Initial-link Force (N) Right	Terminal-link Force (N) Left	Terminal-link Force (N) Right	Sessions
6	1	10	10	0.20	0.20	0.25	0.25	14
	2	10	10	0.20	0.20	0.25	0.67	16
	3	10	10	0.20	0.20	0.67	0.25	17
	4	10	10	0.20	0.20	0.25	1.09	24
	5	10	10	0.20	0.20	1.09	0.25	14
	6	10	10	0.20	0.20	0.25	1.51	28
	7	10	10	0.20	0.20	1.51	0.25	17
	8	10	10	0.20	0.20	0.25	1.09	14
	9	10	10	0.20	0.20	0.25	0.25	14
	10	30	30	0.20	0.20	0.25	0.25	22
	11	30	30	0.20	0.20	0.25	1.09	21
	12	30	30	0.20	0.20	1.09	0.25	14
	13	30	30	0.20	0.20	0.25	0.67	15
	14	30	30	0.20	0.20	0.67	0.25	14
	15	30	30	0.20	0.20	0.25	1.51	14
	16	30	30	0.20	0.20	1.51	0.25	13
	17	30	30	0.20	0.20	0.25	1.09	14
	18	30	30	0.20	0.20	0.25	0.25	14
	19	10	30	0.20	0.20	0.25	0.25	16
	20	30	10	0.20	0.20	0.25	0.25	18
	21	10	10	0.25	0.67	0.20	0.20	22
	22	10	10	0.67	0.25	0.20	0.20	24

Table 9--Continued

		Initial-link VI Schedule (s)		Initial-link Force (N)		Terminal-link Force (N)		
Subject	Condition	Left	Right	Left	Right	Left	Right	Sessions
7	1	10	10	0.20	0.20	0.25	0.25	30
	2	10	10	0.20	0.20	0.25	1.09	21
	3	10	10	0.20	0.20	1.09	0.25	17
	4	10	10	0.20	0.20	0.25	1.09	21
	5	10	10	0.20	0.20	1.51	0.25	18
	6	10	10	0.20	0.20	0.25	1.51	19
	7	10	10	0.20	0.20	0.67	0.25	15
	8	10	10	0.20	0.20	0.25	0.67	15
	9	10	10	0.20	0.20	0.25	0.25	14
	10	30	30	0.20	0.20	0.25	0.25	17
	11	30	30	0.25	0.20	1.51	0.25	14
	12	30	30	0.20	0.20	0.25	1.51	16
	13	30	30	0.20	0.20	1.09	0.25	14
	14	30	30	0.20	0.20	0.25	1.09	14
	15	30	30	0.20	0.20	0.67	0.25	16
	16	30	30	0.20	0.20	0.25	0.67	16
	17	30	30	0.20	0.20	0.25	1.09	16
	18	30	30	0.20	0.20	0.25	0.25	14
	19	30	10	0.20	0.20	0.25	0.25	15
	20	10	30	0.20	0.20	0.25	0.25	20
	21	10	30	0.25	0.20	1.09	1.09	15
	22	10	30	0.25	0.20	1.51	1.51	14
	23	10	10	0.67	0.25	0.20	0.20	15
	24	10	10	0.25	0.67	0.20	0.20	14

Table 9--Continued

		Initial-link VI Schedule (s)		Initial-link Force (N)		Terminal-link Force (N)		
Subject	Condition	Left	Right	Left	Right	Left	Right	Sessions
8	1	10	10	0.20	0.20	0.25	0.25	24
	2	10	10	0.20	0.20	0.25	1.09	18
	3	10	10	0.20	0.20	1.09	0.25	15
	4	10	10	0.20	0.20	0.25	1.09	19
	5	10	10	0.20	0.20	0.67	0.25	15
	6	10	10	0.20	0.20	0.25	0.67	32
	7	10	10	0.20	0.20	0.25	1.51	15
	8	10	10	0.20	0.20	1.51	0.25	14
	9	10	10	0.20	0.20	0.25	0.25	15
	10	30	30	0.20	0.20	0.25	0.25	20
	11	30	30	0.25	0.20	1.51	0.25	16
	12	30	30	0.20	0.20	0.25	1.51	15
	13	30	30	0.20	0.20	1.09	0.25	21
	14	30	30	0.20	0.20	0.25	1.09	20
	15	30	30	0.20	0.20	0.67	0.25	14
	16	30	30	0.20	0.20	0.25	0.67	14
	17	30	30	0.20	0.20	0.25	1.09	15
	18	30	30	0.20	0.20	0.25	0.25	14
	19	30	10	0.20	0.20	0.25	0.25	14
	20	30	10	0.20	0.20	0.25	0.25	16
	21	10	10	0.67	0.25	0.20	0.20	14
	22	10	10	0.25	0.67	0.20	0.20	27

