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**EFFECTS OF TERMINAL-LINK RESPONSE TOPOGRAPHY ON CHOICE
BEHAVIOR UNDER CONCURRENT-CHAINS SCHEDULES**

by

Stephen P. Starin

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
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EFFECTS OF TERMINAL-LINK RESPONSE TOPOGRAPHY ON CHOICE BEHAVIOR UNDER CONCURRENT-CHAINS SCHEDULES

Stephen P. Starin, Ph.D.

Western Michigan University, 1988

Previous research has indicated that both absolute response rate and choice behavior differs under concurrent chains requiring different terminal-link responses, even when the reinforcement schedules are nominally identical. To date, no studies have investigated responding under concurrent chains with unequal schedules and different topographies arranged in the terminal links. Moreover, although the delay-reduction hypothesis has been widely tested using concurrent chains in which the same response topography is required in all links, the generality of the delay-reduction hypothesis in describing performance when different terminal-link topographies are required has yet to be examined. The present study was designed to address both of these issues.

Six pigeons responded under concurrent-chains schedules of food delivery. The initial links consisted of concurrent variable-interval 60 s schedules for all subjects. For three subjects, the required initial-link response topography was key pecking; for three others, the required initial-link topography was treadle pressing. Pecking was always required in the terminal link of one chain and treadling always required in the opposing terminal link. All subjects were exposed to five pairs of terminal-link variable-interval schedules over ten conditions. The pairs of variable-interval schedules employed were: 6 s vs. 54 s, 18 s vs. 42 s, 30 s vs. 30 s, 18 s vs. 42 s, and 54 s vs. 6 s.

Comparing data from nominally identical terminal-link schedules revealed that all

subjects generally responded faster to the chain requiring terminal-link pecking than to the chain requiring terminal-link treadling. Regressing obtained choice proportions on their predicted values indicated that choice behavior was not well described by the delay-reduction hypothesis. Instead, a relative insensitivity to time to reinforcement and a strong bias towards the alternative correlated with terminal-link pecking were found. Differences between scheduled and obtained reinforcement schedules were found to be a major contributor to all of the present findings. Without exception, the time to reinforcement for chains requiring terminal-link pecking was shorter than that obtained for terminal-link treadling chains. Differences between the response forces associated with pecking and treadling were also identified as possible factors influencing choice but, because of methodological constraints, the effects of this factor were not empirically evaluated.

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under concurrent-chains schedules**

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Western Michigan University, 1988

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TABLE OF CONTENTS

ACKNOWLEDGEMENTS	ii
LIST OF TABLES	iv
LIST OF FIGURES	v
CHAPTER	
I. INTRODUCTION	1
II. METHOD	16
Subjects	16
Apparatus	16
Procedure	17
III. RESULTS.....	23
Absolute Response Rates	23
Pecking Birds.....	23
Treadling Birds	29
Choice Proportions	34
Pecking Birds.....	34
Treadling Birds	39
IV. DISCUSSION.....	43
BIBLIOGRAPHY.....	55

LIST OF TABLES

1. Summary of Experimental Conditions	18
2. Response Rates and Choice Proportions for Initial-Link Pecking Birds.....	25
3. Response Rates and Choice Proportions for Initial-Link Treadling Birds.....	31
4. Predicted Versus Obtained Choice Proportions.....	35
5. Programmed Versus Obtained Terminal-Link Schedules.....	45

LIST OF FIGURES

1. Absolute Response Rates for Initial-Link Pecking Birds.....	24
2. Absolute Response Rates for Initial-Link Treadling Birds.....	30
3. Results of Simple Linear Regression Analysis for Initial-Link Pecking Birds (Individual Data)	38
4. Results of Simple Linear Regression Analysis for Initial-Link Pecking Birds (Group Data)	39
5. Results of Simple Linear Regression Analysis for Initial-Link Treadling Birds (Individual Data)	41
6. Results of Simple Linear Regression Analysis for Initial-Link Treadling Birds (Group Data)	42

CHAPTER I

INTRODUCTION

Chain schedules comprise two or more reinforcement schedules sequentially in effect, each correlated with a different exteroceptive stimulus. Each schedule and its correlated stimulus is known as a "link" or "component." Responding in non-terminal links is reinforced by a change in the stimulus correlated with that component schedule to the stimulus correlated with the following component schedule. Typically, unconditioned reinforcement is scheduled in the terminal link. The response topographies in the various chain components may be topographically similar or dissimilar. The former are known as homogeneous chains whereas the latter are referred to as heterogeneous chains (Keller & Schoenfeld, 1950).

The experimental analysis of behavior has long used homogeneous chains both to investigate chain performance itself and as a procedure to study other behavioral phenomena including behavioral contrast (Wilton & Gay, 1969), choice (e.g., Moore, 1982), conditioned reinforcement (e.g., Rose & Fantino, 1978), conditioned suppression (e.g., DeCosta & Ayres, 1971), punishment (e.g., MacDonald, 1973), and stimulus control (e.g., Kelleher & Fry, 1962).

In contrast, heterogeneous chains have received scant attention despite their acknowledged theoretical and practical importance (D'Andrea, 1969; Lattal & Crawford-Godbey, 1985). Investigation of heterogeneous chain performance is important for two reasons. First, much human responding is characterized by chained responses and these are most often heterogeneous rather than homogeneous chains. In fact, true homogeneity is very rare in humans (Keller & Schoenfeld,

1950). Only by studying contingencies which closely resemble those found in human affairs can we best meet the ultimate goals of basic research--the prediction and control of human behavior. Second, the study of different response topographies may help to resolve some basic issues facing the experimental analysis of behavior. For instance, the arbitrary nature of the keypeck has been questioned (e.g., Schwartz & Gamzu, 1977) and the study of operants other than pecking may limit or broaden the generality of findings based upon the keypeck. Given that such good reasons exist for its study, it is surprising that only four known investigations have specifically addressed the differences in responding under homogeneous and heterogeneous chains (D'Andrea, 1969; Lattal & Crawford-Godbey, 1985; Starin, 1987; Starin, 1988).

The results of Lattal and Crawford-Godbey (1985), Starin (1987, 1988) indicate that steady-state responding differs under comparable homogeneous and heterogeneous chains. In both, higher rates of responding were obtained under homogeneous chains as compared to their nominally identical heterogeneous chain. Starin (1987) offered two explanations which might account for differential responding under the two chains types, the nature of the terminal-link topographies themselves and "induction" or "generalization." It is conceivable that factors such as awkwardness, effort, and phylogenetic predispositions may increase or decrease the value of one particular response topography as compared to another topography, even when the reinforcement schedules are identical. The stimulus associated with the more valued terminal-link topography would then acquire greater conditioned reinforcing effectiveness than the stimulus correlated with the alternative topography. Consequently, this terminal-link stimulus would engender higher initial-link response rates than the other terminal-link stimulus. Higher initial-link rates in all chains with a common topography would reflect a preference for that topography. For instance, if

birds responded faster under all chains requiring terminal-link keypecking than under chains requiring terminal-link treadling, a preference for pecking would be indicated. Induction or generalization refers to the strengthening effect of reinforcing a particular terminal link topography "spilling over" or generalizing to responses earlier in the chain. Induction effects seem more likely when the topographies are similar (i.e., homogeneous chains) than when they are dissimilar (i.e., heterogeneous chains). In short, in the case of preference, the nature of the terminal-link topographies themselves are critical in determining initial-link response rates whereas in induction it is the similarity of the initial- and terminal-link topographies that play the critical role.

Starin (1987) found higher response rates under chains requiring pecking in both components (henceforth referred to as chain key-key) than under chains requiring pecking in the initial link and treadling in the terminal link (chain key-treadle). Moreover, chain treadle-treadle engendered higher response rates than did chain treadle-key. These findings indicate that differences in the values of the terminal-link topographies themselves could not account for the results. Induction alone was sufficient to explain the data for three of four birds. Lattal and Crawford-Godbey (1985) also found higher response rates under chain key-key but failed to assay initial-link treadling. Consequently, their results shed no light on the induction versus preference interpretations.

The studies of both Lattal and Crawford-Godbey (1985) and Starin (1987) suffer from one major flaw. In both, the chain types were introduced successively. Such procedures do not permit the empirical evaluation of preference for terminal-link conditions. Procedures in which two or more response options are simultaneously available are more sensitive to many manipulations than are single response procedures (de Villiers, 1977; Fantino & Logan, 1979). One method for studying the effects of terminal-link manipulations on preference or choice is the concurrent-chains

procedure (Autor, 1960, 1969). As typically employed, two independent and identical initial-link components are simultaneously available for two different (usually with respect to spatial location) responses. This is also known as the "choice phase." Each of these initial-link responses occasionally produces a stimulus correlated with entry into the corresponding terminal link (also known as the "outcome phase"). At this time the other manipulandum becomes inoperative. Generally, the conditions in the terminal links differ (e.g., with respect to reinforcement frequency, magnitude, or probability) constituting the independent variable. Preference or choice for the terminal-link conditions is the dependent variable and is measured by the distribution of responding in the initial links. These data are generally presented as the relative rate of responding (number of initial-link response to one manipulandum divided by the total number of initial-link responses on both manipulanda) or, less commonly, the relative time spent responding (amount of time responding on one manipulandum divided by the total amount of time responding to both manipulanda) to a particular manipulandum during the choice phase. As generally conceived, the greater the relative response or time allocation to a particular initial-link response option, the greater the conditioned reinforcing effectiveness of its corresponding terminal-link stimulus and hence the conditions arranged in the presence of that stimulus. Organisms are said to prefer the conditions arranged in a particular terminal link when relative response or time distribution is greater than .50; when these measures approximate .50, the subject is said to be indifferent to the terminal-link conditions.

