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THE UNIVERSITY OF ALBERTA

DETERMINANTS OF HUMAN PREFERENCE IN A COMPLEX-CHOICE SITUATION

BY

TERRY WILLIAM BELKE

A THESIS
SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH
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MASTER OF ARTS

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Terry W Belke
(Student's signature)

13556 - 126 St., Edmonton, Alta.
(Student's permanent address)

Date: Nov 27, 1987

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled DETERMINANTS OF HUMAN PREFERENCE IN A COMPLEX-CHOICE SITUATION submitted by TERRY WILLIAM BELKE in partial fulfilment of the requirements for the degree of MASTER OF ARTS.

W. David Pierce

Supervisor

W. C. Hare

Date November 4, 1987

DEDICATION

I wish to dedicate this thesis to my parents, Gerry W. Belke and Irene Belke, for valuing education so highly and encouraging me to do my best. I hope to do the same for my children some day.

ABSTRACT

Four human subjects were exposed to concurrent-chain schedules of reinforcement designed to investigate the descriptive adequacy of four behavioral equations of choice: delay reduction, modified delay reduction, reinforcement density, and overall rate of reinforcement. Results suggested that relative overall rate of reinforcement described the distribution of human behavior in this situation. Deviations of observed from predicted proportions were least for the relative rate equation. Supplementary analysis of local rate of response revealed that subjects emitted higher rates for the initial-link stimulus correlated with the least time to reinforcement in the terminal link. This result suggested that response rate was sensitive to conditioned reinforcement by events signalling transition from initial to terminal links. Surprisingly, these stimuli did not appear to control the distribution of behavior as suggested by the delay reduction and reinforcement density analyses. Finally, response rates were lower in the terminal components of the chains. Videotape analysis revealed that the stimulus that signalled entry to the terminal links functioned to set the occasion for behavior that removed the subject from the response key (lookin away or walking away) and timed out the schedule (e.g., pacing).

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Introduction

Choice is an important aspect of human behavior and fundamental to the explanation of social phenomena. Behavioral studies of choice in simple-choice situations point to relative rate of reinforcement as the principle determinant of choice (Pierce and Epling, 1983). Beyond simple-choice situations, determinants of choice are not well understood. Moving from simple to more complex situations introduces potential new determinants of choice. Current research with animals suggests that conditioned reinforcement and relative rate of reinforcement play a role in determining choice in complex situations (Squires and Fantino, 1971). Comparable research with humans remains to be conducted. The present study explores the performance of humans in complex-choice situations and focuses on the importance of conditioned reinforcement and relative rate of reinforcement as determinants of human choice and preference.

Homans (1969, 1974) stressed the importance of behavior principles for the study of social behavior. According to Homans (1969, p. 4) " the principles of behavioral psychology are the general propositions we use, whether implicitly or explicitly, in explaining all social phenomena." Recent research demonstrates that the basic principles of behavior can be extended to the analysis of social behavior (Bavelas, Hastorf, Gross, and Kite, 1965; Emerson, 1964; Gray, Griffith, von Broembsen, and Sullivan, 1982; Gray, Richardson, and Mayhew, 1968; Gray and Tallman, 1984, 1987; Gray and von Broembsen, 1976; Gray, von Broembsen, Kowalczyk, and Williams, 1976; Hamblin, 1977, 1979; Hamblin and Miller, 1977; Molm, 1985; Molm and Wiggins, 1979; Stafford, Gray, Menke, and Ward, 1986; Sunahara and Pierce, 1982). Based on this evidence, behavioral sociologists attempt to bridge the gap between individual and group behavior processes.

A major focus of this research effort involves the investigation of human behavior in choice situations and the extension of operant principles of choice to humans (Gray and Tallman, 1984, 1987; Gray et al., 1982; Hamblin, 1977, 1979; Stafford et al., 1986; Sunahara and Pierce, 1982). Common examples with social importance involve voting for a candidate or party in an election, choosing a career, selecting a spouse and so on.

Simple-Choice Situations

The behavioral study of choice emphasizes the relative rate of reward (or reinforcement) provided by alternatives. Operant psychologists suggest that the analysis of choice and preference pertains to relations between stimuli and consequences of behavior that lead people to choose one alternative more than another. From this perspective, the most important variables relate to the contingencies of reinforcement operating on the alternatives.

Choice and preference can be studied by arranging a situation that presents an individual with at least two alternatives sources of reinforcement. In a simple-choice situation, reinforcement is delivered when the behavioral requirement for an alternative is met. Behavioral requirements are of two types: response dependent and time dependent. When the requirement is response dependent, reinforcement is contingent on completion of a specified performance. When the requirement is time based, a specified time interval must elapse before a response will produce reinforcement. The behavioral requirements (either time or response dependent) arranged for the alternatives are varied and the distribution of responses between alternatives is the primary dependent measure. Analysis involves investigation of the relations between contingencies of reinforcement and the distribution of responses (i.e., preference).

Two principles appear to account for how humans distribute behavior between alternatives in simple-choice situations. One principle is the matching law (Herrnstein, 1961, 1970). The matching law states that relative rate of response (or time) equals relative rate of reinforcement. For example, if one exchange partner provides reinforcement twice as often as another, ~~then~~ an individual will exchange with that partner twice as often (Conger and Killeen, 1974). Research generally confirms that in simple-choice situations where the behavioral requirements for the alternatives are time dependent, humans distribute behavior (or time) among alternatives in relation to the relative rate of reinforcement (Pierce and Epling, 1983).

The second principle of choice is termed "maximization". Maximization states that individuals distribute behavior between alternatives so as to maximize overall gain (or profit) (Rachlin, Green, Kagel, and Battlio, 1976). Profit is not equivalent to reward; instead, profit is reward minus cost. Maximization differs from matching in that maximization incorporates considerations of effort and reward forgone (response cost) (Homans 1974). Inclusion of cost makes maximization an economic theory of human behavior. The principle of maximization has been applied to the analysis of behavior in sociology (Homans, 1974), behavioral ecology (Pyke, Pulliam, and Charnov 1977; Schoener, 1969, 1971; Krebs and Davies, 1978), and psychology (Rachlin, 1980; Rachlin, Battlio, Kagel, and Green, 1981).

Evidence that humans maximize rather than match in simple-choice situations is less extensive (Hamblin, 1979). Mawhinney (1982) found that humans maximize overall reinforcement in a simple-choice situation designed to discriminate between maximization and matching. Siegal and

Goldstein (1959) found that subjects in a two choice, uncertain-outcome game used different strategies under different reward conditions to maximize expected utility.

Complex-Choice Situations

Beyond these simple situations, determinants of choice are not well understood. More complex situations introduce new variables that require investigation. One variable that has received attention is the relative effectiveness of conditioned reinforcement in behavior sequences or operant chains (Fantino, 1969; Herrnstein, 1964). The present study addresses the importance of conditioned reinforcement as a determinant of human choice.

In a behavior sequence, an individual performs a sequence of actions to produce a consequence. An example of a behavior sequence that is familiar to students is the educational requirements to achieve the status of "professor". Achieving this status requires the successful completion of a sequence of educational hurdles - namely the bachelors, the masters, and the doctorate degree. When the performance required to complete the bachelors degree is met, the individual convocates and graduates to the masters degree. When the requirements for completing the masters degree are met, the individual convocates and graduates to the doctorate degree. Completion of the doctorate degree terminates the process and leads to the achievement of the status of "professor". In operant terminology, the behavior sequence is called a chain and the separate components are links of the chain.

In complex-choice situations, each alternative is a chain or sequence of behavior that leads to reinforcement. In order to simplify analysis, behavior chains are conceptualized as two-component sequences with initial and terminal links. A signal or cue is presented to the individual to respond on either initial link. When both initial components are available, the person can complete the behavioral requirement on either alternative. Since the person can respond to either alternative, this is called the "choice phase", and the distribution of responses to the respective alternatives measures individual preference.

Completion of the response requirement for an alternative results in a simulus change that signals the opportunity to respond in the terminal link. During this terminal component, the individual responds to complete a requirement that is instrumental for reward. Following reinforcement, the choice phase is reinstated and the person can again satisfy the response requirements on either initial link.

The present experiment concerns the relative importance of conditioned reinforcement in complex-choice situations. One possibility is that the stimulus change from initial to terminal links may be a fundamental determinant of choice that is not present in simple-choice settings. During a component, performance is occasioned by a stimulus or cue that signals the component in effect and the appropiate performance required to complete that component. When the requirement for a component is met, the stimulus associated with that component ends and a stimulus associated with the next component occurs. Such a stimulus change serves two important functions in the behavior chain. One function is to signal or occasion the performance required to complete the terminal component. This function is called the discriminative function. The second function is to support or maintain the performance in the initial component. The onset of the discriminative stimulus is correlated with reinforcement in the terminal link and this correlation is sufficient to establish a conditioned reinforcement function. Together these two stimulus functions structure and maintain a behavior sequence.

Models of Choice for Complex-Choice Situations

Herrnstein (1964) and Fantino (1969) suggested that in complex-choice situations the relative strength of the conditioned reinforcers was the critical variable that determined choice. Each developed an equation that described the relationship between relative strength of conditioned reinforcers and choice on concurrent-chain schedules. Concurrent-chain schedules are two or more operant chains operating simultaneously. Each chain is a schedule of reinforcement composed of an initial and terminal link.

The models are based on different conceptions about the temporal relationship between a neutral stimulus and primary reinforcement that results in the neutral stimulus becoming a conditioned reinforcer. Herrnstein's (1964) equation was based on the reinforcement density hypothesis of conditioned reinforcement. According to this hypothesis, the strength of a stimulus as a conditioned reinforcer is a function of the rate of primary reinforcement in its presence. Applied to concurrent-chain schedules, this hypothesis implies that the strength of the conditioned reinforcers is a function of the rates of reinforcement in the terminal links. The reinforcement density equation for choice on concurrent-chain schedules appears as follows:

$$\frac{RL}{RL + RR} = \frac{1/t2L}{1/t2L + 1/t2R} \qquad (1)$$

In Equation 1, RL and RR represent reponse rates during the initial links of the left and right alternatives, respectively. The terms 1/t2L and 1/t2R represent the rates of reinforcement in the terminal links of the respective alternatives. Essentially, the equation states that the distribution of responses in the initial links matches the relative rates of reinforcement in the terminal links.

Insert Figure 1 about here

The behavior chains in Figure 1 illustrate the reinforcement density hypothesis. In Chain A, the duration of the initial link is 90 seconds. After 90 seconds has elapsed, a response produces an event. This event occasions responding in the terminal link (Sd) and reinforces responding in the initial link (Sr). The duration of the terminal link is 30 seconds. After 30 seconds has elapsed, a response produces terminal reinforcement (Sr+). In Chain B, the durations of the initial and terminal links are 30 and 90 seconds, respectively.

According to the reinforcement density hypothesis, the strength of an event as a conditioned reinforcer varies with the rate of terminal reinforcement in its presence. The higher the rate of reinforcement, the greater the strength of this stimulus as a conditioned reinforcer. In Chain A, the event that functions as a conditioned reinforcer is associated with a 30 second terminal link.

This terminal link provides reinforcement after 30 seconds. The same event in Chain B is associated with a terminal link that provides reinforcement after 90 seconds. Thus, the conditioned reinforcer in Chain A is associated with a rate of reinforcement three times as great as the rate of reinforcement associated with the same event in Chain B. Therefore, the strength of the conditioned reinforcer in Chain A is three times as great as the strength of the equivalent event in Chain B.

Extension of the reinforcement density hypothesis to complex-choice situations implies that the allocation of responses in the initial links is a function of the relative strength of the conditioned reinforcers and that the relative strength of the conditioned reinforcers reflects the relative rate of reinforcement in the terminal links. If the chains in Figure 1 were presented to an individual in a concurrent-chains procedure, the reinforcement density hypothesis predicts that the individual will distribute three times as many responses to the initial link of Chain A (75%) as to the initial link of Chain B (25%). Support for the reinforcement density equation (Equation 1) comes from animal studies of preference with concurrent-chain schedules (Autor, 1960; Herrnstein, 1964).

In contrast, Fantino's (1969) model was based on the delay reduction hypothesis of conditioned reinforcement.

This hypothesis states "that the strength of a stimulus as a conditioned reinforcer is a function of the reduction in the time to reinforcement correlated with the onset of that stimulus" (Fantino and Davison, 1983, p. 1). In other words, the strength of a stimulus as a conditioned reinforcer increases with the percentage reduction in the time to terminal reinforcement (Fantino, 1977).

The behavior chains of Figure 1 illustrate the delay reduction hypothesis. Time to terminal reinforcement from the onset of the initial link is 120 seconds for Chain A and Chain B. The average time to terminal reinforcement (T) between the two chains is 97.5 seconds. Calculation of the average time to reinforcement takes into account the concurrent operation of the initial links (see Appendix A). Due to the concurrent operation of the initial links, the average time to reinforcement is not equivalent to the sum of the times to terminal reinforcement in Chains A and B divided by two.

According to the delay reduction hypothesis, the strength of the event that functions as conditioned reinforcement varies in strength with the reduction in average time to terminal reinforcement (T). In Chain A, this event is correlated with a 92% reduction (90 / 97.5 seconds) while the same event in Chain B produces a 30% reduction (30 / 97.5 seconds). Therefore, the strength of the event in Chain A as a conditioned reinforcer is greater than the strength of the equivalent event in Chain B.

When the delay reduction hypothesis is extended to complex-choice situations, two implications follow: "(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). If the chains in Figure 1 were presented to an individual as alternative sources of reinforcement, the delay reduction hypothesis predicts that the individual will prefer Chain A more than Chain B (92% > 30%) and that the strength of this preference will be a function of the size of the difference in delay reduction (92% - 30% = 62%).

Fantino (1969) formulated an equation describing the relationship between relative delay reduction and preference on concurrent-chains schedules.

$$\frac{RL}{(RL + RR)} = \frac{(T-t2L)}{(T-t2L) + (T-t2R)} \qquad (2)$$

In Equation 2, RL and RR represent the rate of response during the initial components of the left and right alternatives, respectively. The value T is the average time to terminal reinforcement. Finally, the terms t2L and t2R represent the time to terminal reinforcement in the respective terminal components of the alternatives.

Equation 2 predicts preference for an alternative under conditions where the average time to reinforcement

(T) is greater than the duration of either terminal link. When T is greater than the duration of the terminal link of the left alternative (t2L) and less than the terminal link of the right (t2R), exclusive preference for the left alternative is expected. Conversely, when T is greater than the terminal link of the right alternative (t2R) and less than the terminal link of left alternative (t2L), exclusive preference for the right alternative is predicted.

In Figure 1, the delay reduction associated with the conditioned reinforcer in Chain A (T - t2L) is 67.5 seconds (97.5 - 30). With the onset of the terminal link stimulus in Chain A, 67.5 seconds of the 97.5 second average time to terminal reinforcement will have elapsed. The delay reduction correlated with the same event in Chain B (T - t2R) is 7.5 seconds (97.5 - 90). With the onset of the terminal link stimulus in Chain B, only 7.5 seconds of the 97.5 seconds will have elapsed. Substituting these values into the delay reduction equation produces a prediction that 90% (67.5 / 75) of responses will be allocated to the initial link of Chain A.

Fantino (1969) investigated the relationship between relative delay reduction and preference using a concurrent-chains procedure. Subjects were six pigeons that responded for food on two alternatives. Fantino manipulated the relative reduction in time to terminal reinforcement of the transitional events by adding equal, and progressively longer, delays to the initial-link schedules. As the time spent in the initial components increased, the average time to terminal reinforcement (T) increased. Based on the delay reduction hypothesis, it was expected that the relative conditioned reinforcement effectiveness of the preferred alternative would systematically decline with increasing time in the initial component and this decline would be shown as a response distribution approaching indifference (e.g., 0.50). This decline in preference for the preferred alternative was expected to take the form of the curvilinear function depicted in Figure 2 (from Fantino, 1969, p. 725).

Insert Figure 2 about here

Initially, the alternative with the higher rate of reinforcement (richer) is exclusively preferred. When the duration of the initial links exceeds 60 seconds, preference rapidly decays towards indifference. Although individual birds showed variability, the mean choice proportions were in accord with the curvilinear function.

Quantitative support for the delay-reduction model has been found in infrahuman studies (pigeons and rats). The equation is also compatible with choice behavior of infrahuman subjects in areas such as observing behavior

(Case and Fantino, 1981), self-control (Ito and Asaki, 1982; Navarick and Fantino, 1976), foraging behavior (Abarca and Fantino, 1982), percentage reinforcement (Spetch and Dunn, 1987), and three alternative choice situations (Fantino and Dunn, 1983). Research with humans in areas such as observing behavior (Fantino and Case, 1983; Fantino, Case and Altus, 1983) and self-control (Millar and Navarick, 1984; Solnick, Kannenberg, Eckerman, and Waller, 1980) also prov[illegible] support for delay reduction.