Appendix B

Summary of Results for Experiment 1

Table 10
Summary of Results for Experiment 1

	Overall Time	Overall Time in Terminal Link		Initial-link Responses Per Minute		Initial-link Time Allocations		Terminal-link Responses Per Minute		Terminal-link Entries	
Condition	Initial Link	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
Rat 1											
1	22.34	0.248	0.248	10.02	21.70	4.38	11.17	52.70	74.28	23.6	36.6
2	20.17	0.258	0.250	21.26	30.91	4.99	8.36	94.21	69.55	27.4	32.6
3	19.52	0.258	0.246	23.34	36.83	5.39	9.65	50.61	89.42	28.2	31.8
4	18.42	0.252	0.250	34.09	36.32	6.81	7.82	86.17	32.72	29.8	30.4
5	17.79	0.250	0.250	34.79	38.60	6.93	7.12	42.47	83.90	29.8	30.2
6	18.48	0.244	0.248	32.10	40.30	6.33	7.84	93.83	40.73	29.0	31.2
7	18.30	0.246	0.382	29.70	46.73	5.94	8.98	44.28	44.79	27.6	32.4
8	19.95	0.248	0.244	21.91	35.85	4.81	8.92	87.99	34.94	28.2	31.8
9	18.28	0.254	0.250	31.55	43.16	6.37	7.61	90.96	70.98	28.6	31.4
10	7.50	0.254	0.250	29.64	52.44	1.82	2.77	92.75	91.39	28.2	32.2
11	7.64	0.250	0.250	34.05	37.52	2.67	2.21	95.26	34.79	30.4	29.4
12	7.50	0.250	0.252	35.78	49.96	2.22	2.91	42.21	81.40	28.8	31.2
13	8.42	0.250	0.254	38.84	31.51	3.05	1.93	81.62	36.31	30.8	29.6
14	7.20	0.252	0.250	46.60	51.98	2.91	2.41	34.68	82.05	29.6	31.0
15	7.80	0.240	0.252	36.91	39.52	2.80	2.25	81.58	36.48	30.2	30.4
16	7.71	0.248	0.252	42.82	41.00	3.30	2.23	46.06	67.25	31.2	29.0
17	7.52	0.250	0.246	38.47	44.54	2.65	2.56	67.45	53.87	29.6	30.6
18	8.40	0.254	0.244	33.02	49.88	2.47	2.63	65.04	66.27	28.0	32.6
19	11.53	0.248	0.244	31.65	40.99	3.59	3.78	72.40	74.98	48.2	23.8
20	11.37	0.244	0.248	18.74	44.94	2.56	3.08	50.66	79.38	14.6	45.6
21	8.80	0.252	0.250	25.74	39.69	2.26	2.39	39.06	39.09	27.8	32.2
22	9.47	0.256	0.252	19.53	30.46	2.69	2.57	32.75	35.29	29.2	31.0
23	10.30	0.258	0.254	21.82	15.51	3.11	1.53	57.71	57.18	34.0	26.0
24	11.42	0.240	0.246	9.94	25.73	1.53	3.05	46.67	62.16	22.4	37.6

Note. All time data are expressed in minutes.

