**FIXED-RATIO AND FIXED-INTERVAL SCHEDULE
CONTROL OF MATCHING-TO-SAMPLE ERRORS
BY CHILDREN¹**

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Nine children, ages 4 through 7 yr, matched-to-sample on fixed-ratio, fixed-interval, variable-ratio, and variable-interval schedules of reinforcement. Simultaneous, zero-delay, and 2-sec delay matching were employed. Distributions of errors, in which the greatest number of errors occurred at the ordinal position immediately after reinforcement with fewer errors occurring at subsequent positions in the ratio, were produced by six of six children on fixed-ratio schedules for zero-delay and both of two children for 2-sec delay matching. Only two children of seven produced similar error distributions on simultaneous matching for fixed-ratio reinforcement. Variable-ratio schedules produced slightly lower accuracy for most subjects and no systematic error patterns for any subject. Error distributions occurred for all of the five children who experienced fixed-interval schedules for zero-delay matching. Peak error production occurred in the second fourth of the interval. Similar patterns were not produced on variable-interval schedules of equal reinforcement density. Schedule control of complex discriminated operants in children resembles control over similar responses of nonhuman animals.

Fixed-ratio and fixed-interval schedules of reinforcement have been shown to exert control over the accuracy of nonhuman free-operant performance (Bigelow, 1971; Birch, 1964; Zeiler, 1968; and Zeiler, 1970), discrete-trial behavior (Nevin, 1967) and complex discriminated operants (Boren and Gollub, 1972; Clark and Sherman, 1970; Ferster, 1960; Mintz, Mourer, and Weinberg, 1966; and Nevin, Cumming, and Berryman, 1963).

The latter research, which has employed matching-to-sample, and pigeons as subjects, has shown that on fixed-ratio schedules of reinforcement the greatest number of inaccurate matches occurs on initial matching attempts after reinforcement and that fewer inaccurate

matches occur as the responding proceeds across the ratio to a subsequent reinforced match (Ferster, 1960; Mintz *et al.*, 1966; and Nevin *et al.*, 1963).

Fixed-interval schedules also control matching accuracy, although the precise effects are partially equivocal (Boren and Gollub, 1972; Clark and Sherman, 1970; Ferster, 1960). All of the aforementioned investigators have located maximal inaccurate matching in the first half of the interval between reinforcements. When the interval is further subdivided, the location varies between the first quarter (Clark and Sherman, 1970) and the second quarter (Boren and Gollub, 1972; Ferster, 1960). As there are many procedural differences among these studies, including the use of two-key matching (Clark and Sherman, 1970) and three-key matching (Boren and Gollub, 1972; Ferster, 1960), speculation regarding the discrepancies among the above findings is unwarranted.

As pointed out by Weinstein (1941), the use of matching procedures in human behavioral analysis dates back at least to 1799 and Itard's account of "The Wild Boy of Aveyron". Matching tasks are widespread in educational procedures and are found in tests of intelligence (Terman and Merrill, 1962) and diagnostic tests (Goldstein and Scheerer, 1941;

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Sidman, 1971; and Sidman, Stoddard, and Mohr, 1968). In addition, the conditional discrimination, specifically, matching-to-sample, is postulated as a framework from which to view language acquisition (Sherman, 1971) and modelling (Gewirtz, 1971). However, with the notable exceptions of Sidman's (1969) work on the delay parameter and work on the effects of punishment by Miller and Zimmerman (1966) and Zimmerman and Baydan (1963), there are few parametric studies of the behavior of humans on the matching task.

The present study simply asked whether the patterns of errors produced by nonhuman animals on free-operant and conditional-discrimination tasks would be produced by children performing matching-to-sample. Specifically, the present study investigated the effect of fixed-ratio (FR), fixed-interval (FI), variable-ratio (VR), and variable-interval (VI) schedules of reinforcement on the pattern and number of errors in children's simultaneous and delayed matching-to-sample performance.

METHOD

Subjects

Six girls and three boys ranging in age from 4 through 7 yr served. Under the fixed- and variable-ratio schedules, five girls and two boys were exposed to simultaneous matching; four of the five girls and the two boys to zero-delay matching; and one of the four girls and one boy to 2-sec delay matching. Under the fixed- and variable-interval schedules, five subjects, four girls and one boy, were employed.

