

Choice, Matching, and Human Behavior: A Review of the Literature

W. David Pierce and W. Frank Epling
The University of Alberta

This review concerns human performance on concurrent schedules of reinforcement. Studies indicate that humans match relative behavior to relative rate of reinforcement. Herrnstein's proportional matching equation describes human performance but most studies do not evaluate the equation at the individual level. Baum's generalized matching equation has received strong support with humans as subjects. This equation permits the investigation of sources of deviation from ideal matching and a few studies have suggested variables which control such deviations in humans. While problems with instructional control are raised, the overall findings support the matching law as a principle of human choice.

Choice and preference are pervasive aspects of human behavior. Concurrent schedules of reinforcement (Herrnstein, 1961) provide a procedure for the experimental analysis of choice behavior. This analysis concerns the distribution of time and behavior among alternative sources of reinforcement. Principles of choice have been extended to a variety of species and experimental settings (de Villiers, 1977). Over the past decade this extension has included an analysis of human performance on concurrent interval schedules of reinforcement. Given the importance of choice to an understanding of human behavior, it is critical to review and assess this research.

In order to evaluate human performance in choice settings it is necessary to detail the concurrent procedure. In addition, it is important to stipulate the relationship between behavior and reinforcement known as the matching law. This law was quantified by Herrnstein (1961) as the matching equation. Since this formulation, more generalized equations have been developed in order to account for departures from expected distributions of behavior. The matching equations represent the current behavior analysis of choice. Thus, it is necessary to

examine the adequacy of the matching law in accounting for human behavior.

The Choice Paradigm

Two different ways of programming concurrent schedules have been employed. One method involves two spatially separated response keys; associated with each key is a separate schedule of reinforcement (Ferster & Skinner, 1957). These schedules operate independently of one another with reinforcements being set up by both. Thus, the organism is free to choose between simultaneously available sources of reinforcement. The other procedure, described by Findley (1958), programs reinforcements on a single response key with alternative schedules signalled by different discriminative stimuli. A changeover (CO) key is also provided. A single response on the CO key changes the schedule of reinforcement and associated discriminative stimulus on the response key.

While research with animals has not made a theoretical distinction between these procedures, such a distinction may be important at the human level. For instance, Sunahara (1980) has suggested that the two key procedure without an explicit changeover may model human social interaction where an individual responds to a number of alternative partners, as in group discussion. On the other hand, the single key procedure may model "role taking" where the individual responds differentially to a single partner. In this case, the individual may

Reprints may be obtained from W. Frank Epling, Department of Psychology, or W. David Pierce, Department of Sociology, The University of Alberta, Edmonton, Alberta, Canada, T6G 2E1. An early draft of this manuscript was presented at the Association for Behavior Analysis meetings, Milwaukee, Wisconsin, May, 1982. Authorship was determined by the flip of a coin.

changeover between the reinforcement schedule of the partner as a co-worker and the schedule in effect when the partner acts as a friend. Current evidence suggests that choice can be described by the same underlying principle with either procedure.

In order to quantify and measure choice as a function of alternative sources of reinforcement, it is essential for experimental analysis that the schedules operate independently. This requirement is necessary because choice is the dependent variable, and if choosing one alternative affects probability of reinforcement on the other, then the control of behavior is confounded. For this reason concurrent variable interval (VI) schedules are typically employed, since steady stable rates of response develop and because a time-based schedule may elapse at the same moment that responses to the other schedule are being made. In contrast, ratio schedules are not independent, since responding on one schedule necessarily reduces rate of reinforcement on the other. Because of this property of ratio schedules, exclusive responding to the richest alternative is the expected outcome (Herrnstein and Loveland, 1975).

Even when interval schedules are employed, subjects may rapidly alternate between alternatives. This alternation is called concurrent superstitution (Catania, 1966). Alternation occurs because as time is spent on an alternative the other schedule is timing out. Thus, *changing over* to the other schedule may be adventitiously reinforced. In order to further insure independence of schedules, changeover delay (COD) is programmed. This contingency stipulates that a changeover is followed by a brief temporal interval during which reinforcement is not available. In other words, "the COD specifies the minimal time interval that must elapse between a changeover and a subsequent reinforced response" (de Villiers, 1977, p. 235). This procedure insures that responding on an alternative, rather than switching from one schedule, to another is the reinforced response.

The use of concurrent variable interval schedules and the COD procedure has

allowed for precise specification of the relationship between choice and reinforcement. The matching law and its formal representation in terms of the matching equations have yielded the quantification of choice.

The Matching Law and Quantification of Choice

The matching law states that relative amount of behavior, measured in terms of rate of response or time spent, matches relative rate of reinforcement on alternatives. Herrnstein (1961) demonstrated that this relationship described pigeons' behavior on concurrent VI schedules. Rate of food reinforcement on two keys was varied while setting overall reinforcement at 40 per hour. The distribution of responses on the keys was found to be proportional to the distribution of reinforcement. This relationship is mathematically expressed as Equation 1.

$$R_1/(R_1 + R_2) = r_1/(r_1 + r_2) \quad 1.$$

In this equation, R_i represents overall rate of response on respective alternatives and r_i represents overall rate of obtained reinforcement on the same alternatives. This equation states that the proportion of behavior on a given key matches proportion of reinforcement for responding on that key. Thus, if 40% of the reinforcers are delivered to Key 1 then 40% of an organism's behavior will be distributed to that alternative. The matching relationship can be extended also to situations in which an organism responds on more than two schedules (Herrnstein, 1974; Miller & Loveland, 1974; Pliskoff & Brown, 1976).

Other researchers (Brownstein & Pliskoff, 1968; Baum & Rachlin, 1969) have shown that the matching law can be expressed in terms of time spent on an alternative. Equation 2 expresses the choice relationship in terms of time.

$$T_1/(T_1 + T_2) = r_1/(r_1 + r_2) \quad 2.$$

Here proportion of time, T_i , spent on an alternative is equal to the proportional rate of reinforcement for that alternative. This equation permits a specification of choice behavior when responding is continuous rather than discrete. For example,

behaviors like standing, looking at objects, and talking to others can be addressed in this formulation.

