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GENERALIZATION OF DELAYED MATCHING TO SAMPLE FOLLOWING TRAINING AT DIFFERENT DELAYS

REBECCA J. SARGISSON AND K. GEOFFREY WHITE

UNIVERSITY OF OTAGO, NEW ZEALAND

Four groups of pigeons were trained to perform a delayed matching-to-sample task with a single delay of 0, 2, 4, or 6 s from the outset of training. The longer the training delay, the more sessions were required for all birds to reach the same level of response accuracy. Following initial training, five test sessions that included nonreinforced trials with delay intervals of 0, 2, 4, 6, 8, and 10 s were interspersed between training sessions. Unlike typical forgetting functions in which accuracy decreases monotonically with increasing delay, the forgetting functions from test sessions resembled generalization gradients with the peak of the functions occurring at the training delay. Following additional training for all birds with a 0-s delay, forgetting functions decreased monotonically with increasing delay. The results suggested that remembering can be trained at a specific delay interval, and generalizes to similar delay intervals. Generalization along the temporal dimension of delay may contribute to typical forgetting functions in which accuracy decreases from 0-s delay.

Key words: remembering, generalization, exponential forgetting, delayed matching to sample, pigeon

The delayed matching-to-sample (DMTS) procedure introduced by D. S. Blough (1959) is commonly used to study remembering over relatively short time intervals in nonhuman animals. A delay temporally separates the presentation of a sample stimulus and the opportunity to respond to two or more comparison stimuli. A response to the comparison stimulus that matches the sample is reinforced with access to food. The most consistent finding in DMTS experiments is a decrement in accuracy as the delay increases, that is, the *forgetting function*[1] as illustrated in Figure 1a (White, 1985; White & Wixted, 1999; Wixted, 1989).

Theoretical interpretations of the forgetting function typically assume processes that change as a monotonic function of time (White & Cooney, 1996). That is, forgetting is seen as a temporally related process. Accordingly, the highest accuracy is expected to be recorded at zero delay.

The standard method for training animals to perform DMTS tasks includes, as a first step, simultaneous or zero-delay presentations of sample and comparison stimuli (Cumming & Berryman, 1965). Longer delays are introduced when accurate matching has first been established with zero delay (D. S. Blough, 1959; Grant & Roberts, 1973; Jones & White, 1992, 1994; MacDonald & Grant, 1987; Roberts, 1972; Spetch & Rusak, 1989; Zentall & Sherburne, 1994). For example, in one of the first important studies of DMTS performance, Roberts (1972) trained pigeons with a 0-s delay before testing with a range of delays greater than 0 s. Roberts and Kraemer (1982) claimed that it is difficult to train animals in DMTS tasks if delays longer than 0 s are used at the beginning of training. Their conclusion is consistent with the assumption that forgetting is determined by temporally related processes that

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Reprints may be obtained from either author at the Department of Psychology, University of Otago, Dunedin, New Zealand (E-mail: rebeccas@otago.ac.nz or kgwhite@otago.ac.nz).

[1] Some researchers refer to the forgetting function as a *retention* function, implying the retention of information about the sample, or equivalently, of a cognitive representation, over the course of the delay. Such interpretations are not consistent with the present conclusions, and we prefer to avoid them. Indeed, our use of *forgetting* should not be taken to imply the loss of information over time. Instead, we use the term to refer to the delayed influence of the sample stimuli on the choice response. It would be just as appropriate to refer to the delay-interval functions as *remembering* functions, but *forgetting* more aptly describes the typical decrement in accuracy with increasing delay. Here we show that forgetting at longer delays can be less than at shorter delays, and thus emphasize the inverse relation between forgetting and remembering.

