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SEPARATING THE EFFECTS OF TRIAL-SPECIFIC AND AVERAGE SAMPLE-STIMULUS DURATION IN DELAYED MATCHING TO SAMPLE IN PIGEONS

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Pigeons were studied in two experiments employing delayed matching-to-sample (DMTS) tasks in which the reduction in delay to reinforcement signaled by the onset of the sample stimulus was manipulated by varying sample-stimulus duration. In Experiment 1, the duration of the sample stimulus was either 5 s or 10 s for one sample stimulus and 10 s or 20 s for the other. Subjects matched more frequently when the sample duration was 10 s following the sample associated with the shorter average duration. This finding is analogous to the memory distribution effect found by Honig (1987) in a successive DMTS task that varied retention interval. In Experiment 2, sample duration was either 5 s or 15 s. In Phases 1 and 3 each sample duration was correlated with a particular sample color, and in Phase 2 sample duration and color were uncorrelated. When sample duration was 5 s, subjects matched more frequently when sample duration and color were correlated than when they were uncorrelated. Overall, subjects matched more frequently when sample duration and color were correlated. The data from both experiments support Wixted's (1989) model, which states that one determinant of choice in a DMTS task is the delay-reduction value of the sample stimulus.

Key words: delayed matching to sample, delay reduction, sample duration, choice, key peck, pigeon

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Choice is commonly studied using a delayed matching-to-sample (DMTS) task. In a typical DMTS task, one stimulus (the sample) is briefly presented and, after an interval of time commonly referred to as the retention interval, is followed by two choice stimuli, one of which is identical to the sample. Selecting this stimulus is reinforced. After an intertrial interval (ITI), the process is repeated. The most basic finding from the DMTS literature is that increasing the duration of the retention interval decreases the frequency with which subjects select the matching choice stimulus (Blough, 1959; Grant, 1975; Roberts, 1972). Other studies have shown that lengthening the average ITI increases the frequency with which subjects match (Roberts, 1980), and that matching accuracy varies directly with the ratio of the ITI to the retention interval (Roberts & Kraemer, 1982; White, 1985).

Wixted (1989) proposed a general model of choice in DMTS tasks which states that performance is determined by both trial-specific and between-trial factors. For example, DMTS performance is determined by the size of the retention interval on a given trial (a trial-specific factor) as well as the average size of the retention interval across trials (a between-trial factor). Although Wixted's model included provisions for only one trial-specific factor (namely, retention interval), several other trial-specific factors are well known. For example, Roberts (1972) showed that matching accuracy was greater on DMTS trials in which the sample duration was longer. In addition to trial-specific factors such as these, Wixted argued that DMTS performance is also determined by the conditioned reinforcement value of the sample stimulus as represented by the average reduction in delay to reinforcement associated with the onset of the sample stimulus, also referred to as the sample's delay-reduction value. The greater the delay-reduction value of the sample stimulus, the greater the matching accuracy. The delay-reduction value of the sample stimulus is the difference between the average time to reinforcement signaled by the onset of the sample stimulus, which is calculated by adding the average retention interval and the average sample duration, and the average interreinforcement interval, which is the time between successive DMTS choice phases.

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Note that this method of calculating the delay-reduction value of the sample stimulus assumes perfect matching, which is rarely the case. However, this method is very simple and has been demonstrated to adequately account for data (Hartl & Fantino, 1996; Wixted, 1989). The delay-reduction value of the sample stimuli, and hence matching accuracy, varies directly with the average ITI and inversely with the average retention interval and sample duration.

Wixted's (1989) model is consistent with results of studies that have examined the memory distribution effect. The data from these studies show that the effect of retention interval on matching accuracy varies with the distribution of retention intervals included in a memory task. Honig (1987) studied the behavior of pigeons in a successive DMTS task in which one sample (S1) was followed by a 1-s or a 5-s retention interval and the other (S2) was followed by a 5-s or a 10-s retention interval. Matching accuracy was higher after a 5-s retention interval when the sample was S1 than when it was S2. Given equal sample durations and ITIs, S1 had the greater delay-reduction value because the average retention interval following S1 was 3 s, whereas the average retention interval following S2 was 7.5 s. Therefore Wixted's model predicts greater accuracy following S1 than following S2 for trials in which the retention intervals are the same. The results of this study provide some of the best evidence that performance is determined by both trial-specific temporal values (e.g., the retention interval on a given trial) and average temporal values (e.g., the average retention interval across trials).

Wasserman, Grosch, and Nevin (1982) and MacDonald and Grant (1987) conducted experiments using both successive and two-alternative DMTS tasks in which the sample stimuli were paired with additional stimuli that signaled either long retention intervals or short retention intervals. In both experiments, the frequency of matching increased when the sample was compounded with the stimulus signaling the shorter retention interval and decreased when the sample was compounded with the stimulus signaling the longer retention interval, relative to control conditions in which additional compounded stimuli were uncorrelated with the duration of the retention interval. Furthermore, the duration of the retention intervals was sometimes miscued such that a long retention interval followed a sample compound stimulus that signaled a short retention interval and a short retention interval followed a compound stimulus that signaled a long retention interval. The frequency of matching increased in the former case but decreased in the latter, relative to the uncorrelated condition. The delay-reduction value of the sample stimulus is highest when it is compounded with a stimulus signaling the short retention interval and lowest when the sample stimulus is compounded with a stimulus signaling the long retention interval, whereas when the sample is compounded with a stimulus that is uncorrelated with retention interval, the delay-reduction value of the sample lies somewhere in the middle. All other things being equal, Wixted's (1989) model predicts that subjects will perform best in conditions in which the sample stimulus is compounded with the stimulus signaling a short retention interval, worst when the sample stimulus is compounded with the stimulus signaling a long retention interval, and somewhere in between when the sample stimulus is compounded with a stimulus that is uncorrelated with retention interval, as was the case in these two studies.

