JOURNAL OF THE EXPERIMENTAL ANALYSIS OF BEHAVIOR 1992, 57, 177-185 NUMBER 2 (MARCH)

APPLICATION OF HERRNSTEIN'S HYPERBOLA TO TIME ALLOCATION OF NATURALISTIC HUMAN BEHAVIOR MAINTAINED BY NATURALISTIC SOCIAL REINFORCEMENT

SCOTT D. BEARDSLEY AND J. J MCDOWELL

EMORY UNIVERSITY

Five college students talked to an experimenter about various topics. Time spent looking at the experimenter was reinforced by verbal statements of praise and interest on five variable-interval schedules. Herrnstein's hyperbola provided a good description of the time-allocation data for 4 of the 5 subjects, and accounted for 95% of the variance of the median time-allocation data. The hyperbola provided a significantly better description of the data than a two-parameter ramp function with similar differential properties. Estimates of the asymptote, *k*, of the hyperbola varied among subjects from about 2 to about 15 seconds of eye contact per minute. These estimates were much smaller than the constant 60 seconds of eye contact per minute required by Herrnstein's matching theory. These results support the conclusion that Herrnstein's hyperbola describes naturalistic human behavior maintained by naturalistic social reinforcement as well as it describes the behavior of humans and nonhumans in typical laboratory preparations. The results also indicate that the hyperbolic form of the time-allocation version of Herrnstein's equation is accurate, but that the constant *k* requirement of matching theory may not hold.

Key words: matching law, Herrnstein's hyperbola, time allocation, social behavior, social reinforcement, eye contact, praise, humans

Herrnstein's (1961, 1970) mathematical account of the law of effect has received a substantial amount of research attention. Two areas of study within the matching literature, however, have not been adequately addressed. These are the ability of the hyperbolic form of Herrnstein's equation to describe time allocation of behavior, and the ability of the matching equations to describe naturalistic behavior maintained by naturalistic reinforcers. The present study was designed to address these two problems.

The matching equations have been shown to be good descriptions of nonhuman and human behavior on concurrent (Baum, 1979; Baum & Rachlin, 1969; Davison & McCarthy, 1988; Herrnstein, 1961, 1970, 1974; Wearden & Burgess, 1982) and single-alternative (Bradshaw, Szabadi, & Bevan, 1976, 1977, 1978; Davison & McCarthy, 1988; de Villiers, 1977; Herrnstein, 1974; McDowell & Wood, 1984, 1985) schedules of reinforcement. Despite the large number of laboratory studies on the matching equations, however, no experiment has investigated the time allocation of behavior maintained by single-alternative schedules of reinforcement. The appropriate matching equation for this situation is

$$T = \frac{kr}{r + r_e}, \tag{1}$$

where T represents time spent responding on the instrumental alternative of a single-alternative schedule, r represents rate of reinforcement obtained for instrumental responding, and r_e represents extraneous reinforcement. This equation asserts that time spent responding is a hyperbolic function of obtained reinforcement rate. The asymptote k of Equation 1 is a constant that is theoretically required to equal $T + T_e$, where T_e is the total time spent responding on extraneous (i.e., noninstrumental) alternatives. Evidently, the parameter k must equal the sum of instrumental and noninstrumental time allocation, which is the total session time (Herrnstein, 1979). This theoretically required value for k is an interesting and important feature of Equation 1.

The present study was also designed to extend the basic behavior-analytic work on

We thank Ronald G. Boothe for his helpful advice and for calling our attention to the ramp function. We also thank Lisa Shaw and Mark Pevey for helpful comments and suggestions on the procedure and for assistance in measuring reliability. Requests for reprints should be sent to J. J McDowell, Department of Psychology, Emory University, Atlanta, Georgia 30322.

matching to a more naturalistic setting. The matching law emphasizes the role of context in behavior (Martens & Houk, 1989; Martens & Witt, 1988), allows for predictions of choice between naturally occurring alternatives (Mace, McCurdy, & Quigley, 1990; Myerson & Hale, 1984), and suggests possible alternatives to traditional clinical approaches (McDowell, 1982, 1988). In addition, it has been suggested that the equations have specific implications for behavior therapy (Martens & Witt, 1988; McDowell, 1982, 1988), theories of alcohol abuse (Vuchinich & Tucker, 1983, 1988) and the measurement of sexual preference (Cliffe & Parry, 1980). Matching has also been suggested as a model for small-group interactions (Gray & Stafford, 1988) and group behavior in business organizations (Redmon & Lockwood, 1986). Although the advantages of applying matching theory to naturally occurring behavior have been discussed frequently, relatively few studies have explored matching in naturalistic contexts.

