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CHOICE AS A FUNCTION OF REINFORCEMENT RATIOS IN DELAYED MATCHING TO SAMPLE

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Pigeons were studied in two experiments using a delayed matching-to-sample task. In Experiment 1, 4 subjects were exposed to a task in which the proportion of reinforcement associated with matching and nonmatching, and the overall proportion of reinforcement associated with selecting each choice, regardless of the sample stimulus, were varied. Choice was sensitive to both proportions. A least squares regression analysis showed that Wixted's (1989) proportions of reinforcement model closely fit the data from Experiment 1; however, the model failed to make accurate qualitative predictions for some test conditions. In Experiment 2, 4 subjects were exposed to a delayed matching-to-sample task in which the retention intervals and the reduction in delay to reinforcement signaled by the onset of the sample stimulus were independently varied. When the retention interval was short and when the delay-reduction value of the sample stimulus was high, the sample exerted greater control over choice; the control by the overall proportion of reinforcements for selecting each choice stimulus was correspondingly low. Conversely, when the retention interval was long and the delay-reduction value of the sample stimulus was low, the sample exerted relatively less control over choice; control by the overall proportion of reinforcements obtained for selecting each choice stimulus was correspondingly high. A signal detection analysis found that sensitivity to reinforcement varied directly with retention interval. Data were also consistent with misallocation models. No evidence was found to suggest that pigeons ignore the rate at which selecting individual choice stimuli is reinforced, as has been reported in studies with human subjects.

Key words: delayed matching to sample, base-rate error, retention interval, choice, delay reduction, key peck, pigeons

Choice, typically affected by multiple, often conflicting, sources of control, may be studied using a delayed matching-to-sample (DMTS) task. In a typical DMTS task involving pigeons, subjects are presented with one of two possible sample stimuli for a given period of time. After termination of the sample stimulus the subjects are presented with two choice stimuli, one of which is identical to the sample stimulus. Pecking on this stimulus is reinforced. The interval between the offset of the sample stimulus and the presentation of the choice stimuli is commonly called the retention interval and typically ranges from 0 s to 20 s in studies involving pigeons (Wixted, 1989).[1]

Two factors that may control choice in a DMTS task are the overall proportion of reinforcement obtained for selecting each choice stimulus and the proportion of reinforcement obtained for selecting each choice stimulus given the presentation of one of the two sample stimuli. In a typical DMTS task, the overall proportion of reinforcement obtained for selecting either choice stimulus is equal, because each choice stimulus is associated with reinforcement on half of the trials. In a typical DMTS task, the proportion of reinforcement obtained for selecting each choice stimulus given the preceding sample stimulus is 1 when the sample stimulus is the same as the choice stimulus and 0 when it is not.

Although reinforcement is typically arranged in this manner, other arrangements have interesting theoretical implications. For example, it is possible to arrange reinforcement in a manner in which the overall proportion of reinforcement for selecting each choice stimulus is unequal and the proportion of reinforcement obtained for selecting each choice stimulus given the preceding sample varies, depending on which sample stimulus was presented. In addition, it is possible to arrange reinforcement in a DMTS

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[1] A DMTS task with a 0-s retention interval differs from a matching-to-sample (MTS) task in that the sample is not present when the choice stimuli are presented in the DMTS task, but the sample is present when the choice stimuli are presented in the MTS task.

task such that the overall proportion of reinforcement favors selecting one choice stimulus but the proportion of reinforcement given the preceding sample stimulus favors selection of the other choice stimulus.

Wixted (1989) proposed a general model of choice in a DMTS task. The model views choice as a function of both the overall proportion of reinforcement obtained for selecting each choice stimulus and the proportion of reinforcement obtained for selecting each choice stimulus given the preceding sample stimulus. Given two choice stimuli (X and Y) and two sample stimuli ("X" and "Y"), the equation describing the model reads as follows:

$$\frac{B_{X|\text{“X”}}}{B_{X|\text{“X”}} + B_{Y|\text{“X”}}} = \frac{p(r_{X|\text{“X”}})}{r_{X|\text{“X”}} + r_{Y|\text{“X”}}} + \frac{(1-p)r_X}{r_X + r_Y}, \qquad (1)$$

where $B_{X|\text{“X”}}$ is the number of times that a subject selects Choice X given Sample "X" (i.e., selecting the matching choice stimulus), $B_{Y|\text{“X”}}$ is the number of times the subject selects Choice Y given Sample "X" (i.e., selecting the nonmatching choice stimulus), $r_{X|\text{“X”}}$ is the number of reinforcers obtained from selecting Choice X given Sample "X," $r_{Y|\text{“X”}}$ is the number of reinforcers obtained for selecting Choice Y given Sample "X," and r_X and r_Y are the number of reinforcers obtained for selecting Choices X and Y, respectively. The first proportion on the right side of Equation 1 represents the proportion of reinforcers obtained for selecting a choice stimulus given the preceding sample, and the second proportion represents the overall proportion of reinforcement obtained for selecting that choice stimulus. The degree to which each proportion controls choice is a function of *p,* which varies between 0 and 1. The term *p* is not an independent variable, but rather is derived from the other observable terms in Equation 1. In most DMTS tasks, selecting the nonmatching choice stimulus is never reinforced (i.e., $r_{Y|\text{“X”}} = 0$). When this occurs, Equation 1 reduces to Equation 2 (which was not included in Wixted's paper).

$$\frac{B_{X|\text{“X”}}}{B_{X|\text{“X”}} + B_{Y|\text{“X”}}} = p + \frac{(1-p)r_X}{r_X + r_Y}. \qquad (2)$$

Wixted's (1989) model states that *p* varies inversely with the retention interval and directly with the delay-reduction value of the sample stimulus, which is the reduction in time to reinforcement (assuming a correct choice) correlated with the onset of the sample stimulus. It is determined by dividing the time from the termination of the previous trial to the onset of the sample stimulus (intertrial interval or ITI) by the sum of the ITI and the time elapsed between the onset of the sample stimulus and the onset of the choice phase (Fantino, 1969; Squires & Fantino, 1971). This definition of delay reduction differs from that included in Wixted (1989), which defined delay reduction as equivalent to the ITI. The change allows for comparison of delay-reduction values for samples that are employed in tasks with differing interreinforcement intervals and is consistent with the concept of delay reduction in prior studies (e.g., Fantino, 1969).

Wixted's (1989) prediction that both the sample-specific and overall proportion of reinforcers obtained for selecting each choice stimulus independently affect choice in a DMTS task has not been examined previously. Several studies (Harnett, McCarthy, & Davison, 1984; Jones & White, 1992; McCarthy & Davison, 1991), however, have examined the effects of varying the schedule of reinforcement for matching in DMTS tasks, and therefore the proportion of reinforcement obtained for matching. However, these studies did not directly test Wixted's model because reinforcement was arranged so that the overall proportion of reinforcement associated with each choice stimulus and the proportion of reinforcement associated with matching and nonmatching covaried. Nevertheless, the subjects in these studies tended to select the choice stimulus that was associated with the higher proportion of reinforcement.

Experiment 1 varied the probability of reinforcement for selecting the matching and nonmatching choice stimuli, and therefore the proportion of reinforcers obtained for selecting each choice stimulus given the preceding sample stimulus, independent of the probability of reinforcement for selecting each choice stimulus without consideration of the preceding sample stimulus. This was accomplished in two ways. First, one sample stimulus was presented more frequently than the other.

