

THE PERFORMANCE OF CHILDREN ON CONCURRENT
VARIABLE-INTERVAL VARIABLE-TIME SCHEDULES

A Dissertation
Presented to
the Faculty of the Department of Psychology
University of Houston

In Partial Fulfillment
of the Requirements for the Degree
Doctor of Philosophy

By
John D. Maier
December, 1976

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ABSTRACT

Six 5-year-old children were reinforced on concurrent variable-interval variable-time schedules for a button pressing task. Reinforcers consisted of candies that could either be consumed or traded for other items or activities. The proportion of the total reinforcement available on the two component schedules was varied and the effect of this on relative time and response allocation between the two components was assessed.

It was found that relative time allocation was a direct linear function of relative reinforcement. When greater relative reinforcement was scheduled on one component, relatively more time was allocated to that component. However time allocated to the richer component was not proportionally as great as the reinforcement received on that component, i.e. undermatching was found. This relationship was not adequately described by the matching principle in its simplest form. An even greater degree of undermatching was found when relative response rates were considered as a function of relative reinforcement. The variable-interval and the variable-time components were equally preferred in terms of time allocation. In terms of response allocation two children showed a fairly strong preference for the variable-interval component, and one child showed an almost complete preference for that com-

ponent. The other subjects showed a slight preference toward responding during the variable-time components. Both relative and absolute local response rates were found to be negative functions of relative reinforcement rates. Using only post-changeover-delay response and time measures did not particularly improve matching.

This experiment indicated that response dependent and response independent reinforcement are equally effective in producing time allocation matching. The results of this experiment were compared to the results of a number of other experiments that also used human subjects responding on concurrent schedules. It was concluded that the degree of matching characteristic to human responding is more variable than that found in lower organisms.

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CHAPTER I

INTRODUCTION

In most situations humans may exhibit any one of a great number of mutually exclusive behaviors. For instance, a person relaxing at home on a weekend may choose to read the newspaper, watch television, mow the lawn, or perform any of a great number of other behaviors. In a classroom situation a student may work on an assignment, look out the window, talk to another student, play with his pencil, etc. All of these behaviors may eventually be manifest, but some will have a higher probability of occurrence than others. What determines which of these alternative behaviors will appear at a given time, or what their rate of occurrence will be over a period of time? Each of these competing behaviors produces a different value of reinforcement. It seems reasonable to assume that the choice of behavior will be determined, to a large extent by the reinforcement that the behavior receives.

In many situations a substantial part of the reinforcement available is response independent, at least in the sense that reinforcer availability requires only the behavior of the recipient placing himself in a situation to receive the reinforcement. No specific response is required to produce the reinforcer. Again, taking the classroom situation as an example, the sights and sounds of the teacher and other stu-

dents, the view out the window, the bulletin board may all be reinforcing and are available noncontingently to the student.

In other cases reinforcement is contingent, requiring the occurrence of a specific discrete response in order to obtain the reinforcer. The most notable classroom example of this type is the requirement that questions be answered correctly in order to obtain the teacher's approval. Do response independent and response dependent reinforcement differ in their effects on human behavior, and what is the consequence of having the two types of reinforcement available in the same situation? These questions, along with the question of what factors determine which behavior of a number of competing behaviors will occur, appear to be of great practical significance in understanding human behavior.

A promising method for studying these problems is offered by concurrent schedules of reinforcement. Concurrent schedules of reinforcement consist of two or more simultaneously available, continuously functioning, schedules of reinforcement. The subject may freely alternate between the component schedules, but may be in contact with and receive reinforcement from only one at a time.

There are two procedures commonly used in concurrent schedule studies. One is the two key method in which each schedule is assigned to an individual response key. The sub-

ject alternates his responding between the two keys. The second procedure is the Findley (1958) method in which the two component schedules are alternately in effect on a single response key. Each component has a discriminative stimulus that is displayed while that component is in effect.

Responses on a second key (changeover key) change both the component in effect and its associated stimulus. The Findley method has the advantage of clearly indicating the change from one component to the other. This makes recording of time spent on each component more precise.

Herrnstein (1961) utilized concurrent schedules to study the effects of reinforcement on competing behaviors. His experiment used pigeons working on a two key concurrent variable-interval variable-interval schedule (conc VI VI). He demonstrated that the relative rate of responding on the two alternative components was proportional to their relative rates of reinforcement. Herrnstein expressed this relationship by the equation:

$$\frac{P_1}{P_1 + P_2} = \frac{R_1}{R_1 + R_2} \quad (1)$$

where P_1 and P_2 are the number of pecks on the right and left keys, and R_1 and R_2 are the number of reinforcements obtained by pecking the right and left keys. This relationship is called response matching.

In addition to matching the relative frequency of reinforcement, relative response rates have also been shown to match relative magnitude of reinforcement (Catania, 1963a) and relative immediacy of reinforcement (Chung & Herrnstein, 1967).

A second form of matching has been demonstrated. It is called time allocation matching and indicates the finding that the relative amount of time that a subject spends in the presence of one schedule, when the option of switching to a second schedule is freely available, is proportional to the relative frequency of reinforcement on that schedule (Baum and Rachlin, 1969). The relationship may be expressed by Equation 1 if p (pecks) is replaced by t (time units).

The generality of the matching principle has been further extended by the recent demonstration that response independent reinforcement, as well as response contingent reinforcement produces time matching. Bauman, Shull and Brownstein (1975) and Brownstein (1971) studied pigeons working on concurrent variable-time variable-time schedules (conc VT VT) and concurrent variable-interval variable-time schedules (conc VI VT). A variable-time schedule is similar to a variable-interval schedule except that it is response independent and delivers reinforcers without regard to the subject's behavior. The studies of Brownstein and his associates showed that both of the concurrent schedules produced

time allocation matching. The direct relationship between the proportion of time spent on a schedule and the proportion of reinforcement received on that schedule remained, regardless of whether or not a specific discrete response was required in the schedule.

In the conceptualization of Killeen (1972) and Rachlin (1973) matching is the result of a process of equalization of local reinforcement rates. While a subject is working on one schedule component the schedule on the second component will also run until it sets up a reinforcement. The longer the schedule on the first component runs, the greater is the probability that the second component will set up a reinforcement. When a schedule changeover occurs the first response after the changeover has a high probability of reinforcement. The probability depends on the time since the last changeover and on the density of the scheduled reinforcement for that component. All subsequent responses have a lower, and approximately equal, probability of reinforcement. As a consequence the local rate of reinforcement after a changeover is initially high and continually decreases while the subject remains on the component. He remains on the new component until its rate of reinforcement becomes too low. He then changes back to the first component which now has a higher initial reinforcement rate. Rachlin and Killeen contend that by this process of continually switching to the component with the higher rate of rein-

forcement, subjects tend to equalize local reinforcement rates. The subject can equalize local reinforcement rates primarily by appropriate time allocation, and to a lesser degree, by changes in local response rates. If local response rates on each component are high enough to obtain reinforcements within a very short time of their being scheduled when that component is in effect, then local reinforcement rates can be equalized only by distributing time between the two component schedules in the same proportions as the scheduled reinforcement is distributed. If 75% of the available reinforcement is scheduled for a component, the subject must allocate 75% of his time to that component to equalize local reinforcement rates. The result is then time allocation matching. If local response rates are equal, response matching will also result.