Studies of the memory distribution effect clearly show that matching accuracy varies inversely with both the retention interval on a particular trial and the average retention interval. Wixted's (1989) model implies that this joint control occurs because matching accuracy is determined by both the retention interval on each individual trial and the delay-reduction value of the sample, which is a function of the average retention interval. The delay-reduction value of the sample stimulus can be manipulated by changing the duration of the average retention interval and also by changing the average duration of the sample stimulus. The delay-reduction value of the sample stimulus varies inversely with its average duration. Although it is well known that increasing the sample duration facilitates matching (Roberts, 1972), Wixted's model predicts that increasing the average sample duration should also inhibit matching. Experiment 1 varied sample duration in a manner similar to the way Honig (1987) manipulated retention interval. The experiment arranged conditions in which the trial-specific sample durations remained identical while average sample durations differed. Experiment 2 varied the duration of the sample stimuli such that one sample stimulus was correlated with a longer duration, and hence a smaller delay-reduction value, and the other sample stimulus was correlated with a shorter sample duration, and hence a larger delay-reduction value. If differential delay-reduction values of the sample produce the memory distribution effect, the frequency with which subjects match should be greater in situations in which the delay-reduction value of the sample is higher.

EXPERIMENT 1

Subjects were presented with a two-alternative DMTS task in which the sample durations varied. One sample had a duration of either 5 s or 10 s, and the other sample had a duration of 10 s or 20 s. The retention interval was 3.5 s and the ITI was 20 s. Therefore the average interreinforcement interval (assuming perfect matching) was 34.75 s. The average time to reinforcement (assuming perfect matching) signaled by the onset of the sample with the duration of 5 s or 10 s was 11 s, and the average time to reinforcement signaled by the onset of the sample with the duration of 10 s or 20 s was 18.5 s. The delay-reduction value of the sample with the duration of 5 s or 10 s was 34.75 s − 11.00 s or 23.75 s, and the delay-reduction value of the sample with a duration of 10 s or 20 s was 34.75 s − 18.25 s or 16.25 s. Wixted's (1989) model predicts that given equal trial-specific values (i.e., on trials in which the sample duration is 10 s), subjects should exhibit greater matching accuracy following the sample associated with the greater delay-reduction value. Therefore, when the sample duration is 10 s on the current trial, matching accuracy should be higher if that sample is the one that had been either 5 s or 10 s on previous trials than if it is the one that had been 10 s or 20 s on previous trials.

METHOD

Subjects and Apparatus

Eight Indian Mondian pigeons with prior experience in DMTS tasks served as subjects. Subjects were maintained at approximately 80% of their free feeding weights, which ranged from 500 to 720 g, and were given free access to water and grit.

Six operant chambers served as apparatus. Four chambers were rectangular cubes (35 cm by 36 cm by 32 cm). The front wall had an opening (5 cm square), located 9.5 cm above the wire mesh floor and equally distant from the side walls, that provided access to a solenoid-operated hopper that contained grain (milo). The hopper was illuminated by a 1-W miniature lamp whenever the hopper was operated. Three response keys (2.5 cm in diameter) were located 23 cm above the floor; the center key was directly above the hopper opening, and the remaining two keys were located 7.5 cm to either side of the center key. Each key required approximately 0.15 N of force to operate. Located behind each key was a standard IEE projector that provided transillumination of the keys with two light stimuli: green and blue. The front and rear walls of the chambers consisted of metal plates, and the side walls consisted of metal plates lined with black plastic. The chambers were enclosed in sealed plywood boxes. The remaining two chambers were cylinders (36 cm high by 32 cm diameter) constructed of black PVC pipe. An opening (5 cm square) located 8 cm above the wire mesh floor provided access to a solenoid-operated grain hopper. Three response keys measuring 2 cm in diameter were located 24 cm above the wire mesh floor; the center key was directly above the hopper, and the other two keys were located 7 cm to either side of the center key. Each key required approximately 0.15 N of force to operate. The hopper and the response keys were illuminated in an identical manner as those in the square chambers except that the response keys were transilluminated with red and yellow. Ventilation fans provided background noise. Experimental events in both chambers were controlled by computers located in an adjacent room.

Procedure

Experimental training. All pigeons had extensive experience with DMTS tasks and were immediately exposed to the experimental training. Experiment 1 consisted of two phases. In Phase 1, trials began with a sample stimulus that consisted of the illumination of the center keylight. The color of the keylight

Table 1

Number of sessions that each subject remained in each phase of Experiment 1.

Bird	Experiment 1	
	Phase 1	Phase 2
S1	15	13
S2	12	13
S3	14	16
S4	17	14
R1	8	11
R2	10	10
R3	12	9
R4	13	11

in the round chambers was yellow on half the trials and red on the remaining half. After either 5, 10, or 20 s, one peck to the center key caused the key to go dark; that is, termination of the keylight was on a fixed-interval (FI) 5-s, FI 10-s, or FI 20-s schedule. If the keylight was red, the FI requirement was 5 s for half of the trials and 10 s for the remaining half; that is, a mixed-interval (MI) 7.5-s schedule. If the keylight was yellow, the FI requirement was 10 s for half of the trials and 20 s for the remaining half (MI 15 s). After termination of the sample, the retention interval, during which all lights in the chamber were turned off, was initiated. The retention interval lasted 3.5 s. Following the retention interval, the side keys were illuminated. One key was illuminated yellow and the other red, with the red keylight being on the right key for half of the trials. One peck to the key—a fixed-ratio (FR) 1 schedule—that was the same color as the immediately preceding sample resulted in delivery of grain for 3 s, after which the ITI was initiated. If the subject pecked the key that was not the same color as the sample stimulus, the ITI was initiated immediately. The ITI lasted 20 s, during which time the chamber was darkened. After the ITI, the next trial began. Trials in the square chambers were identical to those in the round chambers except that the keylights were illuminated either blue or green.