Table 10--Continued

	Overall Time	Avg Time in Terminal Link		Initial-link Responses Per Minute		Initial-link Time Allocations		Terminal-link Responses Per Minute		Terminal-link Entries	
Condition	Initial Link	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
Rat 2											
1	19.43	0.250	0.256	21.75	26.18	7.63	6.98	78.05	66.18	29.6	30.4
2	19.64	0.256	0.252	27.34	17.68	7.83	6.29	97.35	53.64	30.6	29.4
3	20.09	0.248	0.250	25.16	24.85	6.47	7.54	44.80	105.54	30.0	30.0
4	18.11	0.252	0.248	37.73	33.69	7.88	5.99	115.61	71.36	30.6	29.4
5	19.06	0.252	0.250	25.50	32.74	7.31	6.33	85.45	82.63	30.8	29.2
6	18.77	0.250	0.256	33.70	22.69	8.30	5.67	110.27	46.69	31.6	28.6
7	18.72	0.248	0.252	25.54	29.99	7.24	7.07	35.08	104.77	31.0	29.0
8	19.15	0.252	0.250	33.06	19.29	8.50	5.11	113.63	57.52	32.6	27.4
9	17.94	0.248	0.252	36.06	29.01	8.13	5.97	112.00	99.09	31.0	29.0
10	9.59	0.248	0.242	46.58	28.74	3.08	2.03	110.59	95.11	34.2	26.4
11	7.20	0.248	0.252	58.22	37.84	3.66	1.70	104.39	67.87	34.2	26.4
12	7.30	0.254	0.254	56.77	36.76	3.52	1.83	68.74	115.03	33.8	27.0
13	7.86	0.246	0.242	52.31	30.45	3.70	1.69	86.77	58.86	33.6	26.8
14	7.30	0.248	0.254	43.31	42.83	2.70	2.44	27.29	123.97	30.4	30.0
15	8.19	0.250	0.246	49.05	18.84	4.21	1.25	95.96	35.51	37.0	23.4
16	7.75	0.254	0.252	44.02	38.27	2.55	2.79	26.14	106.08	30.6	30.0
17	7.16	0.258	0.246	59.10	32.82	3.21	1.68	105.87	39.69	33.6	27.0
18	7.40	0.252	0.244	56.45	32.07	3.07	2.28	110.59	95.11	33.0	27.2
19	10.70	0.248	0.236	35.72	44.48	4.11	3.65	91.27	100.35	17.6	42.6
20	11.05	0.248	0.248	34.51	19.47	3.90	2.63	80.97	74.33	44.4	15.6
21	20.09	0.248	0.252	24.31	23.86	5.65	6.21	26.05	28.61	30.0	30.0
22	19.31	0.250	0.250	22.68	23.41	6.00	5.67	27.06	31.40	29.6	30.4
23	9.55	0.242	0.248	34.47	32.68	3.10	1.46	82.95	90.20	35.8	24.4
24	9.30	0.254	0.252	26.58	28.16	1.76	2.25	85.05	84.64	29.6	30.4

Table 10--Continued

	Overall Time	Avg Time in Terminal Link		Initial-link Responses Per Minute		Initial-link Time Allocations		Terminal-link Responses Per Minute		Terminal-link Entries	
Condition	Initial Link	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
Rat 3											
1	22.62	0.252	0.252	17.45	11.44	7.95	5.29	57.04	53.10	31.2	28.8
2	21.69	0.256	0.252	13.58	16.51	5.57	6.53	29.24	61.79	28.8	31.2
3	21.64	0.240	0.246	31.82	9.07	11.52	2.84	76.03	30.51	35.4	24.6
4	21.80	0.252	0.252	16.50	16.84	6.11	5.11	29.55	57.34	29.4	30.6
5	21.85	0.242	0.248	22.82	10.30	8.85	3.32	49.73	31.87	34.8	25.2
6	21.16	0.250	0.252	16.57	17.64	5.71	6.13	38.65	42.36	29.6	30.6
7	21.35	0.260	0.240	22.75	11.41	7.71	3.92	59.95	36.24	32.4	27.6
8	20.40	0.248	0.248	23.04	11.90	8.15	4.60	58.26	24.95	32.2	27.8
9	23.34	0.256	0.248	15.39	14.93	5.54	6.91	65.75	43.20	28.6	31.4
10	9.91	0.252	0.248	19.09	17.02	2.16	2.23	61.76	56.47	29.8	30.6
11	10.67	0.250	0.250	23.60	10.52	3.06	1.55	64.26	31.86	35.8	24.2
12	9.72	0.254	0.250	31.49	14.20	3.23	1.46	69.68	33.90	36.4	23.6
13	9.16	0.250	0.250	22.24	23.72	2.46	2.64	34.25	65.39	29.6	30.8
14	9.83	0.254	0.256	28.96	12.52	2.85	1.55	64.21	28.96	37.4	22.6
15	9.93	0.244	0.240	26.03	13.54	3.25	1.53	51.02	22.09	34.8	25.4
16	10.58	0.252	0.246	20.62	21.65	2.14	2.77	30.00	61.68	27.8	32.2
17	10.14	0.256	0.254	23.23	13.90	3.26	1.87	55.41	33.25	35.0	25.0
18	9.09	0.254	0.250	17.28	22.51	2.05	2.39	35.99	60.93	28.0	32.2
19	9.80	0.254	0.250	26.60	18.17	3.35	2.12	61.76	56.47	33.6	31.4
20	15.32	0.250	0.248	16.72	15.60	3.72	3.05	51.38	58.10	19.6	40.4
21	13.03	0.242	0.232	26.15	12.45	3.90	2.60	66.33	68.21	43.6	16.4
22	11.84	0.248	0.250	7.29	19.63	1.51	2.70	56.87	64.96	22.8	37.2
23	12.35	0.250	0.248	14.71	12.30	2.04	3.15	64.76	68.61	25.6	34.4

