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HUMAN CHOICE PERFORMANCE ON CONCURRENT-CHAINS SCHEDULES IS NOT AFFECTED BY THE CONSUMABILITY OF THE TERMINAL REINFORCER AND IS BETTER DESCRIBED BY MAXIMIZATION THAN MATCHING

BY

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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 HUMAN CHOICE PERFORMANCE ON CONCURRENT-CHAINS SCHEDULES IS NOT AFFECTED BY THE CONSUMABILITY OF THE TERMINAL REINFORCER AND IS BETTER DESCRIBED BY MAXIMIZATION THAN MATCHING submitted by TAMMI YOLANDA KWAN in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE.

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Abstract

In Experiment 1, humans were tested with a concurent-chains VI VI schedules with unequal initial links. In addition to testing subjects with token reinforcement, probe sssicns with food reinforcement were added to examine whether human performance is affected by the consummable nature of the reinforcer. The results indicate that choice allocation is not affected by the consummability of the reinforer. Performance in sessions with tokens was similiar to performance in probe sessions with food.

The data in Experiment 1 was best described by matching and maximization equations. The goal of the Experiment 2 was to examine whether matching or maximization best describes human performance. Subjects were tested with concurrent-chains schedules with initial links of VI VR and terminal FR1 links. Performance was best described by the maximization equations.

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Human Choice Performance on Concurrent-Chains Schedules is not Affected by the Consumability of the Terminal Reinforcer and is Better Described by Maximization than Matching

In a recent study, Belke, Pierce, and Powell (1989) examined humans and pigeons with concurrent-chains VI VI schedules and found performance differences between humans and pigeons. Human choice behavior was best described by the matching and maximization equations but pigeon performance was best described by delay reduction equations. However, the nature of the terminal reinforcer may have been responsible for this performance difference. Although the schedules were identical for humans and pigeons, pigeons were given terminal reinforcement that was consumable on presentation and humans were given tokens.

Experiment 1 examined whether the consumability of the terminal reinforcer affects human choice behavior in concurrent-chains VI VI schedules. Humans were tested with concurrent-chains VI VI schedules with two types of terminal reinforcement, food and tokens.

The second experiment was designed to examine whether humans are better described by matching or maximization models of choice. Humans were exposed to concurrent-chains schedules with VI VR initial links and terminal links of FR1. Initial links of VI VR were chosen because Herrnstein and Heyman (1979) argued that such schedules produce data that can not be predicted by both maximization and matching models.

Experiment 1

Concurrent-chains schedules of reinforcement involve the simultaneous presentation of two or more operant chains. Each chain is composed of an initial and a terminal link. Responding to the initial links produces the opportunity to respond for reinforcement in a terminal link. In a recent study, Belke, Pierce, and Powell (1989) used the concurrent-chains procedure with initial and terminal links of variable interval (VI) schedules to investigate the choice behavior of pigeon and human subjects. Humans responded in a manner that maximized the overall rate of reinforcement for an experimental session, although matching (Herrnstein, 1961) could not be ruled out. In contrast, pigeons responded so as to reduce the relative time to reinforcement.

Belke, Pierce, and Powell (1989) have argued that the performance differences between pigeons and humans may be the product of a procedural difference in reinforcement. Pigeons were reinforced with food - a reinforcer that was consumed upon presentation. Human, however, were reinforced by tokens that were not immediately consumed. Instead, tokens were exchanged for money at the end of each session.

The study reported here investigated whether human performance is influenced by the consumable nature of the terminal reinforcer. A concurrent-chains VI VI schedule with unequal initial links (i.e. VI30s VI90s vs VI90s VI30s) was the same as in Belke et al.'s (1989) study. However, in the present investigation, probe sessions in which food was the terminal reinforcer was examined. Choice was measured as the allocation of responses to the initial links. The choice proportions obtained in the probe sessions were then compared to expected values predicted by delay reduction, matching and maximization models.

Delay Reduction, Matching and Maximization

Because the performance of subjects in Belke et al.'s (1989) study was best predicted by delay reduction (Squires & Fantino, 1971) and maximization (Houston, Sumida, & McNamara, 1987) models of choice behavior, these models were the focus of the study reported here. The matching (Herrnstein, 1961) model was also included because Belke et al. (1989) could not conclusively rule out this model as an account of their human data. The following is a brief summary of each model and its corresponding equation.

Fantino (1971) suggested that the relative rate of response in the initial links of a concurrent-chains is a function of both the relative overall rate of reinforcement and the relative reduction in the expected time to reinforcement that is signalled by the onset of the terminal link. The delay reduction equation is expressed as:

$$\frac{RL}{RL + RR} = \frac{rL\,(T - t2L)}{rL\,(T - t2L) + rR\,(T - t2R)} \,. \qquad (1)$$

In this equation, RL and RR are the number of responses to the left and right initial links, respectively, and t2L and t2R represent the expected time to reinforcement in the corresponding terminal links. The terms rL and rR are the rates of reinforcement of the left and right alternatives and are calculated by the equations $rL = 1/(t1L + t2L)$ and $rR = 1/(t1R + t2R)$. The terms t1L and t1R are the expected times of entry to the terminal links from the left and right initial components, respectively. The term T is the expected time to reinforcement in the terminal links from the onset of the initial links (see Appendix for the calculation of T).

Belke, Pierce, and Powell (1989) noted that Equation (1) can be reduced if delay reduction is not functional. In this case, the terms (T-t2R) in Equation (1) are equivalent to T. When the multiplier, T, is factored out of this equation, Herrnstein's (1961) matching equation is obtained, and it is expressed as:

$$\frac{RL}{RL + RR} = \frac{rL}{rL + rR} . \qquad (2)$$

According to this equation, relative rate of response is a function of relative rate of reinforcement.

Finally, choice proportions on concurrent-chains schedules can be predicted by Houston, Sumida, and McNamara's (1987) maximization equation. This equation was developed from a maximization model which predicts that animals will allocate their behavior in a manner that produces the greatest overall rate of reinforcement for a session. The equation is expressed as:

$$\frac{1}{v} = \frac{2r + \frac{1}{u_1} + \frac{2}{u_2}}{E(N1) + E(N2)} + D1 + \frac{E(N2)\,(D2 - D1)}{E(N1) + E(N2)} . \qquad (3)$$

In this equation, the term v is the overall rate of reinforcement for a session. The expected travel time from one alternative to another is represented by r. The terms E(N1) and E(N2) are the expected number of entries into the terminal links. The values D1 and D2 represent expected time to reinforcement in the terminal links and are equivalent to the terms t2L and t2R in Equation (1). The terms u_1 and u_2 are the switch rates that would maximize v. The only constraint on these rate is that $u_1 + u_2 = 1/I$, where I is the reciprocal of the sum of the two changeover rates. The values of u1 and u2 which results in the maximum v value are then used to obtain the relative rate of responding by Equation 4:

$$\frac{RL}{RL + RR} = \frac{u_1}{u_1 + u_2}. \tag{4}$$

The calculations completed to solve equation (3) are outlined in the method section.

This study tested whether consumability of the terminal reinforcement is a variable that influences choice performance. Data was analyzed to assess whether Belke et al.'s (1989) results with humans could be replicated. Specially, the accuracy of the delay reduction, matching, and maximization equations was evaluated.

Method

Subjects

Three male university students, ranging from 19 to 23 years old, were subjects. Subjects were solicited by advertisement from a summer employment agency for students. The advertisement requested participants for a two week study of choice and preference, in which they would have the opportunity to earn a maximum of $50.00 a day. Subjects had no prior experience in psychological experiments. The subjects' search for summer employment via an employment agency provided evidence that money was an effective reinforcer for them. All subjects said they ate daily lunches of sandwiches, fruit, beverage and snacks.

To ensure that the experimental procedures would not present possible health problems to the subjects, they filled out a questionnaire regarding their health. All subjects expressed a lack of health concerns (e.g. diabetes, hypertension, stomach ulcers) which would prevent them from standing for long periods of time and abstaining from food for six consecutive hours. None of the subjects required a special diet or had any known food allergies.

Apparatus

A human operant chamber was constructed to resemble a standard operant chamber for pigeons. The chamber was a room that was 3.16 m X 5.07 m. The experimental apparatus was the same one used for humans in the Belke, Pierce, and Powell (1989) study. It was a free standing structure with a height of 1.2 m and base of 2.5 m X 0.03 m. In the center of the experimental apparatus was a token dispenser with a height of 80 cm and a base of 20 cm X 20 cm. Internally, the token dispenser was equipped with a vending machine coin dispenser, a modified pigeon hopper with an attached metal plate, and a relay. Nickle-size aluminum tokens (2.2 cm diameter) engraved with "25" on one face, were dropped by the token dispenser onto the metal plate of hopper. The hopper remained in a horizontal position for 4 s at the end of a terminal link and subjects had the opportunity to retrieve a token through a 7 cm X 7 cm opening in front of the dispenser. The hopper plate retracted after 4 s and any token that was not retrieved during this time dropped into a collection bin that was inaccessible to the subject.