Sessions consisted of 96 trials and were conducted daily until the proportion of trials on which the selected stimulus matched the sample did not vary by more than 6% for five consecutive sessions. After this stability criterion had been met, Phase 1 ended and Phase 2 began. Phase 2 was identical to Phase 1 except that the sample with the FI value of either 5 s or 10 s now had an FI value of either 10 s or 20 s and vice versa. The number of sessions that each subject remained in each experimental phase is shown in Table 1.

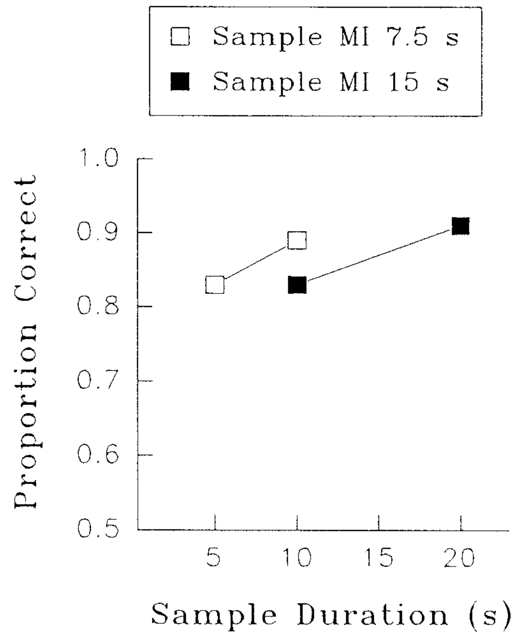

Fig. 1. Mean proportion of trials in which subjects correctly matched given the sample with a duration of either 5 s or 10 s (Sample MI 7.5 s) and given the sample with a duration of either 10 s or 20 s (Sample MI 15 s).

Results and Discussion

Figure 1 shows the proportion of trials in which subjects matched given the sample with the duration of 5 or 10 s (MI 7.5 s) and the sample with either a 10-s or 20-s duration (MI 15 s), averaged across the last five trials of Phases 1 and 2 for all 8 birds. Matching accuracy increased directly with sample duration, illustrating the trial-specific effects of sample duration. When sample duration was 10 s, however, subjects matched more frequently when the MI 7.5-s sample was presented than when the MI 15-s sample was presented. Figure 2 shows the performance of individual subjects when the sample duration was 10 s (collapsed across the last five trials of Phases 1 and 2). Across both phases of the experiment, subjects matched more frequently given the MI 7.5-s sample than the MI 15-s sample. This was the case for every subject. A paired *t* test showed that the more frequent

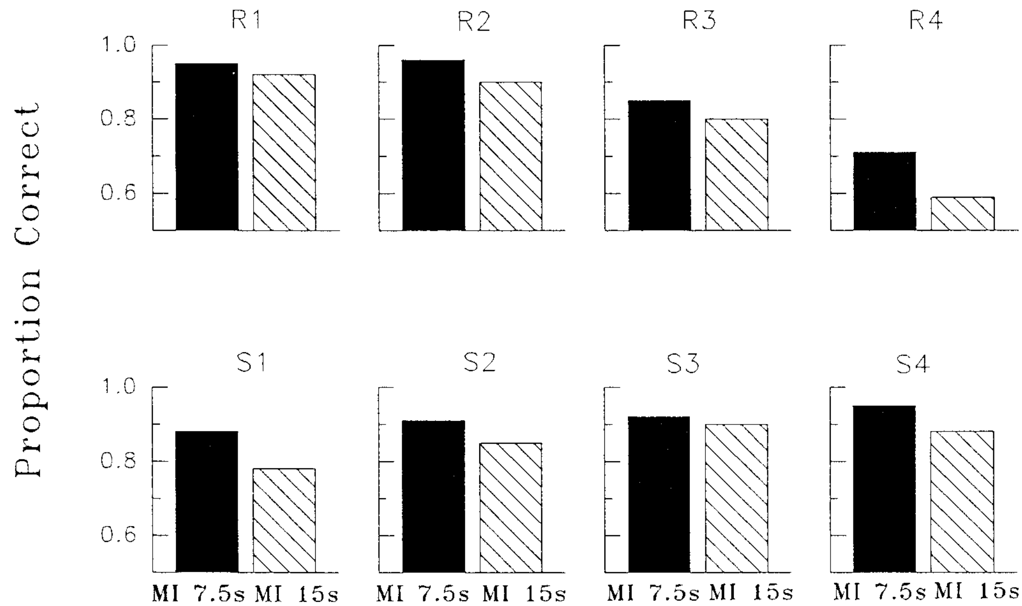

Fig. 2. Mean proportion of matches given a 10-s retention interval. Each panel shows data from a different pigeon. For each panel the dark bar denotes the proportion of trials on which the subject matched given the sample with the accompanying 5-s retention interval (Sample MI 7.5 s), and the hatched bar denotes the proportion of trials on which the subject matched given the sample with the accompanying 20-s retention interval (Sample MI 15 s).

matching given the MI 7.5-s schedule was significant, $t(7) = 5.69$, $p < .05$.