Second, selecting the choice stimulus that was identical to the sample stimulus occasionally did not result in reinforcement, whereas selecting the choice stimulus that was not identical to the sample stimulus occasionally did result in reinforcement. In addition to permitting a test of Wixted's (1989) model, Experiment 1 permitted an assessment of the degree to which pigeons may commit the base-rate error, a robust phenomenon in the human decision-making literature, in which people neglect the molar frequencies of various possibilities and overemphasize trial-specific information (Goodie & Fantino, 1995, 1996).

Wixted's (1989) model predicts that when the retention interval is short or the delay-reduction value of the sample is large, choice should be controlled primarily by the proportion of reinforcement obtained for selecting each choice given the preceding sample. In the typical DMTS task, this control results in subjects selecting the matching choice stimulus on nearly every trial. When the retention interval is long or the delay-reduction value of the sample stimulus is small, choice should be controlled primarily by the overall proportion of reinforcement obtained for selecting each choice stimulus. In the typical DMTS task, in which each choice stimulus is equally likely to be associated with reinforcement, such control results in subjects selecting each choice equally often, regardless of the sample stimulus.

These predictions are well supported by data showing that matching frequency varies inversely with retention interval (Blough, 1959; Grant, 1975; Roberts, 1972) and directly with the ITI and, by extension, delay reduction as well (Roberts & Kraemer, 1982; White, 1985). Those studies did not examine fully the role of delay reduction in a DMTS task, however, because subjects were tested only in conditions in which selecting the matching choice was always reinforced, selecting the nonmatching choice was never reinforced, and each choice stimulus was associated with reinforcement on half of the trials. The effect of delay reduction might differ if reinforcers in a DMTS task are arranged differently. To date, no published study has examined the issue.

Experiment 2 independently varied the retention interval and the reduction in delay to reinforcement associated with the onset of the sample stimulus. Experiment 2 extended the procedures used by Roberts and Kraemer (1982) and White (1985) by studying the effects of delay reduction and retention interval when the overall proportions of reinforcement obtained for selecting each choice stimulus are not equal. Both of the present experiments provided data assessing the relative effects of the overall proportions of reinforcements obtained for selecting each choice stimulus and the proportion of reinforcements obtained for selecting each choice stimulus given the preceding sample stimulus, and thus provided a test of Wixted's (1989) model. In addition, data from both experiments were analyzed in terms of other models of DMTS behavior (i.e., Davison & Tustin, 1978; McCarthy & Davison, 1991).

EXPERIMENT 1

Experiment 1 employed a DMTS task in which selecting one choice stimulus (Choice A) resulted in reinforcement on 75% of the trials and selecting the other choice stimulus (Choice B) resulted in reinforcement on the remaining 25% of the trials. Experiment 1 was conducted in four phases. In each phase, the probability of reinforcement for selecting the matching and nonmatching choice stimuli was varied. Furthermore, these probabilities differed depending on whether the sample was the same color as Choice A (Sample A) or Choice B (Sample B).

For the four phases of this experiment, Wixted's (1989) model makes the following prediction: Given Sample A, subjects should always select Choice A. Both the ratio describing the reinforcers obtained for matching Sample A and the reinforcers obtained for selecting Choice A, regardless of the preceding sample stimulus, favor selection of Choice A. Because reinforcers in this study were delivered by a probabilistic schedule, the left and right sides of Equation 1 can be equal only when the subject selects Choice A exclusively.

Given Sample B, the model's predictions depend upon the phase of the experiment. In Phases 1 and 2 (see Table 1), the model predicts that subjects should select the matching choice stimulus less frequently when Sample B is presented than when Sample A is presented. Moreover, Wixted's (1989) model im-

Table 1

Probability that selecting the matching and nonmatching choice stimuli will be reinforced over different phases of Experiment 1 given presentation of Sample A or B. The probability that selecting the nonmatching choice stimulus will be reinforced was obtained by subtracting the probability that selecting the matching choice stimulus will be reinforced from 1.00. "Frequency of Sample A" denotes the number of times out of 100 trials that Sample A was presented.

Phase	Frequency of Sample A	Matching		Nonmatching	
		A	B	A	B
1	75	1.00	1.00	.00	.00
2	68	.95	.69	.05	.31
3	62	.90	.50	.10	.50
4	50	.75	.25	.25	.75

Note. The order in which each subject experienced each phase was as follows: S1: 1, 2, 3, 4; S2: 2, 1, 4, 3; S3: 3, 4, 2, 1; S4: 4, 3, 1, 2.

plies that the proportion of trials on which a subject should select Choice B given Sample B will be smaller in Phase 2 than in Phase 1. For Phase 4, subjects should select Choice A given Sample B, because both the ratio describing the reinforcers obtained from matching given the preceding sample stimulus and the ratio describing the reinforcers obtained without regard to the sample stimulus favor selecting Choice A. For Phase 3, the model predicts exclusive preference for Choice A given Sample B as well. Although not readily obvious, this prediction follows for these reasons. The proportion describing the reinforcement obtained for matching must equal the proportion of trials on which subjects matched, because matching and nonmatching were equally likely to be reinforced. The proportion describing the overall reinforcement proportion for selecting Choice B will always be less than the proportion of reinforcement given Sample B, because on all of the trials in which Sample A is presented, subjects should select Choice A and receive reinforcement on 90% of those trials. Because the term on the left of Equation 1 is a weighted average of the two terms on the right (with p and $1 - p$ being the weights), the left and right sides of Equation 1 can be equal only when $p = 1$ (which, by definition, cannot occur) or when subjects select Choice A exclusively.

METHOD

Subjects

Four experimentally naive adult Indian Mondian pigeons served as subjects. Subjects were housed individually in a room separate from the experimental area, where they were given free access to water and grit. Subjects were maintained at approximately 85% of their free-feeding weights by means of additional feeding, when necessary, with pigeon chow at the end of an experimental session or at the approximate time of an experimental session when the subjects were not studied. Free-feeding weights were determined by providing all pigeons with continuous access to both milo and pigeon chow for at least 2 weeks prior to assessing free-feeding weights. All birds were then weighed daily for 7 days. The average weight over these 7 days was each pigeon's free-feeding weight. The mean free-feeding weight of the 4 pigeons was 715 g (range, 650 to 750 g).

Apparatus

Each pigeon was assigned to one of four custom-built operant conditioning chambers (35 cm by 36 cm by 32 cm). The front and rear walls consisted of metal plates, and the side walls consisted of metal plates lined with hard black plastic. The front wall had a 5-cm square opening, located 9.5 cm above the wire-mesh floor, that provided access to a solenoid-operated hopper filled with milo. The hopper was illuminated by a 1-W miniature lamp whenever the hopper was raised. Three custom-built Plexiglas response keys, each measuring 2.5 cm in diameter, were located 23 cm above the wire-mesh floor, the center key directly above the hopper and one key 7.5 cm on either side of the center key. Each key required 0.15 N of force for the operation of the microswitch mounted behind the key, which allowed responses to be recorded. A standard IEE projector, located behind each key, provided transillumination of the key with either blue or green light. Chambers were housed in double walled wooden enclosures, with continually operating fans providing ventilation. All experimental events and data collection were controlled by IBM® clone computers with Intel® 286 microprocessors that were programmed using Borland's Turbo Pascal, located in an adjacent room. The computers were connected to the chambers via a custom-built interface.

Procedure

Preliminary training. All subjects initially were trained in an autoshaping procedure. That is, they were presented daily with 50 pairings of visual stimuli and grain. Every 45 s, one of the three keys was transilluminated with either a blue or green light for 5 s. The particular key, as well as the color, was determined randomly. After termination of a stimulus, pigeons received 7-s access to grain. Three pecks to a transilluminated key terminated the stimulus and allowed immediate hopper access. Autoshaping continued until all subjects were consistently pecking at the lighted keys.