A wooden response key housing (15 cm wide, 20 cm deep, 15 cm high) was located at each end of the apparatus. Access to a response key was possible through a hole (2.5 cm diameter) in the center of each housing unit. The response keys were identical to those used for pigeons and could be transilluminated by a white, red, or green light. The height of the response keys was adjusted to be 0.14 m above the standing height of each subject during experimental sessions. A response key and a light assembly were attached to a metal plate (15 cm X 15 cm) within each housing. The response key housings were also separately equipped with a Sonalert Audible Signal (28 V DC).

Directly opposite the token dispenser was a Vendura Visi-Vend vending machine, with a height of 2.02 m and a base of 89 cm X 80 cm. The vending machine was modified so that it was operated by responses to the programmed keys rather than by coins inserted in a slot at the side of the machine. The vending machine was kept at 5 C. It was equipped with 10 selection racks with each rack containing 15 stainless steel triangular compartments (10.5 cm wide, 16.5 cm deep, 10.5 cm high). A compartment's content could be seen through a glass door (10.5 cm X 15 cm) that could be opened and closed. A locking mechanism kept the doors locked and released the lock when food became available. When reinforcement was available, the locks were released for 4 s and the doors could be manually opened. A 4 s tone from the vending machine's Sonalert (28 V DC) indicated the opportunity to open a door and to obtain the contents of the corresponding compartment. On the right hand side of each glass door was a glass-covered window (7.7 cm X

9.7 cm) in which labels corresponding to the contents of each rack were placed.

The locking mechanism for the doors was programmed so that only one food item could be obtained during the 4 s reinforcement period. Attempts to open two doors at the same time or to open a second consecutive door during the 4 seconds were ineffective.

Barriers were set up to enclose the token apparatus and the vending machine so that an area of 2.45 m X 0.91 m existed between the two devices. The only other piece of equipment in the room was a Canon VC-20 Model #136 camera located in a corner, behind the vending machine and facing the token dispenser. During experimental sessions, a Kleenex box was placed on one side of the vending machine and a garbage pail was placed on the other side.

In an adjacent room, an Apple IIe computer arranged experimental events and recorded data. A VCR and monitor was also present and was used to film experimental sessions. Interfacing was completed with Coulbourne Instruments programming equipment.

<u>Procedure</u>

<u>Daily sessions</u>. Subjects reported to the laboratory at 0800. From 0800 to the time of departure from the laboratory, food and caloric beverages were ingested only during the probe session. Water was available during the breaks between sessions. An experimental session was completed when 40 reinforcers were delivered. At the end of token sessions, each token was exchanged at a value of 25 cents.

Subjects were required to complete four experimental sessions with tokens prior to the probe session with food. This procedure insured that subjects were food deprived for a minimum of 6 h. For subjects that ate regular lunches, this level of deprivation was sufficient to establish food as an effective reinforcer. Subjects responded in the probe sessions to obtain food. After the food sessions, subjects completed a fifth token session for the day. Except for a 20 min break after the fourth token session, all other sessions were followed by 10 minute breaks.

Concurrent-chains schedules. Subjects were presented with a concurrent-chains schedules. A VI30s VI90s chain was on one response alternative and a VI90s VI30s was on the other alternative. A 3 s changeover delay (COD) was implemented.

At the start of a session, both keys were transilluminated with white light that signalled the availability of an initial link. After the initial link had elapsed, the next response to that alternative had two effects. The white light on that key changed to either a red or a green light. The colored light signalled the opportunity to respond in the corresponding terminal link. At the same time, the other response key became dark and inoperative. The red light was associated with the terminal link of VI90s and the green light was associated with the terminal link of VI30s.

When the programmed time for a terminal link had elapsed, the next response provided access to reinforcement. During reinforcement, both keys were completely darkened and inoperative. Reinforcement was either 4 s of access to a food item or to a token, depending on the reinforcement condition. Once reinforcement was delivered, both keys were again transilluminated with white light and the two initial links were operative. An experimental session was completed when 40 reinforcers were delivered. At the end of token sessions, each token was exchanged at a value of 25 cents.

A colored light was always associated with the same terminal link but its key position alternated. Half the sessions were completed with the red light and the corresponding VI 90 s terminal link present on the right key. For the other half of the sessions, the red light and the VI 90 s terminal link were present on the left key. This alternating procedure was implemented to control response bias due to position preference.

Instructions. Upon arrival at the laboratory, subjects were asked to empty the contents of their pockets, and to remove their watch and jacket. This ensured that subjects did not have any timing devices. At the beginning of a session, subjects were escorted to the experimental chamber and were read the following instructions:

> There are no instructions. Do not touch the camera. The session will begin in a moment.

When the session was completed, the experimenter entered the chamber and read the following instructions:

> The session is finished. Do you have any tokens to exchange?

After each session, subjects were given a ten minute break. They were read the following instructions:

You have a 10 minute break. You may leave the laboratory lounge to go to the washroom or to the water fountain. Do not go anywhere else except to the washroom or the water fountain.

Before a food session, subjects were given a 20 minute break rather than the usual 10 minute break. They were read the instructions for the 10 minute break, except the number 10 was replaced with 20. The 20 minute break was implemented to allow the experimenter time to load the vending machine with food, to place the food labels behind the glass-covered windows, and to turn the vending machine on so that it would internally cool to the predetermined temperature.

Food Reinforcement. Besides establishing a 6 h deprivation period prior to a food session, the following three procedures were implemented to further ensure that the food items presented were effective reinforcers. First, subjects completed an extensive list of their favorite lunch foods. Subjects then rated each food item on a 1 to 10 scale with the rating of 1 representing low satisfaction and the rating of 10 representing high satisfaction. During food sessions, a subject was presented only with food items that he had rated as 8, 9, or 10. Second, the food items were prepared daily under the subjects' specifications. Third, satiation to food items due to repeated presentations was controlled by presenting 9 new food items every day with no food item presented twice in 3 consecutive days.

During each food session, subjects were presented with 3 beverage alternatives, 3 sandwich alternatives, 2 fruit or vegetable alternatives and 2 snack food alternatives. Beverage items were served in volumes of 20 ml and were presented in crystalline wine glasses (volume of 125 ml). Each sandwich item was 1/16 of a full sandwich made with bread (7.5 cm X 7.5 cm, 0.5 cm thickness). Solid food items were presented on paper plates (4.5 cm diameter) and wrapped in transparent plastic wrap.

Preliminary Training for Token Sessions. Subjects were magazine trained to the token dispenser with physical access to both keys blocked. Access to keys was removed by lowering the keys behind a plexiglass shield. The experimenter pressed a switch in the adjacent room and released tokens from the token dispenser every 5 seconds. Each token was released onto the raised metal platform and was available for 4 seconds. Once the subject has picked up a token, the experimenter immediately entered the chamber and asked "Do you have any tokens to exchange?". The token was exchanged for 25 cents. Next, subjects were required to obtain 4 tokens before the experimenter entered to exchange them for one dollar ($1.00).

After the completion of magazine training, subjects worked through 5 token-training sessions, which are summarized in Table 1. A session was completed when 20 tokens were delivered.

In the first two sessions, both keys were programmed with a FR1 FR1 chain schedule. In Session 1, only the right key was accessible and the subjects were given the opportunity to press this key to obtain tokens. Subject 1 did not press the raised key after 20 minutes during the first session. The subject was shaped by successive approximation and again exposed to the conditions of Session 1. In the second session (Session 2), only the left key was accessible and the subjects were given the opportunity to press this key to obtain tokens. Tokens were exchanged after the completion of each training session.

In Sessions 3 to 5, one key was associated with the VI30s VI90s chain schedule and the second key was associated with the VI90s VI30s chain schedule. In Session 3, only the key associated with VI90s VI30s chain schedule was accessible. In Session 4, only the key associated with the VI30s VI90s chain schedules was accessible. Finally, in Session 5, both keys were accessible.

Insert Table 1 about here

Preliminary Training for Food Sessions. Following training for token reinforcement, subjects were deprived of food and caloric beverages for 6 consecutive hours and then magazine trained with physical access to both keys blocked. The token dispenser was inactivated. The compartments of the vending machine was filled with food and the appropriate labels for the food items were placed behind the glass windows. Both the food compartments and the glass windows for name labels were illuminated. The experimenter pressed a switch that activated the vending machine's Sonalert and released the locking mechanism on the glass doors for 4 seconds. The experimenter continued to press the switch until a subject has obtained 10 food items from the vending machine by manually opening the glass doors.