There is currently some controversy over the most appropriate way to express the relationship between relative time or response rate and relative reinforcement. Herrnstein (1970) advocates the use of proportions of the total, as expressed in Equation 1. The disadvantage of Equation 1 is that it holds only if there is direct equivalence between the proportion of response or time and the proportion of reinforcement. It has been found that this is not always the case. Equation 1 may be regarded as a special case of the linear equation:

$$\frac{P_1}{P_1 + P_2} \text{ or } \frac{T_1}{T_1 + T_2} = \underline{a} \left[\frac{R_1}{R_1 + R_2} \right] + \underline{b} \quad (2)$$

where P_1 and P_2 are the numbers of responses that occurred on component schedules 1 and 2, T_1 and T_2 are the time spent in the presence of schedules 1 and 2, R_1 and R_2 are the number of reinforcements received on schedules 1 and 2, $\underline{a}$ is the slope, and $\underline{b}$ the intercept of the equation. If $\underline{a}$ and $\underline{b}$ are empirically arrived at Equation 2 may be used to describe linear deviations from matching. When perfect matching occurs $\underline{a}$ is equal to one and $\underline{b}$ is equal to zero, and Equation 2 is equal to Equation 1.

An alternative method of expressing the relative relationships that are found in matching was suggested by Baum (1974). His formulation uses ratios expressed in terms of logarithms, rather than proportions. It is given by the equation:

$$\log (P_1/P_2 \text{ or } T_1/T_2) = \underline{a} \log (R_1/ R_2) + \log \underline{b} \quad (3)$$

where P , T , R and $\underline{a}$ have the same meanings as in Equation 2. In this equation $\log \underline{b}$ expresses the intercept. Again, $\underline{a}$ and $\underline{b}$ are empirically arrived at expressions of deviation from matching. When perfect matching occurs, $\underline{a}$ is equal to one and $\log \underline{b}$ is equal to zero in this equation.

Equation 3 can be expressed in arithmetic terms as:

$$\frac{P_1}{P_2} \quad \text{or} \quad \frac{T_1}{T_2} = \underline{b} \left[\frac{R_1}{R_2} \right]^a \quad (4)$$

In this form it can be seen that Equation 3 is not a linear function, as is Equation 2, but a power function.

Both Equations 2 and 3 have advantages and disadvantages. A disadvantage of Equation 3 is that it may predict a negative time or response proportion if the reinforcement proportion were low and the intercept were negative. The most important difference between the two formulations is that Equation 3, as a power function, appears to describe the accumulating data more accurately than does Equation 2 (Baum, 1974). In most cases the results are similar, but at this point Equation 3 is the preferred formulation.

Systematic deviation from matching is quite common. Baum (1974) cites two broad categories of failures to obtain matching. The first category is undermatching. Undermatching refers to a systematic deviation from the matching relationship with the preference on both alternatives in the direction of indifference to reinforcement. When relative reinforcement favors one component of the schedule, relative time allocated to that component is less than the relative reinforcement received on it. When undermatching occurs the slope, a Equation 3, is less than one. Overmatching could also occur, but is seldom seen in the literature. It is not clear why undermatching should occur.

Bias is the second form of deviation from matching. Bias denotes a systematic preference for one of the alternatives that is not accounted for by reinforcement. When bias occurs the intercept, $\log b$ in Equation 3, deviates from zero. Possible causes of bias include differences in the two required responses, and quantitative or qualitative differences between the reinforcers for the two responses.

It has frequently been found that a changeover delay (COD) is necessary in order to produce matching (Findley, 1958; Herrnstein, 1961). A COD is a procedure by which a minimum time must elapse between a changeover response and the next reinforcement. If a reinforcer is scheduled to occur during the COD interval, it will be postponed until the occurrence of the next response after the COD had elapsed. The COD minimizes the adventitious reinforcement of changeover responses and allows the effects of the two schedules to be temporally separated (Catania, 1966). Without a COD subjects often switch after virtually every response. It has been found that a certain minimum COD duration is needed to produce matching, but beyond that value, matching is maintained within a broad range of COD times (Shull and Pliskoff, 1967). CODs of 1.5 sec or longer have generally been used with pigeons.

Often a high-rate response burst on the response key occurs after each changeover (Pliskoff, 1971; Silberberg & Fantino, 1970). Using conc VI VI schedules, Schroeder (1975)

and Silberberg and Fantino (1970) found that the response rates during the COD were higher than the response rate during the subsequent, post-COD period, and that the response rates during the COD period were nearly constant and indifferent to relative reinforcement, showing extreme undermatching. The response rates during the post-COD period showed a slight overmatching. When the COD and post-COD rates were combined, the result was very close to perfect matching.

Most studies involving concurrent schedules have used conc VI VI schedules. All concurrent interval schedules generally produce good approximations of matching, although some undermatching is a common finding (Lobb & Davison, 1975). This is true whether the study uses conc VI VI schedules (Trevett, Davison & Williams, 1972), concurrent fixed-interval fixed-interval (conc FI FI) schedules (White and Davison, 1973), or concurrent variable-interval fixed-interval (conc VI FI) schedules (Nevin, 1971; Trevett, et al., 1972). It is also true with response independent schedules (Baum, 1973; Brownstein, 1971; Brownstein & Pliskoff, 1968), or a combination of response contingent and response independent schedules (Bauman et al., 1975; Rachlin & Baum, 1972). Bias favoring the VI component in conc VI FI schedules has been reported for both time and response allocation (Lobb & Davison, 1975). When conc VI VT schedules are used there is often a response bias favoring the VI component, although

the absolute VI response rate remains proportional to the absolute VI reinforcement rate (Bauman et al., 1975; Rachlin & Baum, 1972).

In ratio schedules the number of reinforcements is a direct function of the number of responses. With concurrent ratio schedules response matching can only occur if the two ratios are equal or if all responses are confined to one of the schedules. If the two ratio schedules are similar or equal, the subject will usually show no preference between schedules, thus producing matching. If one of the ratios is markedly smaller than the other, responding tends to be exclusively on the richer schedule, trivially conforming to matching as described by Equation 1 (Herrnstein, 1958; Herrnstein & Loveland, 1975).

When interval and ratio components are combined in a concurrent schedule the matching equation again is often trivially confirmed through responding on only one alternative. When responses on concurrent variable-interval variable-ratio (conc VI VR) schedules are distributed between the alternatives, the results are a close approximation of matching (Herrnstein, 1970). Responding is biased toward the VR schedule and time allocation is biased toward the VI schedule (Herrnstein, unpublished). Studies with concurrent fixed-interval fixed-ratio (conc FI FR) schedules report some undermatching with little response bias, but some time allocation bias in favor of the FI schedule (Baum, 1974;

LaBounty & Reynolds, 1973).

The vast majority of matching studies have been done with animals, primarily pigeons. Matching has been less consistently obtained with humans than with animals. Schroeder and Holland (1969) studied college students working on a signal detection task in which the signals were available on a conc VI VI schedule. They reported response matching for the macrosaccadic eye movements. Baum (1975) also studied college students using a signal detection task with a conc VI VI schedule. He found a slight undermatching of time allocation. Bradshaw, Szabadi, and Bevan (1976) reported finding response matching with a conc VI VI schedule. Their subjects were adults working at button pressing task. Schmitt (1974), also using university students working at a button pushing task on conc VI VI schedule, reported that the behavior of his subjects did not conform to matching. Heaps (1974) studied kindergarten aged children working on a conc FR VI schedule. The task on the VI component was lever pressing and the tasks on the FR component were match-to-sample problems on a teaching machine. He found moderate time and response undermatching with almost no bias. Schroeder (1975) performed a series of experiments using human retardates working at a button pushing task on several different concurrent schedules. In Experiment I and II each subject worked on one concurrent schedule while CODs were varied. All of the subjects showed a great deal of undermatching. Experi-

ment III varied the component schedules of a conc FI FR schedule. This produced an almost total lack of matching. Experiment IV used two subjects responding on a conc VI VI and varied the component values. These subjects showed a good approximation of response matching when rates for the total components were considered, and almost perfect matching when only the post-COD response rates were used. Why this experiment should have produced matching while the conc VI VI schedule in Experiment I, using the same parameters, produced undermatching is not clear.