Squires and Fantino (1971) investigated the adequacy of the delay reduction hypothesis as a description of choice behavior with concurrent-chain schedules that were composed of various combinations of initial and terminal-link values. When terminal links were equal and initial links were unequal, pigeons preferred the alternative with the shorter overall time to reinforcement rather than the alternative with the greater delay reduction. Based on this evidence, Squires and Fantino (1971) concluded that preference between alternatives in a complex-choice procedure is a function of both relative delay reduction and relative overall rate of reinforcement. Consequently, Equation 2 was revised to reflect the influence of overall rate of reinforcement as depicted by Equation 3.

$$\frac{RL}{RL + RR} = \frac{rL(T-t2L)}{rL(T-t2L) + rR(T-t2R)} \qquad (3)$$

In Equation 3, the interpretation of the values RL, RR, T, t2L, and t2R remains the same as in Equation 2. The new coefficients rL and rR represent the overall rate of reinforcement for left and right alternatives respectively.

The overall rate of reinforcement for the left alternative is calculated as follows: rL = 1/(t1L + t2L). The terms t1L and t2L represent the average durations of the initial and terminal components of the left chain respectively. The equivalent equation for the overall reinforcement rate of the right alternative is rR = 1/(t1R + t2R). In Figure 1, the overall rate of reinforcement for both Chain A and B is 1/120 seconds.

This revision extended the generality of the delay reduction model from complex-choice situations to both complex and simple-choice situations. When the terminal links of the concurrent-chains are reduced to zero seconds duration or delay reduction is not a functional variable in the situation, Squires and Fantino's equation reduces to Herrnstein's (1961) matching equation. The matching equation is as follows:

$$\frac{RL}{RL + RR} = \frac{rL}{rL + rR} \qquad (4)$$

In Equation 4, RL and RR represent the rates of behavior distributed to left and right alternatives respectively. The terms rL and rR are defined in Equation 3 and represent the overall rates of reinforcement provided by the respective alternatives.

This link between the matching equation and Squires and Fantino's delay reduction equation implies that the effect of overall reinforcement rate in complex-choice situations is related to matching in simple-choice situations. This further suggests that some form of matching equation could describe the distribution of behavior on concurrent-chain schedules. Herrnstein's reinforcement density equation represents one extension of matching through conditioned reinforcement. An alternative extension can be made through overall reinforcement rate. Fantino and Herrnstein (1968) suggested that rate of reinforcement integrated over total experimental time rather than just the terminal links could account for preference in the initial links. This relationship between overall rate of reinforcement and the distribution of responses in the initial links would be expressed as Equation 4.

This relative rate equation predicts preference when the rate of reinforcement on one alternative does not always exceed the rate of reinforcement on the other. When the rate of reinforcement on one alternative <u>always</u> exceeds the rate on the other, exclusive preference for the alternative with the highest rate of reinforcement is predicted. This situation occurs for concurrent-chains schedules when the total time to reinforcement on one alternative (sum of initial and terminal-link values) is less than the terminal-link duration of the other alternative. Expressed as an equation, exclusive preference occurs when $(t1i + t1t) < t2t$ (Houston, Sumida, and McNamara, 1987). In this equation, the values $t1i$ and $t1t$ refer to the durations of the initial and terminal links of the first alternative. The duration of the terminal link of the second alternative is denoted as $t2t$.

For example, if the initial link in Chain A of Figure 1 was 30 seconds rather than 90 seconds, then the time to terminal reinforcement (sum of the initial-link and terminal-link values) for Chain A would be 60 seconds rather than 120 seconds. Exclusive preference for Chain A would be predicted by the overall rate of reinforcement equation, since the time to terminal reinforcement in Chain A $(t1i + t1t)$ is less than the duration of the terminal link $(t2t = 90$ seconds) in Chain B.

The business executive who regularly flies between Edmonton and Toronto provides an everyday example of concurrent-chains schedules and models of choice. The executive can fly with either Air Canada or Canadian Airlines. Relevant conditions at the time of booking flights could account for the executive's choice between these alternatives. Suppose the task of booking a flight on either airline involved a two component sequence. The first component is calling the airline. If all lines are busy, an answering service cuts in to inform the client that all lines are currently busy and requests the customer to call back. The caller can either dial the same number again or dial the number of an alternative airline. If a line is open, the caller is placed on hold until a booking agent becomes available. The second component then is waiting on hold for a booking agent to become available.

Since the answering service message at Air Canada is longer, time spent dialing to get placed on hold differs between the airlines. Assuming an equal rate of calls to both airlines, this difference in the recorded messages could mean that it takes approximately 10 minutes of repeated dialling to get placed on hold at Air Canada, but only 5 minutes on average at Canadian Airlines. However, Air Canada employs twice as many booking agents as Canadian. Therefore, the average time on hold (the second component) differs between the two airlines. The average time on hold is 5 minutes at Air Canada and 10 minutes on average at Canadian. Though the total time to book a flight by either airline is 15 minutes, the time spent dialing and waiting on hold differ for the two alternatives. The average time to book a flight between the two alternatives is 11.65 minutes.

The four models of choice make differing predictions for the executive's behavior. Both the reinforcement density and delay reduction models stress the relative strength of the conditioned reinforcers in the behavior chains as determinants of preference. Although both models predict preference for booking flights on Air Canada, they differ with respect to the degree of preference expected. This difference in prediction reflects the underlying difference in analysis of conditioned reinforcement.

The reinforcement density equation predicts that the caller should spend more time dialing to get through to Air Canada than to Canadian Airlines. The caller spents half as much time on hold at Air Canada as at Canadian. Thus, the rate of terminal-link reinforcement is twice as great for Air Canada. Based on this difference in relative hold time (5 minutes versus 10 minutes), the reinforcement density equation (Equation 1) predicts that the caller should spend twice (66%) as much time dialing to get through to Air Canada.

The delay reduction hypothesis also predicts that the caller should spent more time dialing to get through to Air Canada than to Canadian. When the caller gets placed on hold at Air Canada, 6.65 minutes (11.65 - 5) out of the 11.65 minutes on average to book a flight (57%) will have elapsed. On the other hand, when the caller gets placed on hold at Canadian, only 1.65 minutes (11.65 - 10) out of the 11.65 required to book a flight (14%) will have elapsed. Repeated experience with this difference in the percentage reduction in time to reinforcement between alternatives (57% - 14% = 43%) leads to a preference for booking flights with Air Canada. Specifically, the delay reduction equation (Equation 2) predicts that the caller should spend 80% (6.65 / 8.3) of his/her time dialing to through to Air Canada.

The modified delay reduction equation holds that preference is a function of both relative strength of conditioned reinforcers and relative overall rate of reinforcement. In the airline example, this model predicts preference based on relative strength of conditioned reinforcement only, since the alternatives do not differ in overall rate of reinforcement. Therefore, Equation 3 also predicts that the caller should spend 80% of his/her time dialing to get through to Air Canada.

Finally, the overall rate of reinforcement model differs from the other models in that conditioned reinforcement plays no role in determining preference. Preference is determined by relative rate of reinforcement. In the airline example, the alternatives do not differ in rate of reinforcement. The time required to book a flight by either airline is 15 minutes. Consequently, the relative rate equation predicts no preference for either alternative (50%).

Experimental Analysis of Concurrent-Chain Schedules

A primary concern of this study is the descriptive adequacy of alternative models of choice. However, it is also important to provide an experimental analysis of human performance on concurrent-chain schedules of reinforcement. Experimental analysis can reveal determinants of behavior that are not captured by theories of choice. This is especially necessary in new areas of research or when laboratory procedures are extended to humans.

Although models of choice emphasize relative measures of behavior (i.e., proportions), Skinner (1938) has suggested that rate of response may be a sensitive measure for operant research. The analysis of local rate of response can also reveal the effects of conditioned reinforcement on concurrent-chain schedules. For example, if the conditioned-reinforcement effectiveness of two events differ, then response strength will also differ for the respective consequences. More precisely, rate of response will be higher for the more effective conditioned reinforcer. Now, it is well known that the closer a stimulus is to primary reinforcement, the greater the conditioned reinforcement effectiveness of this stimulus. When one behavior chain provides a stimulus correlated with an average of 30-sec to reinforcement and another with [illegible]-sec, the response rate will be higher for the stimulus correlated with more immediate reinforcement. A conditioned reinforcement analysis of both local response rates is therefore of interest as a description of human performance on concurrent-chain schedules of reinforcement.

A second question for an experimental analysis concerns stimulus control of behavior. A typical finding of nonhuman research is that the rate of response during the initial links is less than the rate of response for the terminal links (Fantino and Davison, 1983). Generally, this result is interpreted as a result of temporal distance from reinforcement. The terminal-link stimulus which occasions responding is closer in time to reinforcement than the equivalent stimulus in the initial component. This difference in temporal proximity to terminal reinforcement controls differential response rates in the initial and terminal links. Mean response rates were therefore examined for the initial and terminal links on both alternatives.

Casual observation of human performance in the present experiment indicated that the onset of the terminal-link stimuli set the occasion for behavior <u>other</u> than responding on the key. In addition, subjects appeared to show a greater tendency to engage in other behavior in the terminal links than in the initial links. These observations suggested that direct analysis of rate might reveal stimulus differences between initial and terminal components. Additionally, videotaped episodes of subject's performance were coded to identify on-task and off-task behavior. Also, the time between the onset of the opportunity to respond and the first response was examined to describe the tendency to respond in the presence of a discriminative stimulus.

Finally, subjects' responses to a post experimental questionnaire were analyzed. The questions assessed discriminations of the contingencies in effect and the relevant variable influencing how subjects chose between the alternatives. This analysis takes advantage of the human subjects' ability to report on their experiences which is not usually available in research with other species (but for an exception, see Lubinski and Thompson, 1987). However, from an operant perspective, the contingencies controlling verbal descriptions of one's behavior are not necessarily the same as the contingencies controlling actual choice behavior. For this reason, verbal report is considered less reliable than direct measures of behavior for analysis.

Summary

The present study examined the four models of preference with a concurrent-chains procedure. Concurrent-chain schedules of reinforcement were arranged according to schedules programmed by Fantino (1969). Subjects worked at alternative response keys to produce tokens that were exchanged for money. Response proportions in the initial links were examined to assess the descriptive adequacy of four models of choice. Response rates in initial and terminal links were measured to assess the conditioned reinforcement and discriminative stimulus functions of the stimuli signaling transition from initial to terminal links.

Method

Subjects

Four male university students were solicited by advertisements in the campus newspaper to serve as paid subjects in a study of preference. All applicants were contacted and brought to the laboratory for an in-person interview or given an interview over the phone. A copy of the interview is given in Appendix B. Subjects were selected on the basis of two criteria: lack of prior participation in experimental research and expressed need for money. Each subject signed an employment contract stating that remuneration was 25 cents per token earned during the experiment and stipulating a $25 bonus for completion of all scheduled sessions.

Apparatus

The study was conducted in an experimental room at the Center for Experimental Sociology. Dimensions of the room were 3 m. wide, 4.5 m. long, and 2.5m. high. Other than the apparatus and a table, the room was empty. Entry to the experimental room was through a sound attenuating door with a 30 cm. by 30 cm. observation window (i.e., a "one-way" window). On the wall opposite the apparatus was a 0.9 m. by 2.9 m. observation window. The subject's performance was recorded through this window by a video camera located in the adjacent control room. The walls of the experimental room were insulated to attenuate external sounds. Classical music was played over three speakers located in the room. A pitcher of drinking water and a glass were placed on the table. The table was located opposite the apparatus in the right corner of the room.

The experimental apparatus, depicted in Figure 3, was a free standing structure of the following dimensions: 2.5 m. long, 1.2 m. high, and 30 cm. wide. A single response key was affixed at each end of the structure. The height of the response keys was adjustable and was set for the height of each subject. In the center of the structure was a token dispenser. The token dispenser was an 80 cm. high, 20 cm. wide, and 20 cm. deep wooden box with a standard coin dispenser from a vending machine, a modified pigeon hopper, and a relay inside. A metal plate was attached to the pigeon hopper to form a platform onto which the coin dispenser dropped tokens. Tokens were retrieved through a 7 cm. square hole in the face of the wooden box. Operation of the token dispenser and the hopper was handled through the relay. Tokens were "nickel" sized aluminum slugs with "25" stamped on one face.

Response keys were illuminable, translucent microswitches that required a force of 20 gms. to operate. Each response key could be illuminated by a white, red or green light. Stimulus lights were mounted behind each response key. The response key and stimulus light assembly was attached to the back of a 15 cm. by 15 cm. metal plate. A 2.5 cm. diameter hole in the center of the metal plate provided access to the response key. The metal plate was attached to a 15 cm. wide by 15 cm. high by 20 cm. deep housing that was mounted on a 1.2 m. long steel pole. In addition to the response key, a Sonalert Audible Signal (28 V DC) was installed in each housing.

Insert Figure 3 about here

An Apple IIe computer in the adjacent room controlled the operation of the console and recorded the subject's responses. Interface with the console was handled through Colbourne Instruments programming equipment. A concurrent-chains computer program developed by Dr. C. Donald Heth at the University of Alberta, Canada was used to run the experiment. In addition to the computer record, one minute response summaries were recorded using Coulbourn equipment and pauses to first response in initial and terminal links were recorded on a DIG 900 Compatible Printer.

Procedure

Preliminary training

In the first session, subjects were trained to retrieve tokens and exchange them for money. Each subject was asked to remove his watch and escorted to the experimental room by the researcher. Once inside the room, the subject was read the following:

> There are no instructions. Do whatever you want within the confines of the barriers. Feel free to take a drink of water whenever you want. We will begin in a moment.

Then the researcher went into the adjacent control room and pressed a button to release a token from the token dispenser. If the subject retrieved the token, the researcher entered the room and asked the subject if he had a token to exchange. The reasearcher gave the subject 25 cents in exchange for the token. If the subject did not retrieve the token, the researcher waited 10 seconds and then released another token. This procedure continued until 5 consecutive tokens were collected and exchanged.

In the next phase, four tokens in a row were released and exchanged for $1. Following this phase, 20 tokens were released and exchanged for $5. Finally, 40 tokens were released and exchanged for $10. Session one terminated with the completion of this phase.

In session two, the researcher began training subjects to press the response keys to earn tokens. Subjects were escorted to the experimental room and given the same instructions. Both response keys were illuminated with white light and programmed so that one response on either key produced a token. Subjects remained in the room for thirty minutes. If a subject pressed the keys and earned tokens, then that subject advanced to the first experimental condition. If a subject failed to press either key, the subject was removed and a shaping procedure was implemented. Performance was shaped by method of successive approximation over the next few sessions. Subjects 1 and 2 advanced to the experimental conditions. Subjects 3 and 4 failed to press the keys and a shaping procedure was implemented. Two sessions were required to shape key pressing in both subjects. Subjects 3 and 4 advanced to the first experiment condition as soon as they were reliably responding on the response keys to produce tokens.

Concurrent-chain schedules

A standard concurrent-chains choice procedure (Autor, 1960, 1969) was used. Each alternative consisted of a two component sequence of responses that involved completion of the time and response requirements for initial and the terminal links. In a concurrent-chains procedure, the initial links are concurrent. Concurrent means occurring at the same time. Since both initial links are available at the same time, and subjects can respond to either alternative, this part of the procedure is known as the choice phase. The response distribution during the initial components provides a measure of preference.

Insert Figure 4 about here

The concurrent-chains procedure, shown in Figure 4, began with both response alternatives illuminated by white stimulus lights. Subjects pressed either left or right keys that were spatially separated by a distance of 2 meters. This separation insured that subjects could not simultaneously respond to both alternatives and insured discrimination of the concurrent-chain schedules. A series of different schedules were programmed for the initial links and these schedules arranged access to the terminal links on a variable interval basis. Variable interval schedules are "schedule[s] of intermittent reinforcement in which reinforcements are programmed according to a random series of intervals having a given mean and lying between arbitrary extreme values" (Ferster and Skinner, 1957, p. 734). Reinforcement occurred with the first response following the elapse of the time interval.

During the intial link of each alternative, when the time interval elapsed, the next response on that key produced the following changes: 1) the alternate key became dark and inoperative (i.e., the white light went out), and 2) a change of colour (i.e., white to either green or red) occurred on the operative key signaling the opportunity to respond on the terminal-link schedule.