After the autoshaping procedure, subjects received training in a DMTS task. Every 20 s subjects were presented with a blue or green sample stimulus on the center key. Key color was determined randomly and was blue 50% of the time. The first peck on the key after 5 s had elapsed terminated the stimulus (i.e., a fixed-interval 5-s schedule) and resulted in the transillumination of the side keys, one blue and one green, in a random configuration (the right key was blue 50% of the time). Pecking the side key that was the same color as the sample stimulus resulted in presentation of grain for 3 s followed by 20 s in which no key was transilluminated (ITI). Pecking the stimulus that was not the same color as the sample stimulus resulted only in the onset of the 20-s ITI. Subjects were given 200 trials per day and continued in this condition until they selected the matching choice stimulus on at least 85% of the trials for five consecutive sessions. The number of these sessions varied across subjects and ranged between 25 and 40.

Experimental training. Subjects were studied under a DMTS procedure in which the probability that selecting one choice stimulus (Choice A) would result in reinforcement was .75 on each trial and the probability that selecting the other choice stimulus (Choice B) would result in reinforcement was .25 on each trial. The choice that would be eligible for reinforcement was selected independently for each trial. Choice A was blue for half of the subjects and green for the remaining half. The probability that selecting the matching or nonmatching choice stimulus would be reinforced was varied over four experimental phases as shown in Table 1. Table 1 also presents the number of times Sample A was presented in every 100 trials and the order in which each subject experienced the different phases. Each subject remained in each phase until the proportion of trials in which the subject matched Sample A was within .08 for five consecutive sessions and the proportion of trials in which the subject matched Sample B was within .08 for five consecutive sessions. The number of sessions in each phase varied across subjects and phases and ranged from 8 to 25. Each session lasted 200 trials or 2 hr, whichever came first. Sessions were conducted 6 days a week at approximately the same time.

RESULTS AND DISCUSSION

Choice proportions for each bird collapsed across the last five sessions of each phase are shown in Figure 1 (see also Appendix A). In Phase 1, in which the probability of reinforcement for selecting the matching choice stimulus was 1.0 given either sample stimulus, the mean proportion of trials on which subjects chose the matching choice stimulus was .98 given Sample A and .92 given Sample B. This pattern of responding was consistent across all subjects and was representative of the data across all five sessions from which data were collected. A paired t test showed that the proportion of trials on which subjects selected the matching choice stimulus was significantly greater when Sample A was presented than when Sample B was presented, $t(3) = 4.33$, $p < .05$.

These data suggest that choice was sensitive to both the proportion of reinforcement obtained for selecting each choice stimulus given the preceding sample stimulus and the overall proportion of reinforcement obtained for selecting each choice stimulus. Subjects selected the matching choice stimulus on 95% of the trials, on average, suggesting sensitivity to the proportion of reinforcement associated with matching and nonmatching; but they selected the matching choice stimulus more frequently when the sample stimulus was the same color as the choice stimulus associated with a higher overall proportion of reinforcement. This is nonoptimal performance in terms of maximizing reinforcers per session, because reinforcement would have occurred most often, in Phase 1, had

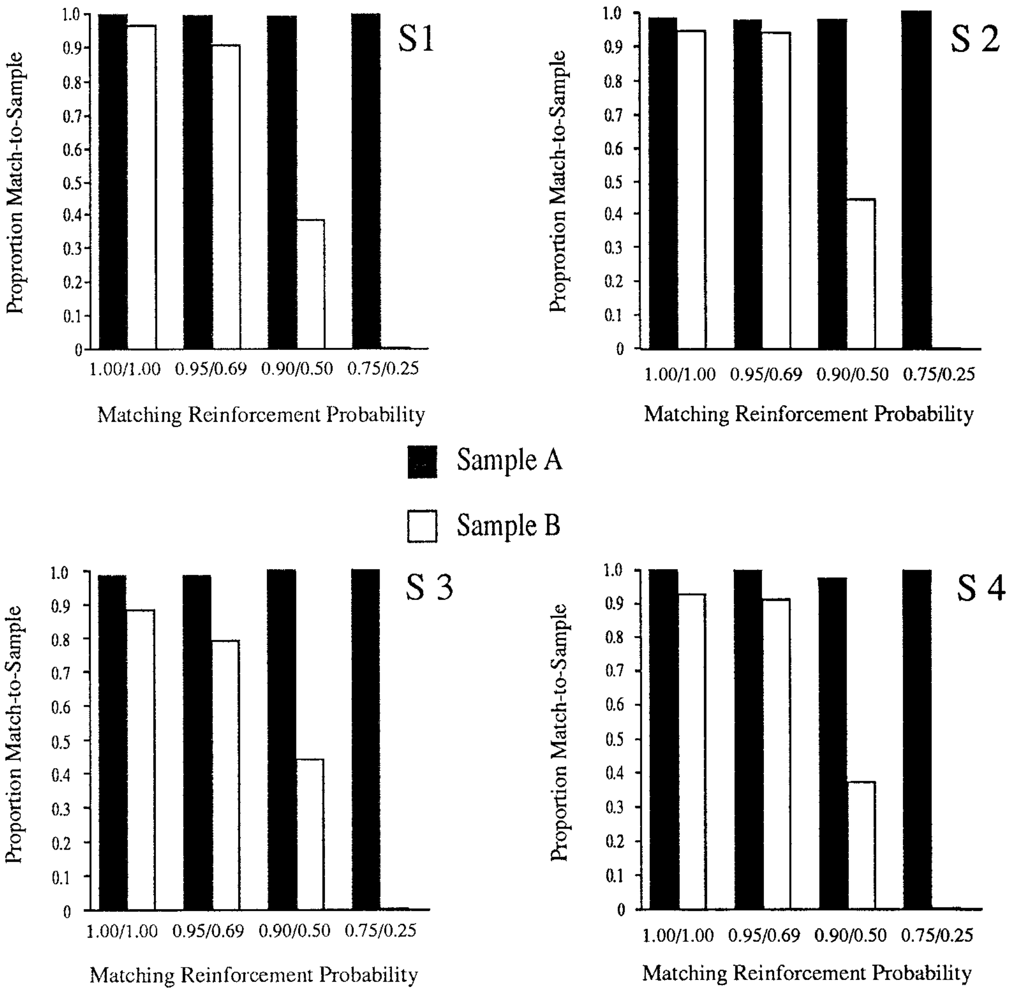

Fig. 1. Proportion of trials on which each subject selected the matching choice stimulus given Sample A (dark bars) and Sample B (light bars) across all four phases of Experiment 1, in which subjects were exposed to differing probabilities of reinforcement for selecting the matching choice stimulus. The *x* axis gives the probability that selecting the choice stimulus that matched Sample A and Sample B was reinforced, and the *y* axis marks the proportion of trials on which the subjects selected the matching choice stimulus. Each panel presents data for a different subject. The order in which the subjects were exposed to the various phases is given at the bottom of Table 1.

subjects always selected the choice stimulus that was the same color as the sample stimulus. These data are also consistent with Wixted's (1989) model, which predicts that subjects will deviate from optimal behavior and tend to select the choice stimulus that is more frequently associated with reinforcement.