Of the few studies of matching in naturalistic contexts, some are observational in nature (Carr & McDowell, 1980; Martens, Halperin, Rummel, & Kilpatrick, 1990; Martens & Houk, 1989; McDowell, 1982). Others have modified basic laboratory experiments to demonstrate that the matching equations may have relevance to natural human environments (Bradshaw & Szabadi, 1978; Buskist & Miller, 1981; Cliffe & Parry, 1980; Mace et al., 1990; Oscar-Berman, Heyman, Bonner, & Ryder, 1980; Szabadi, Bradshaw, & Ruddle, 1981; Vuchinich & Tucker, 1983). Still other studies have examined matching as a description of naturalistic social behavior maintained by concurrently available social reinforcers (Conger & Killeen, 1974; Pierce, Epling, & Greer, 1981; Sunahara & Pierce, 1982). It remains to be demonstrated experimentally that the hyperbolic relationship between single-alternative responding and obtained rate of reinforcement that holds in the laboratory also holds in a naturalistic context. Observational studies suggest that it does (Carr & McDowell, 1980; Martens & Houk, 1989; Martens et al., 1990; McDowell, 1982), but no experimental test has been attempted.

The purpose of the present study was to test experimentally the time-allocation form of Herrnstein's hyperbola (Equation 1), and to test the ability of this equation to describe naturalistic behavior maintained by single-alternative schedules of naturalistic reinforcement.

METHOD

Subjects

Six college students (1 male, 5 female), aged 18 to 21 years, who were recruited by advertisements posted in residence halls, served as subjects in the experiment. Subjects H4 and H5 received course credit for their first four sessions of participation, payments of $5.00 for each additional session, and a bonus of $10.00 for completing the entire experiment. Subjects H7, H8, and H9 received payments of $5.00 for each session completed and a bonus of $10.00 for completing the experiment. Subject H6 dropped out of the experiment after three sessions, and her data were discarded.

Apparatus

Subjects were seated in a small room at a table (72 cm wide, 145 cm long, 75 cm high) that was covered by a beige tablecloth. Subjects sat in a chair placed at one of the short sides of the table, and the experimenter sat to the right of the subject at an adjacent side of the table, approximately 1 m away, so that the experimenter and subject were facing each other diagonally across the table.

Five white index cards (7.6 cm by 12.7 cm), with one letter (A through E) printed on each, were arranged from left to right across the table. Each card was associated with a variable-interval (VI) schedule, as described below. The cards were placed in a long, clear plastic holder that was located 22 cm in front of the subject and extended 70 cm across the table. Glued to the back of each white index card was a colored index card on which was printed a general topic for discussion. One topic was printed on each lettered card. The five general topics, which remained the same throughout the experiment, were (A) current events, (B) campus life, (C) dating and relationships, (D) life outside of college, and (E) recreation. The general-topic cards were placed on top of specific-topic cards of the same color, on which were written specific topics for discussion. Four questions related to the specific topic were also printed on these specific-topic cards. For example, when the VI schedule associated with Card A was in effect, a gold card on which was written the general topic "current events" was placed on the table above a second gold card on which might be printed the specific topic "movies" and the four questions (a) What is your favorite current movie? Why? (b) What are your favorite all-time movies? (c) What kinds of movies do you like? (d) What are your least favorite movies? The general-topic cards were the same throughout the experiment, but the specific-topic cards changed each experimental session, such that no specific topic was repeated for any subject. As noted earlier, when a schedule was in effect the colored side of the general-topic card was showing and was placed on the table above the specific-topic card of the same color. The cards associated with the schedule in effect, therefore, were not only a different color from the other cards but also covered twice the area on the table as each of the other cards (which were the white index cards with single letters printed on them). In summary, each schedule was associated with a discriminative stimulus having a distinctive color, size, and location on the table.

On the table approximately 70 cm from the subject was a microphone directed towards the subject, with its electrical cord disappearing into a drawer attached to the table. The experimenter wore an earphone in his right ear; the earphone was connected to a tape player placed in the same drawer to which the cord from the microphone led. The tape player played an audiotape that signaled when reinforcement was set up under the VI schedules. Underneath the right side of the experimenter's chair was a switch that the experimenter could operate with his right hand to turn off the VI tape until reinforcement was delivered. The switch was out of the subject's view, and could be operated unobtrusively by the experimenter. A foot pedal was located on the floor in front of the experimenter, out of view of the subject, and was connected to a timing device (Lafayette Instrument Co., Model 54035). The tablecloth prevented the subject from seeing the timing device and the electrical cords leading from the drawer next to the experimenter.