Variable interval schedules were also programmed for the terminal links of each alternative. When the time interval elapsed, the next key press produced two changes: 1) the coloured light (red or green) associated with the key went out and 2) a token dropped onto the plate attached to a modified pigeon hopper. The token remained available for 5 seconds and following this period the hopper retracted. If subjects did not pick up the token during this reinforcement period, the token fell into a collection box and was lost to the subject. Subsequent to this reinforcement period, the white lights of the initial links came on, both keys became operative and subjects could choose again between the left and right alternatives.

Experimental Conditions

Condition 1 exposed subjects to unequal initial and terminal-link schedules. A chain VI 30-sec VI 90-sec was programmed for one alternative and a chain VI 90-sec VI 30-sec was programmed for the other. Following this, subjects were exposed to two conditions in which equal VI schedules were programmed for the initial links. Condition 2 was a VI 40-sec VI 90-sec chain on one alternative and a VI 40-sec VI 30-sec chain on the other alternative. Finally, Condition 3 set the initial link schedules at 120 sec. Thus, the contingencies were VI 120-sec VI 90-sec chain for one side and VI 120-sec VI 30-sec chain for the other.

Fantino (1969) programmed variable interval schedules of 40, 120 and 600 seconds for the initial links. With the payoff per token fixed at 25 cents and a session defined as 40 reinforcers, the VI 600 seconds schedules would violate minimum wage laws and likely produce attrition. For these reasons, humans were only exposed to VI 40-sec and VI 120-sec initial-link schedules.

Notice that unequal variable interval schedules were programmed for the terminal links. One terminal link was 30 seconds average duration (VI 30-sec) and the other terminal link was 90 seconds average duration (VI_90-sec). Thus, the terminal-link schedules remained the same across all conditions.

Initial-link and terminal-link schedules were programmed with the interval values reported in Fantino (1969) (see Appendix C). The interval values are exponentially distributed according to a poisson distribution. Consequently, reinforcement was randomly distributed, so that delivery of a token could not be predicted from prior inter-reinforcement intervals.

A sequence of intervals was programmed to create both the initial and terminal-link schedules. Because the session ended when 40 tokens were obtained, subjects did not necessarily receive all the interval values of the operative schedules. In order to correct for this problem, half the sessions began at the first interval value in the sequence and half began with the last programmed interval. Thus, over two sessions, subjects experienced the entire range of interval values. Also, the sequence of intervals for one initial link began with the first programmed interval while the other initial-link schedule began in the middle of the sequence. Again, the starting interval (first or middle) was counterbalanced over sessions within subjects.

Subjects always received Condition 1 before exposure to either Condition 2 or Condition 3. The order of presentation of the equal intial-link conditions was counterbalanced. Subjects 1 and 3 were exposed to Condition 2 followed by Condition 3 and Subjects 2 and 4 received Condition 3 followed by Condition 2.

In order to increase internal validity, Subjects 1 and 4 completed a reversal design (A-B-A) for the equal initial-link conditions. Subject 1 received Condition 2, then Condition 3, followed by Condition 2 again. Subject 4 received the reverse order of these conditions. The overall design allows for both between group and within-subject comparisons. Neither subject met stability criteria for the reversal conditions before the experiment ended. Consequently, the value for the last session was taken to represent these conditions.

One terminal-link schedule was always associated with a green light and the other was associated with a red light. For Subjects 1 and 3, the red light was associated with the VI 30-sec schedule and for Subjects 2 and 4 the green light was associated with this schedule. The location of the key colours and associated schedules were changed from side to side (left to right or right to left) across sucessive conditions. Position, key colours, and schedules are provided for each subject in Table 1.

Insert Table 1 about here

A change over delay (COD) of 1 sec was programmed for the concurrent initial links. The change-over delay is a contingency that states the consequence of switching from one key to the other. This time interval prevents access to the terminal phase from occurring immediately following a switch from pressing one white button to pressing the other. Typically, the concurrent-chains procedure has been used without a change-over delay. However, Davison (1983) found that the inclusion of a change-over delay in a concurrent-chains procedure eliminated interactions between the terminal and initial links and made quantification of the effects of terminal-link values less difficult.

Before each change in conditions, a procedure was implemented to test subjects' sensitivity to the contingencies and to diagnose the presence of behavioral stereotypy (Schwartz, 1982). This procedure involved setting minimal values for the initial-link schedules (VI 5-sec) and reversing the position of the terminal-link colours and associated schedules. Because there is minimal time in the initial links, the difference in reinforcement rate of the terminal links (i.e., 30 sec vs. 90 sec) should produce rapid discrimination and exclusive preference for the richer (VI 30-sec) terminal link. Once the subject made the discrimination, i.e., one session responding only to the VI 30-sec schedule, the next experimental condition was instituted. However, subjects occasionally continued to respond with the pattern developed in the previous condition. This persistence of response pattern was taken to be evidence of behavioral stereotypy and a second discrimination procedure was implemented to handle this situation.

Subjects that demonstrated response stereotypy and insensitivity to the contingencies were separately exposed to each terminal-link schedule with the minimal initial-link value (VI 5-sec). Barricades were arranged to permit responding on only the left or right response key. Subjects earned twenty tokens on the key that had a VI 30-sec terminal link and twenty tokens on the VI 90-sec alternative. In the next session, the subject earned 5 tokens by each alternative separately and then earned the remaining 30 tokens with both alternatives available. If the subject demonstrated strong to exclusive preference for the Chain VI 5-sec VI 30-sec alternative (i.e., greater than 95% of responses), then the subject moved to the next condition. If the response pattern indicative of the previous condition remained evident after this procedure, a third procedure was introduced to break stereotypy.

The third procedure involved introducing long intervals into the VI 90-sec terminal-link schedule. With VI 5-sec initial links and both alternatives available, consecutive intervals of approximately 600 to 900 seconds were arranged for the VI 90-sec terminal link by temporarily disconnecting the apparatus. If the subject demonstrated a marked shift in preference toward the VI 30-sec alternative, then during the next session, the subject was exposed to the concurrent VI 5-sec initial-link condition again. If the subject sampled both alternatives and demonstrated a strong preference for the alternative with the VI 30-sec terminal link, then the subject was moved to the next condition. If the subject failed to demonstrate sensitivity to the contingencies, then the third procedure was implemented repeatedly until the subject demonstrated sensitivity to the contingencies.

Each session terminated when 40 tokens had been dispensed. Tokens were exchanged for money following each session. Following the last experimental condition, subjects filled out a questionnaire that concerned how the subjects chose between the alternatives and their impressions of the study. A copy of the questionnaire is given in Appendix D.

Stability criteria

Performance was judged stable and conditions were changed when the following criteria were met. First, a minimum of ten sessions had to be completed before performance could be judged stable. Second, the overall response rates (number of responses in the initial link divided by session duration) for each alternative had to fall between high and low values of previous sessions for five consecutive sessions (see Appendix E). Third, choice proportions had to vary by 0.10 or less with no evident trend.

Dependent variables

The major dependent variable was the proportion of choice responses allocated to the initial link of the alternative with the VI 30-sec terminal link. This proportion is calculated by dividing the number of responses on the initial-link key of this alternative by the sum of the responses on both initial-link keys.

Response proportions were calculated from a computer summary of each session. Summary measures included initial-link responses, reinforcements, total time, terminal-link responses, terminal-link time, and changeovers for each key as well as session duration. In addition to this session summary, comparable measures were recorded for each changeover during the session. A changeover refers to switching from one alternative to the other. Each time a subject switched from one alternative to another, a record of intial-link responses, initial-link time, terminal-link entries, terminal-link responses, terminal-link time and reinforcements was kept. The record ended when the subject switched between alternatives again and a new record began.

Mean response rates refer to responses per unit time calculated over an interval during which local rates varied (Ferster and Skinner, 1957). In this case, mean response rates were calculated from session summaries. These response rates were simply the number of responses made on a key divided by the time in seconds spent on that alternative. This result was then multiplied by 60 to give a response rate per minute.

Local response rates refer to responses per unit time measured over a short time (Ferster and Skinner, 1957). Rather than impose an arbitrary criterion to define the time period involved, the present study used the changeover response to define a local period of time based on the subject's behavior. The time interval began when a subject switched to an alternative in the initial links and ended when the subject switched away from that alternative. Defined in this way, local response rates could only be calculated for the initial links. The terminal links were not concurrent, consequently no changeovers occurred in the terminal links.

Local response rates were calculated for the initial links as the number of responses emitted by the subject during the interval between changeovers expressed as a rate of response per minute. For example, if a subject emitted 20 responses to the left initial-link key in 10 seconds and then switched over to the right initial-link key, the local response rate was 120 responses per minute (20/10 X 60 sec). These rates were calculated for each occasion the subject was on an alternative and then averaged across all occasions within the record to give the average local response rate per changeover.

Post entry pauses were recorded for the initial and terminal links. A post entry pause (PEP) refers to the number of seconds between the onset of a stimulus that occasions responding (i.e., a white or colored light) and the first response to that stimulus. For example, if a response produced entry to a terminal link, this was indicated by a change of key colour (e.g. white to green or red). The PEP was the time period following a change of key colour to the first response to that key.

Analysis of Choice Proportions for Unequal Initial Links

Condition 1 (unequal initial and terminal links) was designed to test whether choice during the initial components was a function of delay reduction, reinforcement density, or overall rate of reinforcement. Table 2 presents observed and predicted choice proportions for Condition 1 (Chain VI 30-sec VI 90-sec vs. Chain VI 90-sec VI 30-sec). Predicted values from the original delay reduction (Equation 2), the modified delay reduction (Equation 3), reinforcement density (Equation 1), and overall rate of reinforcement (Equation 4) equations are compared with observed values. Choice proportions are the number of responses in the initial link of the alternative with the VI 30-sec terminal link divided by the total number of responses during both initial links. Values represent the average proportion for the last five sessions in a condition. (Tables F-1 to F-4 of Appendix F present the raw data for the last five sessions of each subject in this condition.)

Observed choice proportions for Condition 1 varied between 0.49 and 0.72 with a mean value of 0.60. For Condition 1, both delay reduction equations (Equations 2 and 3) predicted a proportion of 0.90. On the other hand, the reinforcement density equation (Equation 1) predicted

0.75, while the relative overall rate of reinforcement equation (Equation 4) predicted 0.50. Mean absolute deviations of observed from predicted values for the group data were 0.30 for both delay reduction equations, 0.15 for the reinforcement density equation, and 0.10 for the overall rate of reinforcement equation. Based on this criterion of minimizing deviations of observed from predicted, relative overall rate of reinforcement described the data better than either relative reinforcement density or relative delay reduction.

Insert Table 2 about here

Single sample means tests also supported the descriptive adequacy of the relative overall rate of reinforcement equation. In these tests the values predicted by the respective equations were treated as hypothesized population means and tested using the mean of the observed proportions as ~~a~~ sample mean. Such an analysis can not discriminate the "correct" equation, but does reflect the degree of correspondence between the observed and predicted values. The significance levels of the *t* statistic reflect the probability that the observed values could have occurred due to sampling fluctuations if the population mean was as predicted.

This analysis revealed that the sample mean ($\underline{M}$ = 0.60) differed significantly from the value 0.90 ($\underline{t}(3) = -6.31$, $\underline{p}$ = 0.0[illegible] predicted by both delay reduction equations and the value 0.75 ($\underline{t}(3) = 3.13$, $\underline{p}$ = 0.05) predicted by the reinforcement density equation. Only the value 0.50 predicted by the overall rate of reinforcement equation was insignificant ($\underline{t}(3) = 2.17$, $\underline{p}$ = 0.10). Of the four equations, then, the deviations of observed from predicted were most likely due to sampling fluctuations for the relative overall rate of reinforcement equation.

Analysis of Choice Proportions for Equal Initial Links

Equal initial-link conditions were designed to demonstrate the effect of decreasing the difference in delay reductions between alternatives on preference. Preference for the more reinforcing alternative was expected to decline as the difference in delay reductions decreased. This preference decline was expected to follow the curvilinear function depicted in Figure 2. Relative delay reduction was manipulated by extending the duration of the equal initial links from 40 to 120 seconds.

Table 3 presents an equivalent analysis of choice proportions for Conditions 2 and 3 (equal VI 40-sec and VI 120 sec initial links). For the VI 40-sec initial-link condition, observed proportions varied between 0.85 and 0.99 and had a mean value of 0.96 (Tables F-5 to F-11 of

Appendix F present the raw data for the last five sessions of each subject in these conditions). Equations 2 and 3 based on delay reduction predicted exclusive preference (1.0). Equation 4 based on relative overall rate of reinforcement also predicted exclusive preference, since the rate of reinforcement on the VI 30-sec alternative (i.e., the alternative with the higher reinforcement rate) never fell below the rate of reinforcement on the VI 90-sec alternative (i.e., the alternative with the lower reinforcement rate). This situation occurs in concurrent-chain schedules when the duration of the concurrent initial links is less than the difference between the non-concurrent terminal links. Finally, Equation 1 based on reinforcement density in the terminal links predicted 0.75.

Mean absolute deviation of observed from predicted proportions was 0.05 for the delay reduction equations and the relative overall rate of reinforcement equation. In contrast, the reinforcement density equation produced larger errors in prediction, since the mean absolute deviation was 0.21. Thus reinforcement density does not appear to describe the results of Condition 2.

Single sample means tests confirmed the lower descriptive adequacy of the reinforcement density equation. The mean of the observed proportions ($\underline{M}$ = 0.96) did not differ significantly ($\underline{t}(3) = -1.28$, $\underline{p} = 0.14$) from exclusive preference (1.0) as predicted by the delay reduction equations and relative overall rate of reinforcement equation. However, the sample mean was significantly different (t(3) = 5.86, p = 0.01) from the value 0.75 predicted by the reinforcement density equation.

Insert Table 3 about here

The second part of Table 3 presents the results for the VI 120 second initial-link condition. Observed proportions varied between 0.55 and 0.56 with a mean of 0.55. For this condition, the delay reduction equation (Equation 2) predicted 0.75, the modified delay reduction equation (Equation 3) predicted 0.81, the reinforcement density equation (Equation 1) predicted 0.75, and the relative overall rate of reinforcement equation predicted 0.58. Absolute deviations of observed from predicted proportions averaged 0.20, 0.26, 0.20, and 0.03 for these equations, respectively. Clearly, the predictive accuracy of the relative overall reinforcement rate equation was greater than for any other equation.

Single sample means tests showed that the differences between the observed and predicted proportions were significant for all equations. The t values declined from -77.0 (p = .0001) for the modified delay reduction equation to -59.0 (p = .0003) for the original delay reduction and reinforcement density equations. The smallest t value was produced by the overall rate of reinforcement equation (t = -8.0, p = .01). Although the error in prediction of .03 is small, there was virtually no within group variation (i.e., all subjects at the mean) and this accounts for the significant t value for the rate of reinforcement equation. Thus, overall rate of reinforcement provides the most accurate description of the data for Condition 3.

Figure 5 presents the results of the equal, initial-link conditions plotted against the curvilinear function for the decline in preference predicted by the original delay-reduction equation (Equation 2). In general, the results confirmed that preference for the VI 30-sec terminal link decreased as the duration of the initial links increased. Choice proportions declined from an average of 0.96 when the initial links were VI 40-sec to 0.55 when the initial links increased to VI 120-sec (t(6) = 9.68, p = .0002).

Insert Figure 5 about here

Although preference for the VI 30-sec terminal schedule decreased, the decline in preference did not conform to the function defined by the delay-reduction equation. The value 0.55 obtained for the VI 120-sec initial-link condition was 0.20 less than the 0.75

predicted by the delay-reduction equation. Thus, the decline in preference was steeper than predicted.

Figure 6 provides evidence for the reliability of the results obtained for the equal initial-link conditions. Choice proportion values were replicated with Subjects 1 and 4 using a reversal design. The response proportion of Subject 1 declined from 0.99 to 0.56 as the initial links increased from VI 40-sec to VI 120-sec and then returned to 0.95 when the VI 40-sec condition was reinstated. Subject 4 produced response proportions of 0.55 and 0.99 as the duration of the initial links decreased from [illegible] 120-sec to VI 40-sec and then produced 0.52 when the VI 120-sec condition was reinstated. These results suggest that the changes in response proportions were a function of changes in the initial links.

