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DOES EFFORT PLAY A ROLE IN THE EFFECT OF RESPONSE REQUIREMENTS ON DELAYED MATCHING TO SAMPLE?

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The possible role of "effort" in the accuracy of pigeons' performance on a delayed matching-to-sample procedure was investigated by examining the effects of response requirements that accompanied a trial-initiating stimulus and that accompanied a sample stimulus. In the first experiment, the effect of varying the size of a fixed-ratio requirement for responses during an initiating stimulus was compared to that of varying a similar requirement for responses during the sample stimulus. Accuracy increased reliably with increases in the ratio scheduled during the sample stimulus, but was not significantly affected by increases in the ratio scheduled on the key during the initiating stimulus. In another phase of Experiment 1, sample duration was held constant while the ratio requirement was varied during the initiating stimulus. Again, accuracy of matching to sample was not significantly affected by the size of the ratio scheduled during the initiating stimulus. Experiment 2 provided a systematic replication of these results in another group of pigeons and included a more detailed analysis of responding. These results support the view that increases in sample-response requirement facilitate accuracy of delayed matching by increasing the durations of exposure to the sample stimuli, and do not support a role of effort in the sample-response effect. In Experiment 3, the facilitative effect of responses on the sample but not of those on the initiating stimulus was replicated using a simultaneous matching-to-sample procedure. This finding provides further evidence against an interpretation of response-requirement effects that appeals to effort; the finding also suggests that sample exposure might affect initial discrimination of the sample rather than remembering the sample.

Key words: delayed matching to sample, matching to sample, memory, effort, sample fixed ratio, initiating fixed ratio, key peck, pigeons

In the typical delayed matching-to-sample (DMTS) procedure arranged for pigeons, trials consist of (1) presentation of a sample stimulus, (2) a delay—or "retention interval"—during which the sample is not present, and (3) presentation of two comparison stimuli, one that matches the previously presented sample and one that does not. Responses directed at the matching comparison stimulus are deemed correct choices and are reinforced, whereas responses on the nonmatching stimulus are called incorrect and are not reinforced. Because the sample is not present at the time the choice is made, the animal must, in some sense, remember which sample had been presented, if it is to identify the matching comparison stimulus. Variables that affect DMTS performance, such as the length of the delay period (e.g., Blough, 1959), are often interpreted in terms of effects on underlying memory processes (e.g., Grant & Roberts, 1973; Honig, 1978; Roberts, 1972; Roberts & Grant, 1976; Ruggiero & Flagg, 1976; Schwartz, 1984).

Another variable that has been reported to affect DMTS accuracy is "exposure" to the sample; that is, DMTS accuracy is enhanced by larger fixed-ratio (FR) requirements on the sample key (e.g., Roberts, 1972; Sacks, Kamil, & Mack, 1972; Wilkie & Spetch, 1978), or by longer response-independent durations of sample presentation (e.g., Farthing, Wagner, Gilmour, & Waxman, 1977; Maki & Leith, 1973; Roberts & Grant, 1974; Roitblat, 1980). For example, in the study by Roberts (1972), exposure to the sample stimuli (fields of colored light on a pecking key) was varied by requiring 1, 5, or 15 responses on the sample key to terminate the sample and proceed with

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the trial. Accuracy increased as a function of increases in this sample-peck requirement, and this effect was approximately parallel across delays of 0, 1, 3, and 6 s between the sample termination and the onset of the comparison stimuli. In the study by Roberts and Grant (1974), the colored sample stimuli were presented following a single peck on a trial-initiating stimulus; the samples lasted for fixed periods of time independently of responding. Accuracy increased as a function of increases in the sample presentation time, ranging from 0.5 s to 8 s, and this occurred with delays of both 0 s and 1 s.

These findings have been important for several of the memory interpretations of DMTS performance. For example, trace-decay theory (e.g., Roberts & Grant, 1976) assumes that a memory trace of the sample develops and increases in strength as a function of exposure to the sample, and then decays in its absence. Choice of the comparison stimuli is said to be under the control of this trace of the sample, and accuracy is said to vary as a function of the strength of the trace at the time the choices are made. According to this view, increases in exposure to the sample, whether produced by a larger FR requirement or by a longer presentation time, facilitate DMTS accuracy by increasing trace strength. Other theorists (e.g., Farthing et al., 1977; Maki, Gillund, Hauge, & Siders, 1977; Roitblat, 1980) have interpreted the effects of sample responses or sample presentation times in terms of effects on the "encoding" of sample information in memory. According to these views, longer sample presentations or more sample responses improve DMTS accuracy because the increased exposure to the sample provided by these manipulations allows for more complete encoding of the sample information.

A major assumption of such theories concerning the effects of sample duration and sample responses is that the critical factor is amount of exposure to the sample. Although a minimal amount of exposure to the sample may be essential for accurate DMTS performance, it is not necessary to assume that increases in response requirement beyond FR 1, or increases in presentation time beyond a second or two, produce their effects solely through the increase in exposure to the sample they provide. It is possible that some of the effect is due, instead, to increased time and behavior that have been invested in the trial by the time the choice is made. Such increases may improve performance because errors are more costly in time or energy.

This effort or work-time hypothesis has been proposed in a variety of different contexts by a number of authors (e.g., Blough, 1966; Elsmore, 1971; Williams, 1972). For example, Blough suggested that "hard work" (multiple response requirements) and punishment (produced by incorrect choices) may operate in similar ways to improve stimulus control in discrimination tasks: "When shock may await them, rats look before they run; equally, if work is involved, animals may look before they respond" (Blough, 1966, p. 376). An effort interpretation was also proposed by Sacks, Kamil, and Mack (1972) in one of the early studies demonstrating an effect on DMTS accuracy of a ratio requirement on the sample key. Since then, however, little attention has been paid to the effort hypothesis of sample-response effects in DMTS; instead, investigators have focused on memory processes in interpreting these effects.