After the completion of magazine training, subjects worked through three training sessions with food. During each session, subjects were required to obtain 10 food reinforcements. Refer to Table 2 for a summary of the schedules and conditions used. The keys were programmed with the VI30s VI90s concurrent-chains schedules. In Session 1, subjects were required to obtain reinforcements from the key controlled by the VI90s VI30s chain schedule. The key controlled by the VI30s VI90s chain schedule was inaccessible. Session 2 was identical to the first session except that the key controlled by the VI30s VI90s chain schedule was no longer available. In the third session, both keys were accessible.

Insert Table 2 about here

During the training phases, subjects opened the doors of the vending machine and ingested the food. Obtaining and ingesting the food indicated that it was an effective reinforcer.

Stability Criteria. Choice was measured as the allocation of responses during the initial links. The stability criteria used for the token sessions in this study were identical to those used in Belke, Pierce, and Powell's (1989) study. First, a subject had to complete at least 10 token sessions. Second, the values of the highest and lowest choice proportion of 5 consecutive sessions had to be within a range of 0.10. Third, the response rates for the two alternatives (the number of responses to an initial link divided by the total session time) had to fall within previous ranges of response rates for five consecutive sessions.

To illustrate the third criterion, consider that 3600 responses were emitted to the initial link of alternative A during a 1 h session. The response rate for this alternative would be 1.0/s. If the highest and lowest response rates for alternative A in previous sessions were 1.2/s and 0.5/s, respectively, then 1.0/s would fall within the range of variation. However, if the previous highest response rate was 0.9/s, the new range for alternative A would be 0.5/s - 1.0/s. This procedure was implemented to determine whether response rates were stable for each chain. When response rates for both alternatives fell within their respective range of variability for five consecutive sessions, the third criterion was satisfied.

After subjects reached stability criteria on token sessions, data from the next three food sessions were used for analysis.

Solving the Maximization Equation. The choice proportion predicted by the maximization equation (Equation 3) was solved using the following procedures. The variable r was set at 4 s. This value is the sum of the 3 s COD and the 1 s travel time between keys. The values of D1 and D2 were 30 s and 90 s, respectively. The values of E(N1) and E(N2) were solved using the general equation,

$$E(N_i) = c_i + y_i/u_i. \quad (5)$$

In this equation, y_i is the expected time to the terminal link of i from the initial link of i, and c_i is the probability of entry into a terminal link on arrival at alternative i. The values of c_1 and c_2 were obtained using the equations (Houston, Sumida, & McNamara, 1987):

$$c_1 = 1 - \frac{u_2}{y_1 + u_2} e^{(-2y_1 r)} \qquad (6)$$

and

$$c_2 = 1 - \frac{u_1}{y_2 + u_1} e^{(-2y_1 r)}. \qquad (7)$$

A Mackintosh Excel spreadsheet program was used to obtain the switch rates u_1 and u_2, that would maximize v. The value of u_1 was initially set as 0 and was incremented by 0.001. The switch rate, u_2, was decremented accordingly via the equation $u_2 = 1/I - u_1$, with the value of I estimated from the obtained switch rates of u_1^* and u_2^*. For each pair of switch rates, v was calculated. Calculation stopped when v was at a maximum value. The u_1 and u_2 values that maximized v were then used to calculate the expected proportion of responses to the VI90s VI30s chain (Equation 4).

<u>Results</u>

Analysis was completed using the data from token sessions which satisfied the stability criteria and from the food probe sessions which followed these token sessions. Table 3 contains a summary of the mean number of responses and the mean amount of time allocated in the initial links, the mean number of entries into the terminal links, the mean number of changeovers per session, and the mean number of sessions to stability in the token sessions.

Insert Table 3 about here

The mean proportion of responses allocated to the VI90s VI30s alternative are summarized in Table 4. To assess whether consumability of the terminal reinforcer influences performance, an analysis of variance was completed between the response proportions obtained in the two reinforcement conditions. The analysis yield a value of $F = 0.23$. This value was not significant (alpha = 0.05). The performance of humans on concurrent-chains schedules appears to be unaffected by the consumability of the reinforcer.

Insert Table 4 about here

Table 5 is a summary of the deviations between the obtained mean proportions and the proportions predicted by Equations (1), (2), and (3). Absolute mean deviations are also included in this table. The magnitudes of the absolute mean deviations are indexes of the equations' descriptive accuracy. The delay reduction equations is least accurate in describing human performance. The largest absolute values are associated with this equation. In contrast, small absolute values are associated with the matching and the maximization equations. The absolute values, however, do not provide enough information to discriminate which equation, (2) or (3), is more accurate in describing human performance.

Insert Table 5 about here

Table 6 contains a summary of the I values, the obtained switch rates in the initial links, the switch rates predicted by the maximization equation, the absolute deviations of obtained from predicted switch rates. In general, the absolute deviations are not large. The subjects appear to have switch rates that are consistent with the values predicted by the maximization equation.

Insert Table 6 about here

Discussion

The results indicate that the performance differences between humans and pigeons in Belke, Pierce, and Powell's (1989) study were not due to the nature of the reinforcer. Human performance on concurrent-chains schedules of food reinforcement is similar to human performance for tokens under identical schedules of reinforcement. Thus, humans show little impulsiveness even when a consumable reinforcer is scheduled. In contrast, pigeons are highly impulsive and are affected by conditioned reinforcement on the respective alternative.

It is possible that response allocation in the food sessions were carryovers from response patterns in the token sessions. In other words, the subjects in the food sessions simply repeated the pattern of responding expressed in the previous token sessions. However, the data obtained when the study was initially conducted under a ABA reversal design, is inconsistent with such an explaination. Under the reversal design, a subject was tested on food sessions without prior exposure to tokens. For the two food sessions completed by this subject, the obtained choice proportions were 0.55 and 0.50. The similarity of these proportions to those shown by Subject 1 and 2, using the probe design, mitigates a carryover interpretation.

The initial design was an ABA reversal with subjects run to stability on food and token reinforcement. However, the study was conducted during the summer months and competition from other employment sources was high. Although 3 subjects were hired to complete one session per day, all subjects resigned from the study within a few days. The primary reason was that jobs offering more hours of work and higher daily pay became available. Also, there was some concern about repeatedly depriving subjects of food over many weeks in order to acheive stability.

The results from the analysis of the descriptive accuracy of the three equations, and of the similarity between the obtained and predicted switch rates, were similar to the results of Belke, et al.'s (1989) study. Humans do not appear to perform in accord with the delay reduction equation. Performance is best described by the matching and maximization equations. Although matching cannot be ruled out, the small deviations between the obtained and the predicted switch rates suggests that humans behave in a manner which maximizes overall rate of reinforcement.

Experiment 2

The purpose of this experiment is to examine whether maximization or matching better predicts human performance on concurrent-chains schedules with VI VR initial links and FR1 terminal links. In the simple concurrent VI VR procedure, responding to the VR satisfies the ratio requirement and does not stop the VI timer. Thus, while a subject is responding to the VR alternative, a reinforcer may be setting up on the VI option. In contrast, the VR requirement does not count down when the subject is responding to the VI key. Initial links of the VI VR were chosen for this study because Herrnstein and Heyman (1979) argued that data obtained with simple concurrent VI VR schedules can not be interpreted as being consistent to both the matching and maximization equations because they predict different outcomes. Maximization predicts predominate responding to the VR schedule. In contrast, matching typically predicts predominant responding to the VI schedule (Heyman & Herrnstein, 1986). Concurrent-chains schedules with FR1 terminal links should be functionally equivalent to simple concurrent VI VR schedules.

Using pigeons as subjects, Herrnstein and Heyman (1979) found strong evidence for normative matching and weak evidence for maximization. Modified schedules of concurrent VI VR were used in this study in order to determine whether human behavior can best be predicted by the matching or the maximization equations.

Method

Subjects

Two male undergraduate students, 19 and 23 years old, were hired from a municipal employment office. Subject 1 had never participated in a psychological experiment before. Subject 2 participated in Experiment 1 of this paper.

Training

The training procedure for Subject 1 was identical to those used for token-training in Experiment 1.

Procedure

Subjects were presented with two concurrent-chains schedules of reinforcement. One key was programmed with a VI initial link and the second key was programmed with a VR initial link. For each initial link, 40 values were calculated using an equation by Flesher and Hoffman (1962) and randomized. Completion of an initial link produced a change of key colour and the presentation of a FR1 terminal link on that alternative. A single response in the terminal link produced reinforcement. When a terminal link was entered on one key, the other alternative became inoperative until reinforcement was delivered.

Each initial link was associated with a white key light. The terminal links were associated with colored key lights. The FR1 terminal link that followed the VI link was associated with a red key light and the FR1 link that followed the VR link was associated with a green key light. A COD of 3 s was arranged in the initial links.

An experimental session was terminated after the delivery of 40 reinforcers. Reinforcement was a token that was exchangeable for 25 cents at the end of each session.