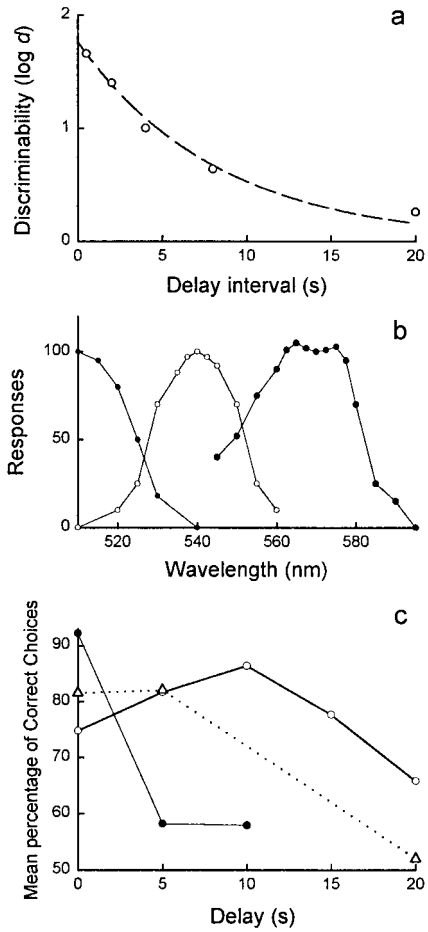

Fig. 1. (a) A typical forgetting function showing discriminability (log *d*) decreasing as a function of increasing delay based on data reported by White (1985, Figure 2). (b) An example of a set of generalization gradients showing response frequency as a function of test wavelength following training of pigeons to respond to 510-, 540-, or 570-nm wavelengths, replotted from P. M. Blough (1972, Figure 4). (c) A reanalysis of Spetch and Rusak's (1992, Tables 3 and 4) data showing mean percentage of correct choices as a function of delay in a delayed symbolic matching-to-sample task following training with a single 0-s delay (filled circles), a single 5-s delay (open triangles), or a 10-s delay mixed with other delays (open circles).

bridge the temporal gap between sample and choice.

An alternative view offered in the present paper is that the result of training with 0-s delays and testing with a range of delays greater than 0 s follows the principles of stimulus generalization. In other words, remembering in DMTS procedures is discriminative behavior under the control of both the stimulus dimension of the sample and its delay to the time of remembering. Thus construed, temporal distance is a dimension of the sample (Fetterman, 1996; White, 1991).

Fetterman (1995) arranged a DMTS procedure in which samples were short (2-s) and long (10-s) durations. Following extensive 0-s delay training, sample durations were changed to 2, 2.75, 3.8, 5.25, 7.24, and 10 s, and accuracy was tested with delays of 0, 2, 5, and 15 s. At each delay the generalization gradients along the duration dimension were ogival. The influence of delay was shown by a general flattening of the gradients as the delay lengthened. Thus remembering was governed by both sample duration and the temporal delay from the sample to choice. The greatest discrimination occurred for the original stimulus values used in training, that is, the short and long durations and the 0-s delay.

In an early stimulus generalization experiment, Guttman and Kalish (1956) trained groups of pigeons to respond to single stimuli of specific wavelengths. When wavelength was varied in generalization tests, response probability along the wavelength dimension decreased monotonically with increasing distance of the test value from the training value. In particular, the gradients peaked at the value of the training wavelength. A similar result was reported by P. M. Blough (1972) for maintained generalization, and is illustrated in Figure 1b. These and other results from numerous studies of gradients of generalization along a dimension of the single training stimulus (Honig & Urcuioli, 1981) confirm the conclusion that the gradients peak at the training value.

Spetch and Cheng (1998) reported the results of generalization tests along the dimension of duration following delayed discrimination with short and long durations as discriminative stimuli. Following training in which the response opportunity immediately followed the sample duration (0-s delay), control by duration in the test was strong, but weakened when the opportunity to respond was delayed by 5 s and 10 s (cf. Fetterman, 1995). Spetch and Cheng also included a training condition with a 5-s delay from the sample duration to opportunity to respond. In the subsequent test, control by duration

was equally strong with delays of 0, 5, and 10 s, and control at the 5-s delay was stronger following training with the 5-s delay than following training with the 0-s delay.