Evidence consistent with the interpretation that appeals to increases in effort requirements as leading to more accurate performance was provided in a study by Ferster (1960). In that study, the samples were red or white light on the center key; a single peck on this key terminated its light and produced the comparison stimuli (red and white on the side keys). A peck on the matching comparison key produced either conditioned reinforcement (a brief illumination of the food-magazine light) or primary reinforcement (food); a peck on the nonmatching comparison key produced a 1-s timeout during which the chamber was dark. Primary reinforcement occurred upon completion of an FR schedule of matching responses (i.e., after a fixed number of correct trials). Accuracy improved markedly as the FR was increased from 4 to 20. This effect of intermittency of reinforcement is difficult to interpret in terms of memory processes, but it is readily accommodated by the effort hypothesis. Mintz, Mourer, and Weinberg (1966) showed that when a fixed number of correct trials was required per reinforcement (an FR contingency), pigeons made more errors on trials that were early in the FR sequence than on trials that were later in the FR sequence.

Elsmore (1971) has provided evidence suggesting that effort may affect performance in simple discrimination tasks. In a discrete-trial successive discrimination, the response key was either red or white; the reinforcement probability correlated with completion of an FR schedule was .25 during red trials and .5 during white trials. The value of the FR was always the same for both stimuli, but varied from FR 1 to FR 64 across different phases of the experiment. With small FR requirements, there was no systematic difference in behavior in the presence of the two keys; but with larger FR values, shorter latencies occurred in the presence of the stimulus that accompanied the higher probability of reinforcement. A number of other studies have found a positive relation between fixed-ratio size and response accuracy or speed of learning in tasks such as response "counting" (Ferster, 1958), alternation learning (Gonzalez, Bainbridge, & Bitterman, 1966; Williams, 1971a), successive discrimination reversal learning (Williams, 1971b), oddity-from-sample learning (Zentall, Hogan, & Holder, 1974), and probability learning (Williams, 1972). In view of such results, it seems premature to interpret the effects of sample manipulations in DMTS tasks entirely in terms of memory processes, until the contribution of effort has been assessed.

EXPERIMENT 1

In this experiment, the effect of number of responses required to produce the sample (i.e., FR schedule during a trial-initiating stimulus) was compared with the effect of number of responses required to terminate the sample (i.e., the FR schedule during the sample). If effort plays an important role in the response-requirement effect seen in DMTS studies, then increases in both the FR that accompanies the initiating stimulus and the FR that accompanies the sample should improve accuracy because both increase the total amount of effort prior to the choice. Memory-trace interpretations, on the other hand, would predict an effect of manipulating the FR that accompanies the sample, but not of manipulating the initiating FR, inasmuch as features of the initiating stimulus are not correlated with features of the sample.

METHOD

Subjects

Nine adult White King pigeons, which had served previously in an autoshaping experiment, were housed individually with free access to water and grit. They were maintained at approximately 85% of their free-feeding weights by food obtained during and after experimental sessions.

Apparatus

Four birds (Birds 1, 2, 3, and 4) were tested in cylindrical operant-conditioning chambers (36 cm in height and 33 cm in diameter), and the remaining 5 birds were tested in 35.5-cm cubical chambers. Each of the chambers contained three horizontally aligned translucent response keys, which required a force of 0.13 N to operate. Stimulus projectors mounted behind each key were used to transilluminate the keys with white, green, or red light. A solenoid-operated grain hopper was located below the center key; a lamp within the hopper was illuminated during presentation of grain. Each chamber also contained a houselight mounted above the center key, but it was not illuminated during these experiments. Experimental contingencies were controlled and data were recorded by a PDP-8E® computer located in an adjacent room.

Procedure

Baseline DMTS training. Each bird initially received from one to four sessions of autoshaping that established reliable pecking on each key when it was illuminated white, green, or red. Next, the birds were given 50 sessions of 0-s delay matching-to-sample training. Trials began with the center key illuminated white (the trial-initiating stimulus). A single peck at this initiating stimulus immediately changed the white light to either red or green (the sample stimuli). The sample terminated after 5 s, independently of responses, and was followed immediately (0-s delay) by illumination of the side keys, one with red and one with green light (the comparison stimuli). A peck on the comparison key of the same color as the preceding sample was reinforced with 4-s access to grain; a peck on the nonmatching comparison key simply terminated the trial. Approximately 50 trials, each separated by a 30-s intertrial interval (ITI), occurred during each daily session, which lasted a maximum of 50 min.

Following 50 sessions of training with the 0-s delay, a variable-delay procedure was instituted in which 50% of the trials contained

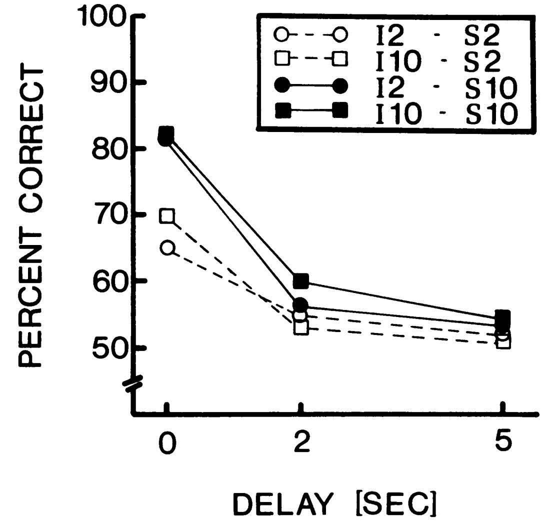

Fig. 1. Mean percentages of correct matching responses, as a function of delay under each of the four conditions in Phase 1 of Experiment 1. The unfilled circles (I2–S2) indicate data from the condition in which an FR 2 was in effect during both the initiating stimulus and the sample stimulus; unfilled squares (I10–S2) are from the condition with FR 10 during the initiating stimulus and FR 2 during the sample; filled circles (I2–S10) are from the condition with FR 2 during the initiating stimulus and FR 10 during the sample; and the filled squares (I10–S10) are from the condition with an FR 10 during both. The effect of size of the sample FR can be seen by comparing the solid and the dashed lines; the effect of size of the initiating FR is indicated by circles and squares.