Subjects completed 5 different sets of VI VR initial links, as summarized in Table 7. Stability Criteria for each set of VI VR initial link was identical to those used for the token conditions in Experiment 1.

Insert Table 7 here

Results

A summary of the results are presented in Table 8. The average total amount of time (T), number of responses (R), and the number of reinforcement (Rf) to each initial link are given in columns one to six. The ratio of time, response, and reinforcement are in columns seven to nine. Ratios were calculated from the appropriate values in the first six columns. The values in columns ten to twelve were obtained by logarithmic transformation of columns seven to nine.

Insert Table 8 about here

It is obvious when columns one to four are examined that humans allocate the majority of their responses and time to the VR alternative. This is qualitative evidence for reinforcement maximization because maximization predicts predominate responding to the VR.

The accuracy of the normative matching equation in describing the data was examined first. Based on the qualitative results, it was expected that this matching equation would not accurately describe human performance. The normative matching equation is expressed by the equation (Baum, 1974):

$$\frac{B1}{B2} = a \frac{(R_1)^b}{(R_2)} . \tag{8}$$

In this equation, the terms B1 and B2 are the measures of performance at alternative 1 and 2, respectively. For the current experiment, alternative 1 is the VI schedule and alternative 2 is the VR schedule. Therefore, B1 is the measure of performance, either the number of key presses or the time spent, at the VI alternative, and term B2 is the corresponding measure at the VR alternative. The terms R_1 and R_2 are the rates of reinforcement at the VI and VR alternative, respectively, and are calculated by the equations rL = 1/(VI + IRT1) and R_2 = 1/(VR (IRT2)). The terms IRT1 and IRT2 are the obtained interresponse times at the VI and VR alternative, respectively. Interresponse time is calculated by dividing the time spent at an alternative by the corresponding number of responses emitted to that alternative. The terms "a" and "b" are constants, and Baum (1974) suggested that "a" is a measure of preference to an alternative not accounted by existing measures, and "b" is a measure of the relative value of the rates of reinforcement, R_1 and R_2, as perceived by the subject. In the normative form of the matching equation, the value of constants "a" and "b" is 1.0.

The log transformation of Equation (8) is expressed by Baum (1974) as:

$$\log (B1/B2) = b \log (R_1/R_2) + \log a . \qquad (9)$$

The accuracy of Equation (9) was examined. Figures 1 to 4 were plotted from values in Table 8 and slopes and intercepts were calculated. For each figure, the solid line was fitted to the data by the method of least squares, and the dashed line represents the normative equation with a slope of 1.0 and an intercept of 0.

Figures 1 and 2 examines response ratios as a function of reinforcement ratios. Both intercepts were positive and higher than 0, but the slopes are different between the two subjects. The positive intercepts indicates more time spent responding to the VI link than predicted by the reinforcement ratios. Slopes of Figure 1 and 2 are both positive but the slope in Figure 1 is 0.72, a value indicative of undermatching, and the slope in Figure 2 is 1.46, a value indicative of overmatching. The two slope values are not close to the value of one, the value predicted by the normative matching law. Variations of the matching law may be able to account for the obtained slope values. For example, overmatching predicts slopes of greater than one, and undermatching predicts slopes of less than one. However, neither overmatching nor undermatching is predictive of performances by both subjects.

Insert Figures 1 & 2 here

Figure 3 and 4 examines time ratios as a function of reinforcement ratios. The intercepts for two figures are both negative, but the intercept for Subject 1 does not deviate significantly from the value of zero, a value predicted by the normative version of the matching equation. The slopes for the two figures are positive. But once again, the slopes deviate in different directions from the value of one. In general, no single version of the matching equation is able to account for all the values obtained.

Insert Figures 3 & 4 here

Another strategy is to ask whether maximization or matching is more accurate in describing time allocation for each reinforcement schedule. Heyman and Herrnstein (1986) developed matching and maximization equations for calculating the expected proportions of time allocated to the VI schedule. Because the maximization account predicts predominate responding to the VR, humans appear to have allocated their behavior so as to maximize reinforcement. Before, examining actual values of expected proportions, the equations used for calculations are described.

The equation for calculating an expected proportion, according to the matching account, can be expressed as:

$$p = \frac{(VI + IRT1)\ (VR)\ (IRT2) + I\ (VR\ (IRT2) - VI - IRT2)}{VI\ (VI + IRT1) + VR\ (IRT1)\ (IRT2)} \quad (10)$$

In this equation, the term, p, is the proportion of time allocated to the VI alternative, and the term, I, is the reciprocal of the sum of the two changeover rates. The terms VI and VR are the expected time and expected number of responses to reinforcement, respectively. The terms IRT1 and IRT2 are the interresponse rates on the VI and VR schedules, respectively.

The predicted p values consistent with the reinforcement maximization account of choice can be found by the equation expressed as:

$$R = \frac{p}{VI + IRT1} + \frac{1 - p}{VI + I/p} + \frac{1 - p}{VR\,(IRT2)} \quad (11)$$

The term R is the overall rate of reinforcement for a session. The first quotient is the expected rate of reinforcement at the VI schedule for a proportion of time. The second quotient is the expected rate of reinforcement that sets up at the VI alternative when it is not attended. The third quotient is the expected reinforcement rate at the VR alternative.

To solve for a value of p that would produce a maximum overall reinforcement rate for a schedule, a Macintosh Excel spreadsheet program was used to solve Equation (11). The value of p was initially set at 0.00 and then incremented by 0.01. For every p value, the overall reinforcement rate, R, was calculated until a maximum value was reached. There is generally a range of p values that results in a maximum reinforcement rate.

Table 9 contains the obtained and predicted p v alues for humans, as well as the I values. The important observation is that both equations predict predominate or near exclusive responding to the VR alternative. Thus, predominate time allocation to the VR schedule is not exclusive to the maximization account. Not only did matching predict p values of less than .50, but matching and maximization predict almost identical values for most of the schedules, and it is not possible to determine whether matching, or reinforcement maximization better describes human performance on concurrent VI VR schedules.

Insert Table 9 about here

Similar p values from Equation (10) and (11) was puzzling because Herrnstein and Heyman (1979) had used concurrent VI VR schedules to examine pigeons because they believed that such schedules produce data that can not be consistent with both accounts of choice. Although predicted p values were not calculated from Equation (10) and (11) in Herrnstein and Heyman's (1979) study, it was later stated by Heyman and Herrnstein (1986), in their study with VT VRT schedules, that Equation (10) "typically predicts values of p greater than .50".

To assess this statement, the obtained and predicted p values for Equations (10) and (11) were calculated from the pigeon data reported in Herrnstein and Heyman (1979). Table 10 contains the calculated values. Predicted p values were not calculated when there was exclusive responding to the VI schedule because the value of IRT2 can not be determined with an absence of responding to the VR alternative. From the pigeon data, 19 p values were calculated. Of the 19 values, only six were greater than 0.50 and one of these six values was greater than 1.0, an invalid value because proportions can not be greater than 1.0 or less than 0.0. This latter value is tagged with the symbol "*". Invalid predicted values from Equation (10) will be discussed later in this paper. The important observation is that Equation (10) do not typically predict values greater than 0.50 for pigeons.

Insert Table 10 about here

The schedules for humans and pigeons were identical. The only values that differed were those for I and IRTs. In this study, the failure to obtain different predicted p values for matching and maximizing is due mainly to short interresponse times of humans, and not different I values. Table 11 contains the average interresponse times of humans and Herrnstein and Heyman's (1979) pigeons. The interresponse times for pigeons are at least twice as large as those for humans. Humans' interresponse times are relatively small, compared to those of pigeons', and similar for both VI and VR schedules.

Insert Table 11 about here

To examine how the magnitude of IRT values affect the p values predicted by Equation (10), the equation was solved for a range of IRT values. The I values was arbitrarily set at 6.0. For our purposes, it does not matter what the I value is set to, because p values calculated with Equation (10) are not greatly affected by this parameter. Animals usually exhibit I values in the range of 2.0 to 10.0. Table 12 contains the p values for different combinations of I and IRT values for a concurrent VI30s VR30 schedule. Calculations were made with IRT1 = IRT2 = IRT. For a given IRT value, the p values are not significantly different at different I values. Again, invalid p values are tagged.

Insert Table 12 about here

With I equal to 6.0, Equation (10) was solved for different IRT values and reinforcement schedules. The p values are contained in Table 13.

Insert Table 13 about here

Figure 5 illustrates the effect of IRTs on p values. Tagged values were not plotted. As the value of IRT decreases, the value of p also decreases. Humans respond at IRTs of approximately 0.20 s. At such fast IRTs, p values are less than equal to 0.19. However, for higher IRT values of approximately 1.0 s, Equation (10) generally predicts exclusive responding to the VI.

Insert Figure 5 about here

The relationship between IRT and p appears linear. The value of the slope increases if the VI value is held constant and the VR value increases, and when the VR value is held constant and the VI value decreases.