Apparatus

Matching-to-sample was conducted in a small dimly illuminated room containing a 23- by 16- by 13-in. (58- by 41- by 33-cm) console. Two form stimuli, composed of 0.25-in. (0.6 cm) white horizontal or vertical lines embedded within a 1.5 in. (3.8 cm) white square on a black background, were projected onto three clear 2- by 1.5-in. Plexiglas keys (5.1- by 3.8 cm) via three IEE one-plane read out projectors (Series 10) located on the face of the display unit. The operation of either of two microswitches located behind each of the keys with a force of 175 g (1.8 N) defined responding. The two choice keys were horizontally aligned 7.0 in. (18 cm) from center to center, while the sample key was centered 4.5 in.

(11.4 cm) above the midline of the choice keys. Five vertically aligned stimulus lights, 1.5 in. (3.8 cm) from center to center, were located 2 in. (5.1 cm) from the right-hand edge of the stimulus display console. The topmost light flashed after each correct match.

Mexican five-centavo coins were delivered via a National Cash Register Coin Dispenser located 6.5 in. (16.5 cm) to the right of the stimulus display console. The coins were exchanged at a 2:1 cent rate in an adjoining room, which housed arrays of candy, gum, toys, and vending machines. Electromechanical equipment housed in a third room controlled the experimental events and recorded the data.

General Procedures

All subjects were transported Monday through Friday to and from the laboratory by laboratory personnel, studied at approximately the same time each day, and allowed to terminate an individual session or the experiment at their request. Immediately after the arrival of the child at the laboratory and before the first session, the experimenter introduced him to the items that could be purchased. After this, each child was escorted into the experimental room, seated before the illuminated stimulus display console, and given roughly the following instructions by the experimenter: "This is how you can play a game, win tokens, and get to keep toys and candy. See the figure? (Indicates sample stimulus.) Touch it like I am doing. Now look down here and touch the one that is exactly like the one on top. (Indicates correct choice.) Now you do it—you play the game and win tokens." If the child made an error, the instructions were repeated until a minimum of two consecutive correct matching responses was emitted. The experimenter then left the room. Each experimental session terminated after the child obtained 30 tokens. At that time, the five-centavo coins were exchanged or saved in a bank for future exchange.

Under all experimental conditions, a trial was initiated by the illumination of a figure on the sample (center) key. After the child made an observing response by depressing this key, both choice keys were illuminated, one with the same figure on the sample key, and the other with the non-matching figure. In the simultaneous matching-to-sample condi-

tion, the three keys remained illuminated until a response was made on either of the two choice keys. Under zero-delay conditions, a response to the sample darkened it and simultaneously lit the two choice keys. Under 2-sec delay conditions, a response to the sample darkened it and the choice keys lit after the delay had timed out. Responding during the delay produced no scheduled consequences.

A correct match was followed by a 1-sec flash of white light, occasionally a five-centavo coin, and the next trial in the sequence. The delivery of coins was contingent on the number of correct matches required by the fixed- and variable-ratio schedules of reinforcement that were in effect during the experiment, and by the first correct match occurring after specific intervals of time had elapsed during the interval schedules. Under this scheme, it should be noted that errors, *i.e.*, responses to the non-matching figures, did not constitute responses that contributed to progression through a given ratio. Errors were not followed by coins or the flash of light, but did result in the illumination of the sample key with the next figure in the stimulus sequence.

An 18-trial stimulus sequence using Jenkins' (1965) design was employed. In this sequence, each stimulus appeared nine times as a sample, and the appearance of the stimuli in left and right choice positions was evenly balanced. No sample appeared more than three times consecutively. Subjects were started daily from randomly chosen locations in the stimulus sequence.

Specific Procedures

Seven children were started on continuous reinforcement (CRF) for matching and, after reaching stability, were shifted to fixed-ratio schedules. Values of fixed-ratio schedules ranged from FR 3 to FR 10. Three children were shifted to fixed-interval schedules after experiencing ratio schedules for matching. Two children were started on CRF and shifted directly to fixed-interval schedules. Interval values ranged from FI 12-sec to FI 40-sec. In general, children proceeded from smaller to larger ratios and smaller to larger interval values.