Deviation from matching seems to be quite common. However, any function, whether it is perfect matching or not, that conforms closely to Equation 2 or 3 is extremely useful for purposes of prediction and control.

CHAPTER II

STATEMENT OF THE PROBLEM

In any human work or academic situation there is always reinforcement available that is not dependent on task related responding. If we are interested in increasing task related responding we need to take this availability of extraneous reinforcement into account. The conc VI VT schedule offers a potentially useful laboratory parallel of this situation. Through the analysis of human performance in a laboratory situation it may be possible to learn a great deal about the characteristics and controlling variables of behavior that occurs in a natural environment where a target response is intermittently reinforced and at the same time other reinforcement is noncontingently present. Prior to the present study there was no research available on humans response on conc VI VT schedules.

The present study is an analysis of human behavior on conc VI VT schedules of reinforcement in which the relative reinforcement on the two components was varied, and the effects on time and response allocation were assessed. It is an attempt to evaluate and expand the applicability of the matching principle.

CHAPTER III

METHOD

Subjects

Six children enrolled in the University of Houston Child Care Center kindergarten class served as subjects. All were between 5 and 6 years old at the beginning of the experiment. Children A, D, and E were males, and B, C and F were female. Child A had participated in a pilot study similar to this experiment. All of the others were experimentally naive.

Apparatus

A plywood console containing the experimental apparatus is shown in Figure 1. The console was located in a large (approximately 3.5 x 3.5 m), well lighted and ventilated store room. It was 123 cm high, 65 cm wide, and 61 cm deep. The console had a Formica covered desk built into it that was 32 cm deep and 57 cm above the floor. On an aluminum panel on the wall in front of the desk were mounted, from left to right: an opening through which M&M candies were dispensed, a cylindrically shaped light, a square pushbutton switch, a diamond shaped light, and a round pushbutton switch. The bottom of each of these was approximately 5 cm above the desk. The M&M dispenser opening was 5 cm square and 16 cm from the left wall. The locally constructed dispenser apparatus was enclosed behind the panel. The 1.2 cm cylindrical

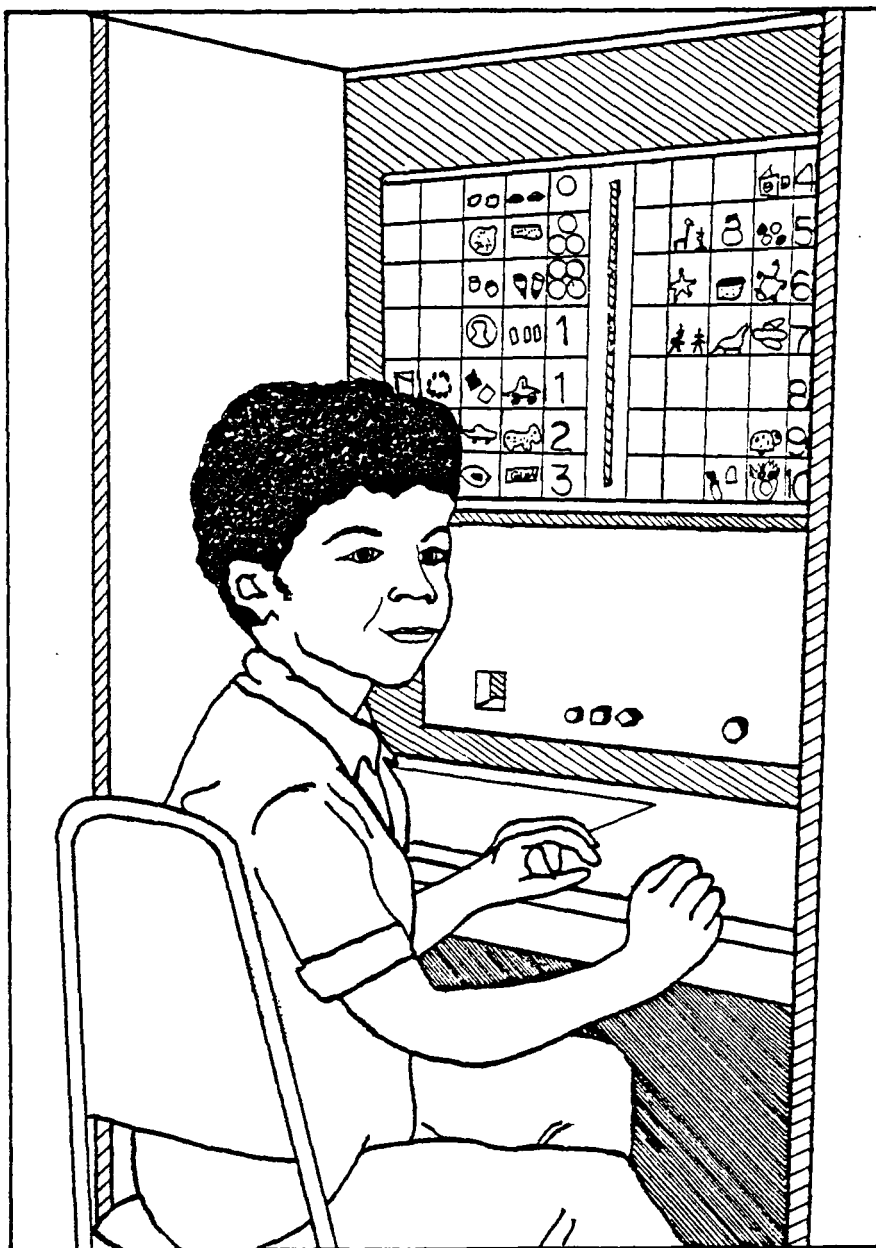


Figure 1

A subject at the experimental apparatus

light was amber in color and located 10 cm to the right of the dispenser opening. The square pushbutton switch (Radio Shack catalog number 275-618) was 1.1 cm across and red in color. It could be operated by a force of 3.3 N. Depressing it caused either the cylindrical or diamond shaped light to turn on and the other light to turn off. The diamond shaped light was 1.2 cm on a side, blue in color, and mounted 2.5 cm to the right of the square pushbutton. The round pushbutton switch (Radio Shack catalog number 275-609) was 1.4 cm in diameter and black in color. It required a force of 4.0 N to depress it. When it was operated auditory feedback was provided by a relay mounted behind the panel. The round pushbutton switch was positioned 13 cm to the right of the diamond shaped light and 19.5 cm from the right wall.

Standard electro-mechanical equipment was used to schedule, record, and time events. This equipment was enclosed in a case and located in a room across a hall about 15 m from the experiment area.

Procedure

The subject was seated in a small chair in front of the experimental apparatus. A screen 123 cm high was placed around him. The experimenter was usually present in the room during the experiment, but discouraged questions or talking.

The effects of five conc VI VT schedules were investigated. The Findley (1958) procedure was used. The round black button on the console functioned as the response key.

The square red button between the lights functioned as the changeover key. The amber cylindrical light was the discriminative stimulus for the VI schedule, and the blue diamond shaped light was the discriminative stimulus for the VT schedule.

M&M candies were used as reinforcers. The children could consume the candies immediately, save them for later consumption, or use them as tokens to trade at the end of the session. Among the things that the children could trade for were other edibles, inexpensive toys, and playing games. A trade-in menu was used. From 12 to 20 items, ranging in price from 1 to 40 M&Ms were available at any one time. A few items on the menu were changed each day in order to prevent the children from satiating on any one item. Drawings of the items that could be traded for that day and their prices were displayed on a chart at the front of the desk. Another chart for grouping the candies in rows of five was placed on the desk. Prices were shown in terms of single M&Ms or rows of five candies. The children rapidly learned to operate in this economy.