Procedure

Subjects' eye contact with the experimenter was reinforced by verbal statements of praise and interest delivered according to VI 17-s, 25-s, 51-s, 157-s, and 720-s schedules. Interval values were calculated by Fleshler and Hoffman's (1962) method. Two sets of five audiotapes (one audiotape for each VI schedule) were made to signal the ends of the interreinforcement intervals. One set of tapes was used for each subject, and each tape was started where it had ended the previous session. Subjects worked on one VI schedule for 8 min, rested for 4 min, worked on the next VI schedule for 8 min, rested for 4 min, and so on until all VI schedules were presented. During the rest periods the subjects were asked to leave the room and sit alone in a chair in the hallway. During this time the VI tape was changed. The sequence of VI schedules was quasi-random, with the restriction that all VIs appear once per session. As described earlier, each VI schedule was correlated with a pair of general- and specific-topic cards, and therefore with a discriminative stimulus characterized by a distinctive color, size, and position in the array of cards. This procedure was similar to the VI procedure developed by Bradshaw et al. (1976).

Reinforcement consisted of short phrases such as "good point," "that's interesting," "good idea," "that's right," and "uh-huh," with minor variations. The experimenter also nodded and smiled when delivering a reinforcing statement. Reinforcement was delivered provided the subject was making eye contact with the experimenter when reinforcement set up, regardless of whether the subject was speaking at that time. If reinforcement set up at a time when the subject was not making eye contact, the experimenter stopped the VI tape using the switch under the chair; as soon thereafter as the subject made eye contact, the social reinforcer was delivered and the tape player was restarted. That is, reinforcers were delivered either while the subject was making eye contact with the experimenter or at the onset of eye contact, depending on when reinforcement set up. If reinforcement had set up but had not been delivered by the end of an 8-min schedule segment, it was stored until the next session's schedule segment and was delivered as soon as eye contact was made in that segment.

At the start of the first session, all subjects were read the following instructions:

> We are interested in the opinions of college students on various topics. You will have eight minutes to talk about each topic, and will be given a short rest period between topics. Your

Table 1

Total number of sessions for each subject, average rate of praising statements, duration of eye contact, and its standard error on each VI schedule. Average rate of praising statements and duration of eye contact for median data across subjects are also presented. Notice that the median data for the VI 157-s schedule are based on 4 subjects, and the median data for the VI 720-s schedule are based on 3 subjects (rft/hr = reinforcements per hour; s/min = seconds of eye contact per minute).

		VI 17			VI 25			VI 51		
Subject	Sessions	rft/hr	s/min	*SE* s/min	rft/hr	s/min	*SE* s/min	rft/hr	s/min	*SE* s/min
H4	8	119.06	16.18	2.01	96.56	16.88	2.06	51.56	12.58	1.47
H5	8	29.06	1.09	0.48	22.50	0.88	0.30	12.19	0.45	0.20
H7	8	75.00	4.55	0.74	58.13	3.90	0.63	43.13	3.39	0.63
H8	9	61.88	2.62	0.68	60.94	3.09	0.91	38.44	1.75	0.24
H9	8	107.81	7.49	1.30	95.63	6.44	0.93	60.00	5.56	0.84
Median		75.00	4.55		60.94	3.90		43.13	3.39	

opinions will be recorded, but will be kept completely confidential. After I turn over the topic card and read to you the topic, I want you to talk about that topic until I tell you to stop. Take your time, and if you run out of things to say, I want you to think some more about the topic, and say whatever comes to your mind.

After reading these instructions, the experimenter placed the appropriate lettered card color side up on the table, and read the general topic, specific topic, and four questions to the subject. The recorder used to tape the session and the tape player that signaled the interreinforcement intervals were then started, as was a stopwatch that was used to time the 8-min schedule segments. After 8 min elapsed, the subject was directed to sit in the chair in the hallway. Four minutes later, the subject was called back to the room and the procedure was repeated with the next topic. This continued until all five VI schedules were presented. If a subject ran out of things to say, which occurred infrequently, the experimenter paraphrased the last sentence of the instructions one time. No other prompts or words of encouragement were given.

Prior to starting the experiment, all subjects signed a consent form in which they were told that the purpose of the experiment was to study the opinions of college students, that they would be required to talk about various topics, and that their responses would be recorded. They were also told how they would be paid. Subjects were free to decline to participate in the experiment at this time if they wished. The consent form and payment procedure met APA guidelines for informed consent and were approved by the Emory University Human Subjects Committee. Subjects participated in one session per day (with the exception of Subject H8, who participated in two sessions per day) and were paid for all completed sessions, including any earned bonus, after the last session. Following the last session, subjects were given a questionnaire asking them what they thought the hypothesis of the study was and what they noticed about the experimental arrangement. They were then given a written debriefing statement that described the actual purpose of the experiment.