a 0-s delay, 25% a 2-s delay, and 25% a 5-s delay, in random sequence. This proportion of 0-s delay trials to longer delay trials was used in an attempt to maintain stable levels of stimulus control by the sample (cf. Carter & Werner, 1978). Each bird received 30 sessions of variable-delay DMTS training. Fifty trials were scheduled during each 50-min session. Although the birds usually completed all 50 trials before the 50 min elapsed, occasionally the birds did not complete all of the scheduled trials before the sessions ended.

Test phases. Three phases were conducted, immediately following each other. During the first test phase, each bird was tested under four conditions that varied with respect to the number of pecks required during the initiating stimulus and with respect to the number required during the sample stimulus. In the first condition (I2–S2), two pecks (FR 2) during the initiating stimulus were required to terminate it and produce the sample, and two pecks (FR 2) during the sample stimulus terminated it and produced the delay. Otherwise, all aspects of the procedure were the same as those used in the variable-delay baseline procedure. In the second conditon (I2–S10), two pecks during the initiating stimulus and 10 pecks during the sample stimulus were required to advance each trial. In Condition 3 (I10–S2), 10 pecks during the initiating stimulus and two pecks during the sample stimulus were required, and in Condition 4 (I10–S10), 10 pecks were required during each stimulus. The four conditions occurred for a total of five sessions each over 20 test days. Each condition occurred once during each successive block of four sessions, but the order of the conditions within blocks varied from block to block. On any given day, the same condition was in effect for all birds.

The second test phase was identical to the first except that the FR requirement in each of the four conditions was doubled. Thus, the four conditions in this phase were I4–S4, I4–S20, I20–S4, I20–S20. This phase consisted of four blocks of four sessions each. Each condition occurred once in each block, with the order varying between blocks.

The third test phase consisted of eight sessions. Sample duration was held constant at 5 s (FT 5), and only the response requirement during the initiating stimulus was alternated between FR 1 and FR 20. For all birds, the order of exposure to these schedules over the 8 test days was FR 1, FR 20, FR 20, FR 1, FR 20, FR 1, FR 20, and FR 1.

Results and Discussion

Figure 1 shows the 9 birds' mean accuracy at each delay under each of the four conditions of the first test phase; data for the individual subjects are shown in Table 1. At the 0-s delay, accuracy was substantially enhanced whenever 10 pecks were required during the sample stimulus (as may be seen by comparing filled and unfilled symbols in Figure 1; in Table 1 it is seen by comparing the percentage scores shown in the first two columns with those shown in the second two columns), whereas accuracy was not consistently enhanced when 10 pecks were required during the initiating stimulus (seen in the figure by comparing circles and squares, and in the table by comparing column 1 with column 2 and column 3 with column 4). At the longer delays, accuracy of performance declined and

Table 1

Percentages of correct matching responses (and total numbers of trials tested) under each condition of Phase 1 of Experiment 1.

Delay	0				2				5			
Samp. FR	2		10		2		10		2		10	
Init. FR	2	10	2	10	2	10	2	10	2	10	2	10
Bird 1	66	77	86	91	63	50	52	68	54	51	54	57
	(123)	(125)	(125)	(125)	(59)	(60)	(60)	(60)	(63)	(65)	(65)	(65)
2	57	65	69	81	52	55	55	58	48	48	52	57
	(97)	(102)	(112)	(125)	(46)	(47)	(53)	(60)	(50)	(52)	(58)	(65)
3	59	56	77	72	52	50	68	50	54	49	60	54
	(125)	(125)	(125)	(125)	(60)	(60)	(60)	(60)	(65)	(65)	(65)	(65)
4	72	74	90	90	47	55	65	65	60	55	55	59
	(125)	(125)	(125)	(125)	(59)	(60)	(60)	(60)	(65)	(65)	(65)	(65)
5	71	77	89	81	52	53	58	49	52	51	51	59
	(96)	(112)	(99)	(107)	(46)	(58)	(48)	(51)	(50)	(57)	(51)	(56)
6	56	62	80	75	68	55	57	58	44	49	54	45
	(125)	(125)	(125)	(125)	(60)	(60)	(60)	(60)	(64)	(65)	(65)	(65)
7	62	66	83	94	52	52	45	62	60	45	62	51
	(125)	(125)	(125)	(125)	(60)	(60)	(60)	(60)	(65)	(65)	(65)	(65)
8	82	80	94	92	53	53	60	74	55	52	52	55
	(125)	(125)	(125)	(92)	(60)	(60)	(60)	(43)	(64)	(65)	(65)	(47)
9	62	66	85	86	57	60	50	60	45	62	42	51
	(125)	(125)	(125)	(125)	(60)	(60)	(60)	(60)	(65)	(65)	(65)	(65)

there were no clear differences among any of the four conditions.