Initial training

In the initial training the subject was given some M&Ms. He was told that he could eat them or trade them for other things. He was shown how trading worked. He was then allowed to watch for about 90 sec while another previously trained child worked at the console on a conc VI 30-sec VT

30-sec schedule. The subject was then asked if he would like to try working. The answer was invariably yes. He was then immediately allowed to work for 12 min on the conc VI 30-sec VT 30-sec schedule. After four more daily 12 min sessions on this schedule, the schedule was changed to either a conc VI 18-sec VT 90-sec or a conc 90-sec VT 18-sec schedule. The schedule chosen was opposite to the subject's preference as indicated by time allocation. If he allocated a greater amount of time to the VI schedule, then his new schedule was the one with the richer VT component. After working on this schedule for three sessions, he was changed to the preferred schedule for another three sessions. Child A, who had participated in a pilot study for this experiment, received only the three days of the conc VI 90-sec VT 18-sec and of the conc VI 18-sec VT 90-sec schedules.

Experimental conditions

The experimental conditions consisted of five different conc VI VT schedules. The schedules used were: conc VI 165-sec VT 16.5-sec, conc VI 60-sec VT 20-sec, conc VI 30-sec VT 30-sec, conc VI 20-sec VT 60-sec, and conc VI 16.5-sec VT 165-sec. In all conditions the two components, in combination, were scheduled to provide four reinforcements per min. The schedules were constructed according to the method suggested by Fleshler and Hoffman (1962). The tapes used to schedule reinforcement were 15 to 20 min in duration. Each schedule ran continuously until it set up a reinforcer. It

then stopped until the reinforcer was obtained.

Each experimental condition was in effect for six sessions for each child. Session lengths were 12 min throughout the experiment. The order in which the schedules were presented is indicated in Table 1. The orders were randomly determined for each child. One, and sometimes two sessions were conducted daily with each child. When two sessions were run with the same child in one day, they were at least one hour apart. If a child was not worked with for three consecutive days because of absence or some other reason, on his return he was given an extra session that was not included in the data analysis. Throughout the experiment, including training, a COD of 3.25 sec was used.

Table 1

Order of occurrence of experimental conditions					
Mean intervals of <u>conc</u> VI VT schedules (in sec)					
Subject	16.5-165	20-60	30-30	60-20	165-16.5
A	1,6	4	2	3	5
B	2,6	4	1	3	5
C	3	2	5	1,7	4,6
D	2	3	4	5	1,6
E	1	5	4	2	3
F	5	4	2	1,6	3

CHAPTER IV

RESULTS

The reinforcement menu retained its effectiveness throughout the entire study. A total of 69 different items were available at one time or another on the trade-in menu. The children always appeared eager to attend their daily sessions.

When new schedule conditions were initiated the children adjusted very quickly to them. As had previously been indicated in a pilot study, six 12 min sessions per experimental condition produced data with satisfactory stability.

All results reported here are derived from data totaled for the last 3 days of each condition. This data is shown in the appendix.

Figure 2 shows how the children allocated their time between the two component schedules as a function of relative reinforcement in those components. In the graphs the logs of the time ratio ($VI \text{ time}/VT \text{ time}$) are on the vertical axis, and the logs of the response ratio ($VI \text{ reinforcement}/VT \text{ reinforcement}$) are on the horizontal axis. The solid lines running diagonally through the graphs are the lines of perfect matching. The dashed lines were fitted to the logarithmic data by the method of least squares. Their equations, as

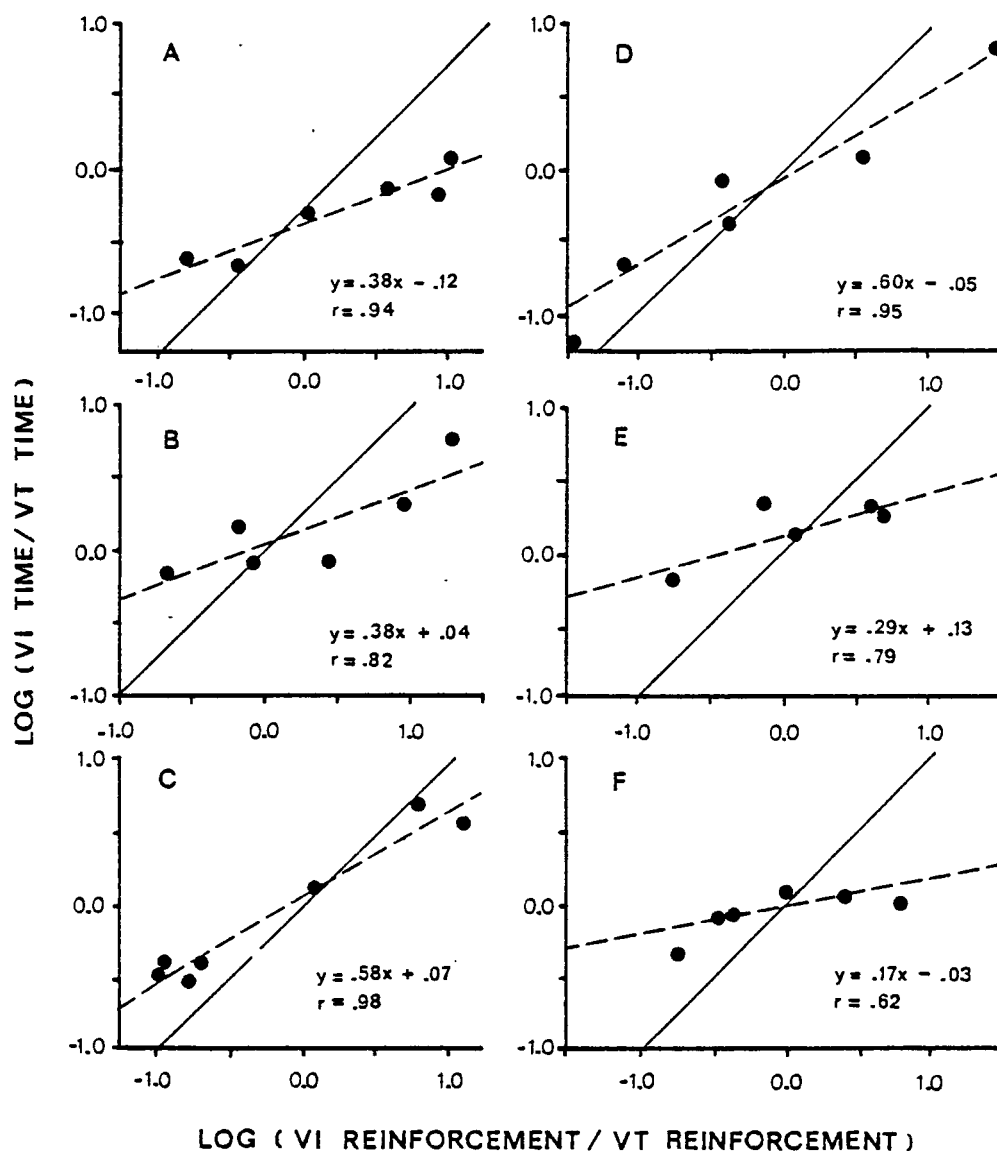


Figure 2

The logarithm of the ratio of time allocated to responding as a function of the logarithm of the ratio of the reinforcement rate obtained on each schedule. The solid diagonal line through each graph is the line of perfect matching. Each graph shows the performance of an individual subject. The dashed line through each graph was fitted by the method of least squares. The line's equation and the correlation for the logarithmic data are given in each graph.

well as the correlations for the logarithmic data, are given in each graph. Each child had a considerable degree of undermatching. The mean slope for the group was .40. When relative reinforcement favored one of the component schedules, relative time allocated to the richer schedule was less than the relative reinforcement received on that schedule. However, the relationship was quite linear as indicated by the high correlations. Taken as a group, there was almost no bias shown. When relative reinforcement was equal, the schedules were equally preferred.