It is possible that the increased frequency of selecting the matching choice stimulus given Sample A may not have been a result of unconditional reinforcement probabilities but rather a result of more numerous presentations of Sample A. That is, the increased frequency of selecting the matching choice stimulus may have been a result of more training on trials in which Sample A was presented, which gave the subjects more opportunity to learn to select Choice A. Although this possibility cannot be completely ruled out, it is important to note that in the preliminary training conditions, subjects were presented both sample stimuli at an equal rate and received well over 1,000 presentations of each sample stimulus prior to the start of experimental training sessions; thus, they had a large number of trials to learn to match given either sample stimulus. Data from the preliminary training sessions are shown in Appendix B. There does not appear to be any systematic preference for either of the choice stimuli, nor was there a position preference.

In Phase 2, in which the probability that selecting the matching choice stimulus would result in reinforcement was .95 if Sample A was presented and .69 if Sample B was presented, subjects selected the matching choice stimulus on 93% of the trials on average. All 4 subjects selected the matching choice stimulus more frequently when Sample A was presented than when Sample B was presented, suggesting once again that pigeons in a DMTS task are sensitive to both the proportion of reinforcement obtained for selecting each choice stimulus given the preceding sample and the overall proportion of reinforcement for selecting each choice stimulus. As in Phase 1, optimal choice behavior would have consisted of selecting the matching choice stimulus on every trial, regardless of sample. The difference in the proportion of trials on which subjects selected the matching choice stimulus given Sample A and Sample B was greater in Phase 2 than in Phase 1 for 3 of 4 subjects. However, a *t* test showed that this difference was not significant, $t\ (3) = 1.91$.

The Phase 2 data are partially supportive of Wixted's (1989) model. As predicted by the model, subjects selected the matching choice stimulus more frequently when Sample A was presented than when Sample B was presented, but they did not do so to a statistically significant greater degree in Phase 2, which is contrary to the predictions of the model.

In Phase 3, in which the reinforcement probability for selecting the matching choice stimulus was .90 given Sample A and .50 given Sample B, subjects chose the matching choice stimulus almost exclusively when Sample A was presented. When Sample B was presented, subjects chose the matching stimulus on 40% of the trials. Because the probability of reinforcement for selecting either choice given Sample B was .5, there was no optimal behavior allocation. Reinforcement would have occurred on half of these trials, regardless of choice. In fact, subjects chose the matching stimulus on less than 50% of the trials, $t(3) = 2.89$, $p < .05$, one tailed. Preference for Choice A is predicted by Wixted's (1989) model; however, the model predicts that the subjects will select Choice A exclusively. We will return to this failure below.

Table 2

Values of *p* and percentage of the variance accounted for (VAC) obtained by fitting the data from Experiment 1 into Equation 1 by means of a least squares regression analysis. The analysis omits data from Phase 4. The right two columns show values of *p* and VAC when Equation 1 was transformed into log ratios.

Bird	*p*	VAC	*p* (log ratio)	VAC (log ratio)
S1	.94	.995	.917	.877
S2	.96	.986	.906	.881
S3	.86	.985	.877	.956
S4	.90	.997	.923	.848

Note. The transformed version of Equation 1 is shown in Appendix C.

Choice given Sample B appeared to be position dependent. Three birds matched on most trials when Choice B was on the left but never when Choice B was on the right. The remaining bird matched on most trials when Choice B was on the right but never when Choice B was on the left. The model does not take position into account.

In Phase 4, in which the reinforcement probability for selecting the matching choice was .75 given Sample A and .25 given Sample B, Wixted's (1989) model predicts exclusive preference for Choice A regardless of sample. No matter which sample stimulus was presented, the probability of reinforcement for selecting Choice A was .75 and the probability for selecting Choice B was .25. In this condition, the sample stimulus was completely uninformative. As predicted by Wixted's model, subjects selected Choice A exclusively.

The data from each bird for Phases 1, 2, and 3 were placed in Equation 1 and fitted by means of a least squares regression with *p* as a free parameter. For each subject, Equation 1 accounted for approximately 99% of the variance. The values of *p* and the percentage of the variance accounted for each bird are shown in Table 2. The model was fitted omitting data from Phase 4, because all 4 subjects exhibited exclusive preference for Choice A. When exclusive preference occurs, any value of *p* will fit the model; therefore, including this condition would not be informative about the validity of the model. Although the current model is written in terms of choice proportions and proportions of reinforcer allocation, most models of choice in a DMTS task are written in terms of the log of the ratio of choice behavior and the log of the ratio of the reinforcer allocation. When Equation 1 was fitted in this more traditional manner (see Appendix C for the transformed equation), it accounted for 89.1% of the variance on average (see Table 2). Values of p were not observed to vary systematically over the three conditions reported in the current analysis, which is consistent with Wixted's (1989) model (because p is thought to be a function of retention interval and delay reduction, which did not vary across conditions).

Although Equation 1 closely fits the data from Experiment 1, it fails to account for the data in two cases. In Phase 2, the difference between the proportion of trials in which subjects matched Sample A and the proportion of trials in which subjects matched Sample B was not significantly different from the difference in Phase 1, although it was greater for 3 of 4 subjects in Phase 2. The lack of a clear effect may be because the proportion of reinforcement for selecting Choice B given Sample B and the overall proportion of reinforcement for selecting Choice B did not differ greatly between Phases 1 and 2. On average, the proportion of reinforcement for selecting Choice B given Sample B was 1.00 in Phase 1 and .92 in Phase 2, and the overall proportion of reinforcement for selecting Choice B was .24 in Phase 1 and .22 in Phase 2. The differences between these proportions may not have been great enough to produce a statistically significant change in behavior.

In Phase 3, Equation 1 predicted exclusive preference for Choice A given Sample B. However, subjects selected Choice B given Sample B on 40% of the trials on average. Wixted's (1989) model is based on the matching law (Herrnstein, 1970). As p approaches 0, Equation 1 reduces to the matching law. The matching law predicts that if reinforcement is delivered on unequal ratio schedules, subjects must select one choice alternative exclusively (the richer alternative in practice, although theoretically subjects could choose either alternative). Prior research has demonstrated that when ratio schedules are similar, although not equal, subjects do not choose exclusively but rather show a nonexclusive preference for the richer alternative (Fantino & Abarca, 1985; Herrnstein & Loveland, 1975; Horner & Staddon, 1987). Choice may be nonexclusive because in these situations the differences between the behavior ratio and reinforcement ratio are too small to affect choice behavior. The current DMTS task is similar to concurrent variable-ratio (VR) schedules in that choices were reinforced probabilistically as a function of how often each choice was selected rather than as a function of time. In the absence of the sample, the current DMTS task reduces to a concurrent VR 1.33 VR 3 schedule. In Phase 3 when Sample B was presented, the left and right sides of Equation 1 could be equal only when subjects chose Choice A exclusively. However, as preference for Choice B decreases from .5, the difference between the left and right sides of Equation 1 rapidly diminishes. Using the p values obtained when Equation 1 was fitted to the data, the values of the left and right sides of Equation 1 are shown in Table 3. Although the two sides of the equation are not equal, the difference between the two sides does not exceed .03 for any subject. Behavior in this situation might not be sensitive to small differences between the reinforcement and behavior ratios and therefore could become stable at some point other than exclusive preference for Choice A.

Table 3

The value of the two sides of Equation 1 in Phase 3 when Sample B was presented, using the p values obtained from a least squares regression analysis of the data from Experiment 1 (shown in the second column of Table 2).