These results were analyzed with a three-way repeated-measures analysis of variance, with initiating-peck requirement, sample-peck requirement, and delay as the three factors. This analysis revealed a highly significant effect of both sample-peck requirement [$F(1,8) = 98.4$, $p < .001$] and delay [$F(2,16) = 79.2$, $p < .001$], but no significant effect of the initiating-peck requirement [$F(1,8) = 0.77$, $p > .1$]. The effect of initiating-peck requirement did not interact significantly with either sample-peck requirement [$F(1,8) = 0.44$, $p > .1$] or delay [$F(2,16) = 0.59$, $p > .1$]. The only significant interaction was that between sample-peck requirement and delay [$F(2,16) = 18.9$, $p < .001$]. These results confirm that accuracy was affected by the number of sample pecks required but not by the number of initiating pecks required.

Figure 2 and Table 2 show the results of the second test phase, in which ratio sizes were doubled. Sample-peck requirement had a substantial effect on accuracy at all of the delays, whereas initiating-peck requirement did not consistently affect performance. A three-way repeated-measures analysis of variance on

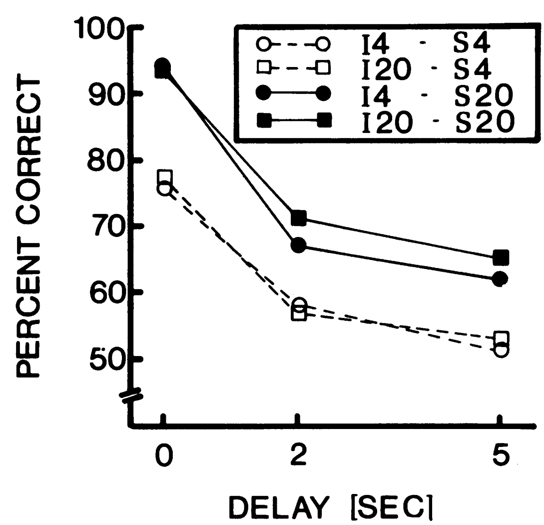

Fig. 2. Mean percentages of correct matching responses, as a function of delay under the four conditions in Phase 2 of Experiment 1. Data shown by unfilled circles (I4–S4) are from the condition with FR 4 during both the initiating stimulus and the sample stimulus; unfilled squares (I20–S4) indicate FR 20 during the initiating stimulus, FR 4 during the sample; filled circles (I4–S20) indicate FR 4 during the initiating stimulus, FR 20 during the sample; and filled squares (I20–S20) indicate FR 20 during both. Solid versus dashed lines indicate the effect of size of the FR that accompanied the sample stimuli; squares versus circles indicate the effect of size of the initiating FR.

Table 2

Percentages of correct matching responses (and total numbers of trials tested) under each condition of Phase 2 of Experiment 1.

Delay	0				2				5			
Samp. FR	4		20		4		20		4		20	
Init. FR	4	20	4	20	4	20	4	20	4	20	4	20
Bird 1	75	81	95	95	60	52	53	68	56	48	59	68
	(96)	(96)	(77)	(93)	(48)	(48)	(38)	(46)	(48)	(48)	(39)	(47)
2	58	70	89	90	54	58	75	77	52	60	72	65
	(96)	(96)	(87)	(96)	(48)	(48)	(44)	(48)	(48)	(48)	(45)	(48)
3	63	71	92	93	54	54	60	85	60	63	60	73
	(96)	(96)	(96)	(96)	(48)	(48)	(48)	(48)	(48)	(48)	(48)	(48)
4	79	76	100	95	63	56	83	83	58	50	73	56
	(96)	(96)	(96)	(96)	(48)	(48)	(48)	(48)	(48)	(48)	(48)	(48)
5	82	87	97	94	69	73	80	64	48	58	56	65
	(96)	(96)	(89)	(86)	(48)	(48)	(44)	(42)	(48)	(48)	(45)	(43)
6	78	77	95	95	54	50	56	63	42	50	67	56
	(96)	(96)	(96)	(96)	(48)	(48)	(48)	(48)	(48)	(48)	(48)	(48)
7	77	76	96	98	44	50	60	63	58	44	52	54
	(96)	(96)	(96)	(96)	(48)	(48)	(48)	(48)	(48)	(48)	(48)	(48)
8	91	88	94	94	67	73	72	75	44	58	73	85
	(86)	(96)	(62)	(52)	(42)	(48)	(29)	(24)	(43)	(48)	(30)	(26)
9	80	75	93	92	59	52	67	69	48	48	48	69
	(79)	(96)	(96)	(96)	(39)	(48)	(48)	(48)	(40)	(48)	(48)	(48)

these data again revealed a significant effect of sample-peck requirement [$F(1,8) = 106.6$, $p < .001$], but no significant effect of initiating-peck requirement [$F(1,8) = 1.55$, $p > .1$]. Furthermore, initiating-peck requirement did not interact with either delay [$F(2,16) = 0.21$, $p > .1$], sample-peck requirement [$F(1,8) = 0.33$, $p > .1$], or delay and sample-peck requirement [$F(2,16) = 0.99$, $p > .1$]. The only other effect that reached significance was that of delay [$F(2,16) = 81.4$, $p < .001$].

The results of Phase 3 of testing are shown in Figure 3 and Table 3. Even in this test phase, with sample duration held constant, the response requirement that accompanied the initiating stimulus had no apparent effect on accuracy of matching. At each of the delays, mean performance was almost identical under the FR 1 and FR 20 conditions, and the data for individual subjects shown in Table 3 reveal remarkably little difference between performances under the two conditions. These observations were confirmed by a two-way repeated-measures analysis of variance that showed a significant effect of delay [$F(2,16) = 44.6$, $p < .001$], but not of initiating-peck requirement [$F(1,8) = 0.31$, $p > .1$], and no significant interaction [$F(2,16) = 0.84$, $p > .1$].