Insert Figure 6 about here

Analysis of Initial-Link Local Response Rates

If subjects were sensitive to conditioned reinforcement, then the initial-link response rate would be greater for the stimulus correlated with the VI 30-sec terminal-link schedule than the VI 90-sec schedule. Table 4 presents local response rates. Local response rates for the initial links of the two alternatives are shown for each subject. The alternatives are designated by the terminal link schedules. Hereafter, the alternative with the VI 30-sec terminal-link is referred to as the "short terminal-link" alternative and the alternative with the VI 90-sec terminal link as the "long terminal-link" alternative.

Rates are reported for the five stability sessions of the three experimental conditions. Inspection of Table 4 shows that initial-link response rates on the VI 30-sec terminal-link alternative were greater than for the VI 90-sec terminal-link alternative. The only exception was for Subject 2 with the VI 120-sec condition (Condition 3).

Differences between initial link response rates were analyzed on both group and individual levels using a repeated measures analysis of variance. The group level design was a 4 X 3 X 2 factorial design with repeated measures. The first factor was subject with 4 levels, second factor was condition with 3 levels, and third factor was terminal link duration with two levels (short and long). Condition and duration were treated as repeated measures. The subject factor was included in the design because individuals showed considerable variation in response rate. In order to assess the effects of differences in relative strength of conditioned reinforcers, the variance due the main effects of subjects was initially removed and all interactions with subject were pooled into error. This results in a reduced error term, since variation due to individual differences is removed. The effects of condition, duration, and condition-by-duration interaction were tested with this reduced error value as suggested by Winer (1971).

Average local response rates were analyzed for the three subjects that completed all conditions. Subject 3, who only completed two conditions, was excluded. Therefore, the design for this analysis was 3 X 3 X 2 with the subject factor reduced to three levels. Results of this group level analysis showed that average local response rates on the initial links of the short terminal-link (M = 77.30) and long terminal-link (M = 40.16) alternatives were significantly different (F(1,10) = 5.54, p = 0.04). Effects of condition and condition-by-duration interaction were not significant (see Table G-1 of Appendix G).

A second analysis of local response rates was performed on the first two conditions for all subjects. This analysis demonstrates that the results of the previous analysis were not an artifact of the exclusion of Subject 3. The design was 4 X 2 X 2 repeated measures analysis of variance. Results from this analysis also showed that the local rates on the initial link of the short terminal-link alternative (M = 67.08) were significantly greater than on the initial link of the long terminal-link alternative (M =

25.95) ($F(1,9) = 5.91$, $p = .038$) with all subjects included. Condition and the condition-by-duration interaction terms remained insignificant (see Table G-2 of Appendix G). Generally, the results from these two group-level analyses show that subjects respond at higher rates in the initial link for the stimulus correlated with the shorter time to reinforcement in the terminal-link (VI 30-sec).

Analysis at the level of the individual was based on a 3 X 2 analysis of variance with one between group factor - condition (one, two, and three) and one within group factor - duration of terminal link (short vs. long) applied to the response rates for the five stability sessions. Since Subject 3 only completed two conditions, a 2 X 2 analysis of variance design was used. Generally, the results were in accord with those from the group level analysis; differences in initial-link local response rates were significant at $p < .05$ for all subjects except Subject 2. Mean response rates on the short and long duration alternatives were $M = 55.27$ and $M = 18.32$ respectively for Subject 1, $M = 23.09$ and $M = 20.32$ for Subject 2, $M = 43.51$ and $M = 14.35$ for Subject 3, and $M = 153.55$ and $M = 81.85$ for Subject 4. This individual level analysis confirmed that local response rates in the initial link of the alternative with the shorter time to reinforcement in the terminal link (VI 30-sec) were greater than those in the initial link of the long, terminal-link alternative (VI 90-sec).

The analysis of variance also revealed significant effects of condition on response rate and significant interaction of condition with duration of terminal link (except for Subject 3). The reader is referred to Appendix Tables G-3 to G-6 for these secondary results.

Insert Table 4 about here

Analysis of Initial-Link and Terminal-Link Mean Response Rates

Concurrent-chain schedules of reinforcement typically generate higher rates of response by pigeons during the terminal components than during the initial links. Inspection of Table 5 shows that contrary to this finding, human subjects responded at higher rates during the initial links than during the terminal components. Repeated measures analysis of variance was applied to initial-link and terminal-link mean response rates. The 4 X 3 X 2 design involved a subject factor with four levels, a condition factor with three levels, and a schedule component factor with two levels (initial and terminal). Main effects due to subjects were removed and interactions with the subject factor were pooled into the error term. Separate analyses were performed for the initial and terminal-link rate differences on the alternative with the shorter time to terminal-link reinforcement (VI 30-sec) and on the longer (VI 90-sec).

Results from these analyses showed that the initial-link response rates were significantly greater than terminal-link rates for all subjects on both the short and long alternatives (see Tables G-7 and G-8 of Appendix G). For the VI 30-sec alternative, the mean initial-link rate (_M_ = 55.22) differed significantly from the mean terminal-link rate (_M_ = 8.37) (_F_(1,15) = 7.76, _p_ = .01). For the VI 90-sec alternative, the difference in mean response rates between initial (_M_ = 32.90) and terminal (_M_ = 8.25) links was also significant (_F_ (1,15) = 4.88, _p_ = .04). Generally, response rates declined in the terminal links.

Insert Table 5 about here

Descriptive Analysis of Verbal Report

Inspection of the subjects' responses to the questionnaire given upon completion of the experiment revealed that subjects generally discriminated the interval contingencies. In response to a question about how the apparatus worked, Subject 1 stated that:

> after a certain amount of time, pushing one of the buttons would cause it to light up. After another wait pushing the ~~button~~ which was lit up would cause a token to drop. Whether the time delays were random or predetermined was a mystery to me.

Subject 2 responded that:

> The time when the tokens would be released was fixed [determined by the researcher], yet I still had to prime [change from initial to terminal link] and release the tokens. No matter how much I pushed, the tokens came at fixed times.

Finally, Subject 3's response was:

> After waiting a certain amount of time, a token could be obtained from the apparatus by pushing a lighted button.

All subjects reported that the delivery of tokens and the production of terminal-link stimuli depended on the elapse of a time interval more than making a certain number of responses.

Subjects were also asked how the alternatives differed. In response to this question Subject 1 reported that:

> One was green and one was red. I think the red one [VI 90-sec] would tend to light up faster,

> but there seemed to be a longer wait for the token to fall. The green one [VI 30-sec] seemed to take longer to light up, but once it was [lit up] the wait for the token seemed shorter.

Subject 4 responded that:

> Green [VI 30-sec] was usually quicker to give tokens, but sometimes it was longer than red [VI 90-sec] when trying to get the color originally. The red button usually came quicker at first, but it took longer to get a bloody token off at it.

These responses not only show that subjects discriminated that one terminal link took longer to produce a token than the other, but also describe the subjects distribution of behavior during the initial links. Subjects generally, allocated more time and responses to the initial link leading to the VI 30-sec terminal link than to the initial link leading to the VI 90-sec terminal link.

Finally, subjects were queried as to how they chose between the alternatives. Generally, the subjects were unanimous in stating that they preferred the alternative that produced a token the quickest. Subject 3 stated that he chose "whichever [alternative] gave the token the fastest." Subject 4 responded that, "I liked green better, so I went after it more. I said before, that green usually gave the tokens quicker and that's what I was after."

Subject 2 stated that he chose between the alternatives "by their reaction time [how quickly they gave tokens]." Finally, Subject 1 reported that he "favored the one which lit up green [VI 30]. But if it took too long [he] would press the red [VI 90] one." In general, these responses suggest that time to reinforcement influenced how subjects chose between responses alternatives.

Descriptive Analysis of Videotapes

Samples of subjects' behavior were recorded for ten minutes approximately one half hour into each session. Due to a shortage of videotapes and technical problems, samples of stability-session performances were only available for a limited number of conditions. Behavior samples were available for the following conditions: Condition 1 for Subjects 2, 3, and 4 and Condition 2 for Subjects 1, 3, and 4. This limitation means that caution should be exercised in the interpretation and generalization of the following analysis.

The videotapes of subjects' performances during stability sessions were coded for "on-task" and "off-task" behaviors. On-task behaviors refer to behavior with reference to the operative key (i.e., pressing the key, looking at the key). Occurrences of on-task behavior were coded 1. Off-task behavior refers to behavior other than pressing or looking at the key. Three categories of off-task behavior were coded. The first category [illegible] behavior, preceded by an on-task response, that removed the subject from the operative key (i.e., looking away or moving away). Behavior that removed the key was coded 2. The second category was timing behavior. Timing behavior is regularly occurring responses that consume a measured quantity of time. Pacing is an example of this response class. Timing behavior was coded 3. Finally, all other behaviors that occurred in the setting such as manipulating tokens, taking a drink, sitting down, leaning on barriers, and drawing graffitti were coded 4. Behavior sequences were coded for complete initial and terminal-link intervals.

Results showed that considerable off-task behavior occurred in both initial and terminal links. During the initial links, Subjects 1, 2, and 3 exhibited off-task behavior such as pacing, leaning on barriers, drinking, etc. For these subjects, the probability of on-task behavior (number of on-task responses to total number of responses) was less than the probability of engaging in off-task behavior (number of off-task responses to toal number of responses). Probabilities of off-task behavior for Condition 1 was 0.56 for Subject 2 and 0.70 for Subject 3. For Condition 2, these probabilities were 0.58 for Subject 1 and 0.65 for Subject 3, respectively. Subject 4, on the other hand, engaged in much more on-task behavior during the initial links. Essentially, Subject 4 pressed the keys and shifted between keys (coded S for shift) in the initial links. Probabilities of off-task behavior were 0.03 for Condition 1 and 0.00 for Condition 2.

During the terminal links, all subjects engaged in off-task behaviors. The respective probabilities of off-task behavior for Condition 1 was 0.71 for Subject 2, 0.71 for Subject 3, and 0.69 for Subject 4. For Condition 2 these probabilities were 0.59 for Subject 1, 0.69 for Subject 3, and finally, 0.67 for Subject 4. Approximately two-thirds of responses during the terminal links were off-task.

Subjects 1, 2, and 4 developed sequences of behavior that consisted of pressing the operative key (1), moving away (2), and pacing (3). This behavior sequence was termed "probing". Subjects engaged in this repetitive sequence of behavior throughout the terminal-link interval. This pattern was most pronounced in Subject 4 because it differed from the behavior of continuous pressing (100%) in the initial links. The probabilities of occurrence of these three categories of behavior during the terminal link for Subject 4 in Condition 1 were equal (0.33). Subject 3 exhibited a different pattern of behavior. Rather than pacing, Subject 3 "waited" out the interval by engaging in other behavior (i.e., leaning on a barrier, drawing graffitti, etc.).

The prevalence of off-task behavior under conditions where only on-task behavior produces reinforcement suggests that off-task behavior serves some function. One possible function is to time out or count off the interval. Pacing the floor is behavior that may serve such a function. Also, as indicated earlier, the four subjects described the interval contingencies on their questionnaires and drew graffitti on the barriers that concerned the programmed intervals (see transcription of the graffitti in Appendix H). Taken together, these results indicate that subjects discerned the interval contingencies and engaged in behavior to bridge the temporal delays.

Coding behavior during the terminal links also revealed that three subjects engaged in behavior that functioned to remove the entry stimulus and operative key: Subjects 1, 3 and 4 consistently (100%) moved away or looked away when the terminal link stimulus occurred. Subject 2, on the other hand, pressed the colored key on 60% of entries (3 of 5) and moved away for the 40% of entries (2 of 5). For most subjects, then, the presentation of the terminal link stimulus occasioned behavior that removed the stimulus and timed out the interval. This observation suggested that an analysis of post entry pause for the terminal links would provide a convenient description of this behavioral tendency.

Analysis of Terminal Link Post Entry Pauses

Terminal-link post entry pauses (PEP) are presented in Table 6 for the stability sessions of the unequal initial-link and VI 120-sec initial-link conditions for each subject. PEP for the VI 40-sec condition are not included, since exclusive responding to the VI 30-sec alternative made PEPs unreliable for the VI 90-sec side (see Appendix I). The PEP refers to the number of seconds between the onset of a terminal-link stimulus and the first response to that key. Inspection of the table reveals that the PEPs for the VI 90-sec schedule were greater than those for the VI 30-sec schedule. Differences in PEPs were examined for the unequal initial-link condition (Chain VI 30 VI 90 vs Chain VI 90 VI 30) and the VI 120-sec equal initial-link condition for each subject using paired t-tests.

Insert Table 6 about here

Results for the unequal initial-link condition, revealed that the differences in PEP were significant for three of the four subjects. For Subject 1, the mean PEP on the VI 30-sec schedule (M = 17.62) was significantly less than the mean PEP on the VI 90-sec schedule (M = 25.49) ($t(4) = -3.45$, $p = 0.026$). Mean PEPs for Subject 3 on the VI 30-sec schedule (M = 54.95) and the VI 90-sec schedule

(M = 120) differed significantly (t(4) = -6.26, p = .003). Subject 4 also responded sooner on the VI 30-sec terminal link (M = 32.15) than on the VI 90-sec terminal link (M = 41.57) (t(4) = -6.17, p = 0.004). Only Subject 2 did not respond significantly quicker on the VI 30-sec terminal link (M = 6.25) than in the VI 90-sec terminal link (M = 10.66) (t(4) = -2.54, p = 0.064) using conventional levels of significance.

For the VI 120-sec condition, the results revealed that terminal-link PEPs were significantly less on the VI 30-sec link than on the VI 90-sec link for two of three subjects. Mean PEPs for Subject 1 in the VI 30-sec terminal link (M = 17.28) and the VI 90-sec terminal link (M = 20.86) differed significantly t(4) = -5.56, p = 0.005). Subject 2 also responded significantly quicker on the VI 30-sec link (M = 27.01) than on the VI 90-sec link (M = 39.44) (t(4) = -2.99, p = 0.04). Subject 4, however, did not respond significantly sooner on the VI 30-sec link (M = 29.44) than on the VI 90-sec link (M = 31.94) (t(4) = -2.0, p = .116).

Generally, the results from these analyses suggest that the time to the first response following entry to the terminal link was less when the average time to reinforcement was 30-sec than when it was 90 seconds.

Discussion

Determinants of Choice

The present results suggest that overall rate of reinforcement was more important than conditioned reinforcement as a determinant of human preference on concurrent-chain schedules. This generalization is based upon comparison of the descriptive accuracy of the delay-reduction, reinforcement-density, and relative-rate equations.

Results from Condition 1 suggested that relative rate of reinforcement governed the distribution of responses in this situation. In this condition, rate of reinforcement was equalized on alternatives so that delay-reduction and relative-rate descriptions of choice could be assessed. Differences between observed and predicted response proportions were less pronounced for the relative rate equation (Equation 4) than for the delay reduction models (Equations 2 and 3). The greater descriptive accuracy of the relative rate equation implies that the distribution of reinforcement was the major determinant of choice.

This result contrasts with findings reported by Fantino (1969) for the same conditions. In that experiment, the data from four pigeons were more in accord with delay reduction than relative rate of reinforcement. Thus, the distribution of behavior by pigeons was apparently under the control of the conditioned reinforcers of the setting. Generally, it appears that reductions in delay of reinforcement signalled by a stimulus were more salient to pigeons than humans who were exposed to similar contingencies of reinforcement.

These general conclusions are supported by Conditions 2 and 3 that directly varied relative delay reduction by adding delays to the initial links. Delay reduction and rate of reinforcement equations predicted that preference for the VI 30-sec terminal-link alternative would decline as the duration of the initial-link schedules increased. However, the rate of reinforcement equation required a larger change in choice proportion (1.00 to 0.58) than the delay reduction equations (1.00 to 0.75 for Equation 2 and 1.00 to 0.81 for Equation 3). the observed degree of decline in preference (0.96 to 0.55) was much steeper (see Figure 5) than predicted by either delay reduction equation, but was in accord with the amount of change expected on the basis of relative overall rate of reinforcement (Equation 4).

The predictive accuracy of reinforcement rate and delay reduction equations was also tested by the deviations of the observed from predicted values. For all conditions, the deviations were substantially less for the relative rate of reinforcement equation. Generally, the data on predictive accuracy support the conclusion that relative rate of reinforcement was more important than conditioned reinforcement as a determinant of human preference in this situation.

Overall Rate of Reinforcement: Matching or Maximizing

One conclusion that can be drawn from these results is that separate principles are not needed to account for preference in simple and complex-choice situations. Human performance on simple concurrent schedules is well described by the matching law (Pierce and Epling, 1983). Results from the present experiment suggest that a form of matching also accounts for human choice on concurrent-chain schedules. The distribution of behavior matched relative rates of reinforcement provided by the alternatives.