The degree to which subjects matched following an FI 10-s sample depended upon whether it was an instance of the MI 7.5-s sample or the MI 15-s sample. When it was an instance of the MI 7.5-s sample, matching accuracy was greater than when it was an instance of the MI 15-s sample. This difference is consistent with Wixted's (1989) model, which implies that the frequency of matching should be higher, other things being equal, for samples correlated with greater delay-reduction values. As stated earlier, the MI 7.5-s sample had the greater delay-reduction value. Responding to the sample occurred at a high rate (2.09 pecks per second given the MI 7.5-s sample and 1.91 pecks per second given the MI 15-s sample), and so the duration of the sample stimulus was very close to the scheduled fixed-interval value. The difference between the rates of responding to the sample was not significant.

Experiment 1 demonstrated that choice in a DMTS task is sensitive to both the trial-specific and the average sample duration, a result that is analogous to the memory distribution effect found when trial-specific and average retention intervals were varied (Honig, 1987). Honig suggested that the memory distribution effect occurred because reinforcement was, on average, more immediate for remembering the sample correlated with a shorter retention interval. This hypothesis has difficulty explaining the current data, however, because retention interval duration was identical in the two conditions. If, however, one assumes that the delay between remembering and reinforcement is calculated from the sample stimulus onset rather than offset, then the average delay to reinforcement is shorter given the MI 7.5-s sample as well. This variation of Honig's account of the memory distribution effect predicts the results of Experiment 1. Wixted's (1989) model differs from Honig's in that Wixted's model states that the average interreinforcement interval, in addition to the average delay to reinforcement signaled by the onset of the sample stimulus, determines the accuracy with which subjects match. Wixted's model, therefore, accounts for data showing that varying the average ITI affects matching accuracy (Roberts, 1980), whereas Honig's account does not.

EXPERIMENT 2

The results of Experiment 1 demonstrated that the memory distribution effect can be produced with manipulations in the distribution of sample durations as well as retention intervals. Moreover, the direction of this effect is consistent with Wixted's (1989) model. Experiment 2 was conducted to examine the effects of signaling the sample duration on matching accuracy. Subjects were presented with a two-alternative DMTS task in which the sample duration was either 5 s or 15 s. In one condition (uncorrelated), the durations of the sample stimuli were presented in random sequence. Therefore, the average sample duration was 10 s for both samples and, because all other temporal intervals were identical, the delay-reduction values of both samples were equal as well. In another condition (correlated), one sample was always presented for 5 s and the other for 15 s. The delay-reduction value of the sample that was 5 s in duration was 28.5 s, and that of the sample that was 15 s in duration was 18.5 in the correlated condition. The delay-reduction values of both sample stimuli were 23.5 s in the uncorrelated condition. The current experiment is conceptually similar to that of Wasserman et al. (1982), which found that subjects selected the matching choice stimulus more frequently when the sample was presented as part of a compound that was correlated with a shorter retention interval. The current study examines whether or not a similar effect occurs when the duration of the sample stimulus is signaled as well. Prior research (Roberts, 1972) has shown that matching accuracy is greater following a longer sample stimulus. Wixted's model predicts that the advantage, in terms of matching accuracy, of presenting the sample that is 15 s in duration should be reduced in the correlated condition because the sample that is 5 s in duration now has the higher delay-reduction value.

METHOD

Subjects and Apparatus

One White Carneau and 3 Indian Mondian pigeons ranging in weight from 450 to 700 g served as subjects. They were maintained in a manner identical to that of the subjects in Experiment 1.

Three experimental chambers, each a rectangular cube (35 cm by 32 cm by 34 cm), were used. Three of the four walls, as well as the ceiling, were constructed of transparent Plexiglas. The fourth wall was constructed of aluminum, and the floor consisted of parallel aluminum bars spaced approximately 0.75 cm apart. Three response windows, each a rectangle 6.5 cm in height and 4.4 cm in width, were located on the aluminum wall. These windows were made of transparent Plexiglas and were situated directly in front of a 14-in. (approximately 35 cm) VGA color monitor. The chamber and the monitor were enclosed in a sealed plywood box. Ventilation fans provided background noise. The chambers were placed in a room in which the lights were turned off, although some light entered from underneath the door.

Two stimuli were presented to the subjects throughout the experiment: two stacked red circles (2.5 cm diameter) (S1) and five green squares (1.25 cm) that were arranged like dots on a die (S2). Both of these stimuli were presented on a white background (5 cm square). These stimuli were displayed on the VGA monitor directly behind the response windows. Pecks were recorded via a microswitch located at the base of each response window. A pellet tray located below the center window and 4 cm above the chamber floor collected Noyes food pellets (Formula C1) dispensed by a 45-mg Gerbrands pellet dispenser. When food was being delivered, the tray was illuminated by a 1-W miniature lightbulb. Presentation of experimental events as well as recording of responses was controlled by an IBM®-compatible computer.

Procedure

Preliminary training. All pigeons had previous experience in DMTS tasks; therefore, subjects were immediately exposed to DMTS training. The pigeons were trained on a DMTS task without a retention interval until they matched on 80% of the trials. Once they had acquired the DMTS performance, the retention interval was increased by 0.5 s on half of the trials and was unchanged on the remaining half. Pigeons were continued on this condition until they matched on 80% of the trials. This procedure continued until the retention interval was 1 s for half of the trials and 6 s for the remaining half.