Bird	$\frac{B_{A\mid``A"}}{B_{A\mid``A"} + B_{B\mid``A"}}$	$\frac{p(r_{A\mid``A"})}{r_{A\mid``A"} + r_{B\mid``A"}} + \frac{(1 - p)r_A}{r_A + r_B}$
S1	0.37	0.34
S2	0.43	0.42
S3	0.43	0.44
S4	0.36	0.36

A second possibility for the model's failure to predict choice in Phase 3 given Sample B is that a position preference partially controlled choice. Had choice been controlled by a combination of position preference and reinforcement ratios, one would expect the subjects to have selected Choice B on some proportion of trials in which Choice B appeared on the preferred side. Sidman (1969) found that as sample stimulus control declined, other factors increasingly controlled choice. Sample stimulus control in the present case may have been weak because the sample had no value in predicting the choice stimulus associated with reinforcement. When Sample B was presented, selecting either choice was equally likely to produce reinforcement. It is possible that, in this case, the sample was exerting little control over choice while other unprogrammed stimuli were controlling choice. Such a possibility is not addressed in Wixted's (1989) model, which views the degree to which the sample stimulus controls choice only as a function of retention interval and delay reduction.

A final possibility for the lack of exclusive preference for Choice A in Phase 3 is undermatching (see Williams, 1989, for a complete description of undermatching and overmatching). As stated earlier, Wixted's (1989) model is based on the matching law. When subjects undermatch, the matching law no longer predicts exclusive preference for the richer of two ratio-like schedules. Although Wixted's model assumes perfect matching, it can be modified to account for undermatching and overmatching. Such a modification was made, and no evidence was found to suggest that choice in this experiment systematically undermatched or overmatched.

EXPERIMENT 2

Experiment 1 demonstrated that choice in a DMTS task is controlled by the overall proportion of reinforcement obtained for selecting each choice stimulus and the proportion of reinforcement obtained for selecting each choice stimulus given the preceding sample. Experiment 1, however, did not investigate how changing the temporal relationship between the sample and choice stimuli would affect choice in a DMTS task. Wixted's (1989) model predicts that choice in a DMTS task will become increasingly influenced by the rate at which selecting each choice stimulus is reinforced regardless of the sample stimulus, given longer retention intervals and given smaller reductions in delay to reinforcement signaled by the onset of the sample stimulus. Subjects should show a bias towards selecting Choice A given longer retention intervals and smaller delay-reduction values. Experiment 2 examined this prediction by studying pigeons in a DMTS task similar to that of Experiment 1 except that both the retention interval and the degree to which the sample stimulus signaled a reduction in delay to reinforcement were varied.

METHOD

Subjects

Four experimentally naive Indian Mondian pigeons served as subjects. The pigeons were maintained in a manner identical to those in Experiment 1. The subjects had a mean free-feeding weight of 660 g (range, 600 to 750 g).

Apparatus

Each pigeon was assigned to one of four custom-made operant conditioning chambers, each a cylinder 36 cm in height and 33 cm in diameter. The walls of the chambers were made of black polyvinyl chloride pipe. Three custom-made Plexiglas response keys, similar to those used in Experiment 1, were located 24 cm above the wire-mesh floor, the center key directly above the hopper and one key 7 cm on either side of the center key. Each key could be transilluminated red or yellow. Other details were identical to those of Experiment 1.

Procedure

Preliminary training. Subjects were trained in a manner identical to those in Experiment 1 except that the keys were transilluminated red and yellow instead of blue and green.

Experimental training. Subjects were placed in a DMTS task identical to that of Phase 1 of Experiment 1 except that two temporal intervals were varied: (a) that between the sample offset and the choice stimuli onset (the retention interval), and (b) that between the end of a trial (either the offset of the choice stimuli on a nonreinforced trial or the end of grain presentation on a reinforced trial) and the onset of the next sample stimulus (i.e., the ITI). Selecting the choice that was the same color as the immediately preceding sample was always reinforced. Varying the retention interval and the ITI produced changes in the reduction in delay to reinforcement signaled by the onset of the sample stimuli. The retention interval was either 2 s or 5 s, and the delay-reduction value of the sample stimulus was either .8 or .2. The four possible combinations of retention interval and delay reduction were

Table 4

Delay-reduction values (D), retention interval values (r) in seconds, ITI values in seconds, and the order in which they appear for each subject in Experiment 2. Also shown are the observed values of p, stimulus discriminability (log d), and point estimates of reinforcer sensitivity (a) for each subject in Experiment 2.

Bird	D	r	ITI	Order	p	log d	a
R1	.8	2	28	1	.78	0.50	0.27
	.8	5	40	2	.52	0.69	0.73
	.2	2	1.8	3	.51	0.53	0.59
	.2	5	2.5	4	.25	0.21	0.65
R2	.8	2	28	2	.66	0.93	0.71
	.8	5	40	1	.21	0.38	0.82
	.2	2	1.8	4	.37	0.57	0.78
	.2	5	2.5	3	.12	0.35	0.82
R3	.8	2	28	3	.66	0.77	0.58
	.8	5	40	4	.39	0.91	1.08
	.2	2	1.8	2	.22	0.31	0.77
	.2	5	2.5	1	.10	0.15	1.15
R4	.8	2	28	4	.90	1.16	0.34
	.8	5	40	3	.21	0.50	0.88
	.2	2	1.8	1	.63	0.99	0.84
	.2	5	2.5	2	.01	0.41	1.03

presented in a different order for each subject. The retention interval, the ITI, and the delay-reduction value of each sample stimulus and the order in which they are presented are shown in Table 4. Session length and the criteria for entering a new phase were identical to those of Experiment 1. The number of sessions that subjects remained in each phase of the experiment ranged from 10 to 25. Sessions were conducted 6 days a week at approximately the same time.

RESULTS AND DISCUSSION

Data from Experiment 2 are shown in Figure 2 (see also Appendix D). When Sample A was presented, subjects selected the matching choice stimulus on 93% of the trials on average. This pattern was similar for all birds and over all phases of the experiment.

When Sample B was presented, subjects' behavior varied over conditions. Specifically, subjects selected the matching choice stimulus on 67% of the trials, on average, when delay reduction was .8 and on 30% of the trials when delay reduction was .2. An analysis of variance showed this difference to be significant, $F(1, 3) = 36.61$, $p < .05$. Also, subjects selected the matching choice stimulus on 60% of the trials when the retention interval was 2 s and on 37% of the trials when the retention interval was 5 s given equal delay-reduction values. An analysis of variance showed this difference to be significant as well, $F(1, 3) = 10.17$, $p < .05$. The relative effects of retention interval and delay reduction differed across subjects. For Subjects R1 and R3, the proportion of trials on which they selected the matching choice stimulus was always greater when the delay reduction was .8 than when it was .2, regardless of the retention interval. For Subjects R2 and R4, the proportion of trials on which they selected the matching choice stimulus was always greater when the retention interval was 2 s than when it was 5 s, regardless of delay reduction.

The results of Experiment 2 showed that both retention interval and delay reduction controlled choice in a DMTS task when the overall probabilities of reinforcement for selecting each choice stimulus were unequal, thus extending the findings of Roberts and Kraemer (1982) and White (1985), who employed equal probabilities of reinforcement for selecting each choice stimulus. Furthermore, the data are consistent with Wixted's (1989) model, which predicts that as retention interval increases or delay-reduction value of the sample decreases, choice is determined to a greater degree by the overall probability of reinforcement associated with selecting each choice stimulus. This joint control is demonstrated by the increasing tendency towards exclusive preference for Choice A, regardless of the sample stimulus given increasing retention intervals and decreasing delay-reduction values. In addition, the value of p from Equation 1 varied directly with the delay-reduction value of the sample and inversely with retention interval, which supports the assertion of the model that p measures changes in both delay reduction and retention interval. Values of p for each subject are shown in Table 4.