Table 10--Continued

	Overall Time	Avg Time in Terminal Link		Initial-link Responses Per Minute		Initial-link Time Allocations		Terminal-link Responses Per Minute		Terminal-link Entries	
Condition	Initial Link	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
Rat 4											
1	22.54	0.250	0.248	18.89	18.11	6.32	8.30	50.90	44.50	28.8	331.2
2	25.71	0.250	0.280	17.22	10.45	10.05	6.86	36.50	21.38	32.6	27.4
3	20.40	0.248	0.246	27.60	21.62	8.18	6.34	30.26	50.33	30.6	29.4
4	19.84	0.254	0.244	31.85	23.05	8.80	5.46	29.39	60.46	32.2	28.0
5	19.51	0.250	0.238	30.65	23.10	9.00	6.11	38.02	35.56	32.2	27.8
6	20.89	0.252	0.246	22.16	25.00	8.21	7.76	26.17	58.57	30.0	29.8
7	21.15	0.250	0.246	34.03	27.96	8.66	6.37	40.29	48.59	30.6	31.4
8	19.06	0.248	0.246	35.58	24.64	8.99	5.30	33.35	31.30	31.6	28.6
9	20.22	0.252	0.254	30.62	21.60	10.11	5.08	33.47	66.74	33.0	27.0
10	8.53	0.252	0.252	31.78	26.55	3.60	2.51	53.62	65.47	32.2	28.4
11	9.33	0.252	0.238	28.85	20.70	3.94	2.75	53.80	33.08	34.0	26.8
12	8.95	0.246	0.256	25.79	27.65	3.69	3.01	32.56	71.57	29.8	30.6
13	8.73	0.248	0.248	31.60	24.07	3.83	2.29	50.47	33.06	32.6	27.6
14	16.44	0.282	0.252	15.95	8.22	6.80	2.68	26.00	42.23	38.2	21.8
15	9.18	0.250	0.252	29.75	18.82	4.11	2.09	46.08	40.28	33.2	27.0
16	9.07	0.248	0.248	29.74	19.50	3.83	1.87	27.46	56.75	35.4	24.8
17	8.93	0.246	0.254	27.82	16.61	4.42	1.55	46.73	37.34	37.0	23.0
18	9.25	0.244	0.252	34.36	16.42	4.95	1.53	50.88	72.89	38.0	22.0
19	11.11	0.252	0.260	28.77	14.05	6.95	1.78	43.71	66.04	48.0	12.4
20	14.56	0.256	0.250	32.43	18.53	9.16	2.48	40.56	66.62	24.8	35.2
21	9.80	0.266	0.260	22.58	17.34	4.14	1.95	42.32	64.22	36.0	24.0
22	9.77	0.254	0.254	31.78	12.54	5.16	1.58	48.04	48.04	39.0	21.6