The reliability of the time-allocation measurements was assessed by an independent observer who viewed two of the experimental sessions through a one-way mirror. The observer independently recorded the time the subjects spent looking at the experimenter. The stability of the time-allocation data was determined by time series analysis on eight consecutive response rates for each VI (alpha = .01; McDowell & Wood, 1984, 1985; Tryon, 1982). Responding on a schedule was considered stable if there was no trend in the data over the last eight sessions.

RESULTS

Responses to the debriefing questionnaire indicated that subjects did not recognize the purpose of the experiment and did not notice that their eye contact with the experimenter was being timed. As a measure of reliability, the independent observer's measurements of duration of eye contact for each of the five

Table 1
(*Extended*)

VI 157			VI 720		
rft/hr	s/min	*SE* s/min	rft/hr	s/min	*SE* s/min
17.81	9.75	1.38	3.75	11.15	2.18
8.44	0.61	0.35	1.88	0.12	0.05
	(not stable)			(data lost)	
22.50	1.01	0.15	7.50	1.27	0.38
20.63	4.47	0.75		(not stable)	
19.22	2.74		3.75	1.27	

schedule segments were correlated with the experimenter's measurements, as suggested by Martens and Houk (1989). The correlation coefficients for the two reliability sessions were .95 and .97, indicating good agreement between the experimenter's and the independent observer's measures of duration of eye contact.

The number of praising statements per hour and the seconds of eye contact per minute were averaged over the first stable eight-session block for each VI condition. Subject H7 was released from the experiment before her responding on the VI 157-s schedule had stabilized, and experimenter error caused her data from the VI 720-s schedule to be lost. Similarly, H9 was released from the experiment before her responding on the VI 720-s schedule had stabilized. Unstable data were omitted from the analysis.

The total number of sessions completed by each subject, the average reinforcement rates and durations of eye contact in each stable condition for each subject, the standard errors of eye contact durations, and the median reinforcement rates and durations of eye contact across subjects are listed in Table 1. Stability was reached on all schedules (with the exceptions noted above) within eight sessions for 4 subjects and within nine sessions for the 5th subject (H8). This is consistent with the findings of other authors who have reported stable responding in humans in similar laboratory arrangements in fewer than eight sessions (Cliffe & Parry, 1980; Conger & Killeen, 1974; Sunahara & Pierce, 1982).

Overall, the durations of eye contact per unit time were low. Subject H5 responded least, with eye contact ranging from 0.1 to 1.1 s per minute. Subjects H7, H8, and H9 responded at a somewhat higher level, with eye contact durations ranging from 1.0 to 7.5 s per minute, whereas Subject H4 showed the greatest amount of responding, with eye contact durations ranging from 9.8 to 16.9 s per minute. The median durations across subjects ranged from about 1 s of eye contact per minute on the VI 720-s schedule to about 5 s of eye contact per minute on the VI 17-s schedule. Note that the medians for the VI 157-s and 720-s schedules are based on 4 and 3 subjects, respectively, and therefore could be more variable upon redetermination than the other medians. The data in Table 1 also show that, in many cases, the obtained rates of reinforcement were substantially lower than the scheduled rates of reinforcement, as would be expected with these low rates of responding.

Seconds of eye contact per minute are plotted as a function of praising statements per hour in Figure 1. Consistent with the extensive literature on the reinforcing effects of verbal praise (e.g., O'Leary & Wilson, 1987), duration of eye contact per unit time increased as the rate of praising statements increased. Herrnstein's hyperbola (Equation 1) was fitted to the averaged data using the method described by McDowell (1981). The smooth curves in Figure 1 are plots of the best fitting hyperbolas. It is evident that Herrnstein's hyperbola provided a good description of the data for 4 of the 5 subjects (the exception being H4), accounting for between 71% and 99% of these subjects' data variance. In the case of H4, the hyperbola accounted for only 33% of the data variance. It is clear that this subject's durations of eye contact varied about the fitted function in such a way that no monotonically increasing function would describe them well (Figure 1). The best fitting hyperbola for the median data is shown in the lower right panel of Figure 1. The hyperbola described the median data well, accounting for 95% of the variance in the durations of eye contact per unit time. Again note that two of these data points (VI 157 s and 720 s) are based on fewer subjects than are the others.