Trials commenced with a sample consisting of either S1 or S2 in the center window. The first response emitted after 10 s (FI 10 s) terminated the stimulus and initiated the retention interval. The retention interval consisted of a period of time in which all lights were turned off. The retention interval was 0 s at the start of pretraining. Following the retention interval, S1 and S2 appeared in the side windows, with S1 appearing on the right on half of the trials. Pecking the choice stimulus that was identical to the sample produced illumination of the food tray for 3 s and delivery of two food pellets. Pecking the other choice terminated the trial. The next trial began after a 20-s ITI in which no stimuli were presented. If the pigeon made an incorrect choice on trial n, a correction procedure was initiated in which the same configuration of stimuli was presented on trial $n + 1$ until the subject selected the matching choice stimulus. There were 150 trials per session, 75 of which were programmed to contain S1 as the sample. However, if trials were repeated, the number of trials on which S1 was the sample could then deviate from 75. Trials were presented in a pseudorandom order, with the constraint that no sample could occur more than eight times consecutively with the matching choice on the same side. The retention intervals at the end of pretraining were 1 s and 6 s, presented equally often in random order.

Experimental training. Subjects were placed in a DMTS task using two stimuli, S1 and S2. The retention interval (1 s or 6 s) and the ITI (20 s) were unchanged from the last phase of pretraining. The sample stimulus remained on for either 5 s or 15 s, after which one peck to the sample initiated the retention interval (i.e., the sample stimuli were associated with FI 5-s or FI 15-s schedules). The sample-stimulus schedule depended upon the phase of the experiment. Experiment 2 was conducted in three phases. In Phase 1 (correlated), the sample-stimulus schedule was an FI 5-s schedule given one sample stimulus (S1 for half of the subjects) and an FI 15-s schedule given the remaining sample stimulus. In Phase 2 (uncorrelated), the sample schedule on each trial was randomly determined, with equal probability to be either an FI 5-s or an FI 15-s schedule. In Phase 3 (correlated), the sample-stimulus schedule was arranged in the same manner as in Phase 1. Subjects remained in each phase until the proportion of trials on which matching occurred showed no upward or downward trend (i.e., a slope between 0.05 and −0.05) for 10 consecutive days, as measured by least squares regression. After behavior stabilized, subjects were studied in the subsequent phase of the experiment. The number of sessions that each subject remained in each phase is shown in Table 2.

Table 2

Number of sessions that each subject remained in each phase of Experiment 2.

	Experiment 2		
Bird	Correlated 1	Uncorrelated	Correlated 2
136	50	15	22
33	21	20	15
126	38	10	22
136	31	18	12

Results and Discussion

Figure 3 shows the proportion of trials in which subjects matched in the last 10 sessions of the correlated (Phases 1 and 3) and uncorrelated (Phase 2) conditions. Subjects matched more frequently when the retention interval was 1 s than when it was 6 s, and subjects also matched more frequently given a 15-s sample duration in both the correlated and uncorrelated conditions. Overall matching accuracy was greater in the correlated condition than in the uncorrelated condition. The difference in matching accuracy given the 5-s sample duration versus the 15-s duration was less in the correlated condition than in the uncorrelated condition.

Individual-subject data from the last 10 sessions of the correlated and uncorrelated conditions are shown in Figure 4. In the uncorrelated condition, all 4 subjects matched more frequently when the sample stimulus duration was 15 s, as expected. In the correlated condition, 3 subjects matched more frequently given the sample that was 15 s in duration, and 1 subject matched more frequently given the sample that was 5 s in duration. The degree to which subjects more frequently selected the matching choice stimulus given a 15-s sample stimulus is shown in Figure 5. The figure shows the difference be-

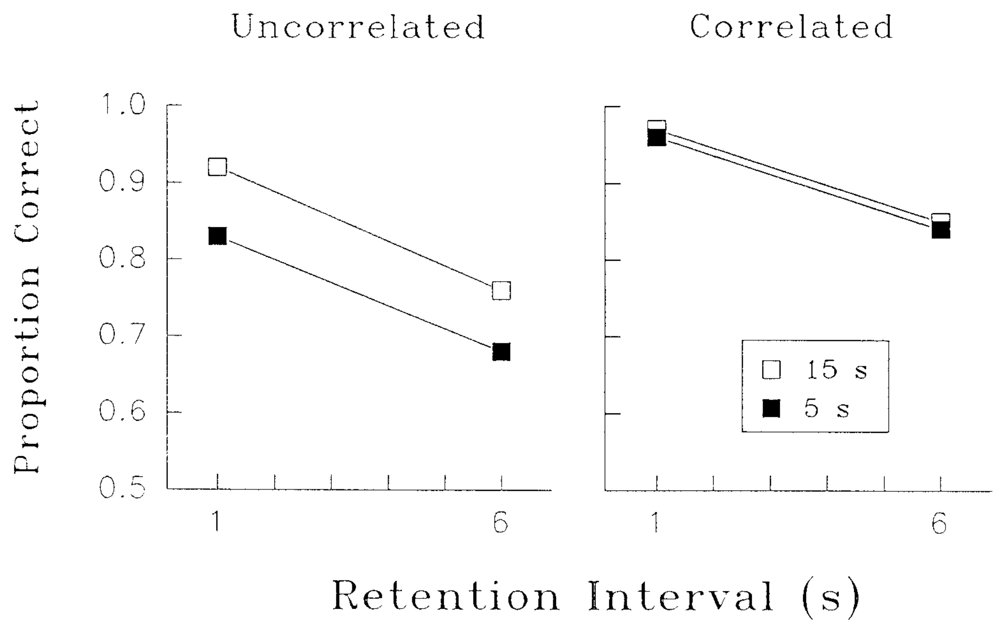

Fig. 3. Proportion of trials in which subjects correctly matched given a sample with a 15-s (open points) or a 5-s (filled points) duration when retention interval was 1 s or 6 s. The data shown are averaged across all subjects and are shown for both the correlated condition (Phases 1 and 3) and the uncorrelated condition (Phase 2).

tween the proportion of trials in which the subjects matched given a 15-s sample duration and a 5-s sample duration. For all 4 subjects, this difference declined when the sample stimulus was correlated with a specific duration. For example, in the uncorrelated condition the proportion of trials in which Subject 33 matched was greater when the sample duration was 15 s than when it was 5 s by .10. In the correlated condition, this difference declined to .04. This pattern also occurred for the remaining 3 subjects.