Equation (10) produces invalid p values for certain combinations of schedules, IRT, and I values. In Table 10, 12, and 13, a number of p values are greater than 1.0. When the equation was solved for the current study, it was broken down to three components. The left and right portions of the numerator are (VI + IRT1) (VR) (IRT2) and I (VR (IRT2) - VI - IRT2), respectively. Finally, there was the denominator. Each component was solved independently, and then used in accordance to Equation (10) to obtain the p value. It was observed that p values were less than 1.0 when the right numerator was a negative value but not when it was a positive value.

Equation (10) was solved for combinations of VI VR schedules, IRTs, and I values to determine how these parameters affected the predicted value. The effect of the I value is examined first. The calculations were completed by assuming an IRT value of 0.2 s for both alternatives. A short IRT value was used because Equation (10) produces invalid p values with a large number of schedules when IRTs are long. The effects of IRT on Equation (10) is discussed in the next section of this paper. The calculations are summarized in Table 14. If the IRT is constant, different I values do not produce significantly different p values for a schedule. It appears that the I value does not have a great effect on the solution of Equation (10) when other parameters are held constant.

Insert Table 14 about here

Schedule and IRT values, however, have a significant effect on whether Equation (10) can be solved for p values less than or equal to 1.0. For each of seven schedules, p was solved for nine IRT values. In the schedules, the VR is always a value of 100. The IRT values were 0.2 s, 0.4 s, 0.6 s, 0.8 s, 1.0 s, 1.2 s, 1.4 s, 1.6 s and 1.8 s. The results are summarized in Table 15. The magnitude of the VI schedule relative to the VR schedule is directly associated with the range of IRT values that can be used to solve Equation (10) for valid p values. When the magnitude is low, the range of IRTs that Equation (10) can use to solve for valid p values is narrow. However, the range of IRTs is broad when the magnitude is high. For example, when the magnitude is 1.0, the acceptable range of IRTs is 0.2 s - 1.0 s. Thus, Equation (10) can solve for valid p values for a broad range of schedule when IRTs are short but not when they are long.

Insert Table 15 about here

<u>Discussion</u>

From the data obtained, no single version of matching was able to explain the slopes and intercepts obtained when the log of reinforcement ratios were plotted against the log of response ratios and log of time ratios. Examining whether matching or maximizing better describes schedule performance, the qualitative data support maximization.

Maximization predicts predominate responding on the VR alternative. Although this prediction is consistent with the obtained data, matching seems to make the same quantitative prediction as maximizing with human subjects.

The problem of similar predictions appear to be the result of the short interresponse times in humans. The value of p varies linearly with values of IRT. The value of p decreases as the value of IRT decreases. Equation (10) predicts high values of p and predominate responding to the VI alternative when IRTs are around 1.0 s. However, the equation predicts low values of p and predominate responding to the VR alternative when IRTs are around 0.2 s.

To solve this problem, the IRTs can be controlled at 1 s. However, when IRTs are long, only certain schedules can be used if Equation (10) is to be solved for p values less than 1.0. Equation (10) does not appear to be robust because a meaningful solution can only be obtained for certain combinations of schedules and IRT values. If the expected value of the VI is much less than VR, the equation yields valid p values for only a narrow range of IRTs. The equation requires modification. If it is to represent the matching account, it should be able to solve for all combinations of schedule and IRT values.

General Discussion

Humans respond differently than pigeons in concurrent schedules. Belke, Pierce, and Powell (1989) tested humans and pigeons on concurrent-chains VI VI schedules and found that human performance is best described by the matching and maximization equations, and pigeon performance is best described by the delay reduction equations. The question of whether the performance difference between humans and pigeons is due to the consumability of the reinforcer was examined in Experiment 1. Human performance was not affected by the consumable nature of the reinforcer, and allocation of behavior did not differ between sessions with tokens and sessions with food.

It is possible that human performance with food reinforcement would resemble those of pigeons if the level of deprivation in humans was equivalent to that of pigeons. Human were tested in Experiment 1 with 6 h of food deprivation. Pigeons in Belke, Pierce, and Powell's (1989) study, however, were deprived to 80% of their body weight. Although humans can not be deprived to the degree that pigeons are, a study with pigeons at different levels of deprivation may offer information on the effects of deprivation on choice performance.

Herrnstein (1990) argued that, although a systematic study of humans in concurrent VI VR schedules has not been reported, anecdotal evidence suggested that humans would behave as pigeons did in Herrnstein and Heyman's (1979) study. Primarily, the suggestion was that humans, like animals, would allocate their behavior in accordance to the matching model. However, the performance of humans and pigeons on concurrent VI VR schedules are different. Humans allocated most of their responses to the VR alternative. In contrast, Herrnstein and Heyman (1979) reported predominate responding to the VI alternative for pigeons. The comparison between human and pigeon performance is made by assuming that the concurrent-chains schedules with initial links of VI VR and terminal links of FR1, used to test humans, is functionally equivalent to a simple concurrent VI VR schedule, used to test pigeons.

There is weak evidence for normative matching in the modified VI VR study with humans. The normative matching equation (Baum, 1974) unable to account for the data in Experiment 2. The obtained slopes and intercepts generally deviated from the predicted values of 1.0 and 0.0, respectively. Further, although the allocation of behavior by humans is consistent with the predictions of Equation (10) (i.e., predominate responding to the VR alternative), this consistency is questionable support for matching because Equation (10) is invalid. It predicts p values less than 1.0 and greater than 0.0 for only certain combinations of schedule and IRT values.

The evidence for reinforcement maximization is stronger. Maximization predicts predominate responding to the VR alternative. Humans in Experiment 2 allocated most of their time and responses to the ratio schedule.

It is possible that a corrected version of Equation (10) would predict values that are consistent with human data. If this occurs, it may be evidence that, although matching may not occur at a molar level (i.e. across a range of schedules), it is operating at a molecular level (i.e. within a given schedule). Until then, humans in concurrent VI VR schedules appear to maximize the rate of reinforcement.

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Table 1

Schedules of Reinforcement and Accessibility of Keys During Token Training Sessions

Session	Schedule		Key(s) accessible
	Left Key	Right Key	
1	FR1	FR1	right
2	FR1	FR1	left
3	VI30-VI90	VI90-VI30	right
4	VI30-VI90	VI90-VI30	left
5	VI30-VI90	VI90-VI30	right,left

Table 2

Schedule of Reinforcement and Accessibility of Keys During Food-Training Sessions

Session	Schedule		Key(s) accessible
	Left key	Right key	
1	VI30-VI90	VI90-VI30	right
2	VI30-VI90	VI90-VI30	left
3	VI30-VI90	VI90-VI30	right,left

Table 3

Mean Number of Responses and Mean Amount of Time Spent in the Initial Links, the Average Number of Entries into the Terminal Links, and the Mean Number of Changeovers per Session

			Responses		Time (s)		Entries		
Condition	Subject	n	VI30	VI90	VI30	VI90	VI90	VI30	COs
Token	1	5	2974	1675	525	667	12.6	27.4	64
	2	5	203	156	723	663	12.2	27.8	41
	3	5	204	326	547	840	14.2	25.8	63
Food	1	3	2838	1803	631	516	11.0	29.0	62
	2	3	212	160	731	639	13.3	26.7	35
	3	3	294	329	364	722	17.0	23.0	44

Table 4

Proportion of Responses to the VI30s VI90s Chain Alternative

	Condition	
Subject	Token (n=5)	Food (n=3)
1	0.64	0.61
2	0.57	0.57
3	0.55	0.47

Table 5

Deviations Between the Mean Proportions of Responses and the Proportions Predicted by the Equations (1), (2), (3). Absolute Mean Deviations are also shown.