The estimated values of k and r_e and the proportion of variance accounted for by the hyperbola are shown in Table 2. The esti-

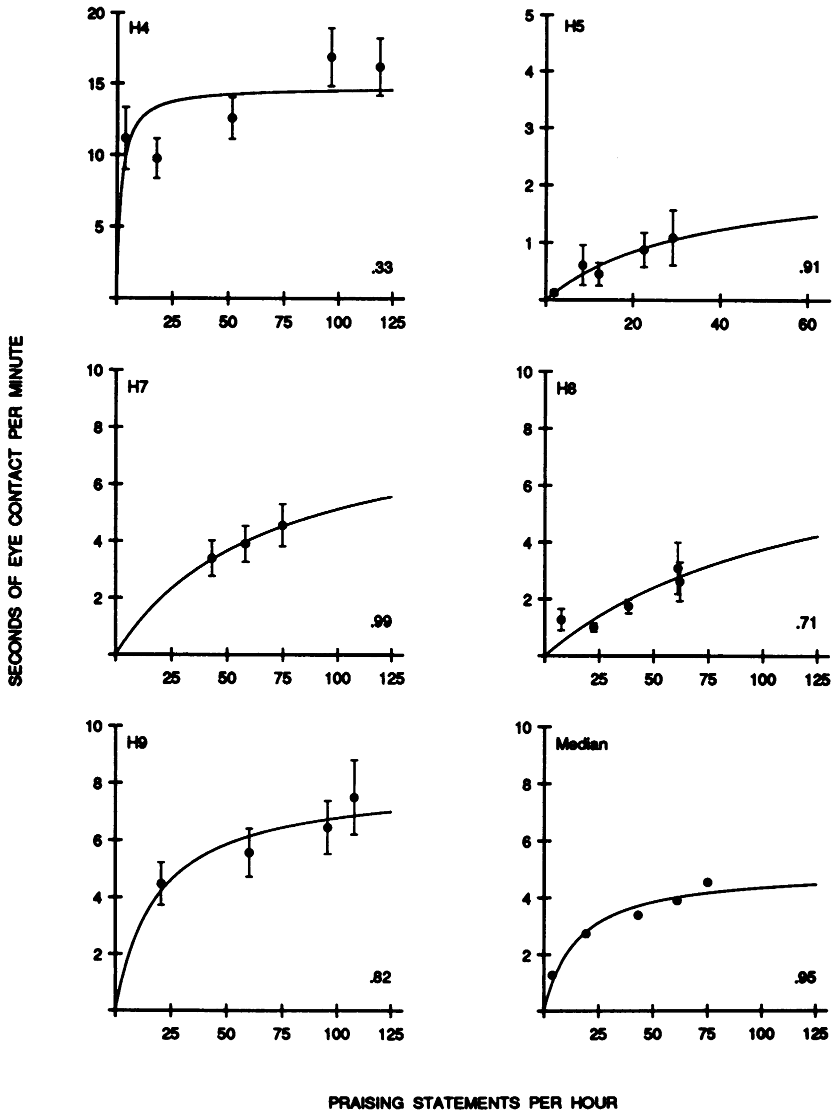

Fig. 1. Seconds of eye contact per minute plotted against obtained rates of contingent praising statements per hour for each subject. Error bars show ±1 *SE*. The best fitting hyperbolic function and the proportion of variance accounted for are shown in each plot. Note the different ordinate scaling for H4 and the different abscissa and ordinate scalings for H5. The median data across subjects, the best fitting hyperbola for these data, and the proportion of variance accounted for are shown in the lower right panel.

mated values of k ranged from 2.3 to 14.8 s per minute across subjects. Subject H5 had the lowest k, Subjects H7, H8, and H9 had somewhat higher and essentially identical ks, and Subject H4 had the largest k. These estimates are consistent with the overall rates of responding produced by these subjects. The estimates of r_e also varied considerably across subjects, ranging from 1.9 to 127.1 reinforcements per hour.

The adequacy of the hyperbola's description of these subjects' data can be evaluated further by comparing the hyperbolic fits with fits of similar function forms. The simplest form with comparable differential properties is a two-parameter ramp function, an example of which is shown in Figure 2. This ramp function consists of a linearly increasing segment and a constant segment. In Figure 2 the linearly increasing segment has a slope of a and a y intercept of zero. The constant segment has a slope of zero and represents a constant re-

Table 2

Parameters of and proportions of variance accounted for (pVAF) by Herrnstein's hyperbola, a ramp function with differential properties similar to Herrnstein's hyperbola, and a hyperbola the y asymptote of which is fixed at 60 s/min. All values were calculated from unrounded reinforcement rate and time-allocation data. Equations fitted to the rounded data in Table 1 may give slightly different values (s/min = seconds per minute; rft/hr = reinforcements per hour).