Both Staddon (1968) and Baum and Rachlin (1969) encountered deviations from matching using Equation 1. However, the data appeared to have regularity that was ordered by considering the ratio of responses to the ratio of the rates of reinforcement. Thus, Baum (1974a) reports the matching relationship in terms of ratios.

$$B_1/B_2 = r_1/r_2 \quad 3.$$

In this formulation B_i represents behavior and r_i rate of reinforcement. This equation is algebraically equivalent to Equation 1. A generalized form of Equation 3 can be stated as Equation 4.

$$B_1/B_2 = k(r_1/r_2)^a \quad 4.$$

A comparison of Equations 3 and 4 indicates that both are identical when k and a are equal to one. In order to test the descriptive adequacy of Equation 4, Baum (1974a) suggests a log linear transformation resulting in Equation 5.

$$\log(B_1/B_2) = a \log(r_1/r_2) + \log k \quad 5.$$

In this form, perfect matching is obtained when a is equal to one and $\log k$ is equal to zero. When the slope, a , or the intercept, $\log k$, take values other than one or zero, systematic deviations from expected matching are present in the data.

Departures from Ideal Matching

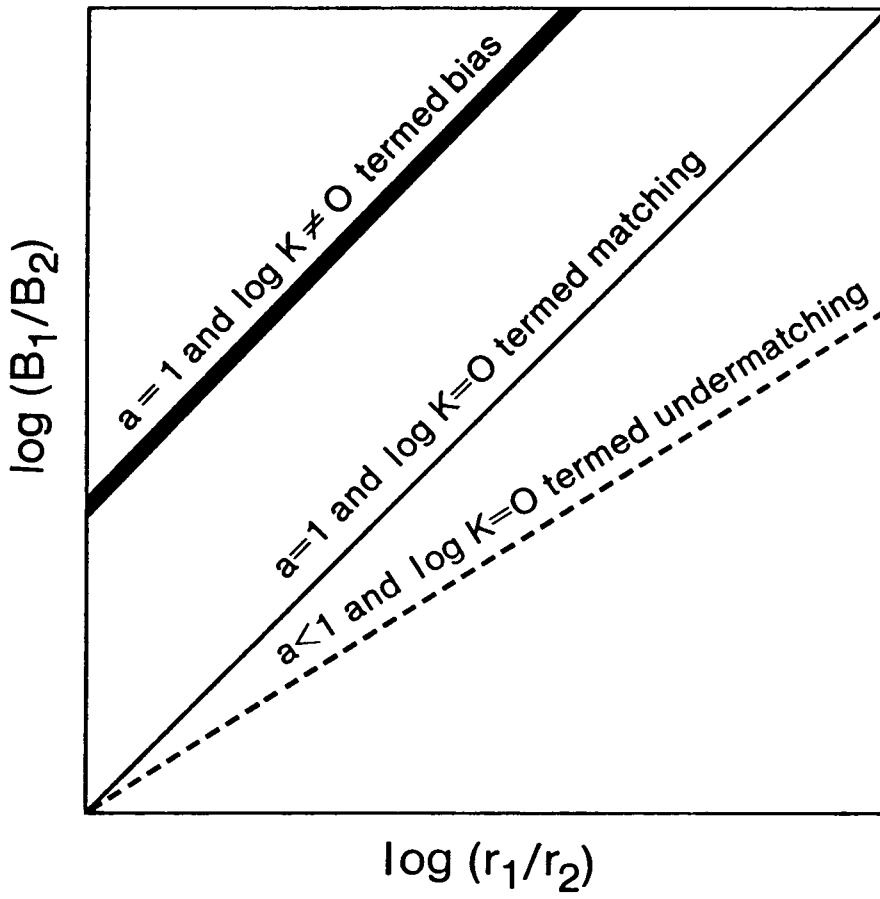
Departures of the slope, a , from the expected value of one are referred to as undermatching and overmatching (Baum, 1974a). The research literature (de Villiers, 1977) suggests that undermatching is most likely, and this is indicated by a slope value of less than one. This situation is portrayed in Figure 1, where log ratio of reinforcement rate is presented on the horizontal axis and log ratio of responses on the vertical axis. The solid thin line represents expected matching of responses to reinforcement i.e., $a = 1$). Undermatching is portrayed by the broken line. Here a unit increase in log ratio of reinforcement produces less than a unit increase in log ratio of responses.

The conditions which control the slope

seem to relate to the concept of sensitivity to the concurrent schedules. This concept has been employed by Bradshaw, Ruddle and Szabadi (1981) and was discussed by de Villiers (1977) in a review of animal studies. Sensitivity labels the fact that the value of the slope varies as a function of COD, discrimination factors, and deprivation for the scheduled reinforcers. Generally, control by the schedules may be adequate or inadequate depending on such conditions. Undermatching is not well understood; Baum (1974a:232-233) has suggested that poor discrimination of the alternatives may be one factor. Adding support to this assumption a programmed COD is often found to improve matching (Schroeder & Holland, 1969; Baum, 1975). However, the function of COD's in facilitating matching are still in dispute (see, de Villiers, 1977: 243-244), with some researchers emphasizing the punishing function of time-out from reinforcement as a critical aspect of the procedure (Pliskoff, 1971). Human data (Baum, 1975) also indicates that a response cost for changeovers may be a powerful variable affecting the slope parameter and sensitivity to the operating schedules. Further research is necessary, however, in order to understand the controlling variables of human sensitivity to alternative sources of reinforcement.