These results clearly showed that DMTS performance was consistently enhanced by increasing the peck requirement during the sample stimulus, but not by increasing the peck requirement during the initiating stimulus. The finding is more consistent with the interpretation that larger sample-response requirements facilitate accuracy because of the resultant increased exposure to the sample, than it is with the interpretation that sample-response requirements produce their effects by altering the amount of effort required to arrive at the opportunity to make a choice resulting in reinforcement.

EXPERIMENT 2

This experiment was designed to replicate systematically the results of Experiment 1, and to provide a more detailed analysis of the way peck requirements affect responding. One question addressed by this experiment was whether FR schedules during sample and initiating stimuli affect rates of pecking at the initiating stimulus or at the two sample stimuli. An examination of rates of responding might provide more information about the locus of the effects of sample-response requirements. For example, one possibility is that larger FR values (or longer sample durations) might offer more opportunity for differential response rates to emerge in the presence of the two sample stimuli. Inasmuch as sample-specific responding has been shown to provide a powerful additional cue to guide behavior to the correct comparison stimulus in MTS and DMTS tasks (e.g., Urcuioli & Honig, 1980; Zentall, Hogan, Howard, & Moore, 1978), it seems possible that some of the effect of increasing sample-presentation time or sample FR requirements might be due to the emergence of differential rates of responding occasioned by the two samples. Perhaps birds respond more rapidly during one sample than during the other when 20 responses are required on both, but not when only four responses are required on both. If this were the case, then facilitation by the sample-specific response rates could account for the sample FR effects seen in Experiment 1.

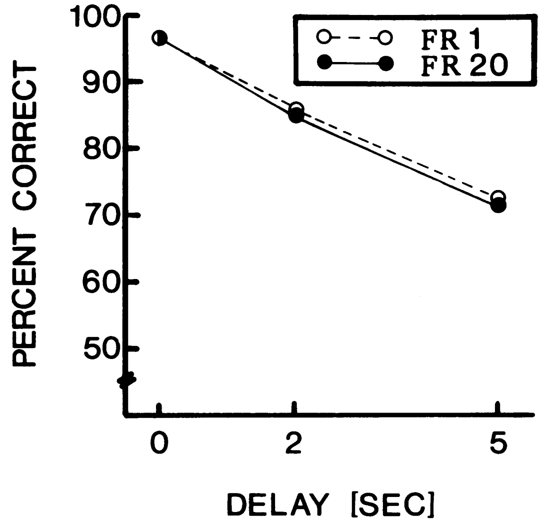

Fig. 3. Mean percentages of correct matching responses, as a function of delay with either an FR-1 (unfilled circles) or an FR-20 (filled circles) requirement during the initiating stimulus, in Phase 3 of Experiment 1.

Method

Subjects

The subjects were 8 adult White King pigeons, all of which had several months of previous experience on a DMTS task. Four of the subjects (Birds 1, 3, 7, and 8) had been exposed to sample durations of 2 s and 5 s during the course of their experimental histories; the other 4 birds had been exposed only to response-independent sample durations of 5 s. For all of the birds, the initiating-stimulus schedule had been FR 1 throughout their previous experimental histories. All birds were maintained at approximately 85% of their free-feeding weights by food obtained during and after experimental sessions. The birds were housed individually with water and grit freely available.

Apparatus

All birds were tested in rectangular operant-conditioning chambers that measured 29 cm high, 32 cm wide, and 35 cm deep. Each chamber contained three horizontally aligned response keys requiring a force of approximately 0.25 N to operate. The keys could be transilluminated with white, red, or blue light by stimulus projectors mounted behind each key. A solenoid-operated grain feeder was located below the center key, and grain presentations were accompanied by illumination of a lamp located in the feeder. The houselight, located behind the response panel, was not used in this experiment. Experimental contingencies were controlled and data were recorded by a PDP-8E® computer located in an adjacent room.

Procedure

Baseline DMTS. Because all birds had received extensive exposure to the DMTS pro-

Table 3

Percentages of correct matching responses (and total numbers of trials tested) in Phase 3 of Experiment 1.

Delay	0		2		5	
Init. FR	1	20	1	20	1	20
Bird 1	95	99	98	92	79	78
	(100)	(98)	(48)	(47)	(52)	(50)
2	94	94	96	92	65	71
	(100)	(97)	(48)	(47)	(52)	(51)
3	93	94	79	75	71	67
	(100)	(100)	(48)	(48)	(52)	(52)
4	96	96	94	92	79	88
	(100)	(100)	(48)	(48)	(52)	(51)
5	97	98	71	71	55	56
	(94)	(94)	(45)	(45)	(47)	(48)
6	100	100	92	88	69	71
	(100)	(100)	(48)	(48)	(51)	(52)
7	100	99	85	81	81	67
	(100)	(100)	(48)	(48)	(52)	(52)
8	98	96	81	91	73	70
	(99)	(75)	(47)	(35)	(51)	(37)
9	98	95	77	88	81	75
	(100)	(100)	(48)	(48)	(52)	(51)

Table 4

Percentages of correct matching responses at each delay, and average numbers of pecks per trial on the red and the blue samples during baseline sessions.