		Equation		
		1 Delay Reduction	2 Matching	3 Maximization
Condition	Subject	Expected=0.90	Expected= 0.50	Expected=0.55
Token	1	-0.26	0.14	0.09
	2	-0.33	0.07	0.02
	3	-0.35	0.05	0.00
	|mean|	|0.31|	|0.09|	|0.04|
Food	1	-0.29	0.11	0.06
	2	-0.33	0.07	0.02
	3	-0.43	-0.03	-0.08
	|mean|	|0.35|	|0.07|	|0.05|

Table 6

The I values, the Obtained and Predicted Switch Rates, and the Absolute Deviations of Obtained from Predicted Switch Rates

			Obtained		Predicted		Deviations	
Condition	Human	I value	u_1*	u_2*	u_1	u_2	D1	D2
Token	1	7.69	0.079	0.051	0.063	0.059	0.016	0.008
		8.55	0.053	0.064	0.057	0.052	0.004	0.012
		10.42	0.034	0.062	0.046	0.042	0.012	0.020
		9.01	0.041	0.070	0.054	0.049	0.013	0.021
		8.85	0.049	0.064	0.055	0.050	0.006	0.014
	2	16.39	0.032	0.029	0.029	0.024	0.003	0.005
		15.87	0.032	0.031	0.030	0.025	0.002	0.006
		20.00	0.026	0.024	0.024	0.030	0.002	0.006
		15.38	0.035	0.030	0.031	0.026	0.004	0.004
		18.18	0.029	0.026	0.026	0.021	0.003	0.005
	3	12.99	0.031	0.046	0.037	0.032	0.006	0.014
		8.13	0.060	0.063	0.060	0.055	0.000	0.008
		21.28	0.014	0.033	0.022	0.017	0.008	0.016
		8.55	0.044	0.073	0.057	0.052	0.013	0.021
		8.62	0.044	0.072	0.056	0.052	0.012	0.020
Food	1	9.90	0.053	0.048	0.049	0.060	0.004	0.012
		9.09	0.063	0.047	0.053	0.065	0.0[illegible]	0.018
		8.40	0.066	0.053	0.058	0.069	0.008	0.016
	2	18.52	0.027	0.027	0.025	0.037	0.002	0.010
		19.23	0.029	0.023	0.024	0.036	0.005	0.013
		20.41	0.027	0.022	0.023	0.034	0.004	0.012

3	11.11	0.030	0.060	0.043	0.055	0.013	0.005

Table 7

Schedules of Reinforcement in the Initial Links

VI	VR
30	30
15	30
40	30
40	45
40	60
30	30

Table 8

<u>The time (s) and the number of responses to each initial link, and the number of reinforcements in the terminal links associated with the VI VR alternatives. The ratio, and log of ratio, of times, responses and entries</u>

		1	2	3	4	5	6	7	8	9	10	11	12
Subject	Schedule	T		R		Rf		T	R	Rf	T	R	Rf
		VI	VR	VI	VR	VI	VR	VI/VR	VI/VR	VI/VR	log ratio	log ratio	log ratio
1	VI30s VR30	32	249	107	1117	4	36	0.13	0.10	0.11	-0.89	-1.00	-0.96
	VI15s VR30	28	208	79	1076	7	33	0.14	0.07	0.21	-0.85	-1.15	-0.68
	VI40s VR30	12	203	63	1178	2	38	0.06	0.05	0.05	-1.22	-1.30	-1.30
	VI40s VR45	6	303	42	1733	2	38	0.02	0.02	0.05	-1.70	-1.70	-1.30
	VI40s VR60	10	381	52	2182	3	37	0.03	0.02	0.08	-1.52	-1.70	-1.10
	VI30s VR30	29	304	99	1136	4	36	0.10	0.09	0.11	-1.00	-1.05	-0.96
2	VI30s VR30	62	216	284	1088	6	34	0.29	0.26	0.18	-0.54	-0.59	-0.74
	VI15s VR30	39	169	358	835	13	27	0.23	0.43	0.48	-0.64	-0.37	-0.32
	VI40s VR30	23	191	48	1082	5	35	0.12	0.04	0.14	-0.92	-1.40	-0.85
	VI40s VR45	151	283	671	1411	12	28	0.53	0.48	0.43	-0.28	-0.32	-0.37
	VI40s VR60	212	300	1053	1599	12	28	0.71	0.66	0.43	-0.15	-0.18	-0.37
	VI30s VI30	41	226	149	1138	5	35	0.18	0.13	0.14	-0.74	-0.89	-0.85

Table 9

The Obtained p Values, and the p Values Predicted by Equation (10) and (11) for Humans

			p Values		
Subject	Schedule	I	Obtained	Equation (10)	Equation (11)
1	VI30s VR30	5.99	0.11	0.06	0.02 - 0.04
	VI15s VR30	6.55	0.12	0.11	0.03 - 0.07
	VI40s VR30	3.93	0.05	0.04	0.01 - 0.03
	VI40s VR45	2.76	0.02	0.15	0.05 - 0.06
	VI40s VR60	3.96	0.03	0.18	0.06 - 0.08
	VI30s VR30	6.82	0.09	0.10	0.04 - 0.05
2	VI30s VR30	7.34	0.22	0.00	0.01
	VI15s VR30	8.30	0.32	0.07	0.01 - 0.05
	VI40s VR30	3.54	0.10	0.06	0.02 - 0.03
	VI40s VR45	8.22	0.35	0.07	0.02 - 0.04
	VI40s VR60	8.06	0.42	0.14	0.06 - 0.07
	VI30s VR30	7.31	0.13	0.07	0.02 - 0.04

Table 10

The Obtained p Values and the p Values Predicted by Equation (10) and (11) for Herrnstein and Heyman's (1979) Pigeons

		p Values		
Subject	Schedule	Obtained	Equation (10)	Equation (11)
3	VI30s VR30	0.39	0.46	0.14
	VI15s VR30	1.00	N/A	N/A
	VI40s VR30	0.48	0.29	0.11
	VI40s VR45	0.75	0.41	0.15
	VI40s VR60	0.89	0.82	0.23
	VI30s VR30	0.76	0.35	0.14
83	VI30s VR30	0.82	0.58	0.20
	VI15s VR30	1.00	N/A	N/A
	VI40s VR30	0.94	0.80	0.26
	VI40s VR45	0.96	0.75	0.27
	VI40s VR60	1.00	N/A	N/A
	VI30s VR30	0.76	0.26	0.11
365	VI30s VR30	0.40	0.24	0.09
	VI15s VR30	0.55	0.42	0.17
	VI40s VR30	0.25	0.11	0.05
	VI40s VR45	0.39	0.39	0.13
	VI40s VR60	0.72	1.14*	0.31
	VI30s VR30	0.38	0.22	0.09

473	VI30s	VR30	0.96	0.31	0.13
	VI15s	VR30	1.00	N/A	N/A
	VI40s	VR30	0.94	0.23	0.09
	VI40s	VR45	0.99	0.95	0.25
	VI40s	VR60	1.00	N/A	N/A
	VI30s	VR30	0.93	0.40	0.16

Table 11

Averaged Interresponse Times for Pigeons and Humans on the VI and VR Alternative. The Average Times for Pigeons were Calculated from Herrnstein and Heyman's (1979) Study

	Interresponse Time	
	VI	VR
Pigeon		
3	0.85	0.52
83	1.60	0.77
365	0.69	0.41
473	1.32	0.61
Human		
1	0.26	0.20
2	0.28	0.20

Table 12

The p Values Predicted by Equation (10) for Combinations of IRT and I Values for the Concurrent Schedule of VI30 VR30. Values were Calculated with IRT1 = IRT2 = IRT.

	IRT							
	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6
2.0	0.15	0.36	0.57	0.77	0.97	1.20*	1.30*	1.50*
4.0	0.09	0.32	0.54	0.75	0.96	1.17*	1.36*	1.54*
6.0	0.04	0.28	0.51	0.74	0.96	1.18*	1.38*	1.58*
8.0	-0.01*	0.21	0.48	0.73	0.96	1.19*	1.40*	1.61*
10.0	-0.07*	0.20	0.46	0.71	0.96	1.20*	[illegible]	1.64*

Table 13

<u>The p Values Predicted by Equation (10) for Different IRTs for Each Concurrent VI VR Schedule. The Values were Calculated with IRT1 = IRT2 = IRT and I Equal to 6.0</u>

Schedule	IRT							
	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6
VI30s VR30	0.04	0.28	0.51	0.74	0.96	1.18*	1.38*	1.58*
VI15s VR30	0.16	0.70	1.21*	1.67*	2.09*	2.45*	2.76*	3.02*
VI40s VR30	0.02	0.19	0.36	0.53	0.70	0.86	1.02*	1.17*
VI40s VR45	0.11	0.37	0.62	0.87	1.11*	1.34*	1.57*	1.79*
VI40s VR60	0.19	[illegible]	0.87	1.20*	1.51*	1.82*	2.10*	2.38*

Table 14

The Predicted p Values as Calculated from Equation (10) for Different Combinations of Schedules and I Values

Schedule	IRT	I	p value
VI10s VR50	0.2	3.0	0.98
	0.2	6.0	0.97
	0.2	9.0	0.96
VI50s VR50	0.2	3.0	0.15
	0.2	6.0	0.10
	0.2	9.0	0.06
VI90s VR50	0.2	3.0	0.00
	0.2	6.0	0.05
	0.2	9.0	0.02

Table 15

Concurrent Schedules of VI VR, the Magnitude of the VI Schedule Relative to the VR schedule, and the Range of IRT that can be Used to Solve Equation (10) for each Concurrent Schedule

Schedule	Magnitude	IRT range
VI20s VR100	0.2	0.2
VI40s VR100	0.4	0.2 - 0.4
VI60s VR100	0.6	0.2 - 0.6
VI80s VR100	0.8	0.2 - 0.8
VI100s VR100	1.0	0.2 - 1.0
VI150s VR100	1.5	0.2 - 1.6
VI180s VR100	1.8	0.2 - 1.8