If only post-COD time is considered instead of time for the entire component, there is a slight improvement in matching and correlations. The slopes are increased by about .02 and correlations improved by less than .01.

As previously indicated, response matching is determined by time allocation and local response rate. The absolute local response rates for the children are shown as a function of the absolute local reinforcement rates in Figure 3. Absolute local rates are computed by dividing the number of responses or reinforcements that occurred in a component by the time that the component was actually in effect. The lines of best fit for each schedule component are indicated in each graph. Ten of the twelve lines have a negative slope. The correlations ranged in absolute value from .00 to .60, with a mean of .32.

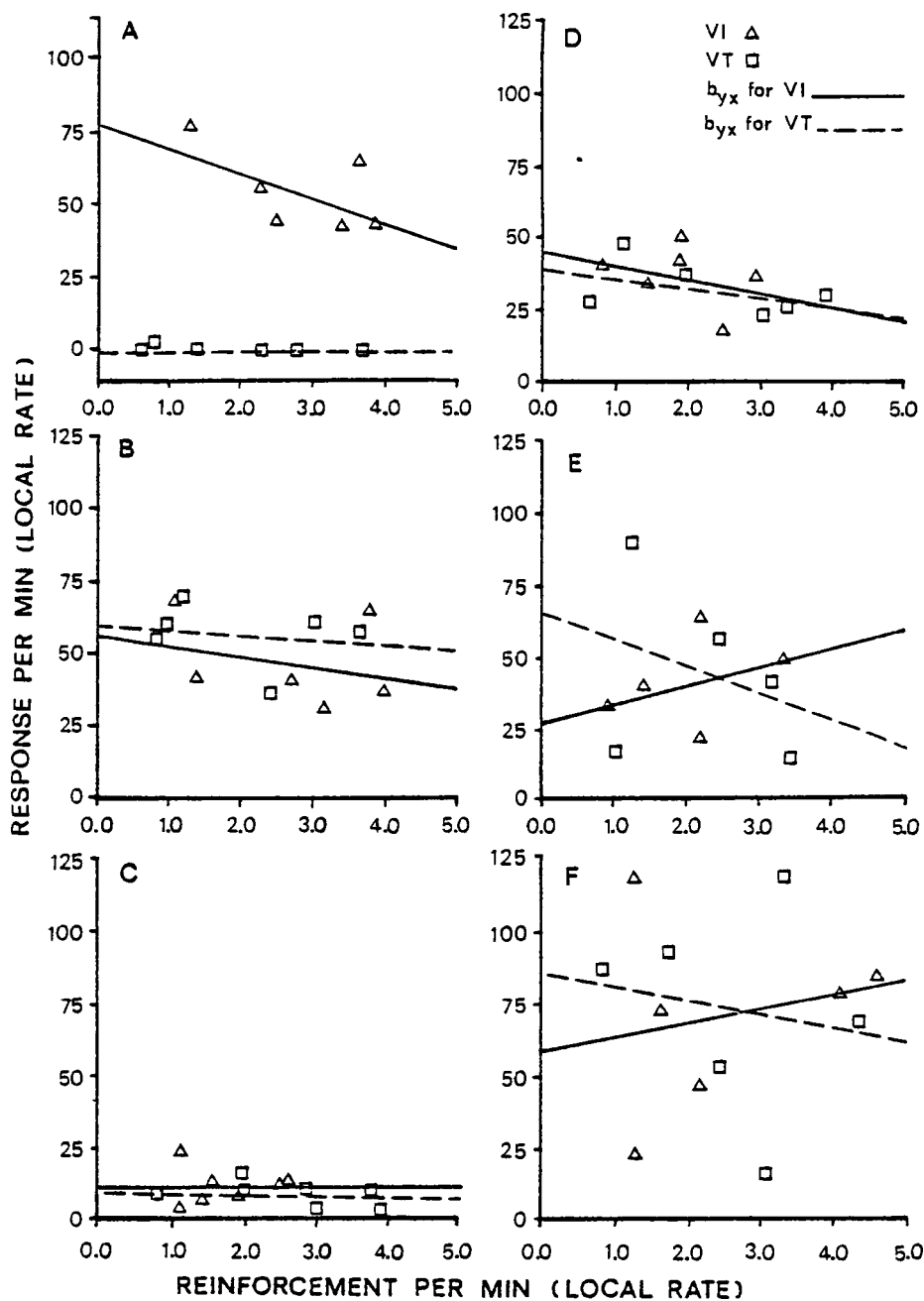


Figure 3

Local response rate as a function of local reinforcement rate on each schedule. Data for the VI and VT components are given separately. Each graph shows the performance of an individual subject. Lines fitted by the method of least squares are shown as b_{yx} .

The local post-COD response rate for all subjects, with the exception of A on the VT component, was lower than the local response rate during the entire component. The mean difference was .05 for the group. There was only a slight and unsystematic variation in this relationship between the different subjects and schedules. The local COD response rate, again with the exception of Subject A on the VT component, was higher than the local rate over the entire component by an average factor of 1.8. The COD response rate showed much greater variability than the post-COD response rate in relation to the rate for the entire component. This is in agreement with previous studies (Schroeder, 1975; Silberberg & Fantino, 1970) that found a transient high response rate immediately after a CO. The rate was unaffected by relative reinforcement. The post-COD response rates are essentially equivalent to the rates for the entire component, reduced by a factor of about .05. The relationship between local response rates and local reinforcement rates is not appreciably altered by the use of the post-COD response rates as opposed to the rate for the entire component. This would be true for both relative and absolute rates. In view of this and of the very slight improvement shown when using post-COD time, rates over the combined COD and post-COD periods were used as a unit for all calculations.

Figure 4 displays relative local response rates as a function of relative local reinforcement rates. Relative