Beginning with Autor (1960), concurrent chains have been used widely to study the effects of many terminal-link variables on initial-link choice behavior. Among the terminal-link variables that have been submitted to experimental analyses are reinforcement delay (e.g., Hursh & Fantino, 1973), frequency (Autor, 1960, 1969;

Herrnstein, 1964), magnitude (Schwartz, 1969), number (Squires & Fantino, 1971), and probability (Autor, 1960, 1969; Herrnstein, 1964); response rate requirements (e.g., Fantino, 1968), and particular schedules of reinforcement (e.g., Duncan & Fantino, 1970). On the whole, these studies indicate that organisms will more often choose (respond to) the alternative correlated with the most favorable terminal-link condition (e.g., the one that provides that greatest frequency of, or shortest time to, reinforcement). Furthermore, the greater the difference in the terminal-link conditions, the greater the degree of preference.

The role of response topography itself as an independent variable has only recently begun to be studied in this context. Starin (1988) arranged a homogeneous chain concurrently with a nominally identical heterogeneous chain. He found that irrespective of whether pecking or treadling was required in the initial links, birds responded faster when terminal-link pecking was required. These data are clearly inconsistent with a previous single-alternative study exploring performance differences under homogeneous and heterogeneous chains (Starin, 1987). The reasons for this discrepancy are unclear but it has been previously reported that "variables that seem irrelevant for the single key may have large effects when responding is reinforced concurrently on each of two keys" (Catania, 1963, p. 300). Hence, performance under single-response procedures is often insensitive to variables affecting concurrent performance. This may have been the case in the study by Starin (1987); a preference for terminal-link pecking may have existed, but due to the nature of the procedure, not apparent. It should be noted that the findings of Lattal and Crawford-Godbey (1985) are not necessarily inconsistent with the those of Starin (1988). In the former study, only initial-link pecking was assessed. It is unknown how these subjects would have responded had they been required to treadle in the initial links.

Another possible explanation for the results of Starin (1987) involves differences in the time to reinforcement between chains requiring terminal-link pecking and those requiring treadling. Although the programmed variable-interval (VI) schedules¹ were identical, the obtained terminal-link VIs were always higher for terminal-link pecking chains. This resulted in a difference of between 5 and 14 reinforcements per hour in favor of the terminal-link pecking chains. Many previous investigations have shown terminal-link delay to reinforcement and reinforcement rate to be the important variables affecting choice in concurrent-chains schedules. It is conceivable, therefore, that the higher response rates engendered by terminal-link pecking chains was not exclusively due to the nature of the topographies required but was, in part, influenced by the differences in reinforcement rates. Starin (1988) addressed this possible confound and concluded that because the relative initial-link response rates under pecking chains were considerably higher than their terminal-link reinforcement rates "terminal-link response topography can be seen to have a large effect that is independent of these reinforcement rates" (p. 281). This conclusion, however, is only speculative and awaits empirical verification.

Not only do concurrent-response procedures allow for the empirical assessment of choice, many authors have suggested that there exists a quantitative relationship between conditions arranged in the various components and choice behavior. Herrnstein (1961), using simple concurrent VI schedules,² first quantified the relation between response and reinforcement rates. He found that the proportion of responses

¹A variable-interval schedule delivers reinforcement for the first response to occur after a variable time period elapses.

²A simple concurrent schedule involves two or more response options being simultaneously available to the subject each reinforced under its own schedule (VIs in this case). This may be conceived of as a concurrent-chains schedule with VIs in the initial links and 0-s terminal links.

allocated to a key was approximately equal to the proportion of reinforcers obtained from that key. This relation may be described by the equation:

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

where R_1 and R_2 are the frequencies of responding to each of the two alternatives and r_1 and r_2 are their respective obtained reinforcement rates. This equation predicts that the relative rate of responding to an alternative will be directly equal to the relative frequency of reinforcement obtained from that alternative. This linear relationship between response and reinforcement proportions has been termed "matching" (of relative response rates to relative reinforcement rates). Davison and McCarthy (1988) have referred to this relation as "strict matching" to distinguish it from other, more general, relationships.

Subsequent studies extended this finding to a variety of procedures, subjects, and types of reinforcement. Furthermore, it has been demonstrated that subjects also match relative response rates to relative reinforcement duration (e.g., Catania, 1963) and immediacy (e.g., Chung & Herrnstein, 1967). Others have shown that subjects will also match relative time spent responding to an alternative to the relative reinforcement rate obtained from that alternative. Time matching has been found using both response-dependent (e.g., Shull & Pliskoff, 1967) and response-independent (e.g., Brownstein & Pliskoff, 1968) procedures. Based on these and their own data, Baum and Rachlin (1969) have argued that time matching is the critical feature underlying all matching relations. Their rationale is that birds peck at a constant rate once they are responding (i.e., local response rate) and that these local response rates are relatively invariant under different reinforcement schedules. Because matching is obtained only when overall response rates are used, Baum and Rachlin (1969) argued that the distribution of time to one or the other alternative, not

response rate, is the major factor responsible for matching.

Equation (1) predicts the *relative* response rates given a set of relative reinforcement rates. It would also be useful to predict *absolute* response rates for each of the alternatives. To do this equation (1) must be modified as:

$$R_1 = \frac{kr_1}{r_1 + r_2} \quad (2)$$

where k refers to the maximal rate of responding³ (i.e., the total response rate for all responses taken together) for a particular subject and is independent of the reinforcement rates. Several implications result from this model of behavior. First, absolute rate of responding (R_1) would increase as its rate of reinforcement (r_1) increases. Additionally, R_1 would decrease as reinforcement for the alternative response (r_2) increases. Both of these predictions have been empirically verified. A third implication is that if $r_2 = 0$ then $R_1 = k$ (because $r_1/r_1 = 1$) irrespective of the reinforcement rate. This prediction of response rate invariance has not received empirical support. Rather, it has been shown that orderly changes in response rate occur as reinforcement rate is changed even when the opposing component of a concurrent schedule is extinction (Fantino & Logan, 1977). The generality of equation (2) is therefore limited and holds only when both r_1 and r_2 are greater than zero.

To account for this difficulty Herrnstein (1970) proposed that in addition to the responses specified by the experimenter, there are a number of unspecified responses available to the subject (e.g., preening). Furthermore, each of these unspecified responses is reinforced under its own reinforcement schedule. These other schedules are likely to have the same effect on behavior as the specified schedules.

³ k is a parameter that is derived from the data once they are obtained. To calculate the value of k , simply solve equation (2) algebraically for k .

Consequently, if the reinforcement rate for an unspecified response increases, R_1 will decrease. To acknowledge these other sources of reinforcement Herrnstein (1970) rewrote equation (2) as:

$$R_1 = \frac{kr_1}{r_1 + r_2 + r_o} \quad (3)$$

where r_o refers to the reinforcement rate for all other behaviors.⁴ This equation is of more generality than equation (2) in that it more accurately predicts both absolute response rate and choice proportions. For choice proportions, equations (2) and (3) are identical (i.e., $R_1/(R_1+R_2)=r_1/(r_1+r_2)$) because the denominators and k cancel out.

A large body of literature indicates that when proportions are used, as in Herrnstein's (1970) formulation, accurate predictions of concurrent performance are often not forthcoming (e.g., Baum, 1974; Lobb & Davison, 1975; Myers & Myers, 1977; Staddon, 1968). Staddon (1968) and Baum and Rachlin (1969), for instance, found that closer approximations to matching occurred when the ratio (rather than relative measures) of response or time allocation to an alternative were plotted as a function of the ratio of reinforcement obtained from that alternative. Thus, transforming equation (1) to its ratio equivalent results in the following equation:

$$\frac{R_1}{R_2} = \frac{r_1}{r_2} \quad (4)$$

where R and r again refer to response and reinforcement frequency, respectively.⁵ A straight line fitted to these data using the least-squares method has the equation:

⁴Several statistical methods exist for estimating k and r_o . Davison and McCarthy (1988) suggest that Wilkinson's (1961; see also McDowell, 1981) method is preferred due to its ease of use and relatively few statistical problems.

⁵The actual symbols used to denote the various variables are often inconsistent across experimenters. For instance, some author's refer to response rate as R , others as B , and still others as P . For sake of consistency, the same symbols will be used throughout this paper although they may differ from those used by certain authors.

$$\log \left(\frac{R_1}{R_2} \right) = a \log \left(\frac{r_1}{r_2} \right) + \log c \quad (5)$$

where a is the slope of the straight line and c is the y-intercept. Logarithmic transforms of this sort are commonly used to transform curvilinear functions into linear functions (e.g., Baum, 1974; Davison & McCarthy, 1988). Equation (5) in arithmetic form describes a power function:

$$\frac{R_1}{R_2} = c \left(\frac{r_1}{r_2} \right)^a \quad (6)$$

Equations (5) and (6) are both known as the "generalized matching law" (Baum, 1974). They are referred to as "generalized" because they allow data that do not conform to Herrnstein's (1970) equation to be expressed in similar terms. When c and a are both one, equations (5) and (6) are equivalent to equation (1). In this case, the least-squares line is a diagonal with a y-intercept of zero and a slope of one. This is also known as the line of perfect matching.