Departures of the intercept, $\log k$, from zero are termed "bias" (Baum, 1974a: 233). Figure 1 illustrates a situation in which bias is indicated by the solid thick line. Baum (1974a) has defined bias as a systematic asymmetry between alternatives that leads one to be reliably preferred over the other. Such preference shifts may relate to procedures that affect the cost of responding on an alternative (i.e., effort) or manipulations that affect the value of the reinforcers received from an alternative (i.e., qualitatively different reinforcers).

Human studies are available which assess the proportional and generalized matching equations and stipulate some of the conditions that affect deviations from matching in human subjects. This review primarily concerns human performance on concurrent VI/VI positive reinforce-



ment schedules since these schedules are most appropriate for testing the descriptive adequacy of the matching relationship. Other more complex schedules involving concurrent chains (see, Fantino & Logan, 1979) and concurrent schedules of negative reinforcement (e.g., Navarick, 1982) are not reviewed, since few have been investigated at the human level and the implications of these schedules are not currently well understood.

SUPPORTING EVIDENCE FOR HUMAN MATCHING

Choice on Concurrent Interval Schedules. Human performance on concurrent interval schedules was first investigated by Schroeder and Holland (1969) using a vigilance task. Subjects responded on two buttons to reset pointers on right and left dials. Detection of pointer deflections was the reinforcer, and eye movements toward the left and right dials were the concurrent operants. Subjects were told to monitor the display of dials and report detecting a deflection by pressing an appropriate button. The operating contingencies were variable-time (VT) schedules, since deflections were not dependent on the prior emission of an eye movement. While four variable-time schedules with average intervals of 9, 20, 30 and 60 seconds were assessed, a single subject did not receive all counter-balanced ratios of these schedules, and individual functions could not be estimated. Subjects were told that "there is a way for you to optimize the number of pointer deflections you receive" (p. 899). This instruction was provided to weaken the initial tendency to scan the dials in a Z pattern. Detection of pointer deflections (i.e., rate of reinforcement) sometimes departed considerably from programmed schedules. Also, the pooled data from 6 subjects failed to show matching of percentage eye-movements with percentage obtained reinforcement in the absence of a COD. This problem was reduced in the pooled data by imposing a COD on changeover in eye fixation. Overall, these results suggest that humans match relative visual behavior to relative

rate of reinforcement and that matching is dependent on a COD to reduce rapid changeovers and achieve functional independence of the schedules (Catania & Cutts, 1963).

A series of experiments on COD and concurrent schedules with developmentally retarded subjects was reported by Schroeder (1975). Both demonstration and instructions were given to establish responding for pennies on red and green keys. Various concurrent interval and ratio schedules were presented to subjects via standard operant programming. In experiment 4 of this study, schedules were VI 30-sec/VI 60-sec to VI 30-sec/VI 300-sec to VI 60-sec/VI 60-sec in that order. Using a 5 sec COD, the pooled data from two subjects indicated matching of key pressing to relative rates of monetary reinforcement according to the proportion equation.

Proportional matching was also assessed by Bradshaw, Szabadi and Bevan (1976) with a button pressing task maintained by monetary reinforcers. Two subjects responded on a single key with a changeover procedure and no COD imposed. Five schedules (VI 720-sec, 157-sec, 51-sec, 25-sec, and 17-sec) were signalled by respective amber lights. In the second phase of the experiment, these five schedules were varied every 10 minutes while a signalled VI 51-sec schedule remained concurrently available. All schedules were presented during a session, and 15 sessions were completed for each subject. The proportional matching equation fit the data for each subject. Least squares regression generated a line that was $y = 0.03 + 0.89(X)$ for subject SM and $y = -0.04 + 0.99(X)$ for subject AM. The regression coefficients were .980 and .981 respectively, indicating that knowledge of proportional rate of reinforcement reduces approximately 96% of the error in predicting proportional rate of response. Human concurrent performance conformed to the matching law at a level equivalent to animal investigations (de Villiers, 1977).

Conger and Killeen (1974) assessed human performance in a group discussion situation. Five subjects were assigned to

groups discussing attitudes toward drug abuse. Each group was composed of three confederates and a subject. Two confederates acted the role of the audience and (on the basis of cue lights) reinforced the subject's talking with brief positive words or phrases. A third confederate prompted speech but did not reinforce talking. Results were analyzed with relative time spent talking to an audience as the dependent variable and relative rate of cues as the independent variable. Because each subject only received two values of proportional rate of reinforcement, the pooled data of the five subjects during the last five minutes on the schedules were analyzed. While the data indicated some variability, linear regression fit the aggregated results with 81% variance explained. The prediction equation, $y = 0.07 + 1.01(X)$ for the pooled data is in accord with Herrnstein's proportion equation. Thus, these results are consistent with individual matching of talking to relative rate of verbal reinforcement. In addition, the data suggest that the matching relationship holds in "natural" social settings.

Baum (1975) investigated the adequacy of the ratio equation in a signal detection task. The experiment was described as a game of detecting and destroying enemy missiles. Red missiles could be detected by holding down the left key and green missiles by depressing the right key. Allocation of signals to the alternatives was varied so that a single subject was exposed to 7 ratios of reinforcement. The major dependent variable was relative time spent holding down left or right keys. When the COD was 2-sec and the probability of response cost for changeovers (i.e., "hits") was .33, two of the subjects matched time ratios to the ratio of reinforcement with greater than 90% variance explained. The equations for Doug ($y = 1.16(X) - .08$) and Noa ($y = .98(X) + .03$) suggested excellent matching of ratio of time spent to ratio of reinforcement rate. A third subject initially undermatched, but increasing the CO response cost to 1.00 and maintaining a 2-sec COD produced a slope close to the expected value ($a = 0.94$). With this pro-

cedure the matching equation explained approximately 93% of the time ratios spent by the subject on the alternatives. Apparently, a response cost for changeovers is effective in producing human sensitivity to the concurrent schedules.