Although matching is suggested by the present results, melioration and maximization perspectives may also provide alternative analyses. Melioration is a process model of choice, developed by Herrnstein and Vaughn (1980), that yields matching at equilibrium. According to the melioration model, subjects compare local rates of reinforcement between alternatives and shift toward the alternative with the higher local rate of reinforcement. Equilibrium occurs when the allocation of time and behavior between alternatives produces equal local rates of reinforcement on the two alternatives.

Difference in local rates of reinforcement is the variable that drives the process of melioration. Subjects respond to differences and allocate behavior accordingly. Melioration has been formulated as:

$$RD = (R1 / t1) - (R2 / t2) \tag{5}$$

In Equation 5, RD refers to the difference in local rates of reinforcement. The values R1 and R2 represent reinforcements obtained from Alternatives 1 and 2, while t1 and t2 represent time allocated to the respective alternatives.

When RD is greater than zero, melioration requires the subject to shift toward Alternative 1. When RD is less than zero, the subject should shift time and behavior allocation toward Alternative 2. Equilibrium occurs when RD equals zero, which is represented as:

$$R1 / t1 = R2 / t2 \tag{6}$$

Equation (6) is the matching law. Thus, at equilibrium, the process of melioration yields matching.

In the present experiment, melioration would result in exclusive preference for the 40 second condition and some distribution of behavior between the alternatives for the 120 second condition. Exclusive preference for the alternative with the higher rate of reinforcement would occur in the 40 second condition since the local rate of reinforcement is always higher for this alternative. In the 120 second condition, local rates of reinforcement are affected by the negative-feedback function of the concurrent initial links. This negative-feedback function means that "the local rate of reinforcement at each alternative is inversely related to the time spent working at it" (Herrnstein and Vaughan, 1980, p. 166). Under these conditions, melioration requires switching between alternatives rather than responding exclusively to one. On a qualitative level, the melioration model prescibes a change in response distributions across these conditions that is consistent with that observed.

Maximization views (Herrnstein, 1982) may also account for the present results. According to the principle of maximization, individuals distribute their time and behavior between alternatives so as to maximize some dimension, such as expected utility, energy intake, hedonic value or reinforcement, within limitations of memory and discriminative acuity as well as limitations imposed by the environment (Herrnstein, 1982, p. 433). Individuals select among different response patterns and their associated outcomes, discarding patterns that provide less in favour of those that provide more, until equilibrium is reached. Equilibrium occurs when outcomes (rewards minus costs) are maximized and can not be improved upon by any further redistribution of responses (Herrnstein, 1982).

In the present experiment, maximizing implied an allocation of responses between alternatives that provides the highest overall rate of reinforcement. Since a session was defined by 40 reinforcements, rate of reinforcement was maximized by minimizing the time required to obtain 40 reinforcements.

Insert Figure 7 about here

Figure 7 depicts hypothetical curves of average time per reinforcement as a function of the proportion of responses allocated to the VI 30-sec terminal-link alternative for equal initial-link values of 40, 60, 80, 120, and 180 seconds. These idealized functions are based on two assumptions: 1) that distribution of responses produce equivalent distributions of reinforcements and 2) that subjects do not switch between alternatives prior to obtaining reinforcement.

According to maximization, distribution of responses should stabilize around the lowest point in these functions. For the 40-sec function, average time per reinforcement is minimal when subjects respond exclusively to the alternative providing the highest rate of reinforcement. At 60 seconds, average time per reinforcement is least for any distribution of responses greater than 50%. The function for 120 seconds is "V" shaped with the minimum value at a 50% distribution. Together these functions describe a step function that drops from exclusive preference to an equal distribution of responses between alternatives as the duration of initial links increase.

The sharp decline in preference observed for the equal initial-link conditions in this experiment is consistent with this step function. Therefore, humans may be viewed as distributing responses and settling on a distribution that minimizes average time per reinforcement (i.e., maximization).

Houston, Sumida, and McNamara (1987) calculated the response proportions for the equal [illegible] link conditions that maximize overall rate of re[illegible]t. Calculation of optimal allocations depend on the frequency of switching in the initial links. The probability of entering a terminal link varies with the freqency of switching. Switching is indexed by the parameter I. The switching index (I) is half the harmonic mean of the interchangeover times. The value of I varies inversely with the rate of switching.

Houston, et al. (1987) calculated optimal allocations for the equal initial-link conditions in Fantino (1969) for two different switch rates. If I = 3 (high rate), the response proportions that maximize reinforcement in the VI 40-sec and VI 120-sec conditions are 1.0 and 0.64 respectively. If I = 12 (low rate), reinforcement is maximized in these conditions with response proportions of 1.0 and 0.65 respectively. Thus, the proportions of responses to the richer alternative that maximize reinforcement vary with switch rates in the initial links.

Choice proportions observed in this study were in accord with exclusive preference required to maximize reinforcement in the VI 40-sec condition and lower than expected for the VI 120-sec condition (M = 0.55). However, Houston, et al. do not expect that individuals function as "literal maximizers". Instead, they argue that subjects "behave in orderly ways that result in high reinforcement rates under certain circumstances." (1987, p. 135). Subjects in the present study, then, functioned as "approximate" rather than "literal" maximizers.

Matching, melioration, and maximization provide viable explanations for the results of the present experiment. Previous research has shown that on concurrent VI VI schedules matching and maximization coincide (Baum, 1981; Rachlin, Green, Kagel, and Battalio, 1976; Staddon and Motheral, 1978). Melioration yields matching at equilibrium. However, the present experiment was not designed to discriminate between these alternative descriptions of choice and preference.

Temporal Delay, Preference, and Human Behavior

One possible reason for the lower accuracy of the delay-reduction model is that the delay values of the present experiment were insufficient to demonstrate an effect on human choice. The delays scheduled in this research were in seconds and minutes. To infrahuman subjects, such as pigeons or rats, delays of seconds or minutes in access to food may be substantive. However, such delay intervals may be insignificant or trivial to humans that tolerate delays of days, weeks, or years.

In a different context, Herrnstein (1981) suggested that differences in time discounting between human and animal species may be so great that simple models can not accomodate the variation. To correct for species differences in time discounting, Herrnstein advocated introducing a parameter _I_ into the normative matching equation. This parameter serves as a scale factor for time discounting. Species that discount time sharply have a high value of _I_. The parameter would also capture the influence of factors other than species or individual differences that affect rate of time discounting. For example, time discounting may depend on past learning, situational factors, type of reinforcer, or response topography.

Results of the current experiment may reflect these differences in time discounting. If human subjects discounted the delay intervals and aggregated time to reinforcement across the initial and terminal links, then relative rate of reinforcement would be the major factor controlling the distribution of behavior. An alternative implication is that delay-reduction equations may have to be modified to include a time discounting parameter because events that signal brief or small reductions may be ineffective for organisms that tolerate long periods of delay.

Other research with humans has shown "that it is difficult to produce effects of delay of reinforcement that can not be readily explained in terms of other variables such as rate or amount of reinforcement" (Navarick, 1986, p. 344). For instance, few studies have demonstrated impulsivity in humans. Solnick, et al. (1980) produced the strongest effect of delay using a negative reinforcement procedure. Only one study using positive reinforcement has demonstrated limited impulsivity (Millar and Navarick, 1984). It may be necessary to program delay reductions for events over extended periods of time in order to show the effects on human preference. However, experimental analysis will be difficult since unknown variables may affect the distribution of behavior and internal validity may be reduced.

Conditioned Reinforcement, Response Rate and Concurrent-Chain Schedules

Conditioned reinforcement refers to a relationship between environmental stimuli and responses of the individual. Stimuli that acquire reinforcing properties through association with other reinforcing events are termed "conditioned" reinforcers (Reynolds, 1975). The strength of these stimuli as reinforcers depends on the nature of the association with the reinforcing events from which they acquire reinforcing properties. One measure of the strength of conditioned reinforcers is rate of response emitted to produce these consequences. Stronger reinforcers support higher rates of response.

Analyses of local response rates confirmed that conditioned reinforcement was operative in the setting. The stimulus correlated with the shorter time to reinforcement in the terminal link (VI 30-sec) supported a higher rate of response during the initial link than the stimulus associated with the longer (VI 90-sec) terminal link. This difference in initial-link response rate indicates that the conditioned reinforcers (red or green key colours) differed in strength.

Such a result is consistent with both reinforcement density (Herrnstein, 1964) and delay reduction (Fantino, 1969) theories of conditioned reinforcement. Although the strength of the conditioned reinforcers between alternatives differed, the relationship of this difference to preference remains unclear. Preference did vary with conditioned reinforcement strength, in that the alternative with that stronger conditioned reinforcer (VI 30-sec) was preferred. However, neither the delay reduction equation

(Equation 2) nor the reinforcement density equation (Equation 1), which are both based on strength of conditioned reinforcement, adequately described preference in this study.

Stimulus Control

Ferster and Skinner (1957) suggested that with fixed interval schedules, reinforcement functions as a temporal discriminative stimulus that sets the occasion for not responding (S¬). On fixed interval contingencies, organisms show a low or zero probability of response following reinforcement. Research has shown that the duration of the post-reinforcement pause (PRP) on fixed-interval schedules varies with the schedule value. The greater the time duration, the longer the PRP (Harzem, 1968; Lowe, Harzem, and Spencer, 1979; Schneider, 1969; Sherman, 1959). This relationship holds for fixed-interval schedules, but weakens as variation in the temporal distribution increases. For variable interval schedules, data from Lachter (1971) showed that duration of the PRP varied as a function of the mean interreinforcement interval (IRI). The greater the mean IRI, the greater the PRP.

This analysis of PRP on interval schedules is consistent with the behavior of our subjects during the terminal links. Verbal reports by subjects suggested that the IRI exerted control over behavior. Also, analysis of videotapes revealed that the onset of terminal-link stimuli (i.e., change of key color) was associated with a low probability of pressing the key and a high probability of behavior [illegible] removed the entry stimulus and timed out the interval. [illegible]ds of pauses upon entry to the terminal links showed that the average post entry pause (PEP) was 34 seconds and that the PEP varied with the average IRI (i.e., 26 sec for the 30-sec IRI and [illegible]1 sec for the [illegible]c IRI). Thus, the pauses following conditioned reinforcement (i.e., entry) in concurrent-chain schedules (PEP) seem to obey similar principles as PRP on simple schedules of reinforcement.

Conclusions

In complex-choice situations, human preference did not reflect the effects of delay-reduction so often reported in nonhuman research (Dunn and Fantino, 1982; Fantino, 1969; Fantino and Davison, 1983; Squires and Fantino, 1971). Rather, relative overall rate of reinforcement seemed to be the most important determinant of preference in this situation. This implies that some form of matching process governs choice in complex-choice situations. Hence, the matching principle that accounts for choice in simple situations (Pierce and Epling, 1983) may generalize to more complex settings.

The implications of these results for human social behavior relates to the importance of relative rate of reinforcement as a determinant of interpersonal choice (Sunahara and Pierce, 1982). To the extent that social interaction can be conceptualized as responding on concurrent or concurrent-chain schedules (see Conger and Killeen, 1974), the distribution of behavior between alternative exchange partners can be expected to correspond with relative rates of social reinforcement mediated by the persons. An exception would occur when the rate of reinforcement provided by one partner always exceeds that supplied by another or when the difference in rate of reinforcement in the terminal components exceeds the average time to reinforcement during the choice phase. In this situation, interpersonal exchange will be exclusively with the more rewarding partner.

The principle of conditioned reinforcement is fundamental to understanding human social behavior. Human behavior typically consists of long behavior chains presumably maintained by primary reinforcement through intervening events that function as conditioned reinforcers (Skinner, 1953). The importance of conditioned, and generalized-conditioned, reinforcement must be demonstrated by direct experimental analysis at the human level. The present study shows that the role of conditioned reinforcement is complex when human behavior is maintained on concurrent-chain schedules using generalized reinforcers as the terminal consequences.

Apparently, local response rate is sensitive to events that signal time to reinforcement. Thus human operant behavior is clearly under the control of conditioned reinforcement. However, the distribution of behavior between alternative sources of reinforcement was not sensitive to the relative strength of the conditioned reinforcers as formulated in the delay-reduction and reinforcement-density models.

Table 1. Position of terminal-link schedules (seconds) and associated key colours by condition for each subject.

Subject 1	Terminal Link		Key Colour	
Condition	Left	Right	Left	Right
1	VI 90	VI 30	Red	Green
2	VI 30	VI 90	Green	Red
3	VI 90	VI 30	Red	Green
4[a]	VI 30	VI 90	Green	Red

Subject 2	Terminal Link		Key Colour	
Condition	Left	Right	Left	Right
1	VI 90	VI 30	Green	Red
2	VI 30	VI 90	Red	Green
3	VI 90	VI 30	Green	Red

Subject 3	Terminal Link		Key Colour	
Condition	Left	Right	Left	Right
1	VI 30	VI 90	Red	Green
2	VI 90	VI 30	Green	Red
3	VI 30	VI 90	Red	Green

Subject 4	Terminal Link		Key Colour	
Condition	Left	Right	Left	Right
1	VI 30	VI 90	Green	Red
2	VI 90	VI 30	Red	Green
3	VI 30	VI 90	Green	Red
4[a]	VI 90	VI 30	Red	Green

[a] Denotes reversal condition

Table 2. For Condition 1, observed choice proportions compared with choice proportions predicted by the reinforcement-density equation (Equation 1), the delay-reduction equation (Equation 2), the modified delay-reduction equation (Equation 3), and the relative overall rate of reinforcement equation (Equation 4), as well as deviations of observed from predicted choice proportions ( ), and mean absolute deviations [ ].

		Chain VI 90 VI 30 vs Chain VI 30 VI 90			
Subject	Observed	Equation 1	Equation 2	Equation 3	Equation 4
1	0.59	0.75 (-0.16)	0.90 (-0.31)	0.90 (-0.31)	0.50 (+0.09)
2	0.72	0.75 (-0.03)	0.90 (-0.18)	0.90 (-0.18)	0.50 (+0.22)
3	0.61	0.75 (-0.14)	0.90 (-0.29)	0.90 (-0.29)	0.50 (+0.11)
4	0.49	0.75 (-0.26)	0.90 (-0.41)	0.90 (-0.41)	0.50 (-0.01)
Average	0.60	0.75 [0.15]	0.90 [0.30]	0.90 [0.30]	0.50 [0.10]

Table 3. For Conditions 2 and 3, observed choice proportions compared with choice proportions predicted by the reinforcement-density equation (Equation 1), the delay-reduction equation (Equation 2), the modified delay-reduction equation (Equation 3), and the relative overall rate of reinforcement equation (Equation 4), as well as deviations of observed from predicted choice proportions (), and mean absolute deviations [ ].

Chain VI 40 VI 30
vs Chain VI 40 VI 90

Subject	Observed	Equation 1	Equation 2	Equation 3	Equation 4
1	0.99	0.75 (+0.24)	1.00 (-0.01)	1.00 (-0.01)	1.00 (-0.01)
2	0.99	0.75 (+0.24)	1.00 (-0.01)	1.00 (-0.01)	1.00 (-0.01)
3	0.85	0.75 (+0.10)	1.00 (-0.15)	1.00 (-0.15)	1.00 (-0.15)
4	0.99	0.75 (+0.24)	1.00 (-0.01)	1.00 (-0.01)	1.00 (-0.01)
Average	0.96	0.75 [0.21]	1.00 [0.05]	1.00 [0.05]	1.00 [0.05]

Chain VI 120 VI 30
vs Chain VI 120 VI 90

Subject	Observed	Equation 1	Equation 2	Equation 3	Equation 4
1	0.56	0.75 (-0.19)	0.75 (-0.19)	0.81 (-0.25)	0.58 (-0.02)
2	0.55	0.75 (-0.20)	0.75 (-0.20)	0.81 (-0.26)	0.58 (-0.03)
3	-[a]	- -	- -	- -	- -
4	0.55	0.75 (-0.20)	0.75 (-0.20)	0.81 (-0.26)	0.58 (-0.03)
Average	0.55	0.75 [0.20]	0.75 [0.20]	0.81 [0.26]	0.58 [0.03]

[a] Subject 3 did not complete this condition.

Table 4. Average local response rate (responses/min.) per changeover by condition in the initial links for the five stability sessions for each subject. The alternatives are designated by terminal-link schedule.