The generalized matching law accounts for two observed deviations from strict matching: bias and undermatching. Bias is a constant preference toward one alternative at all levels of the independent variable. It indicates the magnitude of preference when apparent equality of reinforcement would predict indifference (Baum, 1974). Bias shows up in the data as a displacement of the least-squares line away (up or down) from the line of perfect matching (i.e., a value of c different than 1 or $\log c$ different than zero). The factors responsible for bias within a particular experiment are often unknown. However, a bias may, for example, reflect a tendency of the subject to respond more frequently to a particular location, to a particular key color, or to the alternative requiring the least force. Baum (1974) presents a detailed treatment of bias and some factors responsible for its occurrence.

The other type of deviation from strict matching is undermatching. This reflects

a tendency of the subject to respond at levels nearer indifference than would be predicted by the matching equation. Undermatching is indicated when the slope of the least-squares line (α) is less than one. When $\alpha = 1$, matching is said to obtain. Overmatching, a least-square line with a slope greater than one, has also been reported but much less commonly than undermatching (Baum, 1974). Davison and McCarthy (1988) suggest that this trichotomy (undermatching, matching, overmatching) can be avoided by the use of the term "sensitivity" as the name for any α value. Sensitivity can thus be seen as a measure of the degree of change in responding as a result of a unit change in reinforcement contingencies (e.g., reinforcement frequency, amount, or immediacy). Like bias, the variables responsible for slopes different from one within a single experiment often are unknown but may be due to poor discrimination between alternatives, procedures that allow for the subject to switch between alternatives too frequently, or high deprivation levels (see Baum, 1974, 1979, for detailed treatments).

Quantitative analyses of different response topographies have been conducted using multiple and simple concurrent variable-interval schedules (Davison & Ferguson, 1978; Wheatley & Engberg, 1978; White, 1979). Of most relevance to the present study are investigations by Davison and Ferguson (1978) and Wheatley and Engberg (1978) who employed treadling and pecking in the opposing components of simple concurrent VI schedules. Wheatley and Engberg (1978) found a strong bias towards key pecking when the logarithms of response ratios were plotted as a function of logarithms of reinforcement rate ratios. When log time ratios were plotted against log reinforcement ratios, however, no systematic biases were obtained. All birds also showed undermatching. In contrast, Davison and Ferguson (1978) found a strong bias towards key pecking using both response and time ratios although the bias was smaller using time ratios.

The preceding discussion has focused on the effects of reinforcement frequency on response rate. As mentioned previously, response rate also has been shown to be influenced by amount and immediacy of reinforcement. These variables have been included in versions of the matching equation as:

$$\frac{R_1}{R_2} = \frac{r_1}{r_2} \times \frac{A_1}{A_2} \times \frac{I_1}{I_2} \quad (7)$$

where A and I refer to amount and immediacy of reinforcement, respectively.

Quantitative relationships have also been shown to obtain under concurrent-chain procedures. Both Autor (1960, 1969) and Herrnstein (1964) found that their subjects matched relative initial-link response rate to relative reinforcement rates in the terminal-links. This relationship may be expressed as:

$$\frac{R_L}{R_L + R_R} = \frac{\frac{1}{t_{2L}}}{\frac{1}{t_{2L}} + \frac{1}{t_{2R}}} \quad (8)$$

where R_L and R_R refer to the number of responses to the left and right alternatives during the initial links and t_{2L} and t_{2R} refer to the average durations of the left and right terminal links. This interpretation of responding under concurrent-chains stood less than a decade when Fantino (1969a, 1969b) suggested an alternative formulation.

According to Fantino's delay-reduction hypothesis, as it has come to be called, it is the reduction in time to unconditioned reinforcement correlated with the onset of a particular terminal-link stimulus, not simple terminal-link reinforcement frequency, that gives this stimulus its conditioned reinforcing effectiveness. Consequently, organisms will more often choose the stimulus associated with the greater reduction in time to reinforcement. Furthermore, "the greater the improvement, in terms of temporal proximity to reinforcement, correlated with the onset of the stimulus, the more effective it will be as a conditioned reinforcer" (Fantino, 1977, p. 330). This

formulation may be represented by the equation:

$$\frac{R_L}{R_L + R_R} = \frac{(T - t_{2L})}{(T - t_{2L}) + (T - t_{2R})} \quad (9)$$

where T is the average time to unconditioned reinforcement from the onset of the initial links.⁶ Whenever t_{2L} or t_{2R} is greater than T , entry into that terminal link produces an increase in the average delay to reinforcement. Consequently, equation (9) predicts that responding would be exclusively allocated to the other alternative.

The primary difference between equations (8) and (9) is that the latter predicts that initial-link durations influence choice whereas the former predicts that choice is independent of initial-link durations. To test these predictions Fantino (1969b) exposed subjects to several different but equal initial-link VI schedules while holding constant the terminal-link schedules. Specifically, equal initial-link variable-intervals of 40-s, 120-s, or 600-s were used while holding the terminal-link durations at 30-s versus 90-s. Equation (8) predicts a relative response rate of .75 at all initial-link values whereas equation (9) predicts relative response rates to be 1.00, .75, and .60 for initial-link durations of 40-s, 120-s, and 600-s, respectively. The obtained average proportions of responding were found to be .95, .81, and .60, respectively. These data provide compelling evidence that equation (8) holds only within a restricted range of values while the delay-reduction formulation predicts behavior over a wider range of variable-interval values.

Over the succeeding years the delay-reduction hypothesis has undergone slight

⁶ T is calculated by summing the average time to reach the terminal links from the onset of the initial links plus the average time to unconditioned reinforcement from the onset of the terminal links. For the two alternative choice situation, the average time to reach the terminal links is one-half the value of the variable-interval schedule on the left key plus one-half the value of the right variable-interval schedule. The time to unconditioned reinforcement from the onset of terminal links is one-half of the average left terminal-link duration plus one-half of the average duration of the right terminal-link. One-half is used in each of these cases because there are two equiprobable alternatives.

modification and is now represented by the equation:

$$\frac{R_L}{R_L + R_R} = \frac{\sqrt{r_L}(T-t_{2L})}{\sqrt{r_L}(T-t_{2L}) + \sqrt{r_R}(T-t_{2R})} \quad (10)$$

where r_L and r_R refer to the rates of unconditioned reinforcement for the left and right alternatives, respectively. $r_L = n_L/(t_{1L} + n_L t_{2L})$ where n_L is the number of unconditioned reinforcements obtained during one entry into the left terminal link and t_{1L} is the programmed initial-link duration. Likewise, $r_R = n_R/(t_{1R} + n_R t_{2R})$. Unlike equation (9), equation (10) predicts performance under simple concurrent variable-interval schedules. Also, this version of the delay-reduction hypothesis predicts performance when unequal initial-link durations are arranged (Squires & Fantino, 1971; Fantino & Davison, 1983) and when differing numbers of reinforcers are obtained in the terminal-links. Equation (10) has, therefore, more generality in describing behavior than previous formulations. Indeed, the delay-reduction hypothesis has been extended to the areas of elicited responding (Fantino, 1982), foraging (Abarca & Fantino, 1982), observing (Case & Fantino, 1981), self-control (Ito & Asaki, 1982; Navarick & Fantino, 1976), and three-alternative choice (Fantino & Dunn, 1983) and is now, arguably, the preferred model describing choice in concurrent-chains schedules (Fantino & Davison, 1983).

Fantino and Davison (1983) state that, "Little has been done to further assess or refine [the delay-reduction hypothesis] in the area wherein it was developed: choice for VI schedules within the concurrent-chains framework" (p. 2). Virtually all of the studies that have explored the generality of the delay-reduction hypothesis (e.g., Fantino & Davison, 1983; Fantino & Dunn, 1983; Squires & Fantino, 1971) have employed concurrent homogenous chains. Noticably absent are studies investigating its applicability to concurrent chains requiring dissimilar terminal-link response topographies. A major purpose of the present study, therefore, is to remedy this

situation by examining how well the delay-reduction hypothesis describes choice in these situations. The current study also constitutes a systematic extension of previous work investigating performance differences under homogeneous and heterogeneous chains. Specifically, a wider range of terminal-link VIs and both equal and unequal terminal-link reinforcement schedules will be examined.

CHAPTER II

METHOD

Subjects

Six barren-hen White Carneaux pigeons maintained at 80% of their free-feeding body weight served as subjects. Birds were weighed immediately after experimental sessions and make-up food provided, when necessary. All subjects were individually housed with free access to water and grit in their home cages. All birds had previous histories responding under concurrent-chains procedures (Starin, 1988), therefore no preliminary training was necessary. Birds 1, 2, and 3 were assigned to the initial-link pecking group and birds 4, 5, and 6 were assigned to the initial-link treadling groups.

Apparatus

Two operant chambers measuring approximately 40 cm long, 40 cm deep, and 40 cm across were employed. Each chamber was equipped with two response keys and two foot treadles. The keys were 2.5 cm in diameter, 7.5 cm apart, and 20 cm above the chamber floor. Each key could be illuminated in red, yellow, or green and required a minimum force of .2N to be activated. Two aluminum foot treadles approximately 8 cm long and 2 cm wide were affixed to the response panel, 6 cm from either side wall. The treadles were sloped downward 30 degrees from the vertical with the front edge of the treadles resting 3.5 cm above the chamber floor. A minimum force of 1N with an excursion of 2 mm was required to operate a microswitch. Treadling stimuli consisted of 7.5-W red, white, and green lamps mounted behind a 1.5 cm translucent plastic panel above each treadle. The panels

were 15 cm above the chamber floor and 4 cm from the side walls.

A 5 cm x 6 cm aperture centered in the response panel 7 cm from the floor allowed access to mixed grain. When operated, the hopper was illuminated with a 7.5-W white lamp. A 7.5-W white lamp was mounted in the center of the chamber ceiling to provide general illumination. Ventilation and white masking noise were present throughout the experiment. Experimental contingencies, data recording and analysis were controlled by a Digital Equipment Corporation PDP-8E (Braynard, MA) minicomputer equipped with SuperSked™ (Kalamazoo, MI) software and interfacing located in an adjacent room.