Table 10--Continued

	Overall Time	Avg Time in Terminal Link		Initial-link Responses Per Minute		Initial-link Time Allocations		Terminal-link Responses Per Minute		Terminal-link Entries	
Condition	Initial Link	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
Rat 5											
1	15.93	0.266	0.254	5.60	17.34	1.80	5.18	55.86	73.56	17.4	42.6
2	12.88	0.254	0.258	14.66	15.81	3.04	3.80	87.14	33.82	27.6	32.6
3	8.33	0.246	0.250	8.96	45.38	0.87	5.26	32.48	93.13	17.0	43.2
4	9.53	0.242	0.256	32.21	34.92	2.38	2.80	111.47	54.40	27.0	33.0
5	8.46	0.248	0.256	23.98	49.07	1.91	3.57	60.11	97.38	26.2	34.0
6	8.73	0.248	0.246	25.96	38.11	2.09	3.22	101.63	61.62	26.8	33.4
7	11.59	0.244	0.244	17.28	32.18	2.28	3.23	101.04	76.34	22.8	37.2
8	12.65	0.248	0.248	15.54	30.80	1.64	3.37	84.70	85.99	22.6	37.6
9	9.10	0.256	0.242	21.24	42.12	1.85	3.81	92.77	92.91	24.4	35.6
10	18.43	0.250	0.252	24.81	39.67	6.10	8.11	96.46	76.62	29.6	30.6
11	19.80	0.248	0.254	22.15	33.76	5.39	8.24	99.11	61.62	27.4	32.6
12	19.91	0.256	0.278	24.48	32.32	5.18	8.49	63.55	74.40	28.8	31.2
13	22.24	0.248	0.250	31.32	39.11	6.01	7.76	93.63	31.65	29.0	31.0
14	19.29	0.246	0.254	25.06	38.42	4.89	9.11	36.52	83.62	27.0	33.0
15	18.59	0.254	0.258	23.92	35.94	5.07	8.18	84.79	38.38	28.6	31.4
16	19.15	0.246	0.248	27.02	33.03	5.25	8.46	44.77	83.36	28.2	31.8
17	19.45	0.254	0.248	24.48	30.77	5.56	8.03	66.55	42.08	30.8	31.2
18	18.22	0.254	0.250	27.20	40.51	5.81	8.14	78.06	87.00	29.2	30.8
19	10.82	0.254	0.258	36.57	29.11	4.01	3.47	85.21	86.57	43.0	17.2
20	10.26	0.256	0.248	25.50	45.47	2.74	4.52	80.28	101.53	16.2	43.8
21	8.08	0.250	0.252	36.11	62.53	3.11	2.08	79.77	114.72	32.0	28.0
22	8.97	0.256	0.242	25.16	30.02	2.67	2.59	77.32	87.04	28.6	31.6

Table 10--Continued

	Overall Time	Avg Time in Terminal Link		Initial-link Responses Per Minute		Initial-link Time Allocations		Terminal-link Responses Per Minute		Terminal-link Entries	
Condition	Initial Link	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
Rat 6											
1	11.45	0.256	0.258	20.55	23.11	2.42	4.05	61.14	54.88	27.6	32.6
2	9.30	0.240	0.252	21.15	25.46	3.17	3.47	61.78	53.57	26.4	33.8
3	9.70	0.246	0.248	18.93	25.78	2.07	3.49	59.33	87.19	24.4	35.8
4	9.92	0.250	0.246	26.50	21.74	2.92	2.54	83.53	26.90	29.0	31.0
5	9.11	0.256	0.252	21.94	29.92	1.99	3.42	43.37	91.88	27.8	32.8
6	15.62	0.252	0.250	15.03	13.27	2.42	4.10	83.14	24.23	25.0	35.0
7	9.74	0.256	0.24	16.75	26.20	1.75	3.64	25.38	56.63	25.4	34.8
8	12.64	0.254	0.250	16.47	19.85	2.31	3.47	82.58	23.85	26.6	33.8
9	10.59	0.244	0.254	14.63	27.31	1.74	4.40	78.93	59.77	20.8	39.0
10	26.30	0.264	0.256	13.22	19.92	4.19	10.72	83.74	55.68	27.0	33.6
11	21.63	0.248	0.250	20.40	27.08	5.51	8.18	99.79	26.66	28.6	31.6
12	26.44	0.246	0.250	10.93	15.38	3.53	9.17	32.35	48.19	25.8	34.4
13	20.96	0.248	0.256	17.14	24.22	4.44	7.72	88.50	52.92	28.0	32.0
14	24.50	0.244	0.248	11.32	16.59	4.05	8.01	53.59	46.87	27.0	33.0
15	28.54	0.264	0.256	12.14	12.57	4.33	8.16	70.28	23.35	28.0	32.2
16	28.09	0.254	0.264	11.44	13.67	5.56	9.22	26.97	45.34	28.6	31.4
17	25.75	0.254	0.256	10.32	14.07	5.79	6.34	76.73	20.34	28.6	31.4
18	21.76	0.254	0.250	14.59	20.93	4.27	7.47	80.39	55.30	27.8	32.2
19	12.87	0.256	0.254	10.48	24.78	1.89	4.02	88.11	63.94	15.0	45.0
20	16.03	0.248	0.258	15.42	15.48	3.22	4.53	84.51	57.12	39.2	20.8
21	29.44	0.258	0.258	5.80	4.17	3.20	3.24	78.17	59.67	30.8	29.2
22	12.13	0.252	0.252	9.30	23.80	1.19	3.30	78.88	59.84	21.2	38.8