Seven of the nine subjects were exposed to at least one value of a variable-ratio or a variable-interval schedule for matching that was comparable in reinforcement frequency to

one fixed-ratio or fixed-interval schedule previously experienced. The VI and VR schedules were arithmetic with the longest ratio or interval set at twice the schedule value (*e.g.*, the longest ratio in VR 3 was six), and the shortest value set at one response or 1 sec.

All children started with simultaneous matching and proceeded to zero delay. Four of the nine experienced 2-sec delay conditions after zero delay. The children were generally placed back on smaller ratio and interval values when shifted to delayed matching conditions.

Table 1 describes the precise experimental sequence and number of sessions in each condition for each subject.

Children were shifted from CRF to intermittent reinforcement schedules if they matched at or above the 90% level of accuracy for three consecutive days. Children were shifted from one value of intermittent reinforcement to another and to the various matching-to-sample conditions if accuracy in the final session in a condition varied no more than 5% from the mean of the last three sessions within that condition.

Several subjects did not attain this last criterion in what seemed to be a reasonable number of sessions and were shifted to a subsequent condition in order to maximize the information obtained from their participation (Table 1). Only data that met the foregoing stability criteria are included in the present paper. There were no ascertainable effects of this maneuver on the stable-state data described for these subjects.

RESULTS

All children successfully matched-to-sample at or above 90% accuracy after three to 24 sessions on continuous reinforcement (Table 1).

Figure 1 depicts error performance on simultaneous matching-to-sample under the FR and VR schedules. In this figure (and in Figures 2 and 3), each data point represents the total number of incorrect matches divided by the total number of correct matches in each ordinal position of each fixed- and variable-ratio for the last three sessions of stable responding. As noted above, only matching responses shifted the ordinal position within a ratio; thus, a subject could make an infi-

Table 1

Matching condition, values of the fixed- and variable-ratios and intervals employed, order of presentation, and number of sessions of matching-to-sample performance for all subjects.

<i>Child</i>	<i>Delay</i>	<i>Schedule</i>	<i>Sessions</i>	<i>Child</i>	<i>Delay</i>	<i>Schedule</i>	<i>Sessions</i>
JS	simult	CRF	3	SS	0-sec	FR 5	5 ^a
		FR 3	3			VR 5	6 ^a
		FR 4	3			FI 40-sec	5 ^a
		FR 5	4 ^a			VI 40-sec	4 ^a
		FR 6	5 ^a			CRF	3
		FR 7	5 ^b			FR 3	3
		FR 8	6 ^a			FR 4	5 ^a
		FR 10	4 ^b			FR 5	16 ^a
JC	simult	CRF	4	CS	0-sec	FR 6	11 ^a
		FR 4	5 ^a			FR 7	5 ^a
		VR 4	7 ^a			FR 3	6 ^a
		FI 12-sec	5 ^a			FR 6	8 ^a
	0-sec	FI 24-sec	6 ^a		2-sec	VR 3	4 ^a
		VI 24-sec	5 ^a			CRF	7
						FR 3	26 ^a
						FR 4	14 ^a
LO	simult	CRF	24	GN	0-sec	FR 3	6 ^a
		FR 3	29 ^a			FR 3	7 ^a
		FR 4	9 ^a			VR 3	6 ^a
		FR 5	5 ^a			FI 12-sec	5 ^b
	0-sec	VR 3	6 ^a		simult	FI 12-sec	7 ^b
		FR 3	10 ^a			FI 20-sec	6 ^b
		VR 3	6 ^a			FI 24-sec	8 ^b
						FI 40-sec	7 ^a
SM	simult	CRF	3	CW	0-sec	VI 40-sec	5 ^a
		FR 3	3			CRF	5
		FR 4	3			FI 12-sec	5 ^a
		FR 5	3			FI 20-sec	5 ^a
	0-sec	FR 6	6 ^a		2-sec	FI 12-sec	5 ^b
		FR 7	11 ^a			FI 12-sec	8 ^b
		FR 8	4 ^a			FI 24-sec	7 ^a
		FR 10	6 ^a			VI 24-sec	4 ^a
LT	simult	FR 6	5 ^a			CRF	3
		VR 6	7 ^a			FI 12-sec	6 ^a
		CRF	5			FI 24-sec	8 ^b
		FR 5	7 ^a				
		FR 8	5 ^a				

^aGraphic data are presented from the last three sessions of these conditions.