	Chain VI 90 VI 30 vs Chain VI 30 VI 90		Chain VI 40 VI 30 vs Chain VI 40 VI 90		Chain VI 120 VI 30 vs Chain VI 120 VI 90	
SUBJECT 1						
Session	VI 30	VI 90	VI 30	VI 90	VI 30	VI 90
1	49.97	30.07	28.50	0	88.14	27.04
2	50.88	27.20	21.30	0	87.46	31.02
3	54.22	31.[illegible]	35.56	1.08	93.43	21.80
4	54.13	20.81	19.23	0	85.49	27.38
5	54.99	32.19	22.82	0	85.22	25.20
Average	52.79	28.27	25.48	0.21	87.54	26.48
SUBJECT 2						
Session	VI 30	VI 90	VI 30	VI 90	VI 30	VI 90
1	28.7[illegible]	17.96	12.74	0	30.37	34.87
2	39.23	35.45	9.71	0	17.71	34.09
3	23.65	20.25	10.05	9.46	19.30	43.31
4	20.60	19.01	29.64	0	37.71	34.95
5	34.39	19.51	11.51	13.33	21.03	22.75
Average	29.31	22.43	14.73	4.55	25.22	33.99
SUBJECT 3						
Session	VI 30	VI 90	VI 30	VI 90		
1	43.64	12.60	44.90	4.73		
2	34.39	11.32	20.06	26.26		
3	37.81	27.08	97.50	7.46		
4	64.60	33.57	11.51	5.22		
5	60.76	10.32	19.96	4.96		
Average	48.23	18.97	38.78	9.72		
SUBJECT 4						
Session	VI 30	VI 90	VI 30	VI 90	VI 30	VI 90
1	103.07	72.21	221.55	32.39	148.71	129.10
2	108.71	86.86	205.47	23.71	161.47	149.15
3	131.11	98.19	222.06	54.63	117.76	104.21
4	115.03	79.36	199.21	22.58	115.05	119.87
5	128.39	101.83	202.15	43.80	123.23	108.19
Average	117.28	88.05	210.08	35.42	133.30	122.10

Table 5. Mean response rates (responses/minute) for initial and terminal links of the alternative with the VI 30-sec terminal link and the alternative with the VI 90-sec terminal link.

Mean response rates for the alternative with the VI 30-sec terminal link

	Chain VI 90 VI 30 vs Chain VI 30 VI 90		Chain VI 40 VI 30 vs Chain VI 40 VI 90		Chain VI 120 VI 30 vs Chain VI 120 VI 90	
Subject	Initial	Terminal	Initial	Terminal	Initial	Terminal
1	36.95	6.14	21.04	16.57	51.39	20.17
2	21.36	18.01	11.35	6.87	16.58	6.37
3	19.30	1.26	5.63	1.19	12.91a	1.34a
4	108.52	8.16	203.39	10.05	154.23	4.26
Mean	46.53	8.39	60.35	8.67	58.78	8.04

Mean response rates for the alternative with the VI 90-sec terminal link.

	Chain VI 90 VI 30 vs Chain VI 30 VI 90		Chain VI 40 VI 30 vs Chain VI 40 VI 90		Chain VI 120 VI 30 vs Chain VI 120 VI 90	
Subject	Initial	Terminal	Initial	Terminal	Initial	Terminal
1	19.48	6.83	7.55	6.82	23.26	23.02
2	22.75	13.78	4.95	8.30	20.82	7.89
3	9.69	1.36	5.39	1.08	10.23a	2.39a
4	94.63	12.31	26.72	9.96	149.30	5.27
Mean	36.64	8.57	11.15	6.54	50.90	9.64

a Denotes value for last session in a condition where stability was not reached.

Table 6. Average terminal-link post entry pauses (seconds), for stability sessions of the unequal initial-link and VI 120-sec conditions for each subject. Data for the VI 40-sec condition are not presented due to low numbers of entries into the VI 90-sec terminal link (see Appendix I).

	Chain VI 90 VI 30 vs Chain VI 30 VI 90		Chain VI 120 VI 30 vs Chain VI 120 VI 90	
Subject 1				
Session	VI 30	VI 90	VI 30	VI 90
1	15.91	27.83	15.26	20.76
2	16.25	21.54	18.00	20.63
3	14.42	23.29	20.47	22.48
4	17.98	30.44	17.61	20.76
5	23.93	24.36	15.06	19.67
Mean	17.62	25.49	17.28	20.86
[illegible] 2				
[illegible]	VI 30	VI 90	VI 30	VI 90
[illegible]	6.00	7.08	25.61	39.59
[illegible]	3.56	11.13	39.05	37.70
[illegible]	2.94	12.52	23.23	37.56
[illegible]	11.33	12.95	25.10	35.74
[illegible]	7.44	9.64	22.05	46.61
[illegible]	6.25	10.66	27.01	39.44
Subject 3				
Session	VI 30	VI 90		
1	50.41	134.22		
2	52.20	116.76		
3	61.07	113.46		
4	64.55	98.21		
5	46.53	137.36		
Mean	54.95	120.00		
Subject 4				
Session	VI 30	VI 90	VI 30	VI 90
1	33.55	45.45	32.11	35.95
2	22.00	28.41	35.82	34.11
3	35.55	41.17	27.58	32.95
4	31.46	45.00	30.73	31.94
5	38.18	47.83	21.00	24.73
Mean	32.15	41.57	29.44	31.94

Chain A (Left Alternative)

```
                                              (Sd + Sr)
                                                Event          Sr+
|---------------------------------------------|------------|
             90 seconds                         30 seconds
            Initial Link                      Terminal Link
               (t1L)                              (t2L)
```

Chain B (Right Alternative)

```
          (Sd + Sr)
            Event                                              Sr+
|------------|---------------------------------------------|
  30 seconds                   90 seconds
 Initial Link                Terminal Link
    (t1R)                        (t2R)
```

Time to terminal reinforcement = 120 seconds

```
                                                               Sr+
|----------------------------------------------------------|
```

Chain A (t1L + t2L = 120 sec.)

Chain B (t1R + t2R = 120 sec.)

Average time to terminal reinforcement (T) = 97.73 seconds (see Appendix A for calculation)

```
                                                Sr+
|-----------------------------------------------|
```

Figure 1. Concurrent-chain schedules of reinforcement showing initial and terminal-link durations, overall time to reinforcement, and average time to reinforcement.

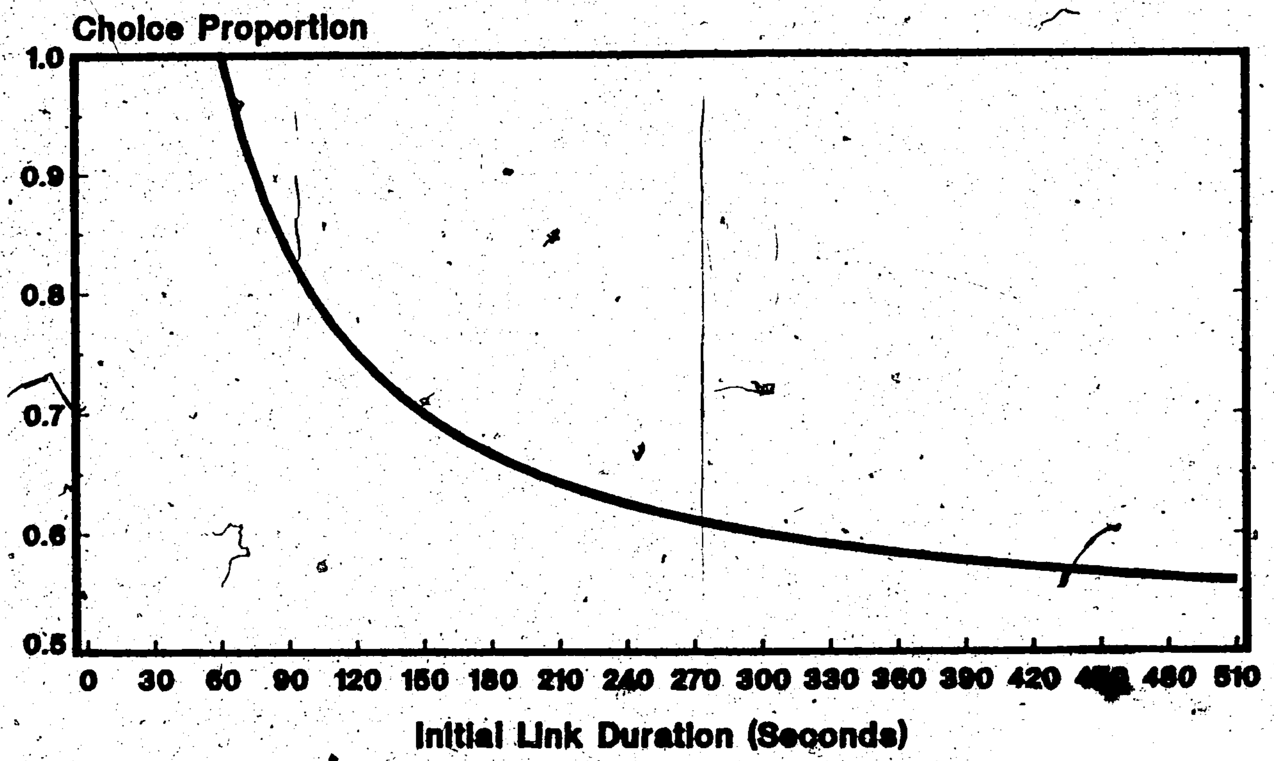

Figure 2. Changes in choice proportions predicted by the delay-reduction equation (Equation 4) across variation in initial link duration. Predictions are based on VI 30-sec and VI 90-sec terminal link schedules. Preference declines from exclusive preference toward indifference as initial-link duration increases.

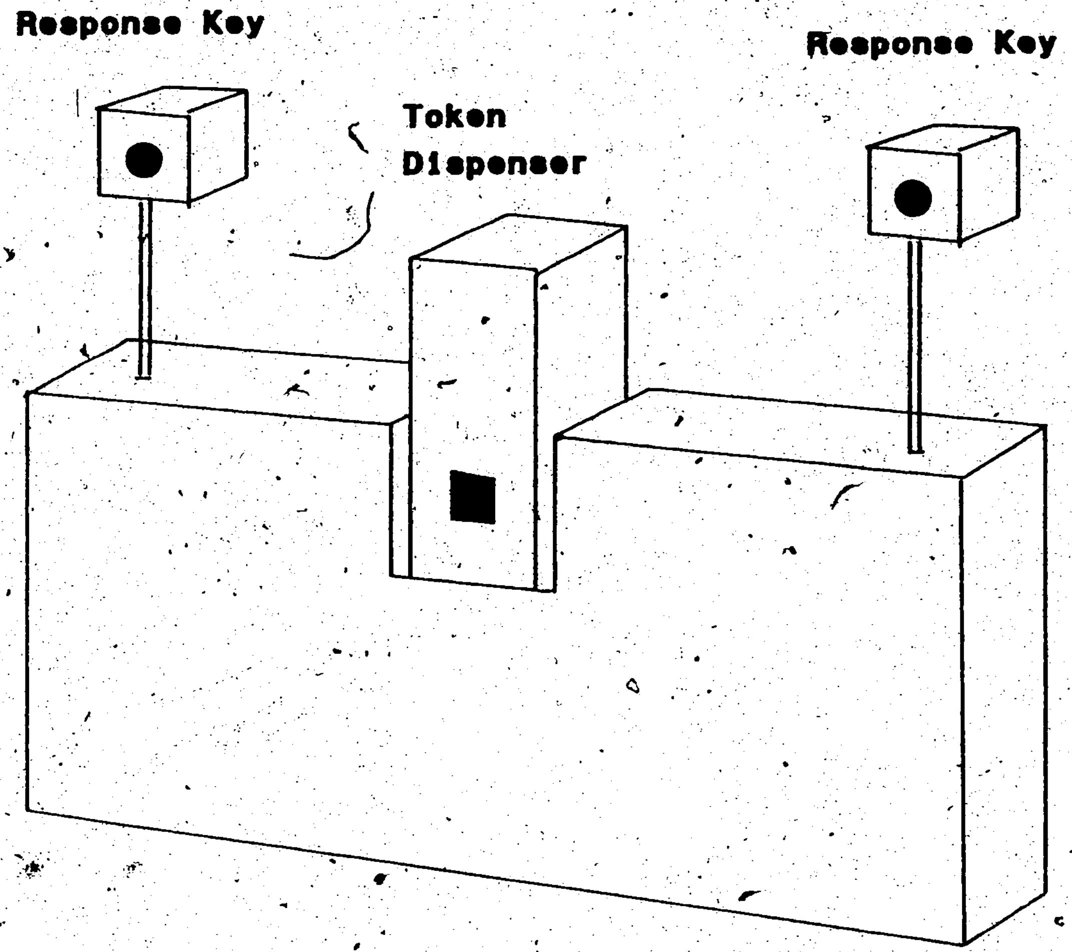

Figure 3. The Experimental Apparatus

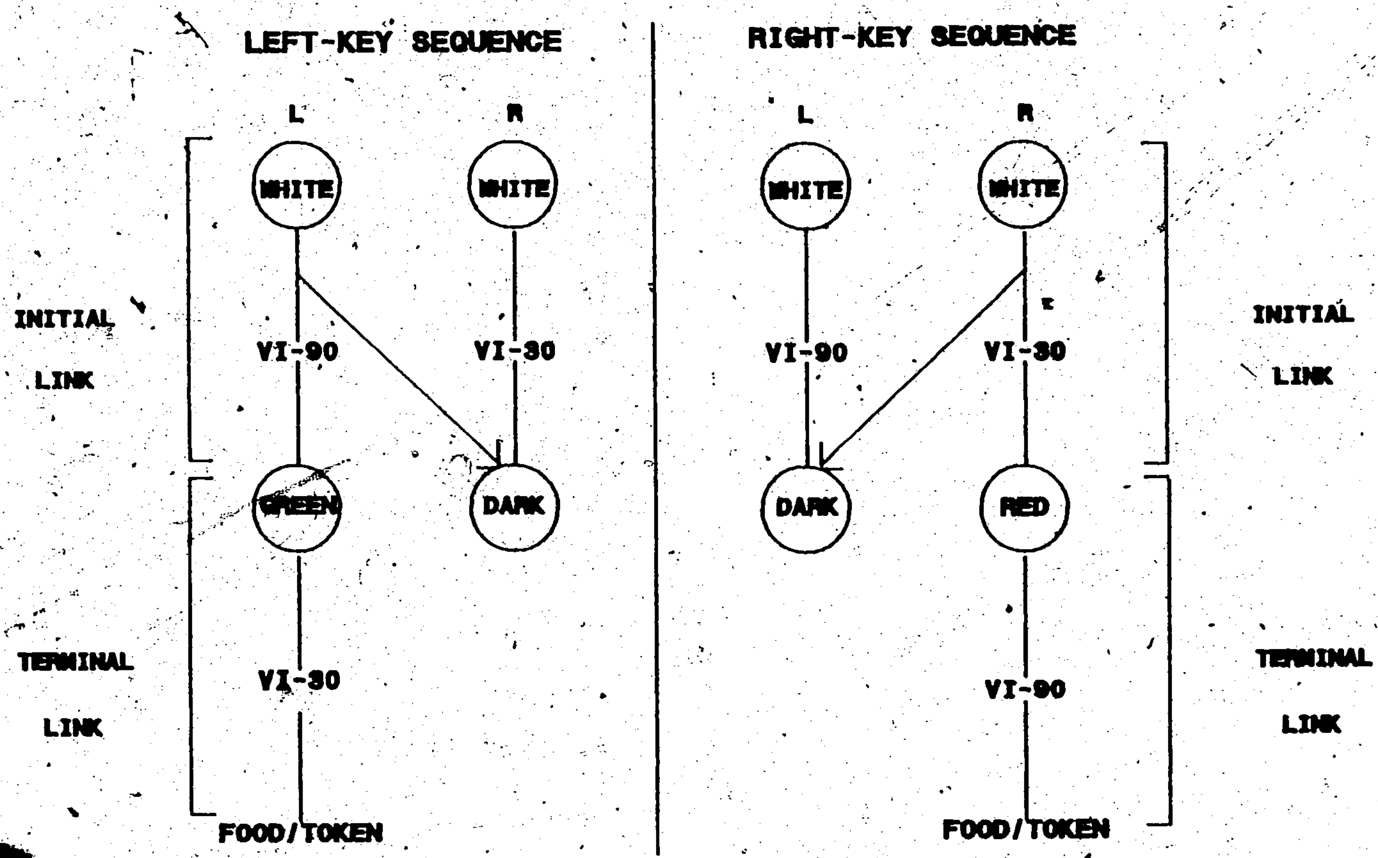

Figure 4. Concurrent-chain schedules showing left and right key sequences. The right alternative is a chain VI 30 VI 90 and the left is a chain VI 90 VI 30.