Table 10--Continued

	Overall Time	Avg Time in Terminal Link		Initial-link Responses Per Minute		Initial-link Time Allocations		Terminal-link Responses Per Minute		Terminal-link Entries	
Condition	Initial Link	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
Rat 7											
1	12.57	0.252	0.248	16.47	12.63	2.59	2.06	57.11	54.70	31.2	28.8
2	11.71	0.250	0.250	27.02	5.15	5.13	0.71	78.15	22.62	45.2	14.8
3	10.53	0.250	0.250	14.87	19.42	2.03	3.84	31.13	69.91	27.0	33.0
4	9.99	0.254	0.256	40.94	8.57	4.73	0.83	80.23	28.90	41.0	19.0
5	9.19	0.252	0.246	16.93	31.41	1.70	3.42	34.24	57.92	25.0	35.4
6	10.06	0.244	0.240	32.70	7.77	4.13	0.85	63.45	26.40	41.0	19.0
7	8.28	0.254	0.250	21.53	28.14	2.00	2.38	28.74	57.74	27.8	32.4
8	9.30	0.256	0.254	31.20	14.96	4.16	1.30	69.20	28.90	38.0	22.2
9	8.27	0.254	0.250	33.66	20.55	3.04	1.51	65.74	54.60	34.0	26.4
10	18.44	0.248	0.252	23.78	18.91	8.06	5.72	56.64	39.97	30.8	29.2
11	18.35	0.246	0.252	25.01	24.87	6.54	7.52	26.66	54.18	29.6	30.4
12	18.69	0.248	0.252	30.44	22.11	8.29	5.31	58.72	26.21	30.8	29.2
13	17.81	0.256	.0250	30.95	28.18	6.90	7.84	27.07	60.46	29.6	30.4
14	20.07	0.248	.0254	28.34	16.74	9.58	5.79	59.58	25.23	31.8	28.2
15	18.02	0.246	0.246	25.33	25.74	6.45	7.07	24.31	61.46	29.6	30.4
16	18.32	0.244	0.246	31.80	21.71	9.57	6.57	50.17	24.43	30.6	29.4
17	19.85	0.254	0.256	23.28	16.59	8.25	4.95	41.74	24.01	31.8	28.2
18	20.13	0.254	0.248	18.96	14.48	7.48	5.98	53.68	46.09	31.2	28.8
19	10.99	0.256	0.248	23.98	28.32	3.55	3.82	53.48	46.13	16.2	43.8
20	11.99	0.252	0.262	29.08	21.79	3.93	4.21	66.75	52.98	37.8	22.2
21	11.71	0.272	0.254	25.77	14.96	3.78	3.40	22.36	20.19	43.4	17.0
22	11.73	0.244	0.230	27.16	13.40	4.61	3.23	24.20	23.82	43.8	13.2
23	9.08	0.252	0.252	13.75	27.13	1.65	3.19	59.59	60.17	26.0	34.0
24	8.84	0.254	0.254	32.17	12.63	3.60	1.60	56.65	55.16	35.8	24.8