Procedure

Because the subjects had prior histories responding under concurrent homogeneous and heterogeneous chains, they were immediately exposed to the experimental conditions. During the choice phase (initial links) subjects responded on two concurrently available keys or treadles. Two independent timers programmed entry into the terminal links on a VI 60 s basis. Responses on a particular manipulandum were occasionally reinforced by production of the stimulus associated with its corresponding terminal-link schedule. Upon entry into a terminal link, responses were effective only on the programmed key or treadle. At this time all other manipulanda became dark and inoperative and initial-link timers were stopped. A 4 s food delivery in the terminal links was arranged under the programmed VI schedule (see Table 1 for scheduled VI values). Immediately after reinforcement, the initial-links were reinstated and the procedure repeated until 45 minutes had elapsed or 40 reinforcements had been delivered, whichever came first. All VI schedules consisted of 10 interreinforcement intervals (IRIs) constructed according to an arithmetic progression suggested by Catania and Reynolds (1968). Their order of

Table 1

Summary of Experimental Conditions

SUBJECT	CONDITION	TERMINAL-LINK	TERMINAL-LINK	INITIAL-LINK	TERMINAL-LINK	TOTAL
		VL (SEC)	TOPOGRAPHY	STIMULI	STIMULI	
		Left/Right	Left/Right	Left/Right	Left/Right	SESSIONS
S1	1	6/54	K/T	R/R	Y/G	30
	2	6/54	T/K	R/R	G/Y	12
	3	18/42	K/T	R/R	Y/G	16
	4	18/42	T/K	R/R	G/Y	10
	5	54/6	K/T	R/R	Y/G	27
	6	54/6	T/K	R/R	G/Y	11
	7	42/18	K/T	R/R	Y/G	10
	8	42/18	T/K	R/R	G/Y	11
	9	30/30	K/T	R/R	Y/G	10
	10	30/30	T/K	R/R	G/Y	10
S2	1	6/54	K/T	Y/Y	G/R	19
	2	6/54	T/K	Y/Y	R/G	13
	3	18/42	K/T	Y/Y	G/R	10
	4	18/42	T/K	Y/Y	R/G	12
	5	42/18	K/T	Y/Y	G/R	13
	6	42/18	T/K	Y/Y	R/G	18
	7	54/6	K/T	Y/Y	G/R	16
	8	54/6	T/K	Y/Y	R/G	10
	9	30/30	K/T	Y/Y	G/R	15
	10	30/30	T/K	Y/Y	R/G	15

Table 1--Continued

SUBJECT	CONDITION	TERMINAL-LINK VL (SEC)		TERMINAL-LINK TOPOGRAPHY		INITIAL-LINK STIMULI		TERMINAL-LINK STIMULI		TOTAL SESSIONS
		Left/Right		Left/Right		Left/Right		Left/Right		
S3	1	6/54		K/T		G/G		R/W		23
	2	6/54		T/K		G/G		W/R		22
	3	18/42		K/T		G/G		R/W		16
	4	18/42		T/K		G/G		W/R		19
	5	42/18		K/T		G/G		R/W		12
	6	42/18		T/K		G/G		W/R		16
	7	54/6		K/T		G/G		R/W		21
	8	54/6		T/K		G/G		W/R		10
	9	30/30		K/T		G/G		R/W		15
	10	30/30		T/K		G/G		W/R		10
S4	1	54/6		K/T		W/W		R/W		12
	2	54/6		T/K		W/W		W/R		11
	3	42/18		K/T		W/W		R/W		11
	4	42/18		T/K		W/W		W/R		10
	5	18/42		K/T		W/W		R/W		10
	6	18/42		T/K		W/W		W/R		10
	7	6/54		K/T		W/W		R/W		10
	8	6/54		T/K		W/W		W/R		10
	9	30/30		K/T		W/W		R/W		10
	10	30/30		T/K		W/W		W/R		10

Table 1--Continued

SUBJECT	CONDITION	TERMINAL-LINK	TERMINAL-LINK	INITIAL-LINK	TERMINAL-LINK	TOTAL
		VI (SEC)	TOPOGRAPHY	STIMULI	STIMULI	
		Left/Right	Left/Right	Left/Right	Left/Right	SESSIONS
S5	1	54/6	K/T	W/W	R/W	23
	2	54/6	T/K	W/W	W/R	22
	3	42/18	K/T	W/W	R/W	16
	4	42/18	T/K	W/W	W/R	19
	5	18/42	K/T	W/W	R/W	12
	6	18/42	T/K	W/W	W/R	16
	7	6/54	K/T	W/W	R/W	21
	8	6/54	T/K	W/W	W/R	10
	9	30/30	K/T	W/W	R/W	15
	10	30/30	T/K	W/W	W/R	10
S6	1	54/6	K/T	W/W	R/W	23
	2	54/6	T/K	W/W	W/R	22
	3	42/18	K/T	W/W	R/W	16
	4	42/18	T/K	W/W	W/R	19
	5	18/42	K/T	W/W	R/W	12
	6	18/42	T/K	W/W	W/R	16
	7	6/54	K/T	W/W	R/W	21
	8	6/54	T/K	W/W	W/R	10
	9	30/30	K/T	W/W	R/W	15
	10	30/30	T/K	W/W	W/R	10

presentation to the subject was determined by the programming apparatus. This consisted of randomly selecting, without replacement, from the list of IRIs. The selection procedure continued until all intervals had been selected and presented at which time all individual intervals were again available and the procedure repeated.

For initial-link pecking birds, homogeneous chains required pecks to the same key in both links. The concurrently available heterogeneous chain required pecking in the initial link and treading in the terminal link. The heterogeneous chain was always arranged on the key and treadle on the opposite side of the chamber from the homogeneous chain. Thus, at a given time both links of the homogeneous chain were arranged on the the left key while the heterogeneous chain was arranged on the right key and right treadle or *visa versa*.

For initial-link treading birds, the homogeneous chain required responses to the same treadle in both links. The heterogeneous chain required responses to the treadle (during the initial link) and key (during the terminal link) located on the opposite side of the chamber.

For all subjects, responses to any nonilluminated manipulandum in either link produced a 3 s blackout during which all timers were stopped and responses had no programmed consequences. For a given subject, the initial-link stimuli were always identical whereas the terminal-link stimuli were different from both each other and from the initial-link stimuli. Stimuli were randomly determined for each subject. Table 1 presents stimulus configurations for each subject.

All subjects were exposed to five different pairs of terminal-link VIs (one VI for each terminal-link topography) while holding constant the initial-link VIs at 60 s. The programmed terminal-link VI pairs were: 54 s vs. 6 s, 42 s vs. 18 s, 30 s vs. 30 s, 18 s vs. 42 s, and 6 s vs. 54 s. After responding had stabilized under a particular pair of terminal-link VIs, the chain types were reversed and responding allowed to stabilize

under these conditions. Next, the chains types were again reversed and a new pair of terminal-link VIs arranged. This procedure continued until the subject had been exposed to each VI value on each key for each chain type. This resulted in ten conditions per subject. Table 1 shows the order of conditions and the number of sessions per condition for each subject. A change in conditions was initiated when the following criteria were met: (a) a minimum of 10 days per condition and (b) a minimum of five consecutive days with no increasing or decreasing trend in response distribution.

The primary dependent variables were absolute and relative response rate to each alternative during the initial links. Absolute rate of responding was calculated by dividing the number of responses to a particular alternative by the total amount of time in the initial links. Relative response rates were calculated by dividing the number of initial-link responses to one alternative by the total number of initial-link responses to both alternatives.

CHAPTER III

RESULTS

Absolute Response Rates

Pecking Birds

All data discussed here and elsewhere are from the last five days per condition averaged over two exposures to each condition, once on each key. Except where noted, data are for chains requiring terminal-link pecking. Figure 1 shows, for each subject, initial-link pecking rates as a function of terminal-link VI. Open squares represent rates of pecking under chains requiring terminal-link pecking (homogeneous chains); filled squares represent rates of pecking under chains requiring terminal-link treadling (heterogeneous chains). To facilitate comparison of responding under similar reinforcement schedules the data are presented according to the programmed terminal-link VI schedule although, with the exception of VI 30 s schedules, the VIs shown on the abscissa could not be in effect at the same time. For example, the first two sets of five data points for S1 depict the absolute pecking rates for terminal-link pecking and terminal-link treadling chains when each terminal link is associated with a VI 6 s schedule of food delivery although these VIs were never present at the same time. Without exception, subjects pecked faster to the chains requiring terminal-link pecking than to the nominally identical terminal-link treadling chains. Subjects also generally showed an orderly decrease in initial-link response rates under both chain types as the terminal-link VIs increased.

Table 2 presents the absolute initial-link pecking rates for all conditions, though

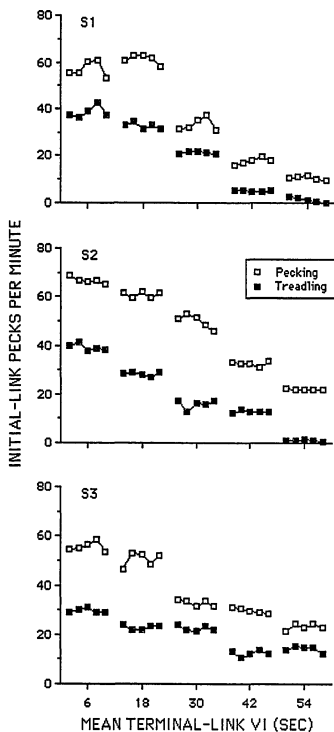


Figure 1. Absolute Response Rates for Initial-Link Pecking Birds.