	Percentage correct			Sample pecks per trial	
Delay	0	5	10	Red sample	Blue sample
Bird 1	99	84	78	9.2	14.0
2	100	90	74	21.5	23.3
3	100	94	91	11.1	10.8
4	99	88	76	10.1	12.3
5	99	98	89	12.6	10.4
6	97	49	56	0.1	0.2
7	100	100	80	7.1	10.6
8	100	94	90	12.2	21.2

cedure, no preliminary training was given. However, prior to manipulations of ratio requirements that accompanied the initiating and sample stimuli, each bird was tested on a baseline DMTS condition for five sessions. Trials began with white illumination of the center key—the trial-initiating stimulus. A single peck terminated this stimulus and produced the sample stimulus—either blue or red illumination of the same key. Following a 5-s period during which sample responses were recorded but otherwise without any programmed consequence, the sample terminated and a delay of either 0 s (50% of the trials), 5 s (25% of the trials), or 10 s (25% of the trials) followed. The side, comparison keys were then illuminated red and blue, with the left–right arrangement counterbalanced over trials. A peck on the comparison key of the same color as the preceding sample was reinforced with 4-s access to grain; a peck on the nonmatching key terminated the trial. Sixty-four trials, each separated by a 30-s ITI, were scheduled during each 50-min session. Occasionally birds did not complete all of the scheduled trials within the 50 min.

Test phase. The design of this test phase was similar to that of the second test phase of Experiment 1. Each bird was tested under four conditions that comprised a two by two factorial of FR requirements during the sample (4 and 20) and during the initiating stimulus (4 and 20). Thus, the four conditions were I4–S4 (FR 4 during the initiating stimulus and the sample), I4–S20 (FR 4 during the initiating stimulus and FR 20 during the sample), I20–S4 (FR 20 during the initiating stimulus and FR 4 during the sample), and I20–S20 (FR 20 during both). Each condition occurred once during each block of four sessions, with the sequence varying between the

Table 5

Percentages of correct matching responses (and total numbers of trials tested) under each condition of Experiment 2.

Delay	0				5				10			
Samp. FR	4		20		4		20		4		20	
Init. FR	4	20	4	20	4	20	4	20	4	20	4	20
Bird 1	98	90	98	98	74	58	92	82	78	78	93	86
	(64)	(45)	(56)	(45)	(31)	(22)	(28)	(23)	(32)	(22)	(29)	(20)
2	86	88	100	100	53	47	69	78	50	56	60	69
	(64)	(64)	(64)	(63)	(32)	(32)	(32)	(31)	(32)	(32)	(32)	(32)
3	94	92	100	100	82	77	100	92	75	75	100	96
	(64)	(60)	(62)	(54)	(32)	(30)	(29)	(27)	(32)	(28)	(30)	(30)
4	90	92	100	98	72	75	100	100	50	73	84	92
	(64)	(52)	(51)	(47)	(32)	(27)	(23)	(25)	(32)	(26)	(26)	(24)
5	96	90	100	100	77	71	100	100	72	56	100	100
	(59)	(52)	(47)	(47)	(29)	(24)	(21)	(22)	(28)	(27)	(23)	(23)
6	98	94	98	100	50	56	89	54	45	66	81	84
	(63)	(54)	(52)	(33)	(32)	(27)	(27)	(23)	(31)	(29)	(30)	(19)
7	100	94	100	100	75	78	100	96	82	74	90	100
	(64)	(52)	(58)	(43)	(32)	(24)	(29)	(23)	(32)	(23)	(29)	(21)
8	92	94	100	100	63	68	97	97	78	62	91	82
	(64)	(62)	(64)	(56)	(32)	(31)	(32)	(30)	(32)	(32)	(32)	(30)
Mean	94	92	100	100	68	66	94	87	66	68	87	89

Table 6

Average sample duration (in seconds) and percentages of correct matching responses for the two samples under each condition of Experiment 3.

Condition	Sample		Subject 1	2	3	4	5	6	7	8
Baseline	Red	Sample duration:	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
		Percent correct:	90	90	98	90	95	75	92	98
	Blue	Sample duration:	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
		Percent correct:	90	93	95	92	98	75	98	94
I4–S4	Red	Sample duration:	2.2	0.7	1.6	1.3	1.2	5.0	1.8	1.3
		Percent correct:	86	73	78	58	82	73	84	74
	Blue	Sample duration:	1.3	0.5	1.6	1.2	1.4	2.6	1.7	0.8
		Percent correct:	89	64	97	92	90	74	94	89
I20–S4	Red	Sample duration:	2.1	0.4	1.5	2.2	1.0	4.3	2.4	1.5
		Percent correct:	87	63	87	81	87	66	94	80
	Blue	Sample duration:	1.9	0.4	1.1	1.4	1.4	2.2	2.6	0.8
		Percent correct:	71	77	82	85	66	88	75	79
I4–S20	Red	Sample duration:	12.9	3.0	5.7	10.1	6.0	13.5	10.0	5.9
		Percent correct:	98	81	100	94	100	85	100	94
	Blue	Sample duration:	7.0	3.0	5.2	6.1	8.4	12.0	7.4	4.2
		Percent correct:	93	83	100	98	100	98	95	100
I20–S20	Red	Sample duration:	11.4	2.9	5.7	9.3	5.5	38.2	10.4	6.3
		Percent correct:	95	91	100	94	100	76	100	95
	Blue	Sample duration:	6.5	2.9	3.3	6.2	10.6	36.1	7.1	5.0
		Percent correct:	87	83	94	100	100	92	98	97

two blocks. In this experiment the testing sequence also varied across birds. Sixty-four trials were scheduled during each test session, but the birds often did not complete all scheduled trials within the 50-min time limit, particularly in larger FR conditions.

Results and Discussion

Baseline levels of accuracy at each delay and number of sample pecks during the 5-s sample presentations (averaged over the five baseline sessions) are shown for each bird in Table 4. Only Bird 6 did not consistently peck the sample during baseline.