Table 10--Continued

	Overall Time	Avg Time in Terminal Link		Initial-link Responses Per Minute		Initial-link Time Allocations		Terminal-link Responses Per Minute		Terminal-link Entries	
Condition	Initial Link	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
Rat 8											
1	14.47	0.260	0.244	7.22	18.61	3.30	5.40	41.50	50.04	21.0	39.0
2	21.42	0.260	0.268	4.71	16.71	5.73	5.64	35.24	20.93	20.8	38.0
3	15.56	0.250	0.246	3.82	25.57	1.70	6.37	16.40	63.27	13.0	47.0
4	11.46	0.266	0.248	8.12	31.05	1.42	5.80	42.36	27.16	15.6	44.4
5	10.91	0.250	0.246	10.54	30.26	1.97	5.05	24.71	55.25	21.6	38.4
6	10.24	0.266	0.250	17.00	21.01	2.69	3.93	28.92	34.06	23.4	32.6
7	13.77	0.282	0.252	12.50	10.65	2.64	2.54	27.71	19.35	33.0	27.0
8	15.07	0.386	0.250	12.03	7.17	3.05	1.90	8.93	50.75	36.0	24.0
9	13.34	0.260	0.250	16.93	9.31	3.92	1.57	32.69	34.06	38.8	21.2
10	23.07	0.258	0.260	15.06	13.34	6.42	6.38	34.15	67.65	32.6	28.0
11	25.50	0.254	0.248	12.30	10.73	6.89	4.87	16.12	65.56	32.6	27.4
12	21.49	0.256	0.254	15.43	15.44	7.62	5.00	39.56	17.99	31.8	28.2
13	22.53	0.282	0.244	15.70	17.19	6.14	5.87	14.22	62.79	32.0	37.2
14	21.78	0.250	0.258	20.36	12.87	7.03	3.89	39.06	22.39	33.2	26.8
15	20.78	0.250	0.248	22.23	13.80	6.22	4.06	28.20	69.08	32.6	27.4
16	21.87	0.248	0.256	23.17	12.15	7.43	3.60	41.24	24.26	34.6	25.4
17	19.38	0.252	0.258	29.52	16.55	7.67	4.26	54.59	24.83	32.8	27.2
18	20.59	0.256	0.252	28.06	17.50	7.54	4.40	51.38	72.70	33.0	27.0
19	15.15	0.252	0.248	23.27	14.74	4.57	2.27	48.56	65.42	21.6	38.4
20	13.54	0.256	0.256	20.49	14.20	3.09	2.56	49.82	63.75	42.6	17.4
21	12.64	0.264	0.250	6.95	14.71	1.32	2.37	60.62	66.61	23.0	37.0
22	13.24	0.262	0.250	18.27	6.43	2.82	1.98	46.57	65.32	35.2	24.8

Appendix C

IACUC Investigator Certification Forms

INVESTIGATOR CERTIFICATION

Title of Project The effects of differential terminal-link effort on responding under concurrent chained schedules.

If any of the above procedures are changed, I will submit a new protocol.

I understand that any failure to comply with the *Animal Welfare Act*, the provisions of the *DPHS Guide for the Care and Use of Laboratory Animals* and requirements set down by the IACUC may result in the suspension of my animal studies.

[signature]	Psychology	10-10-88
Signature: Principal Investigator	***Department***	***Date***

REVIEW BY THE INSTITUTIONAL ANIMAL CARE AND USE COMMITTEE

______ Disapproved ✓ Approved ______ Approved with the provisions listed below

Provisions:
or
Explanation

[signature]	10-25-88
IACUC Chairperson	***Date***

Researcher's Acceptance of Provisions:

[signature]	10-31-88
Signature: Principal Investigator	***Date***
IACUC Chairperson Final Approval	***Date***

Approved IACUC Number 0024

Revised June, 1988

INVESTIGATOR CERTIFICATION

Title of Project The effects of differential terminal-link effort on responding under concurrent chain schedules

If any of the above procedures are changed, I will submit a new protocol.

I understand that any failure to comply with the *Animal Welfare Act*, the provisions of the *DPHS Guide for the Care and Use of Laboratory Animals* and requirements set down by the IACUC may result in the suspension of my animal studies.

Signature: Principal Investigator | *Department* | 8/14/89 *Date*

REVIEW BY THE INSTITUTIONAL ANIMAL CARE AND USE COMMITTEE

______ Disapproved ✓ Approved ______ Approved with the provisions listed below

Provisions:
or
Explanation

IACUC Chairperson | 8-29-89 *Date*

Researcher's Acceptance of Provisions:

Signature: Principal Investigator | 8-29-89 *Date*

IACUC Chairperson Final Approval | *Date*

Approved IACUC Number 0034

Revised June, 1988

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