	Hyperbola			Ramp			Fixed-asymptote hyperbola		
Subject	k (s/min)	r_e (rft/hr)	pVAF	c (s/min)	a (s/min)/(rft/hr)	pVAF	k (s/min)	r_e (rft/hr)	pVAF
H4	14.8	1.9	0.33	13.8	2.97	0.15	60.0	243.3	0.00
H5	2.3	34.3	0.91	1.1	0.04	0.87	60.0	1,494.0	0.86
H7	8.6	66.9	0.99	4.6	0.07	0.77	60.0	845.8	0.49
H8	8.5	127.1	0.71	2.9	0.05	0.70	60.0	1,221.8	0.69
H9	8.0	18.7	0.82	6.5	0.22	0.62	60.0	701.9	0.00
Median	5.0	15.2	0.95	3.9	0.15	0.81	60.0	818.4	0.48

sponse rate equal to c. The transition point between the two segments of the function occurs when reinforcement rate, r, equals c/a. When $r = c/a$, response rate, R, equals $a(c/a)$, or c. A two-parameter ramp function can be written explicitly as

$$R = \begin{cases} ar & 0 \leq r \leq c/a \\ c & r > c/a \end{cases}. \quad (2)$$

According to Equation 2, when r is between zero and the transition point, c/a, inclusive (top line of the equation), $R = ar$; when r is greater than c/a (bottom line), $R = c$. Because the two-parameter ramp function begins at the origin and increases to an upper limit, it will describe any increasing asymptotic data at least moderately well.

Equation 2 was fitted to the present time-allocation data by an iterative method that minimized the sum of the squared residuals about the equation. Parameter estimates and proportions of variance accounted for by the best fitting ramp functions are listed in Table 2. Estimates of c (seconds of eye contact per minute) ranged from 1.1 to 13.8 s per minute. The orders of magnitude of the c parameters were similar to the orders of magnitude of the k parameters from the hyperbolic fits. Subject H5 had the lowest estimate of c, Subjects H7, H8, and H9 had similar, moderate estimates of c, and Subject H4 had the highest estimate. The proportions listed in the sixth column of Table 2 show that, with the exception of H4, the ramp functions provided a reasonably good description of the individual subject data and of the median data.

The hyperbola's and the ramp's descriptions of the data can be compared by comparing Columns 3 and 6 in Table 2. This comparison shows that the hyperbola accounted for a greater proportion of the variance than the ramp in every case. For H8, the fits were almost identical. For H5, the hyperbola accounted for somewhat more data variance than the ramp. For the remaining subjects, the hyperbola provided a substantially better description of the time-allocation data. The difference between the hyperbola's and the ramp's description of the individual subject data was statistically significant (Wilcoxon matched pairs, $T = 0$, $p < .05$, one tail). In addition, the hyperbola provided a better description of the median data across subjects, accounting for 95% of the data variance, compared to 81% of the data variance accounted for by the ramp.

DISCUSSION

The results summarized in Figure 1 and Table 2 indicate that the hyperbolic form of Equation 1 provides a good description of these time-allocation data. The hyperbola accounted for a large proportion of the data variance for 4 of the 5 subjects and accounted for 95% of the variance in the median data. Furthermore, the hyperbola provided a significantly better description of the data than did an elementary function form with similar differential properties (i.e., a two-parameter ramp function). This experiment is the first to study naturalistic behavior maintained by single-alternative VI schedules of social praise. The results indicate that naturalistic human behavior varies

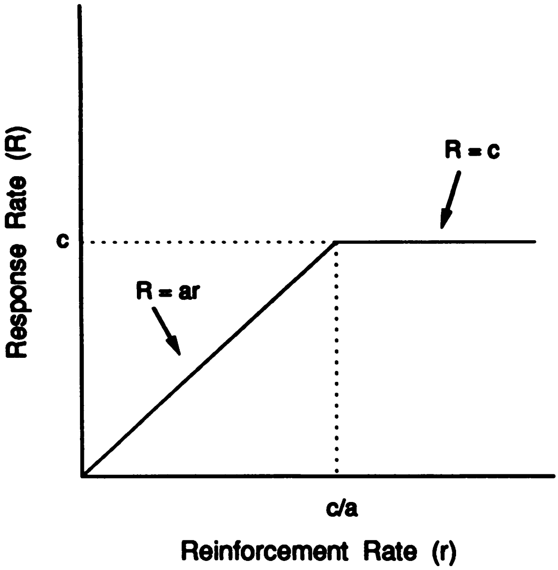

Fig. 2. A two-parameter ramp function with an increasing segment ($R = ar$) and a constant segment ($R = c$). The transition point between segments occurs at $r = c/a$, where $R = a(c/a)$, or c.

with naturalistic reinforcement in the manner required by Equation 1.