A study by Oscar-Berman, Heyman, Bonner and Ryder (1980) assessed concurrent performance of a group of normal subjects ($N = 6$) and a group of patients ($N = 5$) with Korsakoff's psychosis (amnesia). Three concurrent interval schedules (ratios of 3:1, 1:1, and 1:9) were arranged in a single key pressing task with changeover procedure and a 5-sec COD. The reinforcers were nickels dispensed into a recessed receptacle. Performance of normal subjects conformed to the ratio matching equation, but with slope values considerably less than one. The reason for this undermatching was not explored, and because of this, these results may actually argue against generalized matching from some perspectives. The patient group failed to demonstrate adequate matching to relative rate of reinforcement. This failure of matching was attributed to the patient's difficulty in retaining the task requirements from one session to the next. This would result in a failure to establish steady-state control of performance by the concurrent schedules.

Ruddle, Bradshaw, Szabadi and Bevan (1979) reported a modified two key procedure without explicit changeover and no COD. Six subjects were instructed to pull either of two spacially separated levers in order to earn points exchangeable for money. Five concurrent interval schedules were presented to each subject, and the operating schedules were signalled by amber lights. A VI 51-sec schedule always operated on the left while the schedules on the right were varied (VI 3-sec, 17-sec, 51-sec, 171-sec, and 720-sec). Instructions stated "if at any stage, while pulling lever A, you think it would be a good idea to change to (lever B), you may do so, and you may switch back again anytime you wish" (p. 512). Results showed that each subject's performance was described by the ratio equation, although two subjects undermatched and two overmatched. The

correlations for individual subjects ranged between .91 and .99, which indicates a good fit of the generalized matching equation. The grouped data for all six subjects revealed a function, $y = 1.06(X) + .17$, with no significant deviation in slope or intercept and approximately 92% variance explained. These results strongly support the matching law in describing human choice behavior.

While most studies of human concurrent operant performance have employed conditioned generalized reinforcers (typically points exchangeable for money), most animal studies have scheduled primary reinforcers (e.g., food). Buskist and Miller (1981) provide evidence of matching in humans with concurrent schedules of food reinforcement. Subjects were undergraduates who participated to receive class credit in introductory psychology. The operants were pulling on either of two doors of a vending machine to obtain salted nuts (i.e., the edible reinforcer). Over a 6 week period three subjects responded on three concurrent schedules with a constant 3-sec COD: VI 100-sec/VI 40-sec; VI 60-sec/VI 60-sec; and VI 40-sec/VI 100-sec. Regression equations were fit to individual data based on the last four days of a given condition. Log ratio of responses were a function of log ratio reinforcement with no significant deviations of slope and intercept ($r^2 > .95$). While these results confirm human matching on concurrent schedules, the subjects behavior may not have been controlled by primary reinforcement. Subjects were told that the person who obtained the most food over a 5-day period would receive a monetary bonus and a chart indicated the number of cups of food obtained for each session. Although subjects ate the food, they were instructed to do so. Therefore, food may have been a conditioned reinforcer. Thus, this study may be additional evidence for human matching on concurrent schedules of conditioned reinforcement.

Eight studies of concurrent interval or variable time schedules confirm matching of relative time or responses to relative rate of reinforcement. There is also a literature that pertains to deviations from

matching in humans. While departures of the slope and intercept from expected values (Equation 5) disconfirm matching when the source of control is unknown (Baum, 1974a), studies which systematically vary a *known* condition in order to represent the effects in terms of changes in these parameters could be viewed as supporting the matching law formulation. More specifically, these studies are developing a theory of matching in the sense of specifying the conditions which control the values of the bias and sensitivity parameters. This allows for prediction in more "complex" environments where multiple sources of control operate to affect choice and preference.

Control of Deviations from Matching. Several human studies have explicitly attempted to understand the conditions which produce changes in slope or intercept of the generalized matching equation. The previously reviewed Baum (1975) study of human vigilance indicates that varying the COD and imposing a response cost for changeovers may reduce undermatching and produce a slope close to the expected value ($a = 1$). Results suggested that response cost for changeovers may have been the most important controlling variable in this experiment.

Bradshaw, Szabadi and Bevan (1979) reported a single key experiment which included punishment in one component of concurrent interval schedules. The procedures were similar to Bradshaw, et al. (1976) and the operating concurrent schedules were the same as Ruddle, et al. (1979). In addition, a VR34 punishment schedule operated (loss of 1 point) on the unchanging VI 171-sec component of five concurrent VI schedules. In the absence of punishment, ratio of behavior (response rate or time spent) matched ratio of reinforcement (Equation 5), with correlations between .95 and .99 for three female subjects. When responding was punished, response rates declined in the punished component and increased in the unpunished alternative. This contrast effect resulted in a bias toward the unpunished component and also considerable undermatching for each subject.

Apparently, punishment in this case had multiple effects both on preference (i.e., the intercept) and sensitivity to the schedules (i.e., the slope).

The effects of signalling reinforcement has also been investigated. Bradshaw, Szabadi, Bevan, and Ruddle (1979) employed the single key procedure outlined previously. Performance of three subjects was well described by the ratio equation with some undermatching in one subject. When the availability of reinforcement was signalled in one component, response rates reduced but at the same time increased in the other component. This resulted in bias for the unsignalled component with no change in the slope value.

Bradshaw, et al. (1981) have presented evidence that human responding is biased when effort on the response keys is manipulated. In all six of their subjects, the key with the least effort was systematically preferred. Five of the subjects also showed a reduction in response rate for the higher effort component. That was not accompanied by a change in rate on the lower effort key. These researchers note that effort seems to function quite different from punishment applied to one component of concurrent VI schedules.