The data were also analyzed using the signal detection model of Davison and Tustin (for a complete description of the model see Davison & Tustin, 1978; Harnett et al., 1984). Using such a model allows one to observe separately the effects of both stimulus discriminability and reinforcer sensitivity on choice. Values for stimulus discriminability (log d) and point estimates of reinforcer sensitivity (a) are shown in Table 4. Mean stimulus discriminability decreased from 0.73 when delay reduction was .8 to 0.44 when de-

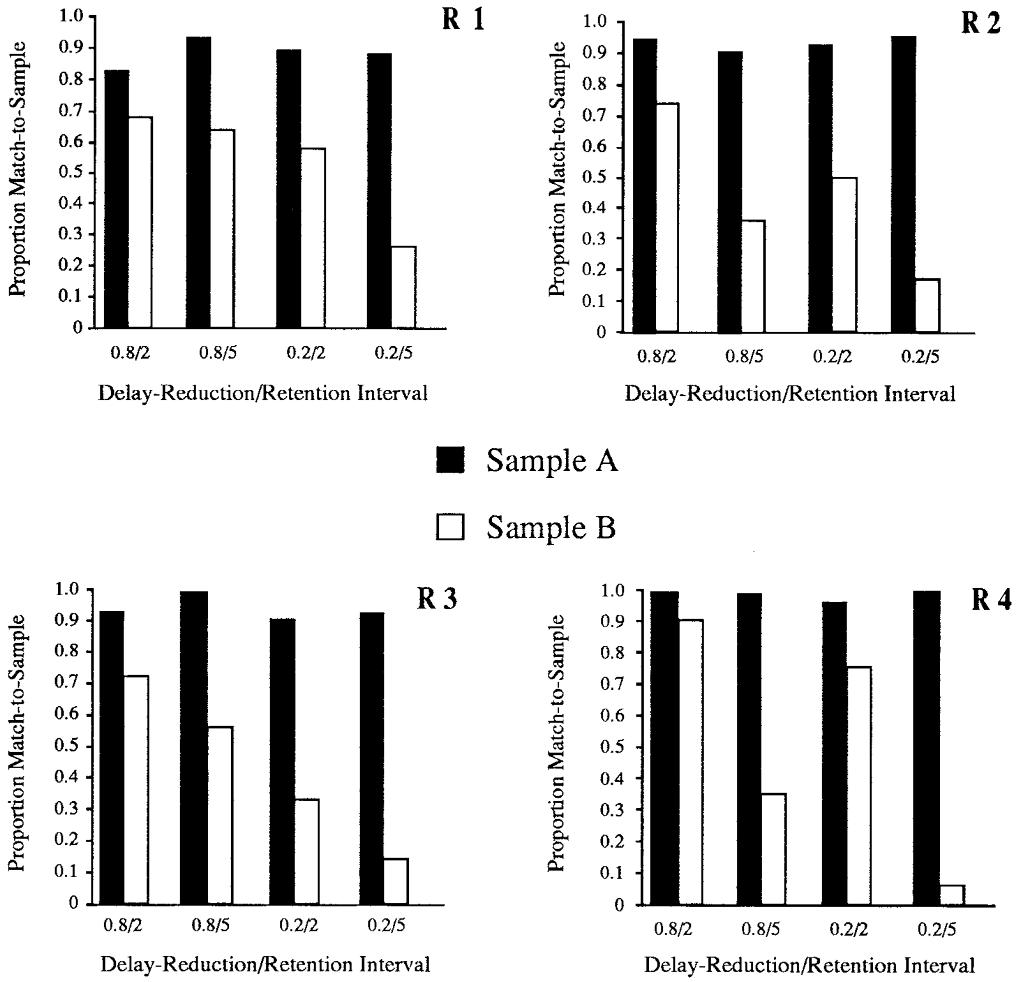

Fig. 2. Proportion of trials on which each subject selected the matching choice stimulus given Sample A (dark bars) and Sample B (light bars) across all four phases of Experiment 2, in which subjects were exposed to differing delay-reduction values of the sample stimuli and retention intervals. The *x* axis gives both the reduction in delay to reinforcement signaled by the onset of the sample stimulus and the retention intervals in seconds. Each panel presents data for a different subject. The order in which the subjects were exposed to the various combinations is given in Table 4.

lay reduction was .2. This pattern was consistent for all 4 subjects. However, an analysis of variance showed that this difference was not significant at the .05 level, *F*(1, 3) = 7.15. Mean stimulus discriminability decreased from 0.72 when a 2-s retention interval was scheduled to 0.45 when a 5-s retention interval was scheduled. This pattern was also consistent for all 4 subjects. Again, however, an analysis of variance showed that this difference was not significant, *F*(1, 3) = 3.57. Mean reinforcer sensitivity increased from 0.61 to 0.90 when the retention interval was increased from 2 s to 5 s. This pattern was consistent for all 4 subjects, and analysis of variance showed this effect to be significant, *F*(1, 3) = 12.97, $p < .05$. Mean reinforcer sensitivity also increased from 0.67 to 0.83 when delay reduction was decreased from .8 to .2. However, an analysis of variance showed that this effect was not significant, *F*(1, 3) = 4.36. There was no systematic relationship between stimulus discriminability and reinforcer sensitivity (Figure 3).

These data are consistent with the results of previous research that reported a decline in stimulus discriminability with increasing retention intervals. The mean stimulus dis-

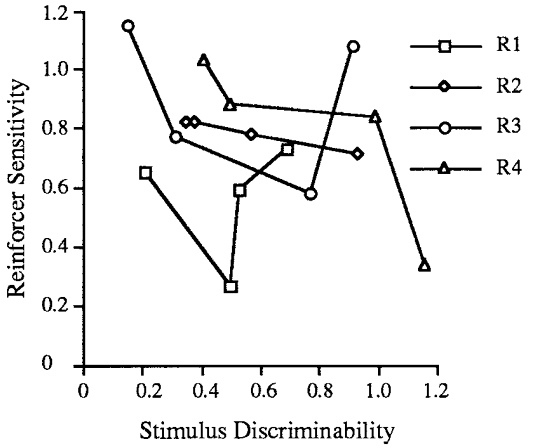

Fig. 3. Point estimates of reinforcer sensitivity (*a*) on the *y* axis given differing values of stimulus discriminability (log *d*) on the *x* axis. Each line denotes data for 1 subject from Experiment 2.

criminability of 0.72 at the 2-s retention interval is greater than the stimulus discriminability of 0.45 at the 5-s retention interval, which, although not statistically significant, did follow the pattern reported in previous research using similar methods (Harnett et al., 1984; Jones & White, 1992). The present data partially support the findings of Jones and White, who found that reinforcer sensitivity varied directly with retention interval. However, unlike the data reported by Jones and White, stimulus discriminability and reinforcer sensitivity did not appear to covary in any systematic manner. With respect to the relationship between stimulus discriminability and reinforcer sensitivity, the current data support the findings of Harnett et al., who found no such relationship.

GENERAL DISCUSSION

The results from the present experiments show that the overall proportion of reinforcers obtained for selecting each choice stimulus and the proportion of reinforcers obtained for selecting each choice stimulus given the preceding sample stimulus controlled choice in a DMTS task. Furthermore, the degree to which they did so depended upon the retention interval and the reduction in delay to reinforcement signaled by the onset of the sample stimulus. When the retention interval was short and when the delay-reduction value of the sample stimulus was high, the sample exerted greater control over choice, and the role of the overall proportion of reinforcers obtained for selecting the choice stimuli was correspondingly low. Conversely, when the retention interval was long and the delay-reduction value of the sample stimulus was low, the sample exerted relatively less control over choice, and the role of the overall proportion of reinforcers obtained for selecting the choice stimuli was correspondingly high.