Although this study was not designed as a test of the formal properties of the matching equations, it is interesting to note that the formal interpretation of one of the parameters of Herrnstein's hyperbola was not supported. Specifically, according to matching theory, k is required to equal the total amount of behavior in an experimental situation (Herrnstein, 1974; McDowell, 1986). For time-allocation data, this means that k is constrained to equal all possible time spent responding, which in the units used in this experiment is 60 s per minute. The values of k obtained in the present study are significantly lower than this, with the largest value being less than one fourth the required value of 60 s per minute. In most cases these ks were well determined: The standard errors of k for the individual subjects, in numerical order, were 1.8, 1.3, 1.1, 11.9, and 1.0 s per minute. The standard error of k for the median data was 0.5 s per minute. Clearly, the theoretically required value of k lies many standard deviations above the means of the sampling distributions of these ks.

An additional method of examining the constancy of k in time-allocation data is to require this parameter to equal the total session time. Although this fixes one of the free parameters in the equation, the fits should nevertheless be reasonably good if k in fact represents the total session time (cf. Baum's, 1979, study of the matching equation's exponent). Hyperbolas with asymptotes fixed at 60 s per minute were fitted to the present data by adjusting the value of r_e until the sum of the squares of the residuals about the fitted function was a minimum. The results of these fits are listed in the last three columns of Table 2. An hyperbola with an asymptote fixed at 60 s per minute accounted for 0% to 86% of the individual subject data variance. With one exception (H5), these fits yielded a poor description of the data and accounted for only 48% of the variance of the median data. For both H4 and H9, the variance of the data points about the best fitting fixed-asymptote hyperbola was actually greater than the variance of the data points about their own mean. These results do not support the interpretation of k as the total amount of behavior. Instead, they are consistent with studies of k for response-rate data that have shown that k is not constant across changes in reinforcement parameters and hence cannot be interpreted as the total amount of behavior (McDowell & Wood, 1984, 1985).

This experiment is one step in the important task of extending basic behavior-analytic research from the laboratory to the natural human environment. It is the first test of Herrnstein's hyperbola as a description of naturalistic behavior (eye contact) maintained by social praise. It is also the first *experimental* test of the time-allocation form of the hyperbola. The results indicate that naturalistic human behavior is governed by naturalistic social reinforcement in the manner required by Equation 1. These results also suggest that the form of the time-allocation version of Herrnstein's hyperbola is correct, but that the requirement that k equal the total session time may be invalid.

REFERENCES

Baum, W. M. (1979). Matching, undermatching, and overmatching in studies of choice. *Journal of the Experimental Analysis of Behavior*, **32**, 269–281.

Baum, W. M., & Rachlin, H. C. (1969). Choice as time allocation. *Journal of the Experimental Analysis of Behavior*, **12**, 861–874.

Bradshaw, C. M., & Szabadi, E. (1978). Changes in operant behavior in a manic-depressive patient. *Behavior Therapy*, **9**, 950–954.

Bradshaw, C. M., Szabadi, E., & Bevan, P. (1976). Behavior of humans in variable-interval schedules of reinforcement. *Journal of the Experimental Analysis of Behavior,* **26,** 135-141.

Bradshaw, C. M., Szabadi, E., & Bevan, P. (1977). Effect of punishment on human variable-interval performance. *Journal of the Experimental Analysis of Behavior,* **27,** 275-279.

Bradshaw, C. M., Szabadi, E., & Bevan, P. (1978). Effect of variable-interval punishment on the behavior of humans in variable-interval schedules of monetary reinforcement. *Journal of the Experimental Analysis of Behavior,* **29,** 161-166.

Buskist, W. F., & Miller, H. L. (1981). Concurrent operant performance in humans: Matching when food is the reinforcer. *The Psychological Record,* **31,** 95-100.

Carr, E. G., & McDowell, J. J. (1980). Social control of self-injurious behavior of organic etiology. *Behavior Therapy,* **11,** 402-409.

Cliffe, M. J., & Parry, S. J. (1980). Matching to reinforcer value: Human concurrent variable-interval performance. *Quarterly Journal of Experimental Psychology,* **32,** 557-570.

Conger, R., & Killeen, P. (1974). Use of concurrent operants in small group research: A demonstration. *Pacific Sociological Review,* **17,** 399-416.

Davison, M., & McCarthy, D. (1988). *The matching law: A research review.* Hillsdale, NJ: Erlbaum.

de Villiers, P. (1977). Choice in concurrent schedules and a quantitative formulation of the law of effect. In W. K. Honig & J. E. R. Staddon (Eds.), *Handbook of operant behavior* (pp. 237-287). Englewood Cliffs, NJ: Prentice-Hall.

Fleshler, M., & Hoffman, H. S. (1962). A progression for generating variable-interval schedules. *Journal of the Experimental Analysis of Behavior,* **5,** 529-530.

Gray, L. N., & Stafford, M. C. (1988). On choice behavior in individual and social situations. *Social Psychology Quarterly,* **51,** 58-65.

Herrnstein, R. J. (1961). Relative and absolute strength of response as a function of frequency of reinforcement. *Journal of the Experimental Analysis of Behavior,* **4,** 267-272.