A social interaction experiment by Sunahara and Pierce (1982) investigated the effects of reinforcement "inequity" on the intercept of the matching function with concurrent VI schedules. Reinforcers were points delivered on counters, and inequity was defined as lack of proportionality between points given to a partner and points received from that individual. During the initial phase of the experiment, both interaction partners (actually subjects interacted with program equipment) acted in an equitable manner, since the points registered on the GIVE to partners B and C counters closely approximated the points RECEIVED from these respective partners, and expected matching was obtained. When partner B became inequitable during the second phase (i.e., GIVE to B > RECEIVED from B), a systematic bias was observed in favor of the other equitable partner in 8

of the 11 subjects. This deflection of the intercept occurred regardless of order of presentation of equity and inequity phases. Further evidence indicated that the intercept value recovered when equitable conditions were restored.

Sunahara and Pierce (1982) interpreted the effects of inequity on the intercept value in terms of stimulus control. This analysis assumed that most people share reinforcement histories which punish reward inequities (Walster, Walster & Berscheid, 1978), and they are reinforced for equitable reward distributions. Thus, an inequitable exchange would acquire discriminative functions. The presence of inequity on one alternative and equity on the other would be expected to reduce responding on the inequitable component. The data supported this interpretation, since responding declined on the inequitable alternative with no change in rate on the equitable component. A reduction in response rate occurred even when the overall payoffs from the inequitable alternative were greater than those received from the equitable component. This similarity in the effects of effort and inequity on human responding on concurrent VI schedules may reflect a common factor. Whether stimulus control or cost variables account for these effects is a problem for future research.

There is evidence that "value" operations may result in deviation of the intercept. This is suggested by an experiment on gambling with several alternative schedules of reinforcement (Hamblin, Clairmont & Chadwick, 1975). Subjects could wager with two dollars which they had earned previously. Choice behavior was described by equations analogous to a multivariate matching function; however, choice was a function of both relative rate of reinforcement (i.e., winning) and the amount of reinforcement (i.e., how much was won). Hamblin (1979) interprets the amount of winnings as a manipulation of value. If the generalized matching equation (Equation 5) were fit to these data, the effect of reinforcer magnitude would be indicated by a shift in the intercept, $\log k$, from zero. Thus magnitude of reinforcement appears to be an operation

which biases responding over and above relative reinforcement rate. This interpretation receives additional support from animal studies (Hollard & Davidson, 1971; Hamblin & Miller, 1977).

Another value operation involves scheduling qualitatively different reinforcers on concurrent alternatives (de Villiers, 1977). The effects of different types of reinforcers can be measured by the bias parameter ($\log k$), and the antilog values can be used to make new predictions about the distribution of behavior when choice is between (or among) new combinations of these reinforcers (Miller, 1976). An experiment by Cliffe and Parry (1980) investigated qualitatively different reinforcers and the predictive use of the matching law. A single male subject, incarcerated for sexual offences against young girls, responded on five VI schedules (720, 360, 240, 180 and 144-sec) for visually presented sexual stimuli (i.e., slides of nude men, women, and "sexually interesting" slides of children). Each VI component was signalled by a different colored light. After initial training, the subject was required to choose between concurrent VI schedules composed of the above values so that overall rate of reinforcement was held at 30 per hour. Schedules operating on the left and right keys were again signalled, but now only one type of sexual reinforcer was produced on each key. In the three conditions of this experiment, the subject chose between a) slides of men or slides of women, b) slides of men or slides of children, and c) slides of children or slides of women.

The matching equation (5) by least squares method fit the data of the first two conditions with r^2 greater than .87 for both response and time ratios. The intercept values indicated bias for slides of women to slides of men (Condition 1) and slides of men to slides of children (Condition 2). The antilog values of the intercepts for both conditions were used to form "quality ratios," and these were subsequently employed to predict the distribution of behavior by the subject in Condition 3 (choice between slides of children or slides of women). Predictions

based on a value equation of the matching law (Miller, 1976), multiplying the quality ratios, were in accord with obtained quality ratios (for both time and responses) for Condition 3. The matching law predicted choice between the alternatives when *both* relative rate of reinforcement and qualitatively different reinforcers were varied.

FAILURES TO CONFIRM MATCHING IN HUMANS

Schmitt (1974) investigated human choice in two experiments which varied either relative rate of reinforcement or relative magnitude of reinforcement. Experiment one employed a single key procedure where five subjects pressed a button to obtain points exchangeable for money. After initial training on separate VI 15-sec and VI 30-sec schedules, a concurrent VI 15-sec/VI 30-sec schedule was in effect. After stability was achieved, subjects responded on concurrent VI 15-sec/VI 75-sec, VI 150-sec/VI 300-sec and VI 150-sec/VI 750-sec. While four concurrent schedules with a 1.5-sec COD were arranged in this study, only two different ratios of reinforcement 2:1 or 5:1 were investigated. In order to keep earnings at a \$2.88 maximum per hour, the point values and the number of points per reinforcement were changed when the concurrent schedules were altered. Thus on concurrent VI 15-sec/VI 30-sec and concurrent VI 15-sec/VI 75-sec schedules a point was worth 0.1 cents with 8 points per reinforcement. On longer schedules a point was valued at 1 cent, and 8 points occurred per reinforcement on concurrent VI 150-sec/VI 300-sec while 10 points were registered on concurrent VI 150-sec/VI 750-sec. It is important to note that this point allocation procedure varied magnitude of reinforcement over concurrent schedules, even though overall reinforcement was constant.

Results suggested large departures of proportion of responses (and time) from proportion of obtained reinforcement. This failure of proportional matching can not be attributed to inadequate exposure to the contingencies, since subjects typically picked-up most of the scheduled

reinforcers. Overall, the data indicated that subjects distributed relatively less time and behavior than would be expected to that alternative with the shortest inter-reinforcement interval. A second experiment held relative rate of reinforcement at 50% and varied the relative magnitude of reinforcement on the two alternatives. Again, subjects failed to show matching of relative response rate and relative reinforcer magnitude. However, results of matching to reinforcer magnitude have been inconsistent at the infra-human level (see, de Villiers, 1977).