A paired *t* test showed this decline in differences to be significant, $t(3) = 2.68$, $p <$ .05 (one tailed). The values used in the *t* test were transformed from the proportion of trials on which subjects matched to logit *p* (Nevin & Grosch, 1990), the formula for which is as follows: Logit $p = \log$ [proportion matching/(1 − proportion matching)]. This transformation was done because the proportion of trials on which subjects matched has a ceiling of 1.0, so the variability of values is constrained as matching accuracy increases. As the overall proportion of trials on which subjects match approaches 1.0, the difference between the proportion of trials on which subjects match given the 5-s sample duration versus the 15-s sample duration may become smaller due to a ceiling effect. It is therefore difficult to determine if the decrease in the difference in matching accuracy between trials with the 5-s sample duration and with the 15-s sample duration observed in the correlated condition was due to the experimental manipulation or was an artifact of the measure used. Using logit *p* represents one way to address this potential problem, because it is an unbounded measure of matching accuracy.

The current data support Wixted's (1989) model in that subjects matched more frequently given longer sample durations, illustrating the trial-specific effects of sample durations. But the advantage of longer sample durations was reduced when the shorter sample duration was also associated with a higher delay-reduction value.

One other noteworthy finding concerns the unexpectedly strong effect of the experimental manipulation on the overall level of performance. All 4 subjects matched more frequently in the correlated condition. This effect may be due to the fact that in the correlated condition both sample color and duration were discriminative cues for selecting

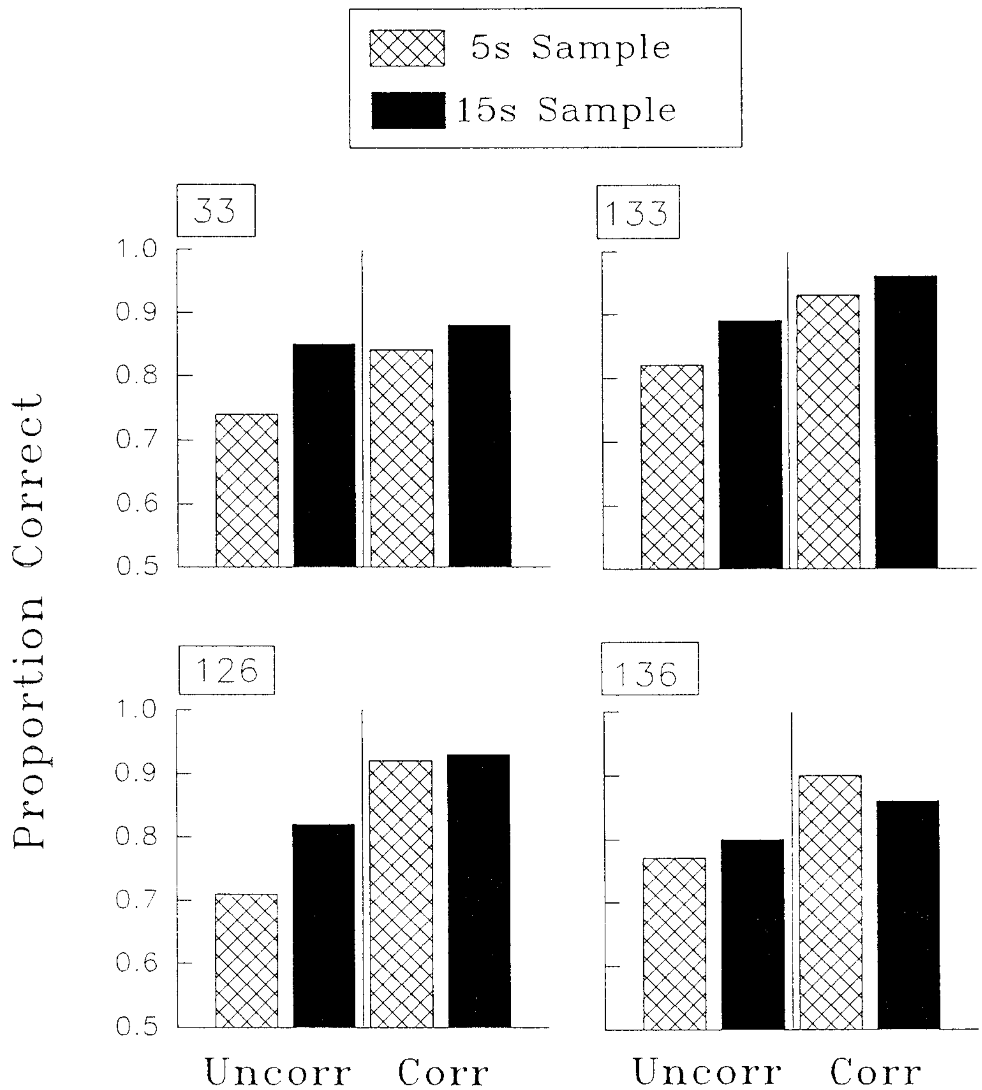

Fig. 4. Proportion of trials in which each individual subject correctly matched given the sample with the 5-s or the 15-s sample duration, collapsed across both retention intervals. The first pair of bars denotes matching when the sample duration was uncorrelated with its color, and the second pair of bars denotes matching when the sample duration was correlated with its color. Note that the second pair of bars indicates the average values of the first and third phases of Experiment 2.