Accuracy of matching at each delay under the four test conditions is shown for each bird in Table 5. The results of this experiment replicate those of Experiment 1 in showing a facilitative effect on accuracy of increases in the sample FR but not of increases in the initiating-stimulus FR. This was confirmed with a three-way repeated-measures analysis of variance, with initiating FR, sample FR, and delay as the factors. The analysis revealed a significant effect of sample FR [$F(1,7) = 185.98, p < .001$] and delay [$F(2,14) = 23.09, p < .001$], but not of initiating FR [$F(1,7) = 0.84, p > .1$]. There was also a significant delay- by sample-FR interaction [$F(2,14) = 659.04, p < .001$], but no other interactions were statistically significant.

Table 6 shows the average duration of each sample stimulus under each condition of the experiment, as well as the overall accuracy of matching on red and blue sample trials. For most birds, FR-4 schedules during the sample resulted in sample durations that were shorter than during baseline, and FR-20 schedules during the sample resulted in sample durations that were longer than during baseline.

Rate of responding during the initiating stimulus (measured from the first to last peck) under the four conditions is shown for each bird in the left portion of Table 7. This measure showed no consistent effects of the size of the FR during either the sample or the initiating stimulus. A two-way analysis of variance performed on these data revealed no significant effect of sample FR [$F(1,7) = 2.65, p > .1$] or of initiating FR [$F(1,7) = 0.228, p > .1$], and no significant interaction [$F(1,7) = 0.028$].

Rates of responding during the red and blue sample stimuli (again measured from the first

Table 7

Average rate of responding (responses per second) during the initiating stimulus and during each of the samples, as a function of sample FR and initiating FR in Experiment 2.

	Initiating stimulus				Red sample				Blue sample			
Samp. FR	4		20		4		20		4		20	
Init. FR	4	20	4	20	4	20	4	20	4	20	4	20
Bird 1	1.9	1.4	1.8	1.2	2.0	2.0	1.6	1.8	3.3	2.5	2.9	3.2
2	3.4	6.9	2.4	5.0	5.6	8.3	6.8	6.8	7.3	8.6	6.8	6.8
3	3.1	3.1	2.8	3.1	2.5	2.3	3.5	3.4	2.7	4.0	4.0	6.3
4	2.1	2.0	1.5	1.8	3.3	1.9	2.0	2.2	3.7	3.0	3.3	3.3
5	1.5	1.9	0.4	2.2	3.3	4.0	3.3	3.6	3.0	3.3	2.4	2.2
6	0.8	2.1	1.7	0.8	1.0	1.3	1.8	0.7	1.6	1.9	1.7	0.7
7	1.9	1.1	1.7	1.0	2.1	1.9	2.0	1.9	2.5	2.1	2.9	2.9
8	4.8	3.1	5.0	3.8	3.0	2.7	3.3	3.2	5.0	5.4	4.8	4.0

peck) are shown for each bird in the middle and right portions of Table 7. Although most birds responded more rapidly during the blue sample than during the red, the FR requirements did not appear to affect these rates. This observation was confirmed by a three-way repeated-measures analysis of variance with sample color, sample FR, and initiating FR as the factors. This analysis revealed a significant effect of sample color on response rates [$F(1,7) = 6.73$, $p < .05$], but not of sample FR [$F(1,7) = 0.019$] nor of initiating FR [$F(1,7) = 0.264$]. Of particular interest was the finding that the interaction between sample color and sample FR did not approach statistical significance [$F(1,7) = 0.28$, $p > .1$], indicating that the birds' tendency to respond at different rates during the two sample colors was not affected by the sample FR schedule.

The finding that the ratio contingency in effect during the sample altered neither the overall rate of sample pecks nor the tendency of the birds to peck at different rates during the two samples suggests that larger sample-FR schedules do not produce their facilitative effects on accuracy through their providing more opportunity for differential sample-response rates to emerge. Even more evidence against this interpretation of sample-FR effects is provided by examining the data for individual subjects given in Tables 5 and 7. For example, both Subjects 2 and 6 responded more accurately when the ratio during the sample was larger, in spite of the fact that they showed less difference between response rates during red and blue samples in the conditions with the FR 20 during the sample than they did with the FR 4 during the sample.

EXPERIMENT 3

The results of the first two experiments failed to provide any support for the interpretation proposing that the number of responses "invested" in a trial might be an important determinant of DMTS accuracy, because the number of pecks required during a trial-initiating stimulus had no apparent effect upon accuracy of matching. On the other hand, the number of pecks required during the sample stimulus had a clear, facilitative effect on DMTS accuracy. Thus, effort appears to play little role in the effect of sample-response requirements in DMTS. Instead, the present results appear to confirm the interpretation based on duration of exposure to the sample. One question remaining, however, is whether the facilitative effect of increases in exposure to the sample is specific to situations in which matching responses are made in the absence of the sample, or whether the effect is a more general aspect of stimulus control. For example, exposure to the sample may influence whether the critical features of the sample (in this case, color) gain control of the subject's behavior on a given trial, but may have no additional influence on the maintenance of this stimulus control once the sample is removed. In other words, it is possible that exposure to the sample has more to do with discriminating the critical features of the sample than with remembering the sample over the delay. In the DMTS task, it is difficult to determine the locus of the facilitative effect of increased exposure to the sample because even the 0-s delay trials involve control by an antecedent stimulus (or "short-term memory"). However, if this explicit short-term memory requirement were eliminated by having the sample remain lit while the choice was made (i.e., a simultaneous matching-to-sample procedure), a facilitative effect of sample-response requirements could not be easily attributed to a *specific* effect on short-term memory. Instead, such a result would suggest that the effect might be on stimulus control in general, and would indicate caution in interpreting the effect of sample-response requirements in DMTS tasks in terms of subjects' ability to remember the sample.