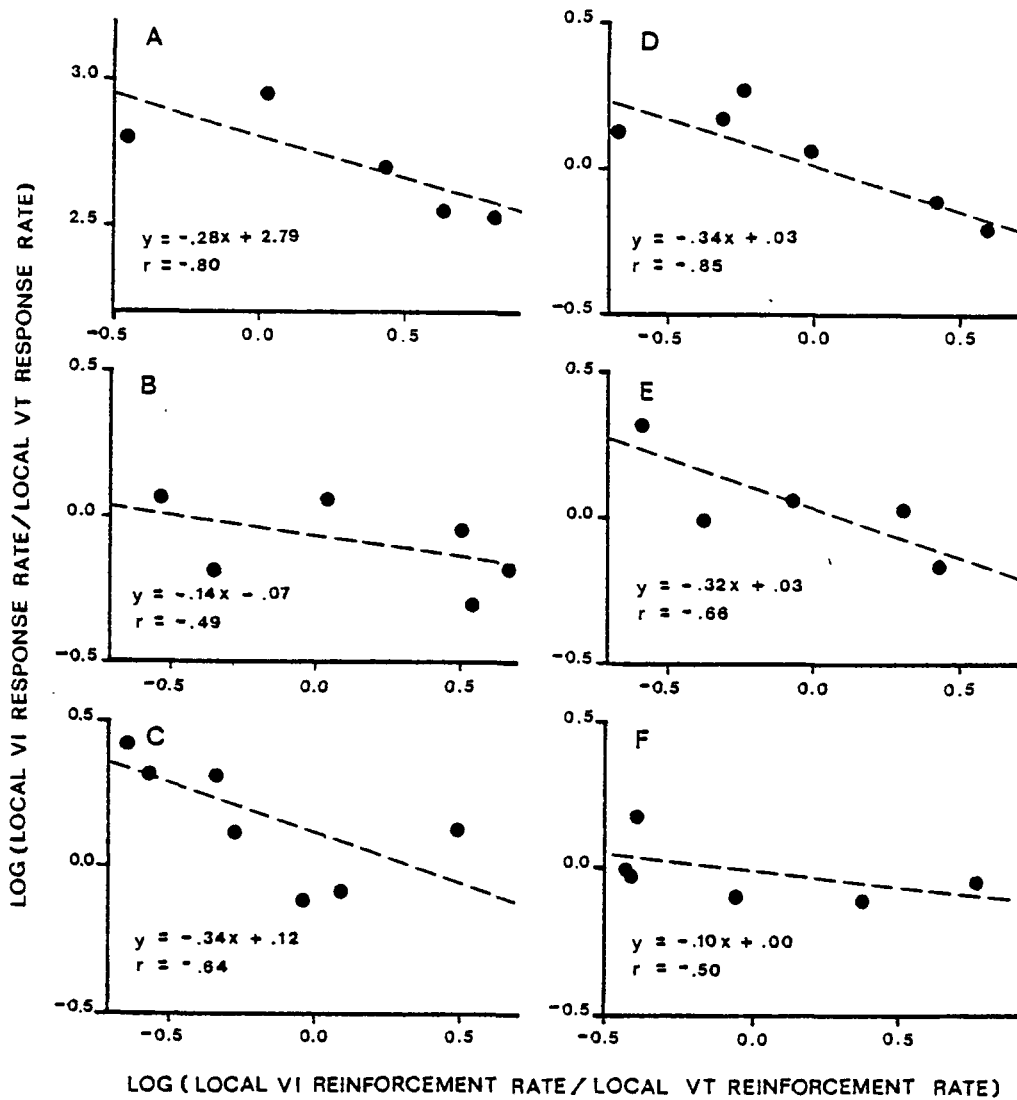


Figure 4

The logarithms of the relative local response rates as a function of the logarithms of the relative local reinforcement rates on each schedule. Each graph shows the performance of an individual subject. The dashed lines through each graph were fitted by the method of least squares. The line's equation and the correlation for the logarithmic data are given in each graph. One data point for child A could not be calculated because no responding occurred during the VT component of that condition.

local rates are computed by dividing the local VI rates by the local VT rates. In Figure 4 the logarithms of the relative local response rates are shown on the vertical axes and the logarithms of the relative local reinforcement rates are shown on the horizontal axes. The dashed line through each graph is the line of best fit derived by the method of least squares. The line's equation and the correlation of the data is given for each graph. The mean slope for the group is $-.66$. All of the children have slopes that are negative to roughly the same degree. The mean correlation for the group is $-.63$. It is clear from this data that local response rates are not constant and unaffected by the relative rate of reinforcement, but that higher relative local rates of reinforcement produce lower relative local rates of responding.

In examining relative response rates, child A presents a special problem. His responding during the VT component completely extinguished in one condition and nearly extinguished in the other conditions. Under these circumstances, relative response rate is a measure of questionable value. If response proportions are used as the relative measure as in Equation 2, they will all be 1.00 or very close to it and yield no meaningful differences. If response ratios are used with the VT response rate as the divisor as in Figure 4, the ratio quotient may range from fairly large numbers to infinity. Very small differences in the number of VT responses can produce large differences in the ratio quotient, probably

distorting relationships. Therefore, relative response rate appears to be an inappropriate measure to use when little or no responding occurs in one of the components. The data for Child A is included for comparison purposes only. Note that on his graph the scale of the log of his relative local response rate is from 2.2 to 3.2 while the scale for the other children ranges from -0.5 to 0.5. The data point for the conc VI 60-sec VT 20-sec schedule could not be calculated because no responding occurred during the VT component of that condition making a response ratio impossible to calculate. Because of this omitted data and because of the probability of distortion of the relationships involved in using ratios here, the line of best fit and correlation presented for A should be regarded with caution.

In spite of these problems which are not encountered when using absolute response rate data, the relative local response rate data is much more consistent than the data for absolute local response rates. It appears that relative response rate measures have a clear advantage over absolute response rate measures in clarifying relationships between response rates and reinforcement rates.

Overall response rate has been the most widely used measure of matching, although it may be of less importance than time and local response rate data (Rachlin, 1973). Overall response rates are determined by local response rates

and time allocation. If local component response rates were constant and unaffected by relative reinforcement, then relative overall response rates and time allocation would produce identical results. However, since local response rates are a negative function of reinforcement and time allocation is a positive function of reinforcement, it should be expected that overall response rates as a function of the overall reinforcement rates would produce intermediate results. This is the case, as can be seen from Figure 5.

Figure 5 shows the relative overall response rate as a function of the relative overall reinforcement rate. The logarithms of the response ratios are plotted on the vertical axes and the logarithms of the reinforcement ratios are plotted on the horizontal axes. The ratios are computed by dividing the number of responses or reinforcements that occurred in the VI component by those that occurred in the VT component. The solid diagonal line through each graph is the line of perfect matching. The dashed lines through each graph is the line of best fit computed by method of least squares. This line's equation and the correlation of the data is given in each graph.

Child A's data is again included for comparison. As in Figure 4, the data point for the conc VI 60-sec VT 20-sec schedule could not be calculated. Again, because of the omitted data and because of the possibility of distorted relationships, the line of best fit and correlation presented