^bDid not attain stability.

nite number of non-matching responses (errors) and responding would remain at the same ordinal position in the ratio until a matching response occurred.

Data were pooled for the last three sessions to increase their reliability. That this was accomplished is suggested by the following analysis: each of the error ratios produced in the first ordinal position in the ratio schedules and the second quarter in the interval schedules for the three criterion sessions was treated as a score for each subject. Kendall's rank correlation coefficients (Siegel, 1956) were computed for these scores with the criterion sessions as variables. The mean coefficient of correlation (τ) between sessions was

0.70 (range: 0.46 to 1.00). To estimate the possible reduction in variance that could result from pooling the criterion sessions, the Spearman-Brown prophecy formula was employed (Cronbach, 1960). The mean correlation coefficient increased to 0.84 (range: 0.72 to 1.00) decreasing unexplained variance 21% and implying the greater reliability of the pooled scores. (The conditions from which graphic data are presented are noted in Table 1.)

On simultaneous matching for two subjects, LO and LT, the postreinforcement error pattern was characterized by the greatest number of errors falling at the first ordinal position (P_1) after the delivery of a centavo coin, and by a decreased error frequency at succeeding

Fig. 1. The ratio of incorrect to correct responses for each subject on simultaneous matching-to-sample as a function of the ordinal position in the response requirement. P_1 = the first ordinal position in the ratio; P_2-n = the second and succeeding ordinal positions in the ratio. Cross-hatched bars denote VR performance.

positions (P_{2-n}). This effect occurred on FR 3, FR 4, and FR 5 for LO, and FR 5 and FR 8 for LT. No similar distribution of errors was evident in the VR 3 matching performance of LO. In contrast, specific sequences of errors could not be ascertained in the data of the five remaining children.

Figure 2 contains error distributions for each subject on zero-delay matching as a function of the ordinal position in the ratio. With the exception of SM's performance on FR 6, the greatest number of errors under fixed-ratio schedules was produced at the first position after reinforcement. The major effect existed between the first ordinal position (P_1) and all subsequent positions (P_{2-n}) in the ratio; however, several instances of successive decreases in errors across the ratio occurred (SS on FR 3; JC on FR 4; and CS on FR 3). In contrast, the VR values employed did not result in similar error distributions.

The ratio of errors to correct matches across the ordinal positions of FR 3 and FR 6 under the 2-sec delay matching procedure is pre-

sented in Figure 3 for CS and SS. Again, the most inaccurate matching occurred at the first position after reinforcement (P_1), with large decreases at subsequent positions (P_{2-n}).

Figure 4 presents the relation between per cent accuracy and ratio size for the last three days of exposure to all three matching-to-sample conditions employing ratio schedules. Data points were produced by dividing the three-day total of errors by total correct matching responses for the same period and multiplying by 100 for each schedule and delay condition. Accuracy was reduced across subjects for comparable schedule values when the matching-to-sample condition was changed from simultaneous to zero delay. With the exceptions of LO and CS, the decrease in accuracy was less than 10%. Accuracy further decreased when conditions were changed from zero delay to 2-sec delay matching for SS and CS.

The accuracy generated by various values of fixed-ratio and variable-ratio schedules can also be compared in Figure 4. For example,

Fig. 2. The ratio of incorrect to correct responses for each subject on zero-delay matching-to-sample as a function of the ordinal position in the response requirement. P₁ = the first ordinal position in the ratio; P_{2-n} = the second and succeeding ordinal positions in the ratio. Cross-hatched bars denote VR performance.

Subject LO showed a near linear function between accuracy and ratio size under simultaneous matching. For the remaining subjects, accuracy changed little as a function of ratio size.

For four of six subjects, accuracy on variable ratio was lower under zero-delay conditions than on fixed ratios of equal reinforcement density. Subject LO's accuracy was also lower on VR 3 than on FR 3 under the simultaneous-matching condition.