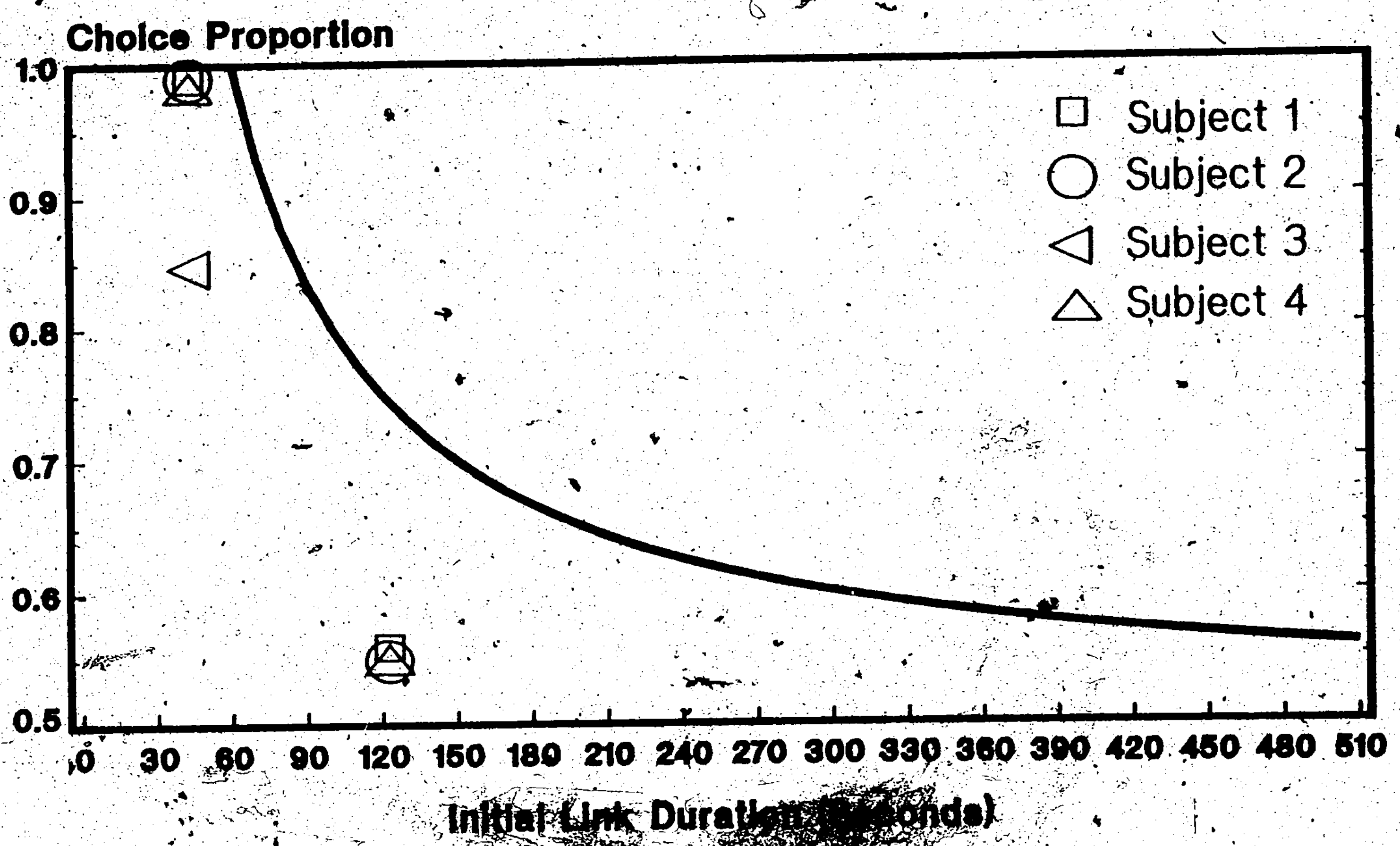

Figure 5. Subject data from VI 40-sec and VI 120-sec conditions plotted against the delay-reduction function.

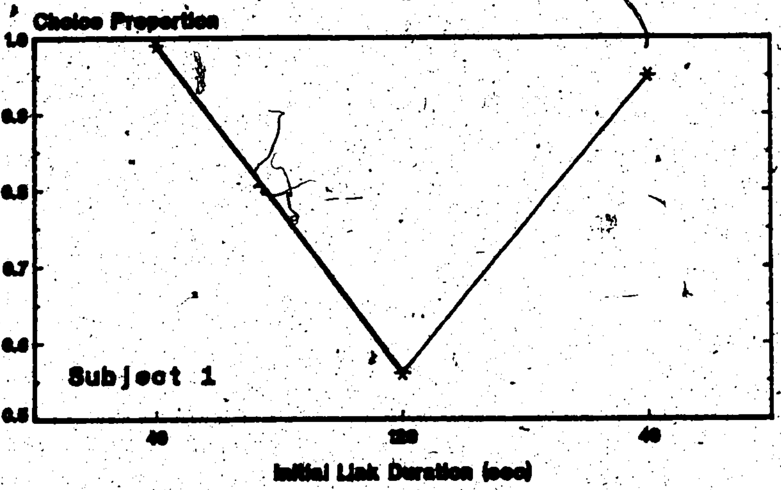

Figure 6a. Choice proportions vary as a function of initial-link duration. Subject 1's response proportion decreased when the initial links increased from VI 40-sec to VI 120-sec and then recovered when the VI 40-sec initial links were reinstated.

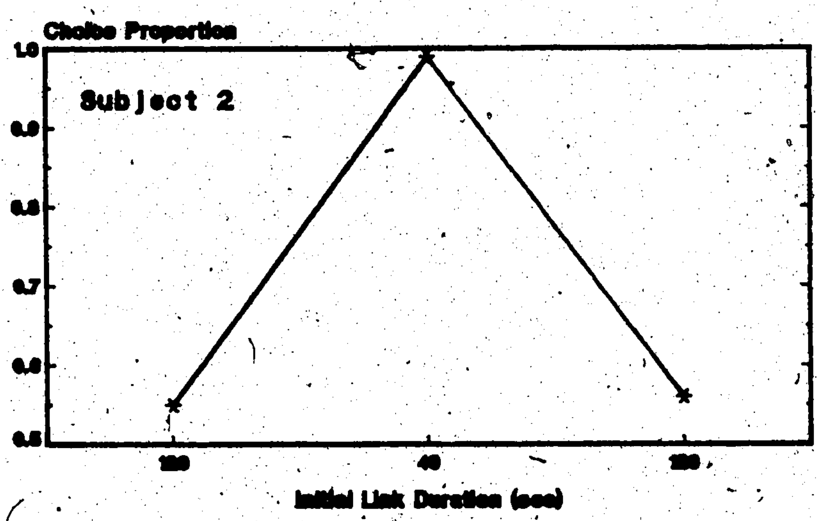

Figure 6b. Subject 4's response proportion increased when the initial links decreased from VI 120-sec to VI 40-sec and then recovered when the VI 120-sec initial links were reinstated.

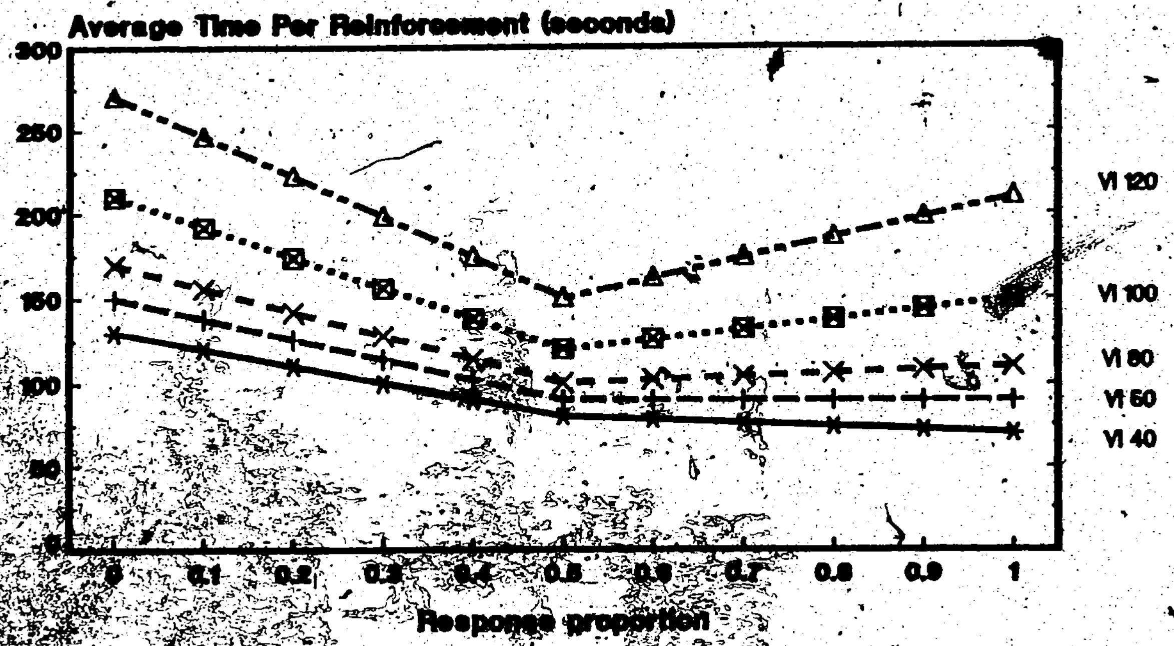

Figure 7. Idealized curves based upon a maximization assumption. For different equal initial-link conditions, the curves portray average time per reinforcement as a function of the proportion of responses allocated to the initial link of the alternative with the VI 30-sec terminal link. Functions are drawn for initial-link values of 40, 60, 80, 100, and 120 seconds. Rate of reinforcement is maximized for an initial-link value at the response proportion that coincides with the lowest point in the function for that value.

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APPENDIX A: Calculation of Average Time to Reinforcement in Concurrent-Chain Schedules

Squires and Fantino (1971) formulated the following equation for calculating average time to reinforcement in concurrent-chain schedules. Average time to reinforcement (T) is a major term in the delay reduction equation.

$$T = \frac{1}{1/t1L + 1/t1R} + (p)\ t2R + (1 - p)\ t2L$$

In this equation, t1L and t1R refer to the average durations of the left and right initial links. The terms t2L and t2R represent the average durations of the left and right terminal links. Finally, the probability of entering the right and left terminal links is represented as p and (1 - p) respectively. The probability of entering the right terminal link is calculated as p = t1L/(t1L + t1R).

Substituting the values from Figure 1 into the equation produces an average time to reinforcement (T) equal to 97.73 seconds.

$p = 90/(90 + 30)$
$p = 90/120$
$p = 0.75$
$(1 - p) = 0.25$

Thus, the probability of entering the right and left terminal links of the chains in Figure 1 are 0.75 and 0.25 respectively.

The average time to reach a terminal link from the onset of an initial link is calculated as follows:

$$\frac{1}{1/t1L + 1/t1R} = \frac{1}{1/90 + 1/30} = \frac{1}{0.11 + 0.33} = \frac{1}{0.44}$$

$$= 22.73$$

Thus, the average time to entry into a terminal link for the chains in Figure 1 is 22.73 seconds.

Finally the average time to terminal reinforcement upon entry into a terminal link is calculated as follows:

$(p)t2R + (1 - p)t2L$
$(0.75)\ 90 + (0.25)\ 30$
$67.5 + 7.5$
75 secpnds

Therefore, the average time to reinforcement for the chains in Figure 1 is as follows:

T = 22.73 seconds + 75 seconds

T = 97.73 seconds

APPENDIX B: Recruitment Interview

1) State your reason or reasons for wanting to participate in this study?

2) How important would this project be for you as part-time or temporary employment?

3) Do you generally show up on time for appointments or do you often miss appointments?

4) Participation in this study requires 5 sessions be completed every week until the study is finished. Session duration varies from 1 to 2 hours. Can you meet these requirements?

5) If sessions have to be run on weekends, does this present any special problems for you?

6) You can earn up to $10 every session and will be paid after each session. How much do you feel that you need the money that participating in this study would provide?

7) Have you ever participated in other studies conducted by the department of Sociology or Psychology? If yes, please describe these studies?

8) Have you ever taken any Sociology or Psychology courses? If yes, please describe the courses?

9) Have you ever seen any films or performed any independent readings in sociology or psychology? If yes, please specify?

APPENDIX C: Schedule Values

Initial-link and terminal-link schedules were programmed with the interval values reported in Fantino (1969). Those interval values in seconds are as follows:

VI 30-sec schedule

38, 32, 9, 22, 30, 5, 62, 7, 24, 24, 15, 16, 12, 65, 8, 48, 17, 34, 44, 6, 24, 91, 84, 72, 32, 20, 8, 9, 12, 22

VI 40-sec schedule

38, 30, 10, 34, 12, 29, 112, 108, 25, 10, 121, 60, 22, 20, 25, 20, 9, 17, 55, 30, 33, 49, 20, 113, 8, 44, 9, 20, 7, 37, 10, 70, 63, 10, 9, 16, 38, 83, 8, 20, 25, 14, 150, 32, 78

VI 90-sec schedule

60, 85, 143, 45, 200, 95, 57, 16, 143, 90, 51, 149, 107, 22, 326, 30, 31, 56, 12, 65

VI 120-sec schedule

24, 113, 54, 56, 66, 80, 264, 195, 205, 83, 8, 146, 230, 40, 238

APPENDIX D: Post Experimental Interview

1) What did you think the study was about?
2) Did you form any ideas about what we were researching during the course of the study? If so, what were they?
3) During the sessions, did you act on any of the ideas you had formed?
4) Describe how the apparatus worked?
5) Describe how you operated the apparatus to earn tokens?
6) Did you have to press the buttons a certain number of times to earn a token?
7) Describe how the two alternatives differed?
8) Describe how the red and green lights differed?
9) Describe what you did while the white lights were on?
10) Did you develop any rules for how you pressed the buttons when the white lights were on?
11) How did you choose between the alternatives in the study?
12) Did you choose between the alternatives differently when:
    a) the white lights took a long time to produce a colored light?
    b) the white lights took a short time to produce a colored light?

13) Describe how you felt about doing the experiment during the experiment?

14) Did you find the experiment boring?

15) If the experiment was boring, why did you continue to do the experiment?

16) Did you ever consider quitting the experiment? If so, why was this?

17) Remember, that I asked during the initial interview how much you felt you needed the money. Has your need for money changed since you began the experiment?

APPENDIX E: Stability Criterion Calculation

A subject's performance was judged stable when the overall rates of response fell between previous high and low values for five consecutive sessions on both keys. Overall response rates in the initial links were calculated as the number of responses made to a key divided by the session duration and expressed as responses per minute. An example is provided from the data for Subject 4 in Condition 1.

Session	Duration	Initial Link Responses			Overall Response Rate		
	(seconds)	Left	Right		Left	Right	
1	5940	1028	205		10.384	2.071	Low
2	5238	623	273		7.136	3.127	
3	4664	1793	468		23.066	6.021	
4	5520	957	204		10.402	2.217	
5	4823	1457	519	High	18.126	6.457	
6	5152	1150	478		13.393	5.567	
7	5261	742	498		8.462	5.680	
8	4832	627	683		7.786	8.481	
9	4800	659	859		8.238	10.738	
10	5048	542	1051		6.442	12.492	
11	4615	653	1097		8.490	14.262	
12	4742	588	1162		7.440	14.703	High
13	4925	437	1000	Low	5.324	12.183	
14	4618	730	1091		9.485	14.175	
15	4805	766	797		9.565	9.952	
16	4358	888	920		12.226	12.666	
17	4911	1020	1098		12.462	13.415	
18	4920	973	903		11.866	11.012	
19	4855	949	1120		11.728	13.841	

The overall rates for the last five sessions on the left and right alternatives fall between the high and low values for each alternative respectively.

APPENDIX F: Stability Data From All Subjects

Table F-1. Stability data from unequal initial-link condition for Subject 1. The left alternative is a Chain VI 30 VI 90 and the right alternative is a Chain VI 90 VI 30.

		Initial Link			
		Responses		Time	
Session	Duration	Left	Right	Left	Right
11	4550	253	333	775	515
12	4457	256	325	715	542
13	4356	282	360	698	565
14	4443	201	349	869	611
15	4645	235	366	775	586

		Terminal Link					
Changeovers		Responses		Time		Reinforcers	
Left	Right	Left	Right	Left	Right	Left	Right
47	48	343	32	2905	333	29	11
46	46	317	51	2637	537	28	12
43	43	380	44	2710	354	28	12
36	37	277	77	2251	682	25	15
40	41	271	32	2866	383	28	12

Table F-2. Stability session data from the unequal initial-link condition for Subject 2. The left alternative is a Chain VI 30 VI 90 and the right alternative is a Chain VI 90 VI 30.