The data supported many, but not all, predictions made by Wixted's (1989) model. The subjects in Experiment 1 selected the matching choice stimulus on almost every trial in Phases 1 and 2, demonstrating control by the proportion of reinforcers obtained for selecting each choice stimulus given the preceding sample stimulus. They did, however, select the matching choice stimulus less frequently when Sample B was presented, even when doing so resulted in a loss of reinforcers, suggesting that there was some control by the overall proportion of reinforcers obtained for selecting each choice stimulus. As the reinforcement probability associated with selecting the matching choice stimulus declined, choice was increasingly controlled by the frequency with which the choice stimuli were associated with reinforcement. Thus, as the sample stimulus became less predictive of reinforcement, subjects selected the matching choice stimulus less frequently given Sample B and tended to select the choice stimulus correlated with the higher overall proportion of reinforcement more often. This finding is consistent with Wixted's model and with the results of White, McLean, and Aldiss (1986) in a free-operant concurrent procedure.

Wixted's (1989) model did not predict the nonexclusive preference for Choice A in Phase 3 of Experiment 1. The model predicts exclusive preference for Choice A, but subjects selected Choice B on about 40% of the trials given Sample B. As discussed earlier, the model's failure to predict nonexclusive preference may have been the result of (a) the subjects' inability to distinguish small differences between their preference for a given choice stimulus and the proportion of trials on which selecting that choice was reinforced, or (b) a position bias or some other source of stimulus control not programmed by the experimenter.

Wixted's (1989) model views choice in a DMTS task as a function of both the proportion of reinforcement obtained for selecting each choice stimulus given a particular sample and the proportion of reinforcement obtained for selecting each choice stimulus without regard for the preceding sample. As such, it can be easily tested in the current studies. The current data also can be applied to other models, even though they address the issue of reinforcement probabilities differently. Signal detection models view choice in a DMTS task as a function of the discriminability of the sample stimulus and reinforcer bias (Davison & Tustin, 1978). Although the issue of reinforcing nonmatching choices has been addressed using signal detection models (Davison & McCarthy, 1980), these models do not systematically incorporate procedures in which selecting the nonmatching stimulus is reinforced, as in the current study. Later versions of signal detection models, commonly known as misallocation models, can be modified to take reinforcement for nonmatching into account (Alsop, 1991; Davison, 1991; Davison & Jenkins, 1985; McCarthy & Davison, 1991). Misallocation models state that outcomes that putatively reinforce matching may, on occasion, actually reinforce another behavior. The subject might be said, on those occasions, to "misattribute" the reinforcer to a response different from the one that actually produced the reinforcer. For example, presenting grain after the selection of Choice X after presentation of Sample "X" may actually reinforce selecting Choice Y after presentation of Sample "X," Choice X after presentation of Sample "Y," or even Choice Y after Sample "Y." The probability of this misallocation is assumed to increase when stimulus discriminability and reinforcer discriminability decline. Stimulus discriminability is thought to be a function of the physical difference between the two sample stimuli and the time interval between the sample stimulus and choice stimuli. Reinforcer discriminability is thought to be a function of the physical difference between the choice stimuli and the time interval between selecting a choice stimulus and reinforcement. The current data were fitted to a misallocation model by means of a least squares regression analysis similar to the analysis of Equation 1.

Table 5

Values of stimulus and reinforcer discriminability (p) and variance accounted for (VAC) when fitting Equation 3 to the data from Experiment 1. Values were derived when the model was written in terms of the log of the behavior and reinforcer ratios.

Bird	p	VAC
R1	.013	.965
R2	.016	.952
R3	.018	.892
R4	.017	.905

McCarthy and Davison's (1991) misallocation model was modified to take into account reinforcement of nonmatching responses and fitted to the data in Experiment 1. This expanded model reads as follows (M. Davison, personal communication, May 16, 1995):

$$\begin{aligned}\frac{\mathrm{B}_{(\mathrm{X}\,|\,\text{``X''}}}{\mathrm{B}_{(\mathrm{Y}|\,\text{``X''})}} = {} & [\mathrm{R}_{(\mathrm{X}\,|\,\text{``X''})} - 2p\mathrm{R}_{(\mathrm{X}\,|\,\text{``X''})} \\ & - p^2\mathrm{R}_{(\mathrm{X}\,|\,\text{``X''})} + p\mathrm{R}_{(\mathrm{X}\,|\,\text{``Y''})} \\ & + p\mathrm{R}_{(\mathrm{Y}|\,\text{``X''})} + p^2\mathrm{R}_{(\mathrm{Y}|\,\text{``Y''})}] \\ & \div [\mathrm{R}_{(\mathrm{Y}|\,\text{``X''})} - 2p\mathrm{R}_{(\mathrm{Y}|\,\text{``X''})} \\ & - p^2\mathrm{R}_{(\mathrm{Y}|\,\text{``X''})} + p\mathrm{R}_{(\mathrm{X}\,|\,\text{``X''})} \\ & + p\mathrm{R}_{(\mathrm{Y}|\,\text{``Y''})} + p^2\mathrm{R}_{(\mathrm{X}\,|\,\text{``Y''})}], \quad (3)\end{aligned}$$

where p is both sample and choice discriminability, $\mathrm{R}_{(\mathrm{Y}|\,\text{``Y''})}$ is the number of reinforcers obtained for selecting Choice Y given Sample "Y," and $\mathrm{R}_{(\mathrm{X}\,|\,\text{``Y''})}$ is the number of reinforcers obtained for selecting Choice X given Sample "Y." All other terms are equivalent to the terms contained in Equation 1. The present model views stimulus and reinforcer discriminability in terms of the probability that a reinforcer will be attributed by the subject to a sample or a response other than that which led to reinforcement. The term p, as in Equation 1, is not an independent variable but rather is derived from the other observable terms in the equation. Stimulus and reinforcer discriminabilities were assumed to be equal because the choice stimuli were identical to the sample stimuli and there was no retention interval or delay between choice and reinforcement in Experiment 1. Estimates of discriminability and the variance accounted for are shown in Table 5. The model accounts for 92.3% of the variance on average. Although Davison's (1991) model does not explicitly view choice as a function of conditional and unconditional reinforcement probabilities, it predicts behavior in the present study at least as well as Wixted's (1989) model.

Experiment 2 demonstrated that as the retention interval increased or when reduction in delay to reinforcement signaled by the onset of the sample stimulus decreased, the proportion of trials on which subjects selected the matching choice stimulus declined given Sample B but not given Sample A. This difference is consistent with the hypothesis that the degree to which the overall proportion of reinforcement associated with each choice and the proportion of reinforcement associated with each choice stimulus given the preceding sample stimulus is determined by the retention interval and the delay-reduction value of the sample. The relative degree to which retention interval and delay reduction affected choice varied from subject to subject. The data in Experiment 2 are consistent with data from other experiments that showed that the delay-reduction value of the sample and retention interval both controlled choice in DMTS tasks (Roberts & Kraemer, 1982; White, 1985). Using signal detection analyses, Experiment 2 demonstrated a direct relationship between reinforcer sensitivity and retention interval. Although no statistically significant relationship between retention interval and stimulus discriminability was found, the present results were qualitatively consistent with those of previous research that found an inverse relationship (Harnett et al., 1984).