Findings of error patterns on interval schedules of matching-to-sample were largely analogous to those for the ratio data. One subject (GN) of the two who experienced an FI schedule of reinforcement for simultaneous matching came to criterion. His data (not presented) contained no systematic error patterns either on the FI 12-sec or the FI 20-sec schedules to which he was exposed. The responding of three subjects presented FI schedules on 2-sec delay matching also failed to attain criterion.

The ratio of errors to correct matching responses of five children across quarters of various values of fixed interval and variable interval on zero-delay matching is presented in Figure 5. In this figure, each data point represents the total number of incorrect matches divided by the total number of correct matches in each mean quarter of each fixed and variable interval for the last three days

Fig. 3. The ratio of incorrect to correct responses for two subjects on 2-sec delay matching-to-sample as a function of the ordinal position in the response requirement. P₁ = the first ordinal position in the ratio; P_{2-n} = the second and succeeding ordinal positions in the ratio.

of stable responding. Mean quarters of the interval schedules were determined by computing one-fourth of the average interval, *i.e.*, one-fourth the designated schedule length. As the longest interval in the variable-interval schedules was twice the length of the average interval, this produced eight possible "quarters" of mean interval length. (This abscissa approximates "time since reinforcement".) The error ratio increased from the first to the second quarter of the interval in all instances except one (JC on FI 12-sec) for all children under fixed intervals ranging from 12 to 40 sec. Errors diminished across the third and fourth quarters for all subjects, except for the fourth-quarter performance of GN on FI 24-sec and JC on FI 12-sec. Similar error distributions were not evident in the variable-interval performance of any subject.

Fig. 4. Matching accuracy under simultaneous, zero-delay, and 2-sec delay conditions, for each individual value of fixed and variable ratio employed.

Figure 6 shows the rate of each subject's zero-delay matching and mismatching responses across quarters of the fixed-interval schedules. The most prominent feature of these data was the large change in rate of responding from the first to the second quarter of the interval. Increases in rate of responding across the remaining quarters of the interval were much less substantial, with several subjects producing fourth-quarter deceleration.

Matching accuracy varied for the four subjects who responded on both fixed- and variable-interval schedules. In two cases (LT and CS) accuracy was slightly higher on fixed-interval, while in two other cases it was slightly lower (GN and JC).

DISCUSSION

The present results indicate that the control exerted by fixed-ratio and fixed-interval schedules of reinforcement over the accuracy of discriminated operants is not limited to the discriminative behavior of lower organisms. On fixed-ratio for zero- and 2-sec delay matching, all of the children who completed the experiment produced distributions of matching-to-sample errors in which the greatest number of errors was located immediately after the delivery of reinforcement. On the other hand, no similar patterns were observed for errors occurring under variable-ratio schedules of reinforcement of similar reinforcement frequency. The systematic decreases in errors across successive positions of the ratio that are seen in non-human work (Mintz *et al.*, 1966; Nevin *et al.*, 1963) were occasionally visible in the present data (*e.g.*, LO in Figure 1 on FR 3 and FR 5; SS, JC, and CS in Figure 2 on FR 3, FR 4, and FR 3, respectively); however, the major effect was in the first position *vis-a-vis* the remaining ordinal positions.

Fixed-interval performance on zero delay was characterized by the location of the greatest number of errors in the second quarter of the interval, while in variable-interval schedules of similar reinforcement frequency, error patterns were largely unsystematic. Error patterns on both fixed-ratio and fixed-interval schedules would appear to be not a function of reinforcement density.

The error effect was weakest, that is, was produced by two of seven subjects on FR and no subject on FI (one reached criterion) under simultaneous matching conditions. Absence of the effect was probably related to overall accuracy; for example, those subjects not producing the error effect on fixed-ratio schedules for simultaneous matching were generally those who emitted the fewest errors (Figure 4). The mean error ratio for LO and LT, who produced the effect on simultaneous matching, was 0.17 (91% accuracy). This can

Fig. 5. The ratio of incorrect to correct responses per quarter of the mean interval for each subject's zero-delay matching-to-sample performance on various FI and VI values. Eight VI mean quarters exist because the longest interval in the VI schedules was twice the length of the average interval (see text). Q₂ = the second quarter of the mean interval; Q_{1-n} = the first, third, and fourth quarters of the mean interval. Cross-hatched bars denote VI performance.