Table 2
Response Rates and Choice Proportions for Initial-Link Pecking Birds

SUBJECT	TERMINAL-LINK TOPOGRAPHY	TERMINAL-LINK VI (SEC)	INITIAL-LINK RESPONSE RATE	PREDICTED CHOICE PROPORTION	OBTAINED CHOICE PROPORTION
	Left/Right	Left/Right	Left/Right	T.L. Pecking	T.L. Pecking
S1	K/T	6/54	53.28/ .30	.92	.99
	T/K	6/54	24.28/19.10	.08	.44
	K/T	18/42	54.52/ 9.77	.73	.85
	T/K	18/42	24.85/21.65	.27	.47
	K/T	30/30	20.21/33.27	.50	.38
	T/K	30/30	9.66/46.41	.50	.83
	K/T	42/18	13.96/39.68	.27	.26
	T/K	42/18	.52/56.84	.73	.99
	K/T	54/6	2.41/52.60	.08	.04
	T/K	54/6	2.46/60.92	.92	.96

Table 2--Continued

SUBJECT	TERMINAL-LINK TOPOGRAPHY	TERMINAL-LINK VI (SEC)	INITIAL-LINK RESPONSE RATE	PREDICTED CHOICE PROPORTION	OBTAINED CHOICE PROPORTION
	Left/Right	Left/Right	Left/Right	T.L. Pecking	T.L. Pecking
S2	K/T	6/54	73.47/ .38	.92	.99
	T/K	6/54	46.87/16.72	.08	.26
	K/T	18/42	74.19/ 4.27	.73	.95
	T/K	18/42	42.09/22.63	.27	.35
	K/T	30/30	50.45/12.37	.50	.80
	T/K	30/30	18.99/49.61	.50	.72
	K/T	42/18	42.33/15.68	.27	.73
	T/K	42/18	21.56/63.12	.73	.75
	K/T	54/6	27.40/31.43	.08	.47
	T/K	54/6	1.68/60.06	.92	.97

Table 2--Continued

SUBJECT	TERMINAL-LINK TOPOGRAPHY		TERMINAL-LINK VI (SEC)		INITIAL-LINK RESPONSE RATE		PREDICTED CHOICE PROPORTION		OBTAINED CHOICE PROPORTION	
	Left/Right		Left/Right		Left/Right		T.L. Pecking		T.L. Pecking	
S3	K/T		6/54		64.77/	1.96	.92		.97	
	T/K		6/54		26.31/24.26		.08		.48	
	K/T		18/42		60.41/	8.15	.73		.88	
	T/K		18/42		27.67/26.08		.27		.49	
	K/T		30/30		30.03/22.37		.50		.57	
	T/K		30/30		22.67/35.61		.50		.61	
	K/T		42/18		33.30/18.47		.27		.64	
	T/K		42/18		16.73/48.68		.73		.74	
	K/T		54/6		22.37/32.95		.08		.40	
	T/K		54/6		26.42/46.21		.92		.64	

not necessarily in the order in which they occurred (see Table 1 for condition order). The first row for S1 shows the data for the condition in which a VI 6 s schedule was arranged on the left side for terminal-link pecking while a VI 54 s schedule was arranged on the right side for terminal-link treadling. Row two presents the data for the condition during which the scheduled VIs on the two sides remained the same as above (VI 6 s vs. VI 54 s), but for which the terminal-link topographies were reversed (i.e., treadling vs. pecking). Comparing pairs of rows such as these allows a finer grained analysis of responding than the summary data presented in Figure 1. The middle column of Table 2 shows initial-link response rates to the left and right keys for a given pair of terminal-link VIs. The values to the left of the slash indicate response rates to the left key whereas values to the right of the slash indicate response rates to the right key. Data are grouped in rows according to similar terminal-link schedules. To examine response rates to the left key under nominally identical schedules, one must compare the values to the left of the slash in each pair of rows. For instance, for S1 under a VI 6 s schedule, the average response rate for the left key when terminal-link pecking is required is 53.28; the response rate on the left key when terminal-link treadling is required is immediately below, 24.28. Similarly, response rates for the right key are shown to the right of the slash in Table 2. Comparing these values for S1 gives a response rate on the right key of .30 for terminal-link treadling chains versus 19.10 for terminal-link pecking chains. Data for the left key indicate that, with two exceptions, birds responded faster to the chains requiring terminal-link pecking. Rates on the right key for all subjects were higher to terminal-link pecking chains. When averaged over both keys, as in Figure 1, all subjects clearly responded faster to the terminal-link pecking chains. The magnitude of these differences ranged from approximately 9 pecks to 40 pecks per minute.

Key biases were clearly evident for all three subjects. As noted above, each

subject was exposed twice to the same nominal VI, once on each key. Comparing the response rates under similar schedules but on different keys allows any biases towards a particular alternative to be detected. In Table 2, when a VI 6-s schedule was arranged on the left key for S1, a response rate of 53.28 was obtained (from the first row of data for S1); when a VI 6 s schedule was arranged on the right key, a response rate of 60.92 was obtained (from the last row of data for S1). Out of the ten possible comparisons per subject, S1 responded faster to the right side nine times (90%); S2 and S3 responded faster to the left alternative nine (90%) and eight times (80%), respectively.

Treadling Birds

Figure 2 depicts initial-link treadling rates for all subjects. Data are displayed in the same format as in Figure 1. Rate data from similar terminal-link VIs, indicates that subjects treadled faster under the chains requiring terminal-link pecking than terminal-link treadling. There were, however, two exceptions to this pattern; when the mean terminal-link VI was 6 s, there was no appreciable response rate difference for S4 while S5 showed minimal rate differences at 18 s terminal-link VIs. Like pecking birds, treadling birds generally showed decreasing response rates as terminal-link VIs increased.

Table 3 presents absolute rate of initial-link treadling for all conditions. In 60% of the possible comparisons, birds responded faster on the left treadle when pecking was required in the terminal-links. Data for the right treadle indicate that in all conditions birds responded faster to the initial links of terminal-link pecking chains.

Like subjects in the pecking group, birds in the initial-link treadling group displayed a systematic bias towards a particular treadle. This is reflected in the response rate differences on the left and right treadles for similar terminal-link

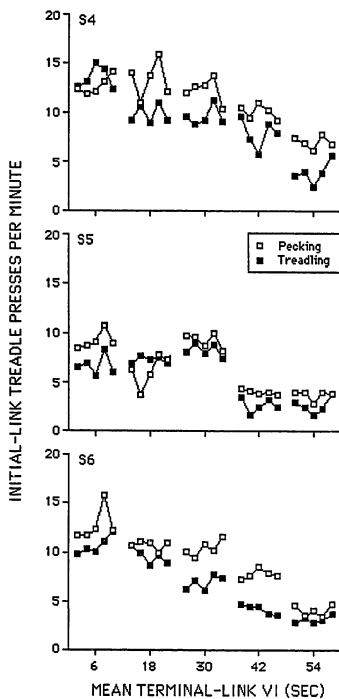


Figure 2. Absolute Response Rates for Initial-Link Pecking Birds.

Table 3
Response Rates and Choice Proportions for Initial-Link Treadling Birds.

SUBJECT	TERMINAL-LINK TOPOGRAPHY Left/Right	TERMINAL-LINK VI (SEC) Left/Right	INITIAL-LINK RESPONSE RATE Left/Right	PREDICTED CHOICE PROPORTION T.L. Pecking	OBTAINED CHOICE PROPORTION T.L. Pecking
S4	K/T	6/54	17.44/02.78	.92	.86
	T/K	6/54	19.57/05.87	.08	.23
	K/T	18/42	16.75/06.37	.73	.72
	T/K	18/42	18.99/07.86	.27	.29
	K/T	30/30	12.48/08.30	.50	.60
	T/K	30/30	10.83/12.02	.50	.53
	K/T	42/18	12.19/06.19	.27	.66
	T/K	42/18	09.34/11.39	.73	.55
	K/T	54/6	08.14/07.43	.08	.52
	T/K	54/6	04.91/07.99	.92	.62

Table 3--Continued

SUBJECT	TERMINAL-LINK TOPOGRAPHY	TERMINAL-LINK VI (SEC)	INITIAL-LINK RESPONSE RATE	PREDICTED CHOICE PROPORTION	OBTAINED CHOICE PROPORTION
	Left/Right	Left/Right	Left/Right	T.L. Pecking	T.L. Pecking
S5	K/T	6/54	0.13/02.78	.92	.78
	T/K	6/54	07.04/03.50	.08	.33
	K/T	18/42	06.80/02.23	.73	.75
	T/K	18/42	06.81/04.91	.27	.42
	K/T	30/30	12.48/05.93	.50	.60
	T/K	30/30	08.10/08.30	.50	.51
	K/T	42/18	03.04/06.11	.27	.33
	T/K	42/18	03.06/06.73	.73	.69
	K/T	54/6	.88/06.22	.08	.38
	T/K	54/6	02.47/08.12	.92	.77

Table 3--Continued

SUBJECT	TERMINAL-LINK TOPOGRAPHY	TERMINAL-LINK VI (SEC)	INITIAL-LINK RESPONSE RATE	PREDICTED CHOICE PROPORTION	OBTAINED CHOICE PROPORTION
	Left/Right	Left/Right	Left/Right	T.L. Pecking	T.L. Pecking
S6	K/T	6/54	11.02/04.56	.92	.71
	T/K	6/54	11.92/05.05	.08	.30
	K/T	18/42	09.01/05.54	.73	.62
	T/K	18/42	11.21/08.63	.27	.43
	K/T	30/30	08.56/07.70	.50	.53
	T/K	30/30	06.20/12.32	.50	.67
	K/T	42/18	06.99/08.31	.27	.46
	T/K	42/18	02.80/13.71	.73	.83
	K/T	54/6	03.07/09.42	.08	.25
	T/K	54/6	01.69/14.50	.92	.90

schedules. Comparisons of responding under nominally identical (with respect to VIs and to response topography) schedules on the two keys shows that two subjects, S4 and S5, responded faster to the left treadle, in 100% and 80% of the conditions, respectively. S6 responded faster to the right treadle 80% of the time.