the matching choice stimulus, whereas in the uncorrelated condition only sample color was a discriminative cue. Another possibility is that stimuli associated with a greater delay-reduction value may evoke responses that have stimulus properties that may serve as discriminative cues. This interpretation is similar to the expectancy account of the differential outcomes effect (Peterson, 1984; Trapold, 1970). The differential outcomes effect refers to the higher matching accuracies that are obtained when the reinforcement for matching differs depending upon which sample stimulus was presented. The expectancy account of the differential outcomes effect states that expectancies (i.e., reinforcer-specific responses, covert and overt) are evoked by the sample stimulus by virtue of their association with the reinforcement outcome. When the outcomes for matching are corre-

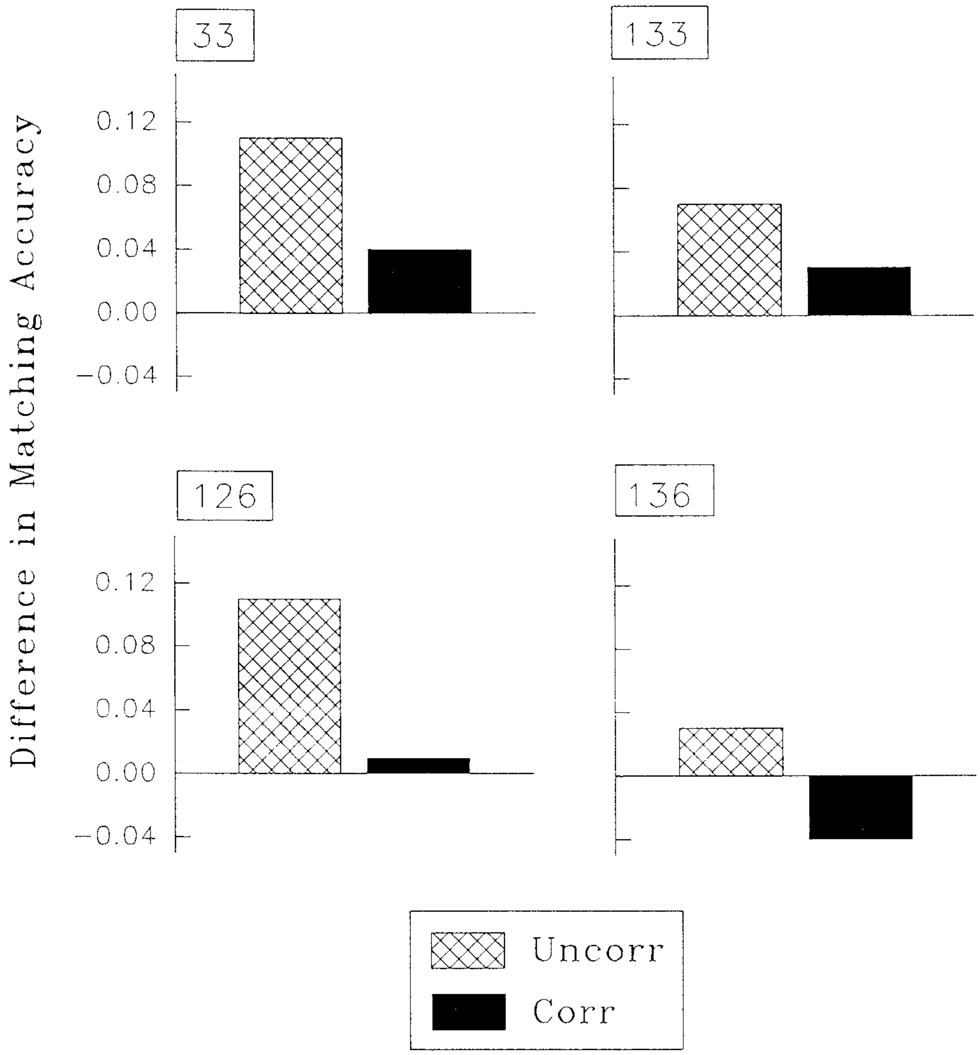

Fig. 5. Difference between the proportion of trials in which each individual subject matched given the sample that was 15 s in duration and the sample that was 5 s in duration in the correlated (solid bars) and uncorrelated condition (crossed bars). Positive values denote greater matching when the sample stimulus was 15 s in duration. Note that the solid bars indicate average values of the first and third phases of Experiment 2.

lated with a particular sample stimulus, each sample stimulus evokes a distinctive expectancy. These expectancies have stimulus properties that serve as additional discriminative cues during the choice phase of a DMTS tasks and, thus, increase matching accuracy. Because each sample stimulus in the correlated condition of Experiment 2 was correlated with a specific reduction in delay to reinforcement, different expectancies may have been evoked by the presentation of the different sample stimuli, thus increasing the overall matching accuracy in that condition.

Experiment 2 demonstrated that subjects select the matching choice stimulus, given the short-duration sample, more frequently when the short duration has been correlated with the sample stimulus than when it is uncorrelated. This finding expands upon Wasserman et al.'s (1982) report of an analogous finding with retention intervals. The results of both studies support Wixted's (1989) model, which states that subjects will match more frequently when the sample signals a large reduction in delay to reinforcement.