Figure 1

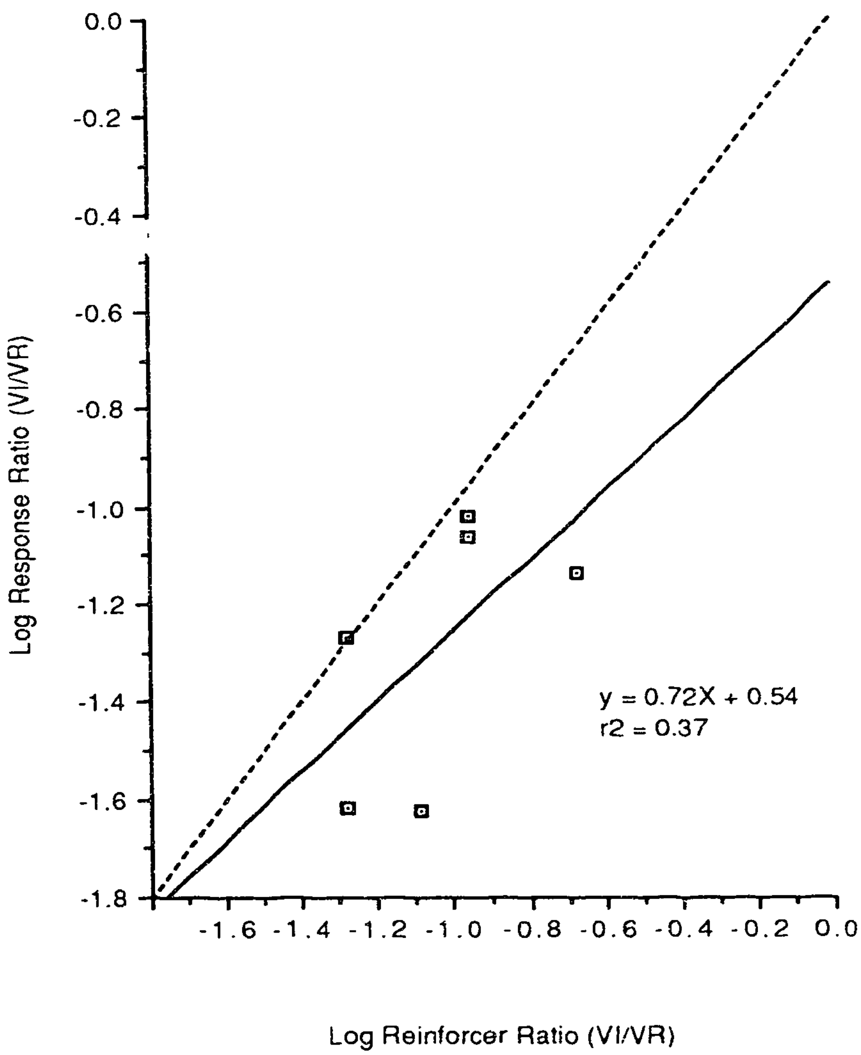

0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
-1.6
-1.8
Log Response Ratio (VI/VR)
-1.6 -1.4 -1.2 -1.0 -0.8 -0.6 -0.4 -0.2 0.0
Log Reinforcer Ratio (VI/VR)
y = 0.72X + 0.54
r2 = 0.37

Figure 2

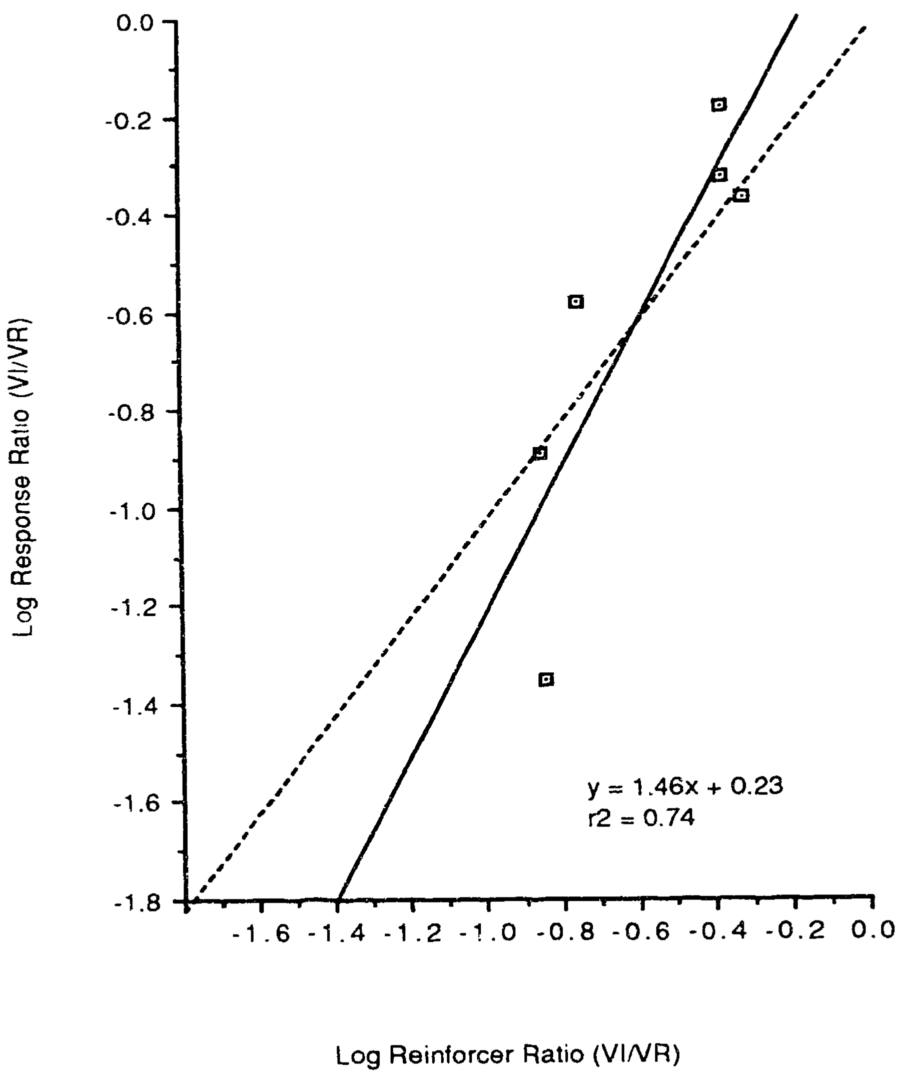

0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
-1.6
-1.8
Log Response Ratio (VI/VR)
y = 1.46x + 0.23
r2 = 0.74
-1.6 -1.4 -1.2 -1.0 -0.8 -0.6 -0.4 -0.2 0.0
Log Reinforcer Ratio (VI/VR)

Figure 3

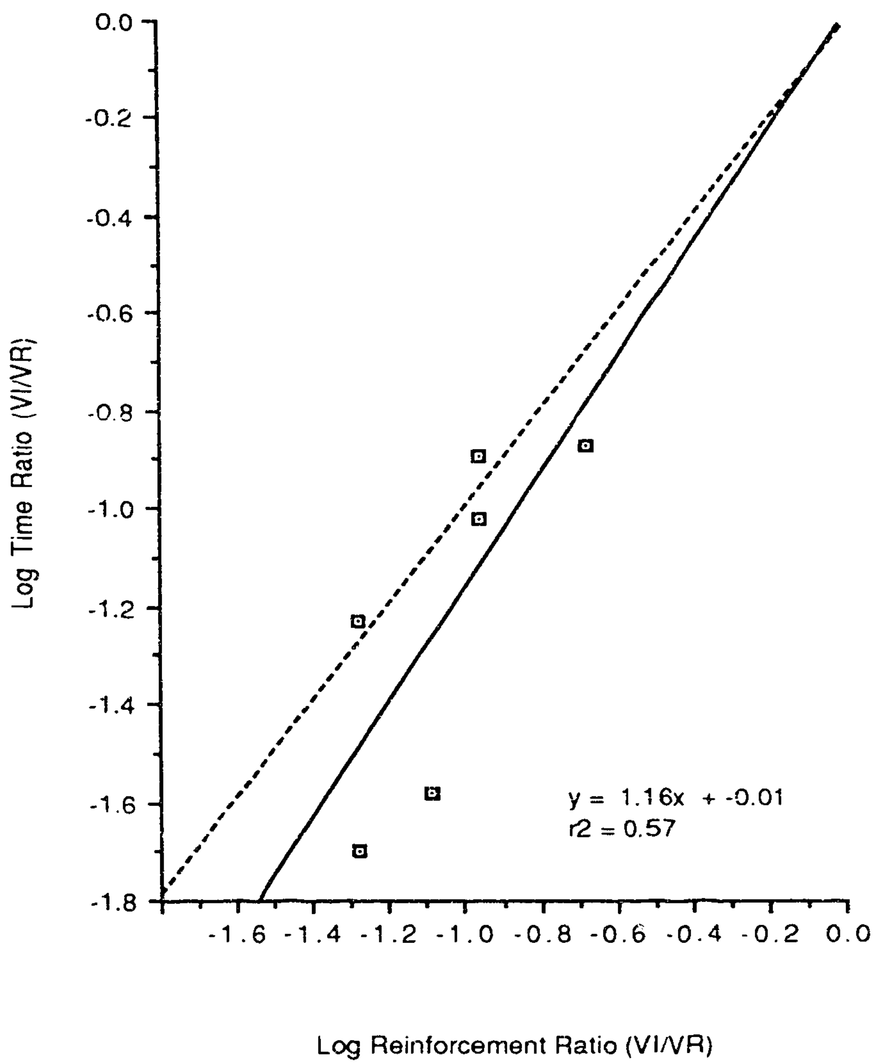

0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
-1.6
-1.8
Log Time Ratio (VI/VR)
y = 1.16x + -0.01
r2 = 0.57
-1.6 -1.4 -1.2 -1.0 -0.8 -0.6 -0.4 -0.2 0.0
Log Reinforcement Ratio (VI/VR)