Schroder (1975) was previously discussed as providing evidence for matching in his fourth experiment. Using the same playing task with retarded subjects, experiment 1 demonstrated that subject ER on concurrent VI 30-sec/VI 360-sec failed to closely match percent responses to percent reinforcement over COD values from 0.3-sec to 30-sec. While increasing the COD from .3-sec to 2-sec greatly reduced changeovers, this reduction was not accompanied by improved matching. Observation of subject AM on concurrent FI 30-sec/FI 360-sec schedules also failed to indicate adequate matching over COD values. Only a single value of relative reinforcement was programmed for each subject, so that it was not possible to fit the matching equations to these data. Two other subjects received concurrent ratio schedules, and both showed almost exclusive responding for the shorter ratio schedule. Such "exclusive preference" is required by the matching equation as applied to ratio schedules (Rachlin, 1976).¹

In another study of proportional matching, Wurster and Griffiths (1979) used a single key procedure and a button pressing task with three human subjects. Reinforcers were points delivered to separate

counters exchangeable for money. Concurrent VI 30-sec/VI 130-sec, VI 30-sec/VI 15-sec, and VI 30-sec/VI 150-sec, schedules were arranged for each subject and a 3-sec COD was imposed. Sessions continued at each value of the concurrent schedules until five sessions occurred in which relative rate of response deviated less than 10% between any two sessions. Results portrayed the last five days on the three concurrent schedules for each subject. With this analysis, the authors concluded that proportion of response did not closely match proportion of reinforcement.

Research of Pierce, Epling and Greer (1981) investigated the concurrent performance of six female undergraduates in a communication setting. Building on the work of Conger and Killeen (1971), this study assessed the ratio equation in log linear form (Equation 5) in a situation where the subject could talk to two concurrently available audiences. The audiences were confederates who reinforced speaking with verbal agreements on the basis of cue lights scheduled by two VI timers. Seven values of the reinforcement ratio were investigated within each subject so that individual functions could be estimated.

Results for the last half hour on each ratio value showed that two subjects conformed to the matching equation, although undermatching and bias were indicated. One subject's performance was not described by the generalized matching equation. Most interestingly, three subjects demonstrated an inverse matching relationship between ratio of reinforcement (i.e., agreements) and ratio of behavior (measured either by response rate or time spent). Essentially, these subjects gave more behavior to the audience which supplied less agreement. The basis for such "inverse matching" is not clear and has not been reported in previous research.

GENERAL DISCUSSION

Summary of Results. A summary of the investigations reviewed in this paper appears in Table 1. Thirteen of the sixteen studies support the statement that human

¹ A second experiment of the series investigated asymmetrical COD's and is not relevant to this review. Also, a third experiment of concurrent interval/ratio schedules is not easily interpreted within a simple concurrent paradigm since characteristic control by the schedules and schedule interaction make interpretation of the data problematical. Further research would be required in a concurrent-chain model (Fantino & Logan, 1979) in order to state the implications of such schedules on choice behavior.

TABLE 1
Studies of Human Matching on
CONCURRENT INTERVAL SCHEDULES

Study	Results	Task	Equation	Deviation
Schroeder & Holland, 1969	Confirm	Signal detection	Proportion equation fit pooled response data with 1-sec COD	Undermatching reduced by imposing COD.
Conger & Killeen, 1974	Confirm	Discussion with audiences who reinforce with positive comments	Proportion equation fit pooled talk time data, $r^2 = .81$ $Y = 0.07 + 1.01(x)$	
Schmitt, 1974	Refute	Working for points exchanged for money. Single key procedure	Unable to fit matching equations since only two ratios of reinforcement investigated: 2:1 and 5:1	
Baum, 1975	Confirm	Signal detection game—detecting and destroying enemy missiles.	Ratio equation indicates time matching ($r^2 > .90$) of Doug $y = 1.16(x) - .08$ and Noa $y = .98(x) + .03$ with 2-sec COD and response cost. Third subject ($r^2 = .93$) matches when response cost is increased.	Undermatching reduced by COD and response cost for changeover
Hamblin, Clairmont, & Chadwick, 1975	Confirm	Gambling game—betting on alternatives	Hamblin 1979 reports that the data were described by a multivariate matching equation. Both rate of reinforcement and magnitude of reinforcement predicted betting behavior. Magnitude of reinforcement would be indicated as bias in the generalized matching equation.	

TABLE 1 (Cont.)

Study	Results	Task	Equation	Deviation
Schroeder, 1975	Exp. 1 Poor Matching Exp. 4 Confirm	Working for points exchanged for money is task for all experiments	No fit of equations possible for Exp. 1 Proportion equation fit pooled data of two retarded children with 5-sec COD	
Bradshaw, Szbadi, Bevan, & Ruddle (1976)	Confirm	Working for points exchanged for money. Single key procedure	Proportion equation Subjects SM ($r = .980$) $y = .89(x) + .03, AM (r_{xy} = .981)$ $y = .99(x) - .04$ individual level matching	
Bradshaw, Szbadi & Bevan, 1979	Confirm	Working for points exchanged for money. Single key procedure	Ratio equation yields good time and response matching for three subjects in absence of punishment $r_{xy} > .95$	Punishment produces decline in response for punished component and increase in response for the unpunished alternative. Both bias and under- matching reported
Bradshaw, Szbadi, Bevan, & Ruddle, 1979	Confirm	Working for points exchanged for money. Single key procedure	Ratio equation fits both responses and time of these subjects when reinforcement availability is not signalled ($r > .978$). No significant deviations	Signalled rein- forcement reduces response rate in signalled comp- onent and increases rate in unsignalled alternative. Only bias parameter is affected.

TABLE 1 (Cont.)