GENERAL DISCUSSION

Experiments 1 and 2 demonstrated that matching accuracy is determined by both the trial-specific and average sample duration. Increasing the sample duration on any given trial increases matching accuracy, whereas increasing the average sample duration, and hence decreasing the delay-reduction value of the sample, decreases matching accuracy. The data from the current study are consistent with Wixted's (1989) model, which states that sample stimulus control in a DMTS task is partly determined by the sample's delay-reduction value. The model's prediction that matching accuracy will vary as a function of the delay-reduction value associated with the sample stimulus is supported by studies that manipulated delay reduction by modifying the average duration of the ITI (Roberts, 1980; Roberts & Kraemer, 1982; White, 1985), the average duration of the retention interval (Honig, 1987; Wasserman et al., 1982), and, now, the average sample duration. These results also seem to be consistent with Dinsmoor's (e.g., 1995) interpretation of the maintenance of observing by condtional reinforcement. In addition, Experiment 2 also showed that correlating a particular sample stimulus with a greater delay-reduction value increased the frequency with which subjects matched that particular sample relative to performance with the same-duration sample when stimulus and duration were uncorrelated. This effect is consistent with Wixted's model and has not been previously demonstrated. In prior studies, an individual sample stimulus was not correlated with a given delay-reduction value.

The current study is also relevant to studies of the differential outcomes effect (Peterson, 1984; Trapold, 1970). In Experiment 2 performance improved when the sample stimulus was correlated with a particular duration. As noted earlier, this may have been due to adding sample duration as an additional discriminative cue or to differential expectancies elicited by each sample stimulus by virtue of their different conditioned reinforcement values. Several studies have examined whether the expectancies that are thought to increase matching accuracy in DMTS tasks when differential outcomes are employed differ as a function of the type of outcome or the value of the outcome (Edwards, Jagielo, Zentall, & Hogan, 1982; Fedorchack & Bolles, 1986). These studies compared DMTS tasks in which common outcomes were employed to DMTS tasks in which two different outcomes of putatively identical value (e.g., wheat and corn as determined by prior food preference studies) were employed. Matching accuracy increased when differential reinforcement outcomes were employed even when the differential outcomes were of equal value, suggesting that expectancies are a function of the type rather than the value of the outcome. However, these studies did not settle the issue, because the value of the outcome was assessed using between-subject rather than within-subject measures. It is entirely possible that every subject preferred one outcome to the other but that averaged over all subjects, these preferences disappeared. Although the current study cannot resolve the issue due to the possibility that sample duration was used as a discriminative cue, it does suggest an alternate approach to studying whether differential sample values produce the differential outcomes effect. Instead of using different outcomes of the same value, the current study used identical outcomes but manipulated the value of the sample by altering its temporal relationship to the outcome.

REFERENCES

Blough, D. S. (1959). Delayed matching in the pigeon. *Journal of the Experimental Analysis of Behavior, 2,* 151–160.

Dinsmoor, J. A. (1995). Stimulus control: Part I. *The Behavior Analyst, 18,* 51–68.

Edwards, C. A., Jagielo, J. A., Zentall, T. R., & Hogan, D. E. (1982). Acquired equivalence and distinctiveness in matching to sample by pigeons: Mediation by reinforcer-specific expectancies. *Journal of Experimental Psychology: Animal Behavior Processes, 8,* 244–259.

Fedorchack, P. M., & Bolles, R. C. (1986). Differential outcome effect using a biologically neutral outcome difference. *Journal of Experimental Psychology: Animal Behavior Processes, 12,* 125–130.

Grant, D. S. (1975). Proactive interference in pigeon short-term memory. *Journal of Experimental Psychology: Animal Behavior Processes, 1,* 207–220.

Hartl, J. A., & Fantino, E. (1996). Choice as a function of reinforcement ratios in delayed matching to sample. *Journal of the Experimental Analysis of Behavior, 66,* 11–27.

Honig, W. K. (1987). Memory interval distribution effects in pigeons. *Animal Learning & Behavior, 15,* 6–14.

MacDonald, S. E., & Grant, D. S. (1987). Effects of signaling retention interval length on delayed matching-to-sample in pigeons. *Journal of Experimental Psychology: Animal Behavior Processes, 13,* 116–125.

Nevin, J. A., & Grosch, J. (1990). Effects of signaled reinforcer magnitude on delayed matching-to-sample performance. *Journal of Experimental Psychology: Animal Behavior Processes, 16,* 298–305.

Peterson, G. B. (1984). How expectancies guide behavior. In H. L. Roitblat, T. G. Bever, & H. S. Terrace (Eds.), *Animal cognition* (pp. 135–148). Hillsdale, NJ: Erlbaum.

Roberts, W. A. (1972). Short-term memory in the pigeon: Effects of repetition and spacing. *Journal of Experimental Psychology, 94,* 74–83.

Roberts, W. A. (1980). Distribution of trials and intertrial retention in delayed matching to sample with pigeons. *Journal of Experimental Psychology, 6,* 217–237.

Roberts, W. A., & Kraemer, P. J. (1982). Some observations of the effects of inter-trial interval and delay on delayed matching to sample in pigeons. *Journal of Experimental Psychology: Animal Behavior Processes, 8,* 342–355.

Trapold, M. A. (1970). Are expectancies based upon different reinforcing events discriminably different? *Learning and Motivation, 1,* 129–140.

Wasserman, E. A., Grosch, J., & Nevin, J. A. (1982). Effects of signaled retention intervals on pigeon short-term memory. *Animal Learning & Behavior, 10,* 330–338.

White, K. G. (1985). Characteristics of forgetting functions in delayed matching to sample. *Journal of the Experimental Analysis of Behavior, 44,* 15–34.

Wixted, J. T. (1989). Nonhuman short-term memory: A quantitative reanalysis of selected findings. *Journal of the Experimental Analysis of Behavior, 52,* 409–426.

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