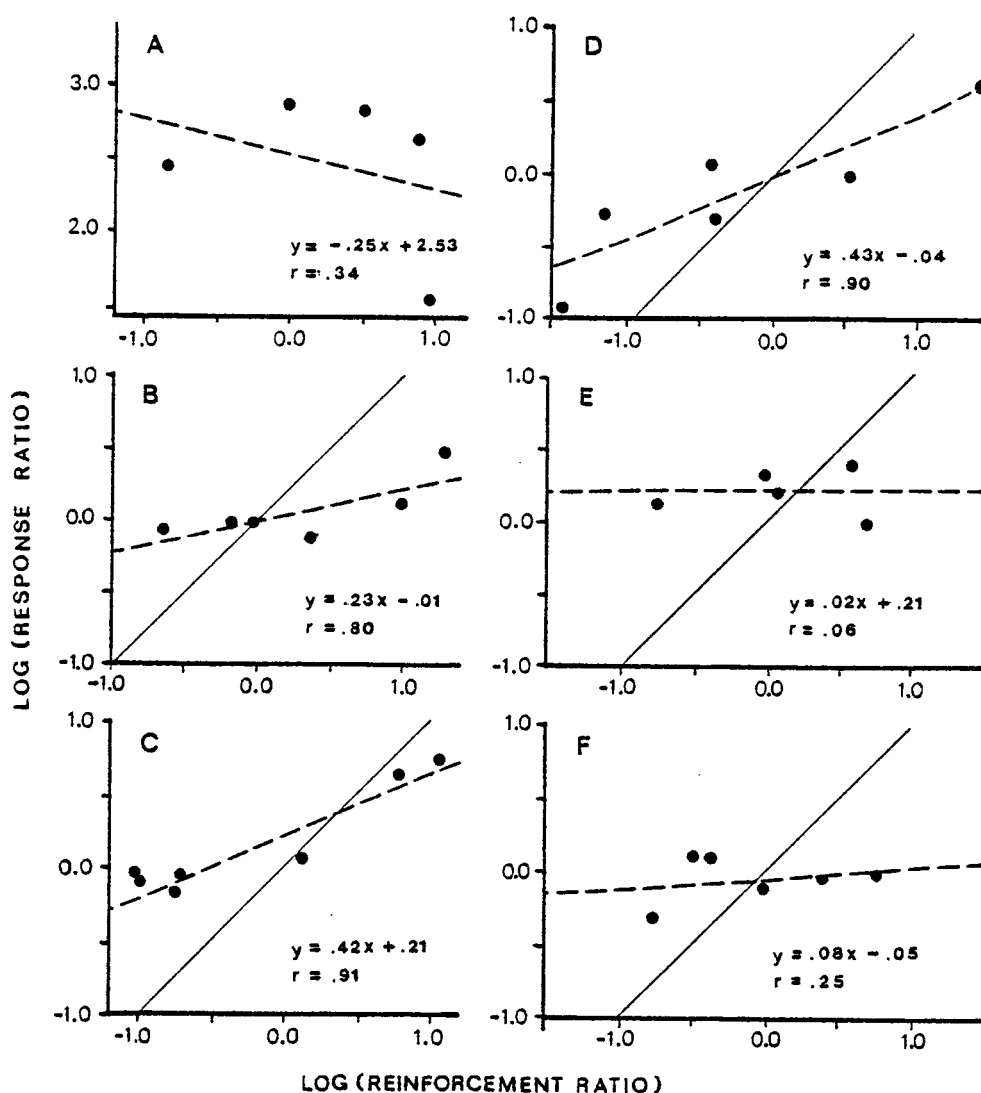


Figure 5

The logarithm of the ratio of VI responses to VT responses as a function of the logarithm of the ratio of VI reinforcements to VT reinforcements on each schedule. The solid diagonal line through each graph is the line of perfect matching. Each graph shows the performance of an individual subject. The dashed line through each graph was fitted by the method of least squares. The line's equation and the correlation for the logarithmic data are given in each graph. One data point for child A could not be calculated because no responding occurred during the VT component of that condition.

for A should be regarded with caution. Note that for his graph, the scale for the log of the response ratio ranges from 1.4 to 3.4, while for the other children the range is from -1.0 to 1.0.

The data for the other five children shows moderate to extreme undermatching. Children B, C, and D have fairly high correlations. Children E and F have approximately the same variation from their lines of best fit, but because of the very slight slopes, the correlations are poor. Children C and E showed a strong VI response bias. With equal relative reinforcement they would produce 60% more VI responses than VT responses. Child A had an almost complete bias toward responding on the VI schedule. The three remaining children showed a slight bias toward VT responding. In comparison with the time allocation data shown in Figure 2, the data in Figure 5 show a good deal more undermatching and are slightly less linear. The differences are especially marked in the cases of E and F.

Using the log transformation of response and reinforcement ratios provides a slightly better approximation to linearity than using VI response and reinforcement as a proportion of total response and reinforcement. The difference in mean correlations is only about .028. However, the mean slope was .05 greater when using the proportions rather than the log transformations.

The relationship between absolute local and overall response rates is similar to that between relative local and overall response rates. As shown in Figure 3 the absolute local response rates as a function of local reinforcement rates generally had a low correlation and a negative slope. The absolute overall response rates were generally a positive function of overall reinforcement rates and had a somewhat higher correlation. The means for the group on the VI component were: slope = 5.48, intercept = 14.35, and correlation = .56. On the VT component the means for the group were: slope = 2.63, intercept = 13.28, and absolute correlation = .42. The slopes were positive on both components for each child with the exceptions of child A on the VT component and child B on the VI component, whose slopes were flat, and of child E on the VT component, whose slope was negative.

It was observed during the course of the experiment that occasionally a subject would produce a burst of rapid responding on the changeover button, causing the two stimulus lights to flash off and on. This inflated the changeover measure without markedly increasing the changeover times. A better estimate of the number of times the subject functionally changed the schedule, that is allowed the COD period to expire and came in contact with the new schedule, is the total COD time divided by the COD. When this estimate of the changeovers per minute was examined as a function of relative

reinforcement, there was no clear pattern among the subjects. Subjects A, D, E, and F had positive slopes, and B and C had negative slopes. Correlations range from .22 to .88. There was no evidence of the inverted U function that is occasionally reported.

CHAPTER V

DISCUSSION

This study found response contingent and response independent reinforcement equally effective in producing time allocation matching. This extends to humans the findings obtained by Bauman et al. (1975) with pigeons responding on conc VI VT schedules. However, the degree of matching found in the two studies differs markedly. While Bauman et al.'s (1975) pigeons produced a close approximation to time allocation matching, the children in the present study had a good deal of undermatching. The results of this study are well described by Equations 2 and 3, but are not consistent with the more limited form of matching expressed by Equation 1.

The degree of undermatching found is perhaps the most significant result of this study. Although these results would not have been anticipated from previous matching studies conducted with animals, they are not inconsistent with results of other human studies. Figure 6 re-examines data presented in a number of studies involving humans responding on concurrent schedules. The figure indicates the degree of matching found in each study. It shows the lines of best fit calculated from data for relative time or response allocation as a function of relative reinforcement on each schedule. Proportions are used here because some of

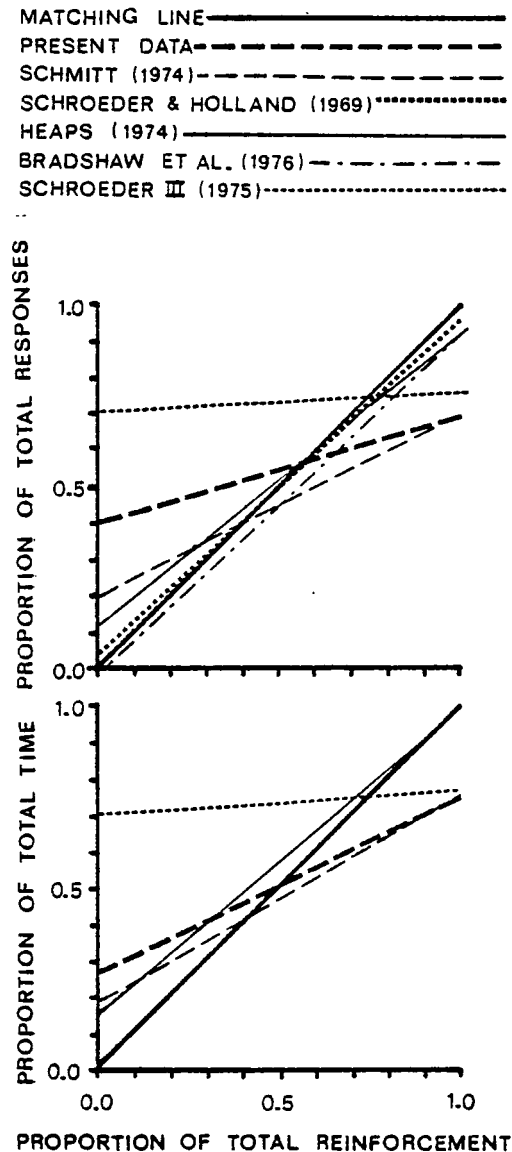


Figure 6

Lines of best fit for the proportion of total response or the proportion of total time as a function of the proportion of total reinforcement. Data is shown for six different studies of human performance on concurrent schedules.

the original studies used them and did not supply sufficient data to convert them to the logarithms of ratios that are used with relative rates in the rest of the present study. The lines of best fit are derived from mean data for each study. The data for the present study, Bradshaw et al. (1976), Heaps (1974), and Schmitt (1974) are the arithmetic means of the individual lines of best fit of each subject in the study. The data for Schroeder and Holland (1969) was computed by combining the data from all of their subjects on all schedules, excluding those schedules not using a COD, and deriving a line of best fit. This procedure was necessary because each subject was tested on only one or two schedules with which a COD was used. Data for Experiment III of Schroeder's (1975) study is from a single subject. The schedules used to obtain the data presented in Figure 6 varied. Bradshaw et al. (1976), Schmitt (1974), and Schroeder and Holland (1969) all used conc VI VI schedules. Heaps (1974) used conc VI FR schedules, while Schroeder's (1975) data is from conc FI FR schedules.