Study	Results	Task	Equation	Deviation
Ruddle, Bradshaw, Szabadi & Bevan, 1979	Confirm	Pull levers for points exchanged for money. Two key procedure	Ratio equation fits six individuals with $r_{xy} > .91$. Pooled data $y = 1.06(x) + .17$ with no significant deviations	
Wurster & Griffiths, 1979	Authors argue refute. Re-analysis favors confirm.	Working for points exchanged for money. Single key procedure	Proportion equation but no least squares estimates. Proportion responses increase with relative reinforcement but fewer responses in high rate component than predicted. Pooled data based on re-analysis, $r_{xy} = .929$, $r^2 = .86$.	
Oscar-Berman, Hegman, Bonner & Ryder, 1980	Confirm but may actually refute since reason for deviation of slope is unknown.	Working for nickels deposited in receptacle. Two key procedure.	Ratio equation some matching with $N = 5$ normals with three data points per subject. No matching by Korsakoff's patients.	Strong undermatching not explained.
Cliffe & Parry, 1980	Confirm	Working for sexual stimuli by inmate incarcerated for sexual offences. Two key procedure.	Ratio equation fit to data to obtain estimates of bias for type of reinforcer on the alternatives.	Quality ratios based on initial estimates of bias predict behavior in new choice situation
Bradshaw, Ruddle, & Szabadi, 1981	Confirm	Working for points exchanged for money on two levers.	Ratio equation matching at individual level for six subjects with equal effort on the alternatives. $r_{xy} > .88$. Pooled data function is $y = .98(x) = .19$ with no significant deviations.	Reduction of response rate in high effort component. Significant bias but no deviation in slope.

TABLE 1 (Cont.)

Study	Results	Task	Equation	Deviation
Buskist & Miller, 1981	Confirm	Pulling on vending machine windows for food	Ratio equation fit three subjects, $r^2 > .95$ for response rate and $r^2 > .83$ for time. No significant deviations for response rate data. Subject 2, some bias for time ratio.	
Pierce, Epling & Greer, 1981	Mixed	Talk to audiences who provide agreement statements.	Ratio equation for time and response data. Two subjects confirm, one subject no relationship, three show inverse matching.	Undermatching noted.
Sunahara & Pierce, 1982	Confirm	Social exchange of points worth money.	Ratio equation fits both time and response ratios in 11 of 12 subjects, median $r^2 = .89$, during equity phase.	Inequity on an alternative reduces responding in that component resulting in bias

performance on concurrent interval schedules is described by the matching law where relative behavior on alternatives matches relative rate of reinforcement. Both proportional and ratio matching have been observed, and various equations by Herrnstein (1961) and Baum (1974a) have been evaluated. At the present time, the ratio equation seems to have more support at the human level. This equation in its generalized form (Equations 4 and 5) permits a more complete analysis of human choice. While the control of behavior by relative rate of reinforcement is emphasized, departures from ideal matching can also be investigated. Several studies have produced and eliminated bias by manipulations of effort, punishment, inequity, and reinforcement magnitude; it is not yet clear how these operations commonly affect preference. Specification of the conditions controlling both sensitivity and bias is a primary requirement for future research at the human level.

Studies of concurrent interval performance with humans must be evaluated in the context of Skinner's (1969) distinction between rule-governed and contingency-controlled behavior. While individuals may distribute behavior in accord with the matching law, the nature of control in human experiments requires direct examination. In this regard, perhaps the most unique aspect of human studies when compared with animal investigations is the frequent use of instructions to establish concurrent responding (Catania, 1981). Some of the best evidence for matching with humans is obtained by Bradshaw and his colleagues, but this research is also notable in terms of instructional control. Close attention to instructions in these studies suggests that subjects were required to distribute their responding between the alternatives. However, instructions do not appear to require matching of relative response rate to relative rate of reinforcement. Additionally, studies are available which show human matching in the absence of extensive instructions (e.g., Conger & Killeen, 1974). Overall, it would appear that matching *per se* can not be attributed solely to

instructional control of human behavior, although some studies may reflect collateral control by both instructions and the operating schedules. Future investigations could either examine instructional control of human concurrent operants or eliminate instructions by directly shaping concurrent behavior (e.g., Matthews, Shimoff, Catania, & Sagvolden, 1977). This procedure may enhance the sensitivity of humans to concurrent schedules.

Three studies failed to confirm matching with human subjects. While these "exceptions" are few in number, they also represent failures to replicate. Within the experimental analysis of behavior, such failures are important because they can suggest limitations to the analysis or unidentified sources of behavior control. The weight of this evidence must, however, be evaluated in accord with substantive and methodological considerations.

The study by Schmidt (1974) failed to obtain proportional matching. At the methodological level there are reasons to question the validity of this investigation. In order to keep session earnings constant, the value and number of points were varied simultaneously with the changing schedules. This procedure may have contributed to poor matching of relative behavior and relative rate of reinforcement. More importantly, the major issue raised by this study concerns what constitutes an adequate test of the matching law? A reasonable evaluation of the relationship between relative response rate and relative rate of reinforcement, expressed in the matching equations, requires the assessment of several values of the independent variable. This allows for statistical estimation of the relationship. However, Schmidt's study investigated only two values of relative rate of reinforcement, 2:1 and 5:1. Given measurement error and uncontrolled sources of variation (Baum, 1974a), it is unlikely that a point to point correspondence would be found. The ratio equation could perhaps represent Schmidt's data as problems of sensitivity or bias if sufficient points were available. Finally, this same problem pertains to experiment one

reported by Schroeder (1975), who investigated a single value of relative rate of reinforcement.

Wurster and Griffiths (1979) also disconfirm matching with three values of proportional rate of reinforcement for each individual. Three values of relative reinforcement are the minimum number of points necessary to fit the proportion equation at the individual level. The present authors conducted a re-analysis of the data from this experiment. Data were based on the last day's performance rather than the last five days. Additionally, aggregated results were used, since this provided nine rather than three data points. Based on this re-analysis, a substantial relationship between proportional rate of response and proportional rate of reinforcement was obtained, $r_{xy} = .929$. Since the individual and aggregate analyses suggest different conclusions, it is not possible to state with confidence whether this study confirms or refutes the matching relationship.