The present experiment was designed to address this issue by comparing the relative effectiveness of peck requirements that accompanied the sample stimulus and peck requirements that accompanied an initiating stimulus in a simultaneous matching-to-sample (MTS) procedure. This experiment also provided a final test of the effort hypothesis for interpreting effects of response requirements imposed during the sample. It seemed possible that an effect of effort might be more detectable in situations that do not explicitly require remembering the sample.

METHOD

Subjects and Apparatus

Four naive White King pigeons, maintained at 85% of their free-feeding weights, served as subjects. The housing conditions and the test apparatus were the same as those described in Experiment 2.

Procedure

The pigeons were first trained to eat from the hopper and to peck at the various keylights during a few initial training sessions. Then, each bird received 10 sessions of training on a simultaneous matching-to-sample procedure that provided a baseline for subsequent comparisons. During this condition, trials began with illumination of the center key with white light (the initiating stimulus). A single peck on that key changed the color of illumination to red or blue (the sample stimulus); 5 s after onset of the sample, red and blue were presented on the two side keys (the comparison stimuli). The sample and the two comparisons remained lit until the bird pecked one of the comparison stimuli. If the bird pecked the comparison key of the same color as the sample, 4-s access to food was provided. Incorrect choices resulted in termination of the trial and initiation of a 15-s ITI. Sixty trials were scheduled during each session, and the sessions lasted a maximum of 50 min. (Usually sessions were completed in about half that time.) The average accuracy over the last three baseline sessions was 87%, 95%, 94%, and 82% for Birds 1, 2, 3, and 4, respectively. The average number of responses per trial at the sample during these baseline sessions was 6.3, 14.1, 7.7, and 1.6, respectively.

The test phase consisted of four conditions that alternated randomly over 20 sessions, such that each condition was in effect for a total of five sessions. In all conditions, the sample stimulus remained lit during the presentation of the two comparison stimuli, but the conditions differed with respect to the number of pecks required during the initiating stimulus and during the sample stimulus. In the first condition (I1–S1), a single peck during the initiating stimulus was required to produce the sample, and a single peck during the sample was required to produce the comparison stimuli. In the second condition (I1–S10), one peck was required during the initiating stimulus and 10 were required during the sample. In the third condition (I10–S1), 10 pecks during the initiating stimulus and one peck during the sample stimulus were required, and in the fourth condition (I10–S10), 10 pecks were required during each stimulus. All sessions consisted of 60 trials, 30 with each sample.

RESULTS AND DISCUSSION

The results are shown in Table 8. Requiring 10 pecks during the sample enhanced the birds' accuracy of simultaneous matching to sample, whereas accuracy was not consistently affected by the peck requirement that accom-

Table 8

Percentages of correct matching responses in Experiment 3.

Condition	I1–S1	I10–S1	I1–S10	I10–S10
Bird 1	89	95	98	95
2	66	86	91	91
3	90	84	95	92
4	94	89	100	98
Mean	85	88	96	94

I = FR during the initiating stimulus; S = FR during the sample stimulus.

panied the initiating stimulus. These results were confirmed with a two-way repeated-measures analysis of variance, with initiating-peck requirement and sample-peck requirement as factors. This analysis revealed a statistically significant main effect of sample-peck requirement [$F(1,3) = 12.99$, $p < .05$], but not of initiating-peck requirement [$F(1,3) = 0.105$, $p > .5$]. The interaction term was not significant [$F(1,3) = 1.01$, $p > .1$]. Thus, even in a simultaneous task, where there is no explicit short-term memory requirement, accuracy was affected by the number of responses required during the sample but not during the initiating stimulus.

GENERAL DISCUSSION

The results of the first experiment showed that the number of pecks required during the sample stimulus had a large and reliable effect on pigeons' accuracy of delayed matching, whereas the number of pecks required during a trial-initiating stimulus, which did not provide increased exposure to the sample, had no effect on accuracy. This finding supports the view that pecks on the sample improve accuracy by increasing exposure to the sample, rather than by changing the effort requirements of the task.

The subsequent two experiments provided further evidence that effort does not underlie the effect of sample-response requirements on accuracy of matching, and attempted to analyze in more detail this effect of sample-response requirement. Experiment 2 examined the possibility that larger FR schedules during the sample might improve accuracy because they provide more opportunity for differential, sample-specific response rates to emerge, which could then provide an additional cue to guide choice (e.g., Urcuioli & Honig, 1980). Although most birds responded more rapidly during one sample than during the other, these differential response rates were not consistently affected by the sample-FR schedule. Furthermore, although for 2 birds the rates of responding during the two samples were not appreciably different, both birds were more accurate with the larger FR schedule during the sample. Thus, the effect of increasing the FR schedule during the sample does not appear to be related to the development of differential rates of responding occasioned by the samples.

The results of Experiment 3 raised the possibility that larger peck requirements during the sample may have a general facilitative effect on stimulus control, rather than a selective effect on short-term memory. In this experiment, accuracy of performance on a simultaneous MTS task, in which the sample is still present when the choice is made, was also affected by the sample-peck requirement but not by the initiating-peck requirement. These results are consistent with earlier studies showing that response requirements can facilitate discrimination in procedures that do not explicitly require the animal to remember a stimulus over a delay (e.g., Elsmore, 1971; Williams, 1971a; Zentall et al., 1974). Thus, larger sample-peck requirements seem to improve accuracy on matching-to-sample procedures by increasing exposure to the sample, but it is possible that this effect has little to do with short-term memory processes per se. Whatever the factors involved in the facilitative effect of sample-peck requirements, the results of the present experiments show that effort alone cannot account for the effects of sample-peck requirements on MTS and DMTS accuracy.

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