		Initial Link			
		Responses		Time	
Session	Duration	Left	Right	Left	Right
20	4684	134	338	526	978
21	4703	297	637	448	1364
22	4729	129	388	390	1356
23	4830	125	300	424	1442
24	4678	216	582	612	1229

		Terminal Link					
Changeovers		Responses		Time		Reinforcers	
Left	Right	Left	Right	Left	Right	Left	Right
30	29	654	248	2447	693	25	15
27	27	650	201	2336	524	24	16
22	22	444	243	2195	774	23	17
27	27	303	98	2203	713	22	18
31	30	536	241	2041	783	22	18

Table F-3. Stability data from the unequal initial-link condition for Subject 3. The left alternative is a Chain VI 90 VI 30 and the right alternative is a Chain VI 30 VI 90.

		Initial Link			
		Responses		Time	
Session	Duration	Left	Right	Left	Right
13	8308	315	203	1135	1137
14	6786	253	157	856	1087
15	6982	271	220	725	997
16	7287	213	122	639	1086
17	8205	298	187	909	1270

		Terminal Link					
Changeovers		Responses		Time		Reinforcers	
Left	Right	Left	Right	Left	Right	Left	Right
18	18	34	66	1842	4157	17	23
12	12	28	70	1197	3620	15	25
17	18	19	88	1109	4146	14	26
12	11	28	166	985	4546	11	29
22	23	25	91	1447	4534	15	25

Table F-4. Stability session data from the unequal initial-link condition for Subject 4. The left alternative is a Chain VI 90 VI 30 and the right alternative is a Chain VI 30 VI 90.

		Initial Link			
		Responses		Time	
Session	Duration	Left	Right	Left	Right
16	4805	766	797	472	625
17	4358	888	920	518	597
18	4911	1020	1098	486	626
19	4920	973	903	557	657
20	4855	949	1120	510	577

Terminal Link							
Changeovers		Responses		Time		Reinforcers	
Left	Right	Left	Right	Left	Right	Left	Right
32	32	139	729	568	3122	11	29
46	45	43	794	347	2862	11	29
46	46	82	781	588	3181	11	29
40	40	24	323	476	3202	11	29
43	43	75	526	618	3114	11	29

Table F-5. Stability session data from the VI 40-sec initial-link condition for Subject 1. The left alternative is a Chain VI 40 VI 30 and the right alternative is a Chain VI 40 VI 90.

		Initial Link			
		Responses		Time	
Session	Duration	Left	Right	Left	Right
21	3292	618	7	1856	16
22	3042	590	0	1667	0
23	3291	506	22	1376	115
24	3077	522	0	1635	0
25	3319	677	0	1785	0

		Terminal Link					
Changeovers		Responses		Time		Reinforcers	
Left	Right	Left	Right	Left	Right	Left	Right
2	1	351	20	1296	94	38	2
0	0	383	0	1345	0	40	0
6	6	334	193	1224	543	34	6
0	0	371	0	1406	0	40	0
0	0	433	0	1502	0	40	0

Table F-6. Stability session data from the VI 40-sec initial-link condition for Subject 2. The left alternative is a Chain VI 40 VI 90 and the right alternative is a Chain VI 40 VI 30.

Initial Link

		Responses		Time	
Session	Duration	Left	Right	Left	Right
9	3924	0	453	0	2137
10	3776	0	327	0	2024
11	3646	0	323	0	1932
12	3318	12	395	63	1798
13	3685	2	367	9	1981

Terminal Link

Changeovers		Responses		Time		Reinforcers	
Left	Right	Left	Right	Left	Right	Left	Right
0	0	0	209	0	1775	0	40
0	0	0	181	0	1727	0	40
0	0	0	140	0	1705	0	40
3	3	45	222	146	1302	3	37
1	1	23	158	60	1624	1	39

Table F-7. Stability session data from the VI 40-sec initial-link condition for Subject 3. The left alternative is a Chain VI 40 VI 90 and the right alternative is a Chain VI 40 VI 30.

		Initial Link			
		Responses		Time	
Session	Duration	Left	Right	Left	Right
12	5834	23	159	312	2299
13	6421	36	214	448	2048
14	6321	43	224	353	2107
15	6323	34	218	402	2009
16	6682	39	170	440	2106

		Terminal Link					
Changeovers		Responses		Time		Reinforcers	
Left	Right	Left	Right	Left	Right	Left	Right
5	5	9	49	615	2561	5	35
7	8	26	53	1147	2745	7	33
6	6	9	59	763	3061	5	35
7	7	17	67	969	2867	7	33
7	7	28	53	1203	2888	6	34

Table F-8. Stability session data from the VI 40-sec initial-link condition for Subject 4. The left alternative is a Chain VI 40 VI 30 and the right alternative is a Chain VI 40 VI 90.

		Initial Link			
		Responses		Time	
Session	Duration	Left	Right	Left	Right
13	3218	4013	42	1150	100
14	2849	3743	25	1104	64
15	3178	4035	43	1143	87
16	3098	3287	35	1032	94
17	3216	3877	50	1156	91

		Terminal Link					
Changeovers		Responses		Time		Reinforcers	
Left	Right	Left	Right	Left	Right	Left	Right
10	9	149	240	1067	878	31	9
7	7	149	67	1072	590	33	7
10	9	141	92	1052	878	31	9
10	10	124	93	1034	904	30	10
11	10	330	209	1081	888	31	9

Table F-9. Stability session data from the VI 120-sec initial-link condition for Subject 1. The left alternative is a Chain VI 120 VI 90 and the right alternative is a Chain VI 120 VI 30.

		Initial Link			
		Responses		Time	
Session	Duration	Left	Right	Left	Right
19	5520	700	896	1734	1039
20	5535	711	870	1714	1009
21	5708	654	847	1903	935
22	5286	686	840	1659	1048
23	5694	695	874	1915	1028

Terminal Link							
Changeovers		Responses		Time		Reinforcers	
Left	Right	Left	Right	Left	Right	Left	Right
82	82	874	266	2051	666	21	19
80	81	670	301	1924	858	19	21
77	77	715	199	2103	730	21	19
77	77	658	294	1691	854	17	23
82	82	855	204	2060	650	21	19

Table F-10. Stability session data from the VI 120-sec initial-link condition for Subject 2. The left alternative is a Chain VI 120 VI 30 and the right alternative is a Chain VI 120 VI 90.

		Initial Link			
		Responses		Time	
Session	Duration	Left	Right	Left	Right
21	6374	574	440	2301	1059
22	6608	357	329	2017	1203
23	5765	483	422	1821	1039
24	5980	702	458	1825	1194
25	6834	525	479	1720	1869

		Terminal Link					
Changeovers		Responses		Time		Reinforcers	
Left	Right	Left	Right	Left	Right	Left	Right
48	48	122	271	1086	1914	23	17
32	31	60	271	1161	2213	20	20
48	47	98	271	904	1953	22	18
28	28	134	304	925	2022	21	19
26	26	118	228	1042	2188	22	18

Table F-11. Stability session data from the VI 120-sec initial-link condition for Subject 4. The left alternative is a Chain VI 120 VI 90 and the right alternative is a Chain VI 120 VI 30.

		Initial Link			
		Responses		Time	
Session	Duration	Left	Right	Left	Right
7	5760	3345	4125	1269	1508
8	5557	3691	4356	1199	1436
9	5632	2627	3820	1194	1571
10	5440	2995	2916	1260	1281
11	5422	2746	3402	1277	1432

Terminal Link							
Changeovers		Responses		Time		Reinforcers	
Left	Right	Left	Right	Left	Right	Left	Right
44	43	132	46	2167	772	22	18
41	40	174	68	1839	1062	18	22
37	37	176	52	2090	742	22	18
40	40	181	82	1827	1039	18	22
36	36	206	53	2047	642	22	18

APPENDIX G: Analysis of Variance Tables

Table G-1. Analysis of variance table for initial-link local response rates for Conditions 1, 2, and 3 for three subjects.

	SSH	SSE	MSH	MSE
CONDITION	1641.76	11203.59	820.88	1120.36
DURATION	6205.35	11203.59	6205.35	1120.36
CONDITION BY DURATION	2436.44	11203.59	1218.22	1120.36

	F-RATIO	DFH	DFE	PROB
CONDITION	0.73	2.0	10.0	0.5047
DURATION	5.54	1.0	10.0	0.0404
CONDITION BY DURATION	1.09	2.0	10.0	0.3739

MEANS

		DURATION		
CONDITION		SHORT	LONG	Row Means
ONE	*M*	66.45	46.25	56.35
TWO	*M*	83.43	13.39	48.41
THREE	*M*	82.02	60.86	71.44
Column Means		77.30	40.167	

Table G-2. Analysis of variance table for initial-link local response rates for Conditions 1 and 2 for all subjects.

	SSH	SSE	MSH	MSE
CONDITION	275.06	10311.55	275.06	1145.73
DURATION	6766.71	10311.55	6766.71	1145.73
CONDITION BY DURATION	1393.16	10311.55	1393.16	1145.73

	F-RATIO	DFH	DFE	PROB
CONDITION	0.24	1.0	9.0	0.6359
DURATION	5.91	1.0	9.0	0.0380
CONDITION BY DURATION	1.22	1.0	9.0	0.2988

MEANS

CONDITION		DURATION SHORT	LONG	Row Means
ONE	M	61.90	39.43	50.66
TWO	M	72.27	12.48	42.37
Column Means		67.08	25.95	

Table G-3. Analysis of variance table for initial-link local response rates for Subject 1.

Source	SS	DF	MS	F	P
Between Blocks					
Condition	9963.830	2	4981.915	354.086	<.001
Error	168.837	12	14.070		
Within Blocks					
Duration	10239.399	1	10239.399	606.765	<.001
Cond. X Dur.	2180.505	2	1090.329	64.611	<.001
Error	202.505	12	16.875		
Total	22755.230	29			

MEANS

DURATION

CONDITION		SHORT	LONG	Row Means
ONE	**M**	52.79	28.27	40.53
	SD	2.29	4.56	
TWO	**M**	25.48	0.21	12.84
	SD	6.60	0.48	
THREE	**M**	87.54	26.48	57.01
	SD	3.40	3.36	
Column Means		55.27	18.32	

Table G-4. Analysis of variance table for initial-link local response rates for Subject 2.

Source	SS	DF	MS	F	P
Between Blocks					
Condition	2253.381	2	1126.691	14.008	.001
Error	965.163	12	80.430		
Within Blocks					
Duration	57.160	1	57.160	1.576	.231
Cond. X Dur.	512.133	2	256.066	7.060	.009
Error	435.259	12	36.272		
Total	4223.096	29			

MEANS

		DURATION		
CONDITION		SHORT	LONG	Row Means
ONE	M	29.31	22.43	25.87
	SD	7.62	7.32	
TWO	M	14.73	4.55	9.64
	SD	8.42	6.38	
THREE	M	25.22	33.99	29.60
	SD	8.53	7.32	
Column Means		23.09	20.32	

Table G-5. Analysis of variance table for initial-link local response rates for Subject 3.

Source	SS	DF	MS	F	P
Between Blocks					
Condition	437.393	1	437.393	1.107	.324
Error	3160.290	8	395.036		
Within Blocks					
Duration	4251.820	1	4251.820	10.248	.012
Cond. X Dur.	0.051	1	0.051	0.000	
Error	3318.994	8	414.874		
Total	11168.548	19			

MEANS

DURATION

CONDITION		SHORT	LONG	Row Means
ONE	M	48.23	18.97	33.60
	SD	13.65	10.64	
TWO	M	38.78	9.72	24.25
	SD	35.12	9.30	
Column Means		43.51	14.35	

Table G-6. Analysis of variance table for initial-link local response rates for Subject 4.

Source	SS	DF	MS	F	P
Between Blocks					
Condition	3519.148	2	1759.574	4.308	.038
Error	4901.445	12	408.454		
Within Blocks					
Duration	38547.354	1	38547.354	853.354	<.001
Cond. X Dur.	40169.903	2	20084.952	444.725	<.001
Error	541.951	12	45.163		
Total	87679.802	29			

MEANS

DURATION

CONDITION		SHORT	LONG	Row Means
ONE	M	117.26	88.05	102.65
	SD	12.19	12.44	
TWO	M	210.08	35.42	122.75
	SD	10.92	13.68	
THREE	M	133.30	122.10	127.70
	SD	20.62	18.02	
Column Means		153.55	81.85	

Table G-7. Analysis of variance table for initial-link and terminal-link mean response rates on the alternative with the VI 30-sec terminal link.

	SSH	SSE	MSH	MSE
CONDITION	229.96	25477.67	114.98	1698.51
COMPONENT	13172.35	25477.67	13172.34	1698.51
CONDITION BY COMPONENT	228.74	25477.67	114.37	1698.51

	F-RATIO	DFH	DFE	PROB
CONDITION	0.07	2.0	15.0	0.9348
COMPONENT	7.76	1.0	15.0	0.0139
CONDITION BY COMPONENT	0.07	2.0	15.0	0.9352

MEANS

COMPONENT

CONDITION		INITIAL	TERMINAL	Row Means
ONE	<u>M</u>	46.53	8.39	27.46
TWO	<u>M</u>	60.35	8.67	34.51
THREE	<u>M</u>	58.78	8.04	33.41
Column Means		55.22	8.37	

Table G-8. Analysis of variance table for initial-link and terminal-link mean response rates on the alternative with the VI 30-sec terminal link.

	SSH	SSE	MSH	MSE
CONDITION	1885.77	11204.54	942.88	746.97
COMPONENT	3644.75	11204.54	3644.75	746.97
CONDITION BY COMPONENT	1378.15	11204.54	689.07	746.97

	F-RATIO	DFH	DFE	PROB
CONDITION	1.26	2.0	15.0	0.3114
COMPONENT	4.88	1.0	15.0	0.0432
CONDITION BY COMPONENT	0.92	2.0	15.0	0.4189

MEANS

		COMPONENT		
CONDITION		INITIAL	TERMINAL	Row Means
ONE	M	36.64	8.57	22.60
TWO	M	11.15	6.54	8.85
THREE	M	50.90	9.64	30.27
Column Means		32.90	8.25	

APPENDIX H: Transcript Of Graffitti Showing Counting Behavior.

Graffitti from the barricades next to the right and left response keys. This graffitti appears to be sequences of interval values for the first ten reinforcers on each alternative.

1 - 32
2 - 102
3 - 121
4 - 42
5 - 12
6 - 81
7 - 134
8 - 31
9 - 132
10 - 22

1 - 13
2 - 58
3 - 56
4 -
5 -
6 -
7 -
8 -
9 -
10 -

+ 7
+ 11 1111
+ 15 ~~1111~~ ~~1111~~
+ 13 1111
+ 17 1111
+ 21 111
+ 26 ~~1111~~ 11
+ 27 ~~1111~~ ~~1111~~ 1
+ 24 1111

+ 28 1111
+ 32 111
+ 37 ~~1111~~
+ 40 ~~1111~~ 11

+ 2
+ 5
+ 7
+ 11
+ 15
+ 17
+ 20
+ 18
+ 16

+ 19
+ 22
+ 10
+ 9
+ 9
+ 12
+ 16
+ 15
+ 13

+ 10
+ 4
+ 8
+ 7
+ 5
+ 8
+ 10
+ 14
+

Note: ~~1111~~ represents four vertical slashes with a horizontal slash through the middle. This collection of symbols represents a count of five.

APPENDIX I: Post Entry Pauses for VI 40-sec Condition

Table I-1. Average terminal link post entry pauses (seconds) for stability sessions of the VI 40-sec condition for each subject.

Chain VI 40 VI 30
vs
Chain VI 40 VI 90

Subject 1

Session	VI 30	VI 90
1	12.26	17.50
2	12.50	-
3	13.29	17.00
4	13.93	-
5	12.33	-

Subject 2

Session	VI 30	VI 90
1	23.73	-
2	20.05	-
3	21.13	-
4	13.73	14.00
5	21.31	-

Subject 3

Session	VI 30	VI 90
1	61.51	63.00
2	72.52	17.00
3	76.63	66.20
4	71.39	56.71
5	72.50	39.00
Mean	70.91	48.38

Subject 4

Session	VI 30	VI 90
1	12.39	14.44
2	10.88	17.71
3	8.87	11.00
4	11.43	11.00
5	9.68	11.50
Mean	10.65	13.13