be contrasted with a mean error ratio of 0.03 (98% accuracy) for the other five children who did not produce the effect on simultaneous matching. Further substantiation for this point accrues from the zero-delay and 2-

sec delay data. These conditions were used to lower the level of matching-to-sample accuracy, and the error effect was observed for all children under all but one value of fixed-ratio and fixed-interval schedules employed. Thus, a minimum number of errors would seem necessary before patterns of errors can be determined. The location of maximum errors on fixed-ratio schedules parallels the results of Mintz *et al.* (1966) and Nevin *et al.* (1963). In Nevin *et al.*, pigeons were used as subjects and the error effect was produced under conditions of simultaneous matching, while Mintz *et al.*, employed pigeons and zero-delay conditions.

The location of maximum errors on fixed-interval schedules for matching replicates the findings of Ferster (1960) and Boren and Golub (1972) with pigeons. Ferster located maximum error responding in the second quarter

Fig. 6. Number of responses per quarter of the mean interval for each subject's zero-delay matching-to-sample performance on various FI values.

when his subjects were exposed to multiple FI-FR schedules of reinforcement. Boren and Gollub located maximum errors in the second to the seventh-twelfth of their intervals. On the other hand, Clark and Sherman (1970) found maximum error responding in the first quarter on FI 8-sec. The latter authors used pigeons and a two-key matching procedure, while Ferster, Boren and Gollub, and the present authors employed three-key matching.

The present data also support Boren and Gollub's findings that errors are related to response rate. Boren and Gollub found that accuracy of matching on fixed-interval schedules was related to rate, such that the highest accuracy occurred at the highest rates; high accuracy also occurred at low rates, while intermediate rates were related to lowest accuracy. Second-quarter rates in the present study were intermediate to rates in the other quarters (Figure 6), and the greatest number of errors was located in the second quarter (Figure 5). There is a likely covariate, however. Figure 6 indicates that a greater change in rate of responding occurred from the first to the second quarter of the interval than between any of the other quarters. In fact, except for the fourth-quarter reversals of JC and LT, the curves are all negatively accelerating. To determine if Boren and Gollub's study contained a similar result, their Table 2 (p. 70) data were transformed to produce median total responses per interval quarter. This was accomplished by summing median errors and median matches within each twelfth of the interval, multiplying by 60 and summing across three successive twelfths of the interval. The resulting functions could not be quantitatively compared with the present data because of the higher rates emitted by the pigeons and because of Boren and Gollub's use of median values. However, a qualitative comparison would appear valid. The resulting data showed considerable qualitative similarity between the responding of pigeons and children. In terms of total responses, the pigeons produced uniform acceleration across the quarters of the interval. For the pigeons as well, the greatest rate change transpired between the first and second quarters. Thus, in both studies, it is possible that high error frequencies were related to the degree of rate change across the interval in addition to, or independent of, the relative response rate.

Neither study provides an adequate test of this possibility.

The present results and the literature on fixed-ratio size and control of matching accuracy appear equivocal between species and discrimination tasks (Bigelow, 1971; Ferster, 1960; and Zeiler, 1968). For example, Ferster found matching accuracy at the 50% level under continuous reinforcement, and his birds showed a steady increase under FR 4, FR 8, and FR 10. In contrast, Nevin *et al.* (1963) reported a decrease from 98% accuracy on CRF to 79% on FR 3. As the size of the fixed ratio increased, two of the birds showed a corresponding increment in matching accuracy, while a third pigeon produced a decrement. No change between the size of the fixed-ratio schedule and accuracy was observed in the present study, except for Subject LO's near-linear relationship between matching accuracy and size of the fixed ratio.

Research by Berryman, Cumming, and Nevin (1963), Blough (1959), and Smith (1967) has demonstrated matching-to-sample accuracy to be functionally related to the amount of delay imposed between sample stimulus offset and choice stimulus onset in pigeons. In addition, Sidman (1969), Sidman, Stoddard, and Mohr (1968), and Weinstein (1941) have shown that level of matching accuracy in humans is related to the amount of delay imposed in the matching situation. Accuracy data from the present experiment were consistent with these findings, although it is possible they were contaminated by an order effect as the children all proceeded from simultaneous to zero- and 2-sec delay matching in that sequence.

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