Choice Proportions

Pecking Birds

Predicted (equation 10) and obtained choice proportions for initial-link pecking birds are shown in Table 2. Obtained choice proportions were determined by dividing the number of initial-link pecks to the key on which terminal-link pecking was required by the total number of pecks to both keys during the choice phase. Several patterns of choice behavior are noteworthy. First, equation 10 requires decreasing choice proportions as the duration of the programmed terminal-link VI for that alternative increases. As predicted, all subjects showed this general response pattern (see Table 2). Specifically, for terminal-link pecking chains, group choice proportions of .92, .86, .65, .49, and .35 were obtained for programmed VIs of 6 s, 18 s, 30 s, 42 s, and 54 s, respectively.

Without exception, higher choice proportions were obtained for terminal-link pecking chains than for otherwise identical terminal-link treadling chains. The upper half of Table 4 presents these data. The data in the right column show the obtained choice proportions for pecking and treadling when equation 10 predicts the proportions shown in the middle column. For instance, the first row of data for S1 shows that under conditions where equation 10 predicts choice proportions of .92, obtained choice proportions for pecking and treadling were .98 and .76, respectively. Of course, it is impossible for choice proportions to ever be greater than .50 for both pecking and treadling at the same time. Table 4 simply presents the data from

Table 4
Predicted Versus Obtained Choice Proportions

SUBJECT	PREDICTED CHOICE PROPORTION	OBTAINED CHOICE PROPORTION
	Pecking/Treadling	Pecking/Treadling
S1	.92 / .92	.98 / .76
	.73 / .73	.92 / .63
	.50 / .50	.61 / .39
	.27 / .27	.37 / .08
	.08 / .08	.24 / .02
S2	.92 / .92	.98 / .63
	.73 / .73	.85 / .46
	.50 / .50	.76 / .24
	.27 / .27	.54 / .15
	.08 / .08	.37 / .02
S3	.92 / .92	.81 / .56
	.73 / .73	.81 / .43
	.50 / .50	.59 / .41
	.27 / .27	.57 / .19
	.08 / .08	.44 / .19
S4	.92 / .92	.74 / .62
	.73 / .73	.64 / .52
	.50 / .50	.57 / .43
	.27 / .27	.48 / .36
	.08 / .08	.38 / .26
S5	.92 / .92	.78 / .64
	.73 / .73	.72 / .62
	.50 / .50	.56 / .44
	.27 / .27	.38 / .28
	.08 / .08	.36 / .22
S6	.92 / .92	.81 / .72
	.73 / .73	.73 / .55
	.50 / .50	.60 / .40
	.27 / .27	.45 / .27
	.08 / .08	.28 / .19

conditions in which the values in the middle column would be predicted by equation 10. For example, there were two conditions in which a choice proportion of .92 would be predicted for terminal-link pecking chains (i.e., VI 6 s [pecking] vs. VI 54 s [treadling] and VI 54 s [treadling] vs. 6 s [pecking]); there were two different conditions in which choice proportions of .92 would be predicted for terminal-link treadling (i.e., VI 6 s [treadling] vs. VI 54 s [pecking] and VI 54 s [pecking] vs. VI 6 s [treadling]). To facilitate comparisons, data from these different conditions are presented together. For all comparisons, terminal-link pecking chains engendered considerably higher choice proportions than the terminal-link treadling chains. The average increase in choice proportions for terminal-link pecking chains over terminal-link treadling chains was .25 for S1, .40 for S2, and .29 for S3.

For VI pairs of 6 s vs. 54 s, 18 s vs. 42 s, 30 s vs. 30 s, 42 s vs. 18 s, and 54 s vs. 6 s, the delay-reduction hypothesis predicts choice proportions of .92, .73, .50, .27, and .08 for the first VI in each pair. Individual choice proportions under each of these schedules are shown in Tables 2 and 4. Obtained group choice proportions for the terminal-link pecking chains were .92, .86, .65, .49, and .35. These data indicate that, except at high terminal-link reinforcement frequencies, equation 10 underestimates choice when different terminal-link responses are required.

Ever since Baum (1974), it has become commonplace to use simple linear regression methods to determine the "goodness" of a formulation. Regressing obtained choice values (Y) on their predicted values (X) allows for the determination of the best-fitting (i.e., least-squares) straight line between the two variables. If there were a perfect relation between predicted and obtained values, the slope of the regression line would be 1.0; a one unit increase (or decrease) in the predicted value would be associated with a one unit increase (or decrease) in the obtained value. A systematic bias towards one particular alternative is reflected in the value of the

intercept of the regression line. When proportional measures are used, values greater than zero indicate a bias toward the alternative being plotted (e.g., being used in the numerator); values less than zero indicate a bias towards the other alternative. Finally, linear regression procedures allow for the determination of a correlation coefficient (r). This value indicates the direction and degree of relationship between predicted and obtained values. More importantly, when squared the correlation coefficient becomes the coefficient of determination (r^2) and indicates the total amount of variability in Y accounted for by X.

Most often, regression procedures are used to find the best-fitting line between the logarithms of response ratios and reinforcer ratios. Ratio logarithms cannot be used in the present case because several predicted ratios are zero and the logarithm of zero is indeterminate (Fantino & Davison, 1983). The use of proportions per se is also contraindicated. Data at the end points may be constrained if reinforcement for one alternative produces exclusive preference for that alternative (Baum, 1979) and, relatedly, variances at the extremes may differ from those in the intermediate ranges. Fantino and Davison (1983) suggest that these problems may be obviated by first transforming the data by an inverse sine transformation (arc sin function) (see also Novick & Jackson, 1974).

In the present study, after predicted and obtained choice proportions had undergone inverse sine transformations, the transformed data underwent a linear regression. Figure 3 presents the results of the linear regression analysis for each subject. The equation for the best-fitting straight line and the correlation coefficient are shown on each panel. A linear regression was also performed for the group data the results of which are shown in Figure 4. The slopes of the regression functions range from .53 to 1.12 for the individual subjects and is .85 for the group. For all subjects, the intercept is positive and ranges from .19 to .43 for the individual birds.

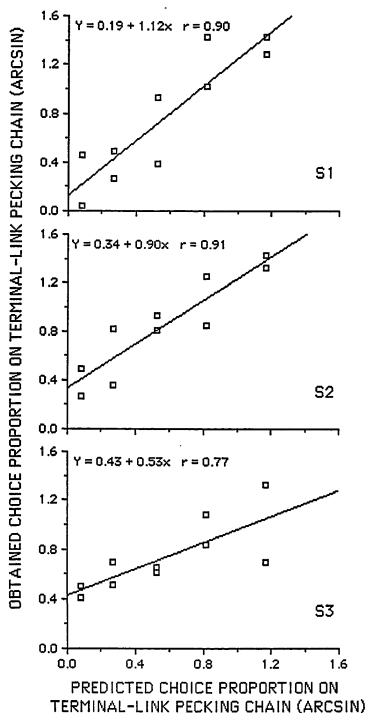


Figure 3. Results of Simple Linear Regression Analysis for Initial-Link Pecking Birds (Individual Data).

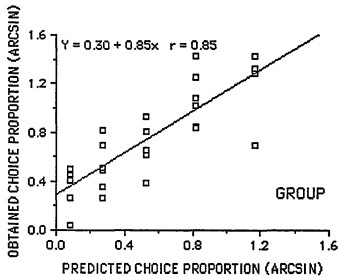


Figure 4. Results of Simple Linear Regression Analysis for Initial-Link Pecking Birds (Group Data).

For the group, the intercept is .30. Because the numerator of the proportion fraction contains values from the terminal-link pecking chains, these data show clearly a strong bias towards the alternative requiring terminal-link pecking. The percent of variability in the obtained values accounted for by the predicted values varies between 59% and 83% and is 72% for the group.

Treadling birds

Tables 3 and 4 show predicted and obtained choice proportions for initial-link treadling birds. Like initial-link pecking birds, initial-link treadling birds showed decreasing choice proportions as the terminal-link VI for that alternative increased. Group choice proportions of .77, .69, .57, .43, and .34 were obtained for terminal-link VIs of 6 s, 18 s, 30 s, 42 s, 54 s, respectively on the terminal-link pecking chain.

Inspection of data from S4, S5, and S6 in Table 4 reveals that higher choice proportions were obtained for terminal-link pecking chains even when the delay-

reduction hypothesis predicts that response distribution should be equivalent for the two alternatives. The average increase in choice proportions for terminal-link pecking chains over terminal-link treadling chains is .12 for S4, .12 for S5, and .15 for S6.

Table 3 shows the predicted and obtained choice proportions for terminal-link pecking chains. These data are also presented in a somewhat different fashion in Table 4. In both, it can be seen that equation 10 tends to overestimate choice at high terminal-link reinforcement rates (short VIs) and underestimate it at low reinforcement rates (long VIs).