As can be seen in Figure 6, humans have great variability in the degree of matching they display, ranging from extreme undermatching to almost perfect matching.

This study and the other results shown in Figure 6 suggest that the perfect or nearly perfect matching relationships often reported in studies involving pigeons may be only one extreme of a possible range of direct linear relation-

ships that exists between time allocation and relative reinforcement rates. The variables that may control the degree of matching exhibited are open to speculation at this time.

One possible explanation of the great variability between studies shown in Figure 6 is that the CODs in the studies that show undermatching were too short. A number of studies with pigeons (Catania, 1963b; Herrnstein, 1961; Silberberg & Fantino, 1970; Stubbs & Pliskoff, 1969) found that no COD or a COD less than 1 sec produced undermatching. The characteristics of the responding produced in this undermatching have not been reported. There is some indication (Catania, 1963b) that the undermatching that occurs when the COD is too short is a result of greater variability in the relationship between time allocation and relative reinforcement rather than a systematic change in that relationship. The data from the present study indicate an orderly linear relationship between relative time and relative reinforcement with little unaccounted for variance.

It appears that the 3.25 sec COD used in the present study should have been sufficient to produce matching if this were the critical variable. The choice of the 3.25 sec COD used here was based on the results of Schroeder and Holland (1969). They found a 1 sec COD sufficient to produce matching in five of their six subjects and a 2.5 sec COD sufficient to produce matching in all of their subjects. Similar results were found in other studies with humans that produced

matching. Baum (1975) produced matching with a 2 sec COD. Bradshaw et al. (1976) produced matching in humans with no COD.

Another result of this study that needs further comment is the relationship found between relative local response rate and relative local reinforcement rate. Single key studies (Catania & Reynolds, 1968) and studies with multiple schedules (Lander & Irwin, 1968; Reynolds, 1963) have consistently found response rate to be a positive function of reinforcement rate. In contrast, studies of conc VI VI schedules have found local response rates to be a slightly negative function of reinforcement (Bauman et al., 1975; Killeen, 1972; Stubbs & Pliskoff, 1969). The magnitude of the negative function found in the present study is in close agreement with the previous work done with conc VI VI schedules. It is also quite consistent between subjects within the study. This negative function accounts for the common finding that time allocation produces better matching than does relative overall response rate (Lobb & Davison, 1975; Shull & Pliskoff, 1967; Silberberg & Fantino, 1970; Trevett et al., 1972).

The final result that merits comment is the failure of responding to extinguish during the VT component. This appears to be a case of superstitious responding (Skinner, 1948). Recently there have been differing interpretations of the superstitious responding phenomena (Herrnstein, 1966; Staddon & Simmelhag, 1971). While this study presents no

data bearing on the interpretation of superstitious responding, it does perhaps specify another situation under which it is likely to occur. The results reported here are similar to those reported by Baum et al. (1975) and Wilkie (1972). Using pigeons and rats respectively, they reported response rates that were very little lower on the VT component than on the VI component of conc VI VT schedules.

It is possible that differences in the method of training used could account for the extinction of responding of child A during the VT component, and the continued responding by the other children. As part of the training for the pilot study, child A was verbally instructed by the experimenter to push the response and changeover buttons. He was allowed to experience the consequence of the button pushing. The experimenter made no comment on the results. The other children were trained by observing a model operating the experimental apparatus. No instructions were used. Whether or not the model responded during the VT component had no effect. Child A served as the model for B and C. Child B, who did respond during the VT component, served as model for children D, E, and F. All of these children subsequently responded during the VT components.

This experiment has two implications that may be of practical importance to people whose work involves modifying human behavior. The first is that when humans may distribute their time between two behaviors, the relative amount of time

allocated to each behavior is directly dependent on the relative reinforcement rate during that behavior.

The second implication is that this relationship will hold whether reinforcement is response dependent or response independent. The fact that reinforcement is response independent seems to have very little effect on either response or time allocation, at least in a concurrent schedule situation.

These two implications should be considered in a training situation. It is probable that the time a student allocates to a behavior being trained will be reduced by the introduction of reinforcement that is not contingent on the trained behavior. Thus, introducing extraneous reinforcement will directly decrease the effectiveness of scheduled reinforcement in producing and maintaining desirable behavior and reduce the overall efficiency of a program. This would indicate that the most efficient training program is the one with the least extraneous reinforcement.

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APPENDIX

Totaled Data for the Last 3 Days of Each Condition

Appendix

Number of changeovers (CO), order of occurrence of each schedule condition, component schedule (Schd), number of reinforcements (Rft), cumulative change-over delay (COD) time and post-changeover delay (PCOD) time, responses during COD and PCOD time for each component. All data is totaled for the last three days of each condition.

Subject	Order	VI							VT						
		Schd	Rft	Time (sec)		Response		CO	Schd	Rft	Time (sec)		Response		PCOD
				COD	PCOD	COD	PCOD				COD	PCOD	COD	PCOD	
A	1	16.5	73	89	1029	96	726	53	165	9	81	810	0	2	
	6	16.5	87	52	1469	61	1018	31	165	9	45	625	1	32	
	4	20	75	64	1163	113	1205	40	60	21	60	858	0	2	
	2	30	43	66	969	71	690	41	30	43	66	1054	0	1	
	3	60	24	56	547	87	470	36	20	72	51	1508	0	0	
	5	165	14	65	570	113	704	37	16.5	94	55	1466	0	3	
B	2	16.5	97	19	1826	22	905	11	165	5	13	305	8	304	
	6	16.5	97	79	1379	116	770	45	165	10	65	639	105	533	
	4	20	62	153	832	245	811	93	60	24	147	1047	223	1157	
	1	30	45	71	925	67	606	49	30	47	66	1110	64	623	
	3	60	28	190	1040	258	568	139	20	44	183	687	255	627	
	5	165	16	78	811	116	879	50	16.5	77	73	1194	103	1100	
C	3	16.5	73	46	1646	9	364	84	165	6	33	411	5	65	
	2	20	74	38	1754	4	380	31	60	12	24	342	4	87	
	5	30	35	40	1080	21	123	43	30	27	31	784	18	110	
	1	60	13	51	457	21	93	110	20	79	79	1574	36	234	
	7	60	15	48	585	10	64	36	20	76	46	1484	9	75	
	4	165	10	42	499	37	179	74	16.5	102	54	1570	33	200	
D	6	165	11	39	573	0	43	25	16.5	101	39	1515	1	50	
	2	16.5	79	50	1873	40	512	66	165	3	40	239	26	106	
	3	20	59	42	1155	57	671	34	60	18	50	910	57	709	
	4	30	20	39	599	58	397	36	30	50	43	1475	47	905	
	5	60	23	47	908	29	512	41	20	61	40	1165	28	432	
	1	165	4	17	110	20	86	10	16.5	114	17	2014	16	873	
E	6	165	8	35	557	35	360	21	16.5	102	33	1539	34	749	
	1	16.5	51	96	1317	92	412	60	165	13	83	674	64	136	
	5	20	76	59	1311	106	1017	44	60	16	55	734	95	1077	
	4	30	46	33	1236	55	1284	21	30	37	32	876	55	788	
	2	60	35	55	1441	84	906	31	20	36	42	632	62	405	
	3	165	13	35	817	26	435	43	16.5	76	29	1314	10	334	
F	5	16.5	85	204	898	456	1072	141	165	14	204	866	346	1206	
	4	20	78	163	976	374	1100	113	60	30	155	870	325	1258	
	2	30	42	95	1078	127	760	58	30	42	77	942	101	813	
	1	60	20	79	891	27	359	49	20	60	66	1117	34	269	
	6	60	32	224	938	282	1103	144	20	72	201	783	342	767	
	3	165	15	156	531	292	1067	197	16.5	84	219	1271	539	2384	