The study by Pierce, et al. (1981) failed to obtain matching in one subject and reported "inverse" matching in three others. Since seven values of the reinforcement ratios were investigated for each subject, problems of estimation are not likely. Additionally, the reinforcers, which were verbal agreements, were the same as those used by Conger and Killeen (1974). These results may be of substantive importance in questioning the generality of the matching law. However, there are no other investigations that report inverse matching. Thus, these data are an anomaly which may have arisen from methodological aspects of the study. Further studies in social settings using verbal reinforcers seem necessary before such a conclusion is reached.

Comparison of the supporting and disconfirming evidence suggests that the matching law description of choice (see, de Villiers, 1977) can be extended to an analysis of human behavior governed by alternative schedules of reinforcement. The reviewed studies confirm matching under highly controlled conditions with interval schedules. In order to have greater confidence in the descriptive ade-

quacy of the matching law at the human level, subsequent experiments must investigate choice under diverse schedules with various forms of interacting components. With a more extensive analysis of stimulus control and reinforcement scheduling in choice situations, it will be possible to assess the generality of the matching law in accounting for diverse aspects of human behavior.

General implications. While the generality of the matching law will be furthered by the experimental analysis of human behavior, it is presently possible to assess this principle on the basis of correlational evidence. In non-laboratory settings, control is necessarily reduced, and many extraneous factors are allowed to operate. In this context, correlational data can be used to establish the external validity of the laboratory research. Hamblin (1979) has reviewed several studies of social behavior which provide correlational evidence for human matching. An observational study of seven children's verbal interaction by Meighan and Burgess (1972) suggested matching of rate of verbalization with rate of communication received from others. Also, Hamblin re-analyzed group discussion data published by Stephen and Mishler (1952) and found that aggregate verbal interaction rates matched aggregate rates of communication from others. Matching was found in groups of various sizes with a median r^2 of .983. This aggregate matching is equivalent to Baum's (1974b) study of aggregate matching by a flock of free-feeding pigeons. In both cases the group process was well described by the matching law.

Since the matching relationship appears to obtain in naturalistic settings, an understanding of human choice based on this principle may increase prediction and control of socially important behavior. In terms of prediction, the matching law, expressed as the ratio equation (Equation 5), may measure and predict the value of sources of reinforcement. For example, a shift in the bias parameter ($\log k$) may reflect conditions of status, equity, social power, etc. (Sunahara & Pierce, 1982). Thus, in a family system approval and at-

tion may be distributed to a child for compliance. In this view, family members are different sources and schedules of reinforcement which are differentially weighted. Prediction of the child's behavior is possible using the ratio equation and the concept of deviations from matching (see Cliffe & Parry, 1980).

The control of human behavior is also increased with an understanding of relative rate of reinforcement. For instance, a decrease in frequency of reinforcement for an alternative should result in an increase in response to the other alternative, even though reinforcement rate from that source does not change. A practical application is suggested when a parent requires behavior change in a child but is unwilling or unable to act as the change agent. The applied analyst may work with the other parent to produce the desired result. Manipulations of effort, punishment, or reinforcer magnitude would also be expected to redistribute behavior to alternatives in known ways according to the generalized form of the matching law.

The matching law presents the behavior analyst with a more complex view of human behavior. The individual is seen as emitting behavior under multiple sources of control. Even in a single operant setting, the person is choosing to respond rather than engage in some other activity. This point was made clear by Herrnstein (1970) when he derived the major principle of the single operant from the matching equations. The quantitative law of effect and its implications for applied behavior analysis have been recently elaborated by McDowell (1981, 1982). It is clear from these articles that in order to change a given target response, consideration must be given to alternative sources of control which operate to increase or decrease problem behavior (Epling & Pierce, 1983).

At the individual level the matching relationship is a descriptive law. However, this law has been employed as an explanatory principle to account for regularities in social interaction and group processes. Behavioral sociologists (Burgess & Nielson, 1974; Gray &

Sullivan, 1978; Gray & von Broembsen, 1976; Gray, Richardson & Mayhew, 1968; Gray, von Broembsen, Kowalczyk & Williams, 1976; Molm & Wiggins, 1979; Wiggins, 1966) have been working on problems of social exchange and power differences in small groups. Recently, Gray, Griffith, von Broembsen and Sullivan (1982) have discussed social matching across multiple reinforcement domains. In their report, the matching law is used to develop a theory of social power which explains the pervasive tendencies of groups to develop and maintain "local exchange imbalance" (i.e., inequalities in the distribution of resources). This theory is not only explanatory but also has specific implications for the control of group power relations. With extensive research, it may be possible to alter established power and status structures of organizations or societies based on the theoretical implications of the matching law for human groups (also see, Pierce, 1975, 1976; concerning the alteration of a status hierarchy).

Clearly, the matching law has profound implications at both the individual and social interaction levels.² Together with the quantitative law of effect, this principle may be the basis of a powerful analysis of human behavior and contribute to the development of a more effective technology of behavior (Skinner, 1953). The experimental analysis of human behavior will benefit from continued research into the implications of the matching law.

² Rachlin (1974) and Ainslie (1975) have developed a theory of self-control and impulsiveness premised on the "value" form of the matching law. Research evidence, based on this model, (Rachlin & Green, 1972; Burns & Powers, 1975; Zakrzewski, 1977; Navarick, 1982) is accumulating concerning delay of reinforcement and commitment. At the social level, this analysis may specify variables which predict and control group responses that have been termed "social traps" (Platt, 1971). These traps are exemplified by the squandering of free-goods as when air or water are contaminated by industrial waste (Marwell & Ames, 1979).

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