Results from the present experiments are also relevant to studies of the base-rate error in human decision making (Kahneman & Tversky, 1972). These studies have found that when human subjects make probability judgments, they tend to neglect the molar frequencies of events, which correspond to the overall proportion of reinforcement associated with each choice stimulus in the present experiments, and overemphasize the more specific sources of stimulus control (such as the sample stimulus in the present experiments). For example, when subjects are asked to determine whether a taxicab involved in an accident was blue or green and are given two sources of information, one concerning the reliability of a witness and the other the proportion of taxicabs that are blue and the proportion that are green, subjects tend to use only witness reliability even when the mathematically correct answer is less a function of witness reliability than of the overall proportion of blue and green taxicabs.

These tasks with humans, however, have all been done with pencil and paper. The existence of a judgmental base-rate error does not necessarily imply a behavioral base-rate error. Behavioral accounts of the base-rate error have been discussed previously (Rachlin, 1989; Stolarz-Fantino & Fantino, 1990, 1995). Experiment 1 can be viewed as a behavioral analogue of Kahneman and Tversky's (1972) study, in which the sample stimulus takes the place of the witness report and the overall proportion of trials on which each choice stimulus is associated with reinforcement takes the place of the base rate. The overall proportion of trials in which matching results in reinforcement in the current experiment is analogous to witness reliability in studies of the base-rate error. The overall proportion of trials on which matching results in reinforcement can be determined using Bayes' theorem (Appendix C) and was 1.00, .87, .75, and .50 for Phases 1 through 4, respectively. Goodie and Fantino (1995) conducted an experiment similar to that of Experiment 1 and found that human choice in a DMTS task was primarily controlled by the overall proportion of trials in which matching was reinforced. In other words, humans made the base-rate error in a behavioral task.

If the pigeons in the current experiment made the base-rate error, they would have matched on every trial in Phases 1 through 3 regardless of the sample stimulus and matched on half of the trials regardless of the sample stimulus in Phase 4. Clearly this pattern did not occur: Subjects predominantly chose the nonmatching choice stimulus in Phases 3 and 4 given Sample B. One explanation for why humans make the base-rate error when pigeons do not is that humans are subject to many tasks, both explicit and incidental, in which grouping like objects is reinforced. The laboratory pigeon has no such history and may easily acquire a response pattern that yields a greater number of reinforcers. Indeed, further research (Fantino, 1995[2];

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[2] Fantino, E. (1995). *Adventures in choice: Behavioral approaches to decision making.* Paper presented at the 14th annual convention of the Northern California Association of Behavior Analysis, Oakland, CA.

Goodie & Fantino, 1996) has shown that humans do not make the base-rate error when a symbolic matching-to-sample task is employed in place of an identity matching-to-sample task, suggesting that prior experience with identity matching may have produced the base-rate error in humans. In any case, pigeons did not make the base-rate error; instead, they behaved in a manner consistent with many of the predictions of Wixted's (1989) model.

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APPENDIX A

Totals (last five sessions) for all 4 birds and all four phases of Experiment 1, showing the number of reinforcers obtained for selecting Choice A (RA) and Choice B (RB), for selecting the matching choice stimulus given Sample A (RmA) and Sample B (RmB), and for non-matching responses given Samples A (RnA) and B (RnB). Also shown are the number of times the subjects chose the matching choice stimulus given Sample A (CmA) and Sample B (CmB), and did not choose the matching choice stimulus given Sample A (CnA) and Sample B (CnB).

Bird	Phase	RA	RB	RmA	RmB	RnA	RnB	CmA	CmB	CnA	CnB
S1	1	748	232	748	232	0	0	748	232	9	11
	2	626	191	615	190	1	11	655	292	10	37
	3	664	69	540	69	0	124	584	149	16	251
	4	752	0	391	0	0	361	521	0	0	479
S2	1	723	247	723	247	0	0	723	247	13	16
	2	666	193	655	192	1	11	681	281	16	22
	3	609	85	499	83	1	110	578	171	21	230
	4	737	0	375	0	0	362	502	0	0	498
S3	1	725	219	725	219	0	0	725	219	24	32
	2	651	144	629	144	0	22	665	246	20	69
	3	641	81	529	81	0	112	598	170	4	228
	4	759	0	370	0	0	389	492	0	0	508
S4	1	751	219	751	219	0	0	751	219	8	22
	2	639	201	625	201	0	14	659	301	5	35
	3	647	83	516	82	1	131	577	149	22	252
	4	754	0	366	0	0	388	488	0	0	512

APPENDIX B

Data from the last 5 sessions of pretraining, showing the total number of times subjects selected Choice A given Sample A (CmA), Choice B given Sample A (CnA), Choice B given Sample B (CmB), and Choice A given Sample B (CnB).

Bird	CmA	CnA	CmB	CnB
Experiment 1				
S1	437	65	444	54
S2	442	55	443	60
S3	453	56	442	49
S4	446	49	459	46
Experiment 2				
R1	441	49	449	61
R2	461	35	469	35
R3	445	61	440	54
R4	430	70	446	54

APPENDIX C

Equations for Bayes' theorem and for the log ratio version of Equation 1.

Bayes' Theorem

$$p(\mathrm{A} \mid \text{``A''}) = \frac{p(\text{``A''} \mid \mathrm{A}) * p(\mathrm{A})}{p(\text{``A''} \mid \mathrm{A}) * p(\mathrm{A}) + p(\text{``A''} \mid \mathrm{B}) * p(\mathrm{B})},$$

where $p(\mathrm{A} \mid \text{``A''})$ is the probability that Event A will occur given a signal stating that Event A will occur, $p(\mathrm{A})$ is the overall probability of Event A occurring, $p(\text{``A''} \mid \mathrm{A})$ is the predictiveness of the signal, $p(\mathrm{B})$ is the base rate of Event B, and $p(\text{``A''} \mid \mathrm{B}) = 1 - p(\text{``A''} \mid \mathrm{A})$.

Log Ratio Version of Equation 1

$$\log \frac{B_{X \mid \text{``X''}}}{B_{Y \mid \text{``X''}}} = \log k - \log(1 - k), \tag{4}$$

where

$$k = \frac{p(r_{X \mid \text{``X''}})}{r_{X \mid \text{``X''}} + r_{Y \mid \text{``X''}}} + \frac{(1 - p)\, r_X}{r_X + r_Y}. \tag{5}$$

APPENDIX D

Data (last five sessions) from Experiment 2 for all 4 birds and for all for combinations of delay reduction (D) and retention intervals (*r*) in seconds, showing the number of times key pecks were reinforced on Choice A given Sample A (CmA) and Sample B (CnA), on Choice B given Sample B (CmB) and Sample A (CnB), and on Choices A and B regardless of sample (RA and RB, respectively).

Bird	D/*r*	CmA	CnA	CmB	CnB	RA	RB
R1	.8/2	535	114	121	58	535	121
	.8/5	337	25	84	47	337	84
	.2/2	663	82	149	106	663	149
	.2/5	670	89	63	178	670	63
R2	.8/2	623	26	144	48	623	144
	.8/5	415	41	71	126	415	71
	.2/2	691	51	129	129	691	129
	.2/5	734	31	41	194	734	43
R3	.8/2	628	47	152	59	628	152
	.8/5	506	10	92	72	506	92
	.2/2	626	74	99	201	626	99
	.2/5	654	53	41	251	654	41
R4	.8/2	620	26	140	16	620	140
	.8/5	605	32	81	150	605	81
	.2/2	710	22	172	57	710	172
	.2/5	683	7	20	290	683	20