Figure 5 shows, for each subject, the results of a linear regression on predicted and obtained choice proportions after each had undergone an inverse sine transformation. Linear regression data for the group are shown in Figure 6. The slopes of the best-fitting straight lines range from .41 to .54 and is .47 for the group. A systematic bias towards the alternative requiring terminal-link pecking is also clearly evident in the positive intercept of the regression line. These values range from .30 to .43 for individuals and is .37 for the group. Finally, for individual subjects, the percent of variability in obtained choice proportions accounted for by the predicted choice proportions varies between 46% and 92%. For the group, the coefficient of determination is approximately 58%.

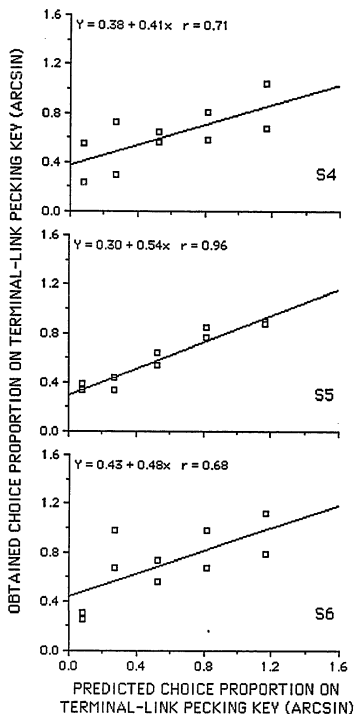


Figure 5. Results of Simple Linear Regression Analysis for Initial-Link Treading Birds (Individual Data).

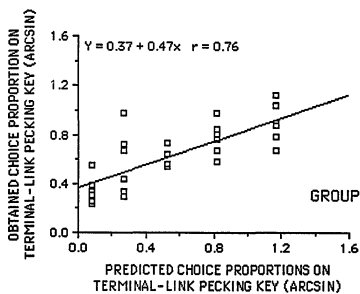


Figure 6. Results of Simple Linear Regression Analysis for Initial-Link Treading Birds (Group Data)

CHAPTER IV

DISCUSSION

The present data show that all subjects' absolute response rates and choice proportions were higher for terminal-link pecking chains than for terminal-link treadling chains. Furthermore, these results obtained for both initial-link pecking and treadling and held under a wide variety of terminal-link VIs. These data are consistent with two previous investigations. Starin (1988), using a concurrent-chains procedure, found higher response rates, and hence choice proportions, under terminal-link pecking chains than under terminal-link treadling chains although only one pair of terminal-link VIs (30 s vs. 30 s) was investigated. The present findings are also consistent with those of Lattal and Crawford-Godbey (1985) who obtained higher response rates under chains requiring pecking in both links than under chains requiring pecking in the initial link and treadling in the terminal link. In their study, however, initial-link treadling was not investigated and a single-response procedure was employed. Such methodological differences between Lattal and Crawford-Godbey (1985) and the present study make it difficult to make strong comparisons between their findings and the present findings. The present data are inconsistent with one earlier investigation. Starin (1987) obtained higher response rates under chains requiring the same topography in both links. Specifically, he found that chain key-key and chain treadle-treadle engendered higher response rates than did chain key-treadle and chain treadle-key, respectively. The reasons for this discrepancy are unclear, but, as discussed in Chapter I, the single-response procedure employed by Starin (1987) may have obscured effects due to response topography that were

apparent in the more sensitive concurrent-chains procedure used here. The present data along with those of Starin (1988) appear to substantiate an explanation based upon a preference for one particular response topography over another. Specifically, this hypothesis states that, other things being equal, birds will respond faster to the alternative requiring terminal-link pecking than to the alternative requiring terminal-link treadling.

Unfortunately, all was not equal in any of the previous studies in this area. To date, all the published studies investigating differences in performance under homogeneous and heterogeneous chains have one additional source of variability--obtained terminal-link duration. Although all previous studies comparing homogeneous and heterogeneous chain performance have used reinforcement schedules that were nominally identical, the actual values of the schedules differed, sometimes quite significantly. For instance, in Starin (1988) the nominal VI in the terminal-links was 30 s for both alternatives. The obtained VIs often differed from these values. This in itself is not significant if the obtained VIs for both pecking and treadling differed from the programmed VIs by the same amount. They did not. The mean VI for pecking was always shorter than the mean VI for treadling. This should not be surprising in light of the fact that birds can peck much faster than they can depress a treadle with their foot. Consequently, birds will emit the response that produces reinforcement sooner after it becomes available when they are pecking than when they are treadling. It is well known that, under concurrent schedules, it is the obtained schedule parameters that influence performance, not the programmed values (e.g., Baum, 1974; Herrnstein, 1970; Shull & Pliskoff, 1967). The higher reinforcement rates for pecking would produce an *a priori* bias towards this alternative.

Table 5 presents the programmed and obtained mean terminal-link VI for each

Table 5

Programmed Versus Obtained Terminal-Link Schedules

SUBJECT	PROGRAMMED TERMINAL-LINK <u>VI (SEC)</u>	OBTAINED TERMINAL-LINK <u>VI (SEC)</u> Pecking	OBTAINED TERMINAL-LINK <u>VI (SEC)</u> Treading
S1	6	6	9
	18	18	20
	30	19	33
	42	44	46
	54	57	61
S2	6	47	26
	18	19	26
	30	32	44
	42	43	65
	54	56	69
S3	6	6	8
	18	19	21
	30	31	33
	42	43	45
	54	56	60
S4	6	7	9
	18	19	23
	30	31	33
	42	43	49
	54	55	59
S5	6	7	11
	18	20	21
	30	32	34
	42	46	47
	54	56	59
S6	6	7	11
	18	19	22
	30	31	34
	42	44	46
	54	58	61

subject in the present study. The second column shows the scheduled terminal-link VI whereas the third and fourth columns show the VIs actually contacted by each subject for pecking and for treadling. Without exception, the average time to reinforcement after the onset of the terminal-links was shorter for pecking than for treadling. The mean decrease in time to reinforcement for S1, S2, and S3 was approximately 3 s, 15 s, and 3 s, respectively. For treadling birds, the mean decrease in time to reinforcement was approximately 4 s, 2 s, and 3 s for S4, S5, and S6, respectively.

These data show clearly that the values scheduled by the experimenter are not necessarily the values contacted by the subjects. Furthermore, gross motor responses such as treadling require a greater amount of time to emit than more discrete responses such as key pecking. Consequently, the rates of reinforcement for the two topographies may differ considerably. Rate of, or delay to, reinforcement has been shown to be an important, if not the most important, factor in determining performance under concurrent schedules (e.g., de Villiers, 1977). It may therefore be the case that different frequencies of reinforcement, and not response topography, are critical in determining performance under concurrent-chains employing different terminal-link response topographies. Previous authors (Lattal & Crawford-Godbey, 1985; Starin, 1987, 1988) all address the potential for control by different reinforcement rates, however, all minimize its importance. This may be an error. Inspection of their data reveals that for every subject in every condition, terminal-link time to reinforcement was shorter for pecking than for treadling. Whether or not differences in reinforcement frequency are the critical variable affecting choice for pecking over treadling is an empirical issue that should be addressed. One way in which this might be done is by using a procedure in which the delay to reinforcement for terminal-link pecking would be yoked to the delay to reinforcement for terminal-

link treadling. This would eliminate any differences in terminal-link reinforcement rates and allow for more unambiguous conclusions regarding the role of topography. As it now stands, birds appear to prefer pecking over treadling, however whether that preference is due to the topography itself or to the different times to reinforcement is an open question and one that is in need of resolution.

One other aspect of the present data (absolute response rates) is consistent with previous studies. All subjects showed generally decreasing response rates as the mean VI for that terminal-link alternative increased. Said another way, as the frequency of terminal-link reinforcement decreased, the frequency of initial-link responding to that alternative also decreased. These findings substantiate a wide body of literature (e.g., Autor, 1960, 1969; Gollub, 1977; Kelleher & Gollub, 1962; Shull & Spear, 1987). Indeed, terminal-link schedules or delays play an integral role in Fantino's (e.g., 1969b, 1977, 1981) delay-reduction hypothesis as well as all other quantitative models of performance under concurrent-chains procedures (e.g., Davison & Temple, 1973; Killeen, 1982).

Three quantitative trends in the present data merit comment: The slopes of the regression lines, indicating sensitivity to the experimental contingencies; the intercept of the regression lines, indicating bias towards one alternative or the other; and, the coefficient of determination, indicating the "goodness of fit" of the delay-reduction hypothesis in predicting performance. When, after undergoing inverse sine transformations, obtained relative response rates were plotted against predicted relative response rates, the slope of the regression function varied between .53 and 1.12 (.85 for the group) for initial-link pecking birds and between .41 and .54 (.47 for the group) for initial-link treadling birds. Baum (1979), in a review of generalized matching under simple concurrent VI schedules, defined "good" matching as any slope falling between .90 and 1.11. According to this criterion, the response slopes

of only two of the present birds came close to showing good matching; the remainder displayed severe undermatching. Wearden and Burgess (1982) reviewed 13 studies since Baum (1979), again those employing simple concurrent VI schedules, and reported that the mean response slopes from all laboratories other than Davison's was .87; the mean response slopes from Davison's laboratory was somewhat lower at .84. Both of the aforementioned reviews excluded data from studies employing concurrent-chains procedures, hence comparisons of the present findings to these may not be profitable. For our purposes it would be more instructive to know the slopes of regression functions typically obtained under concurrent chains; unfortunately, these data are often not provided. Most likely this is due to the fact that there is no commonly accepted quantitative model with which the results may be analyzed. In fact, at least four different models have been used (Davison & Temple, 1973; Fantino, 1969b, 1977, 1981; Killeen, 1982; Vaughan, 1985). Recently, however, Fantino and Davison (1983) conducted an extensive investigation into the fit of the delay-reduction hypothesis to concurrent homogeneous chains. Response slopes in their study varied between .72 and .92 for individual subjects and averaged .80 for the group. More recently, Davison (1987) analyzed raw data from 10 studies employing concurrent-chains with terminal links consisting of fixed or variable intervals or delays to reinforcement. Three of these studies employed VIs in both the initial and terminal links. In these, the group response slopes ranged from .65 (Squires & Fantino, 1971) to .90 (Fantino, 1969b).