Herrnstein, R. J. (1970). On the law of effect. *Journal of the Experimental Analysis of Behavior,* **13,** 243-266.

Herrnstein, R. J. (1974). Formal properties of the matching law. *Journal of the Experimental Analysis of Behavior,* **21,** 159-164.

Herrnstein, R. J. (1979). Derivatives of matching. *Psychological Review,* **86,** 486-495.

Mace, F. C., McCurdy, B., & Quigley, E. A. (1990). A collateral effect of reward predicted by matching theory. *Journal of Applied Behavior Analysis,* **23,** 197-205.

Martens, B. K., Halperin, S., Rummel, J. E., & Kilpatrick, D. (1990). Matching theory applied to contingent teacher attention. *Behavioral Assessment,* **12,** 139-155.

Martens, B. K., & Houk, J. L. (1989). The application of Herrnstein's law of effect to disruptive and on-task behavior of a retarded adolescent girl. *Journal of the Experimental Analysis of Behavior,* **51,** 17-27.

Martens, B. K., & Witt, J. C. (1988). Ecological behavior analysis. In M. Hersen, R. M. Eisler, & P. M. Miller (Eds.), *Progress in behavior modification* (Vol. 22, pp. 115-140). Newbury Park, CA: Sage.

McDowell, J. J. (1981). Wilkinson's method of estimating the parameters of Herrnstein's hyperbola. *Journal of the Experimental Analysis of Behavior,* **35,** 413-414.

McDowell, J. J. (1982). The importance of Herrnstein's mathematical statement of the law of effect for behavior therapy. *American Psychologist,* **37,** 771-779.

McDowell, J. J. (1986). On the falsifiability of matching theory. *Journal of the Experimental Analysis of Behavior,* **45,** 63-74.

McDowell, J. J. (1988). Matching theory in natural human environments. *The Behavior Analyst,* **11,** 95-109.

McDowell, J. J, & Wood, H. M. (1984). Confirmation of linear system theory prediction: Changes in Herrnstein's *k* as a function of changes in reinforcer magnitude. *Journal of the Experimental Analysis of Behavior,* **41,** 183-192.

McDowell, J. J, & Wood, H. M. (1985). Confirmation of linear system theory prediction: Rate of change of Herrnstein's *k* as a function of response-force requirement. *Journal of the Experimental Analysis of Behavior,* **43,** 61-73.

Myerson, J., & Hale, S. (1984). Practical implications of the matching law. *Journal of Applied Behavior Analysis,* **17,** 367-380.

O'Leary, K. D., & Wilson, G. T. (1987). *Behavior therapy: Application and outcome* (2nd ed.). Englewood Cliffs, NJ: Prentice-Hall.

Oscar-Berman, M., Heyman, G. M., Bonner, R. T., & Ryder, J. (1980). Human neuropsychology: Some differences between Korsakoff and normal operant performance. *Psychological Research,* **41,** 235-247.

Pierce, W. D., Epling, W. F., & Greer, S. M. (1981). Human communication and the matching law. In C. M. Bradshaw, E. Szabadi, & C. F. Lowe (Eds.), *Quantification of steady-state operant behaviour* (pp. 345-352). Amsterdam: Elsevier/North-Holland.

Redmon, W. K., & Lockwood, K. (1986). The matching law and organizational behavior. *Journal of Organizational Behavior Management,* **8,** 57-72.

Sunahara, D. F., & Pierce, W. D. (1982). The matching law and bias in a social exchange involving choice between alternatives. *Canadian Journal of Sociology,* **7,** 145-166.

Szabadi, E., Bradshaw, C. M., & Ruddle, H. V. (1981). Reinforcement processes in affective illness: Towards a quantitative analysis. In C. M. Bradshaw, E. Szabadi, & C. F. Lowe (Eds.), *Quantification of steady-state operant behaviour* (pp. 299-310). Amsterdam: Elsevier/North-Holland.

Tryon, W. W. (1982). A simplified time-series analysis for evaluating treatment interventions. *Journal of Applied Behavior Analysis,* **15,** 423-429.

Vuchinich, R. E., & Tucker, J. A. (1983). Behavioral theories of choice as a framework for studying drinking behavior. *Journal of Abnormal Psychology,* **92,** 408-416.

Vuchinich, R. E., & Tucker, J. A. (1988). Contributions from behavioral theories of choice to an analysis of alcohol abuse. *Journal of Abnormal Psychology,* **97,** 181-195.

Wearden, J. H., & Burgess, I. S. (1982). Matching since Baum (1979). *Journal of the Experimental Analysis of Behavior,* **38,** 339-348.

Received August 31, 1990
Final acceptance October 4, 1991