Figure 4

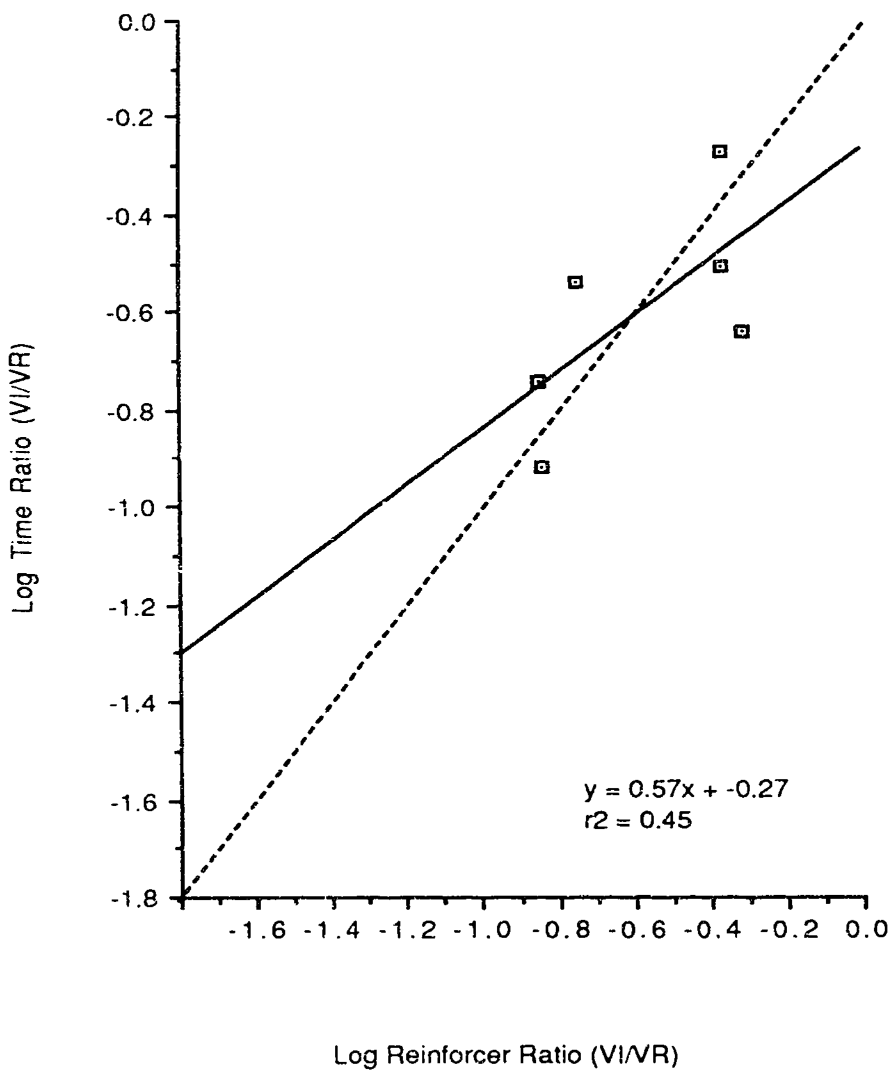
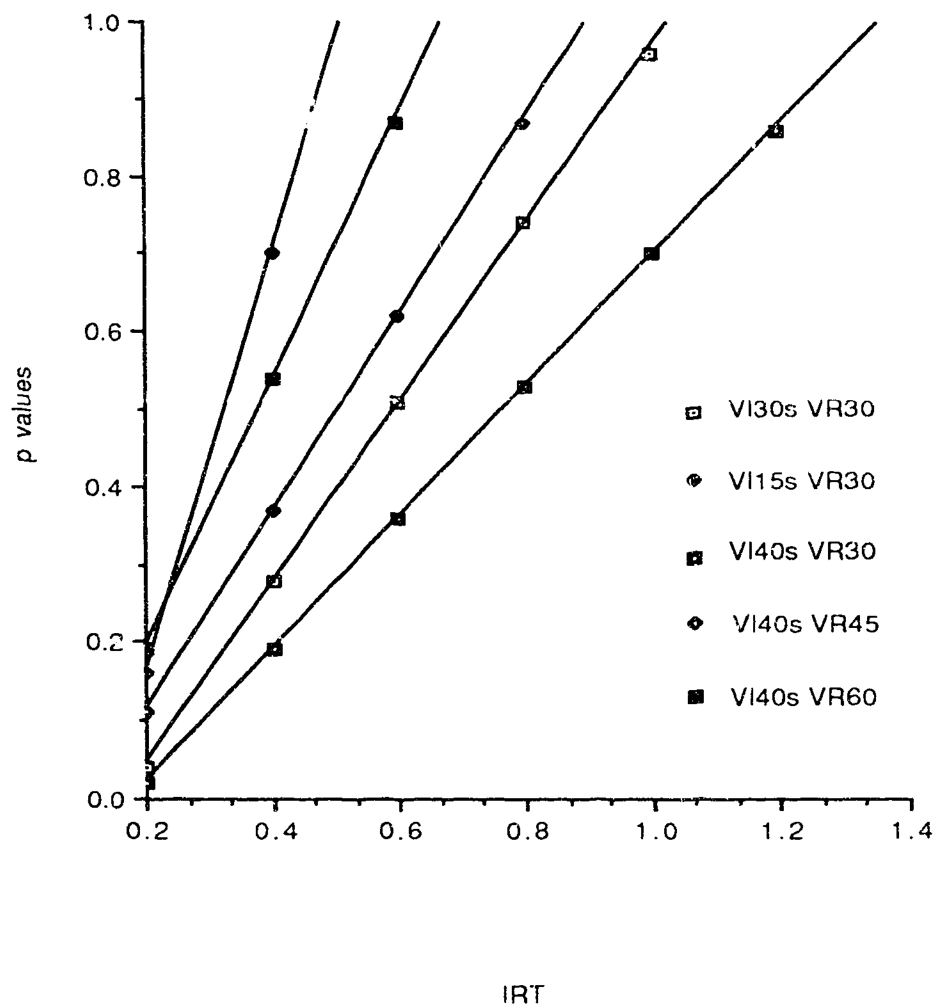

0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
-1.6
-1.8
Log Time Ratio (VI/VR)
y = 0.57x + -0.27
r2 = 0.45
-1.6 -1.4 -1.2 -1.0 -0.8 -0.6 -0.4 -0.2 0.0
Log Reinforcer Ratio (VI/VR)

Figure 5


1.0
0.8
0.6
0.4
0.2
0.0
p values
0.2
0.4
0.6
0.8
1.0
1.2
1.4
VI30s VR30
VI15s VR30
VI40s VR30
VI40s VR45
VI40s VR60
IRT

Appendix

To obtain T, two subvalues are calculated and summed. First, the value of the expected time to a terminal link is calculated with the equation:

$$\frac{1}{1/t1L + 1/t1R}$$

This value is added to the value of the expected time to reinforcement from the onset of a terminal link. This latter value is calculated by the equation:

$$(1\text{-}p)\ t2L + (p)\ t2R,$$

where (1-p) and (p) represents the probability of obtaining access to the left and right terminal links. The value (p) is equalled to t1L/(t1L + t1R).

To illustrate the calculation of T, consider the concurrent-chains schedules of VI30s VI90s versus VI90s VI30s. The expected time to a terminal link would be 1/(1/30 + 1/90) = 22.5 seconds. The expected time to a reinforcement in the terminal link would be (.75) (90) + (.25) (30) = 75 seconds. The value of T is 22.5 seconds + 75 seconds = 97.5 seconds.