In the present study the response slopes obtained with initial-link pecking birds are generally consistent with those found when pecking is exclusively required. When treadling was the required initial link topography, however, flatter response slopes were obtained. The reasons for the differences between response slopes is unknown, however, Davison and Ferguson (1978) speculate that treadling may be less sensitive

to reinforcement rate than key pecking. Given that the only difference between the initial-link pecking group and the initial-link treadling group was the topography required and that considerable differences in response slopes resulted, the present findings appear to substantiate the conclusions of Davison and Ferguson (1978). The factors responsible for the relative insensitivity of treadling to reinforcement frequency remain to be determined, however.

A second aspect of the quantitative data of concern is with the intercept of the regression function. In the present case, all intercepts were positive. Because pecking was used at the numerator, this indicates a systematic bias towards terminal-link pecking. The intercept values for pecking birds ranged between .19 and .43 (.30 for the group); for treadling birds the intercept was between .30 and .43 (.37 for the group). No previous studies employing concurrent chains with different terminal-link responses have been conducted but two studies have employed pecking and treadling in the opposing components of simple concurrent VI schedules (Davison & Ferguson, 1978; Wheatley & Engberg, 1978). Both studies found a systematic bias towards pecking over treadling when response measures were used; when time allocation was used smaller biases were obtained. Use of response measures when requiring responses of different topographies has one major drawback, the topographies themselves engender different response rates. Thus, the bias towards pecking found in procedures using simple concurrent schedules is likely an artifact of the fact that key pecking can be emitted much faster than treadle pressing. In the present procedure this problem was obviated by requiring the same response topographies in the initial links. Any obtained differences in the bias parameter cannot be due to the different rates inherent in the topographies but rather due to a true preference for one topography over the other. The current results suggest that a strong preference for pecking over treadling exists even when the initial links are

equated with respect to topography.

Several variables that may be responsible for bias have been suggested (Baum, 1974). The two most relevant to the present study are differences response requirements and differences between scheduled and obtained reinforcement frequencies. Clearly, very dissimilar responses were required in the terminal links of the present study. A major difference between them is the amount of force required by each manipulandum. The key required a nominal value of .2N whereas the treadle required approximately 1N. This is a large difference and, quite likely, had a considerable effect on choice. Although the effects on choice of different force requirement have yet to be empirically demonstrated in concurrent-chains schedules, Chung (1965) and Hunter and Davison (1982) reported that response force does affect choice behavior under simple concurrent schedules. Many of the variables found to affect choice under simple concurrent schedules have also been shown to affect choice under concurrent-chains schedules. Therefore, it is reasonable to assume that the differing response forces required in the terminal links of the present study had an effect on choice, producing a bias towards the alternative requiring the least effort.

Another factor implicated in producing bias is the difference between programmed and scheduled reinforcement rates. In the present study, there were discrepancies between these two rates with terminal-link pecking chains being associated with a shorter delay to reinforcement than terminal-link treadling chains (see Table 5). It is therefore plausible that the obtained bias towards pecking is due, to some extent, to the higher rate of reinforcement associated with this terminal-link topography. This possibility can be tested by considering a quantitative model employing obtained rather than scheduled delays to reinforcement and will be performed below.

The final aspect of the quantitative data of interest is the percent of variability in the obtained data accounted for by the delay-reduction hypothesis. For pecking birds this amount was between 59% and 83% and was 72% for the group. For treading birds, the variability accounted for ranged from 46% to 92% and was 58% for the group. Davison (1987) used the delay-reduction hypothesis to analyze data from several concurrent-homogeneous chains studies. When responding in both the initial and terminal links was reinforced under VI schedules, the (mean) variance accounted for ranged between 56% and 95%. Fantino and Davison (1983) report that 88% of the variance in their study was accounted for by the delay-reduction hypothesis. The present study obtained accounted for variances that were somewhat smaller than other studies employing concurrent chains. This finding should not be surprising given that the delay-reduction hypothesis predicts performance solely on the basis of delays to reinforcement. The addition of differing response topographies adds another source of variability not taken into account by this model. If the effort associated with the two topographies is a major factor affecting choice, along with delay to reinforcement, its inclusion in a quantitative model should predict performance better than one based exclusively on time to reinforcement. Unfortunately, the development of such a model in the present case is impossible. The treadle required considerably different forces to operate depending upon where on the treadle the subject stepped. Casual observation showed that differences in where subjects stepped occurred frequently. Furthermore, the two treadles in the chamber were not calibrated such that they required exactly the same amounts of force but rather microswitches were chosen such that they required approximately the same amount (1N) of force. Although it is reasonable to assume that response force affects choice in concurrent-chains schedules, without adequate quantification and calibration, any attempt at modifying the delay-reduction hypothesis to incorporate response force would be

premature.

When concurrent chains requiring different terminal-link topographies are arranged, the delay-reduction hypothesis provides only a moderately accurate description of the data. Although the exact reasons for this are unknown, there are two major variables that may be seen as causing trouble for the delay-reduction hypothesis, differences between scheduled and obtained reinforcement rates and differing amounts of force associated with pecking and treading. It was noted above that concurrent-chain performance may be more sensitive to obtained reinforcement rates than to scheduled reinforcement rates. Moreover, the obtained bias may also be due to these differences. If so, replacing in equation 10 the scheduled values with the obtained values should produce a better description of the data. It should be noted at the outset that I am not proposing that the delay-reduction hypothesis be modified to include obtained initial- and terminal-link durations. Indeed, one of its greatest strengths is its *a priori* predictive capabilities. Instead, I suggest merely that one way we can ascertain whether or not the present results were due to differences between scheduled and obtained reinforcement rates is by looking to see if using obtained values offers any benefit over scheduled values. After replacing the scheduled values in equation 10 with the obtained values, both sides of the equation underwent inverse sine transformations. A linear regression analysis was then carried out as before. The new regression equations for initial-link pecking birds follow, with the previous equations shown in parentheses: $Y = .16 + 1.02x$ ($Y = .19 + 1.12x$) for S1, $Y = .27 + .84x$ ($Y = .34 + .90x$) for S2, $Y = .44 + .47x$ ($Y = .43 + .53x$) for S3, and $Y = .28 + .79x$ ($Y = .30 + .85x$) for the group. For treading birds, the regression equations are: $Y = .33 + .46x$ ($Y = .38 + .41x$) for S4, $Y = .28 + .58x$ ($Y = .30 + .54x$) for S5, $Y = .26 + .62x$ ($Y = .43 + .48x$) for S6, and $Y = .29 + .55x$ ($Y = .37 + .47x$) for the group. With only one exception, the magnitude of bias is smaller

using the obtained delays to reinforcement rather than the programmed delays, although the differences in bias between the two are generally quite small. This indicates that the shorter time to reinforcement associated with terminal-link pecking contributes to the obtained biases but only to a moderate degree. It is likely that differential efforts associated with the two topographies is another contributor to bias. For four of six subjects, the response slopes were closer to matching using the obtained delays to reinforcement. This latter finding shows that initial-link performance is often, but not always, more sensitive to the obtained values than to the programmed values. That two birds did not show increased sensitivity when using the obtained times to reinforcement is somewhat surprising in light of previous research, using simple concurrent VIs, showing that subjects are most sensitive to the reinforcement frequencies actually contacted by the subject. This is especially surprising for S2 for whom less sensitivity was found when using obtained time-to-reinforcement and was also the subject with the greatest deviations between scheduled and obtained terminal-link VIs. No explanation for this can be offered.

Although it was generally found that using obtained rather than scheduled times-to-reinforcement produced closer approximations to matching and less bias, these findings do not, however, provide trouble for the delay-reduction hypothesis in analyzing previous studies. In studies in which the terminal-link response topographies are similar, it can be expected that there would only be minimal deviations between scheduled and obtained values. Furthermore, any such discrepancies should be approximately equal for the two terminal-links.

The percent of variability accounted for by the revised and, in parentheses, the original delay-reduction hypothesis were 76% (81%), 67% (83%), 48% (59%), and 64% (72%) for S1, S2, S3, and the pecking group as a whole, respectively. For treadling birds these values were 64% (50%), 86% (92%), 81% (46%), and 76%

(58%) for S4, S5, S6, and the group. Overall, the use of obtained versus scheduled reinforcement delays had little impact on the amount of variability accounted for. In all cases, there remains a substantial amount of the variability unaccounted for by time-to-reinforcement. It is quite likely that the different efforts associated with the two different response topographies is involved and is an area in need of exploration.

It now appears that the delay-reduction hypothesis is in need of modification if it is to accurately describe performance under chains in which different terminal-link forces are required, especially when responses other than key pecks are required in the initial links. Because, as noted in Chapter I, human responding is largely characterized by concurrent heterogeneous chains and because the ultimate goals of basic research are the prediction and control of human behavior, quantitative analyses of such schedule performance has both theoretical and practical implications.

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