Spetch and Rusak (1992) used 2-s and 8-s presentations of the food hopper light as the sample stimuli in a DMTS procedure. Their results are illustrated in Figure 1c. After training with a 0-s delay, pigeons' mean accuracy with test delays of 0, 5, and 10 s decreased across delays. Following further training with only 5- and 10-s delays, accuracy was tested at delays of 0, 5, 10, 15, and 20 s. The resulting forgetting function recalculated from their data resembled a generalization gradient, in that accuracy peaked at 10 s (Figure 1c). Spetch and Rusak also trained 8 naive pigeons using a 5-s delay from the outset of training. When performance was tested with delays of 0, 5, and 20 s, accuracy was high at 0 and 5 s and decreased to chance levels at 20 s (Figure 1c).

In a similar experiment, Spetch (1987) trained 6 pigeons first with a 0-s delay, then with a delay of 10 s, and finally with a delay of 20 s. Accuracy was tested at a range of delays following each retraining. Accuracy decreased with increasing delays following training with the 0-s delay, but remained constant across delays following training with the 10-s and 20-s delays.

In summary, the results of the experiments reported by Spetch and her colleagues support the idea that the peak in DMTS accuracy at 0 s in the forgetting function is due in part to training with a 0-s delay. When delays longer than 0 s are used to train DMTS responding, the resulting forgetting functions do not always peak at the shortest delay. When Spetch and Rusak (1992) exposed pigeons to long delays and then tested at a range of delays, the resulting forgetting function resembled a generalization gradient in that accuracy peaked at the most familiar delay interval (Figure 1c).

The present experiment investigated the effect of training delay on subsequent performance when tested with a range of delays in a DMTS task. Experimentally naive pigeons were trained to perform a standard DMTS task using a single delay of 0, 2, 4, or 6 s from the outset of training. Once the pigeons were responding accurately at their training delay, test sessions that included nonreinforced trials with delays of 0, 2, 4, 6, 8, and 10 s were conducted.

The number of training sessions required to reach a stable level of accurate responding was expected to increase as the training delay increased, because in a DMTS task, increasing the delay increases the difficulty of the discrimination (Cumming & Berryman, 1965; White, 1985, 1991; White & Bunnell-McKenzie, 1985; White & Wixted, 1999). Jackson-Smith, Zentall, and Steirn (1993) found that, in acquisition of a DMTS task, pigeons trained with a 0.5-s delay required significantly more training sessions than did pigeons trained with a 0-s delay.

Forgetting functions generated from test sessions for birds trained with delays of 2, 4, or 6 s were expected to differ from those of birds trained with a 0-s delay. We expected forgetting functions to resemble generalization gradients, with peak accuracy occurring at the training delay.

METHOD

Subjects

Thirteen experimentally naive homing pigeons, aged between 1 and 5 years, served as subjects. The birds were individually housed in wire cages measuring 40 cm deep, 50 cm high, and 40 cm wide and had free access to water and grit. The birds were weighed daily and maintained at 85% ± 10 g of their free-feeding weights through postexperimental feeding of a mixture of wheat, corn, peas, and commercially prepared pellets. If a bird's weight fell outside the range, it was excluded from experimental sessions until its weight was within the range.

Apparatus

Seven experimental chambers were used, five Med Associates Inc. chambers and two custom-built chambers. Birds were allocated to chambers in such a way that training condition was not confounded with chamber type. The Med Associates chambers measured 29.5 cm high, 29.5 cm wide, and 24.5 cm deep. The side walls of the chambers were made of transparent plastic. Cardboard partitions separated the chambers. Three translucent plastic response keys, 2.1 cm in diameter, were recessed 1 cm into the front panel of each chamber, 21 cm from the grid floor

and 6 cm apart. The keys could be illuminated red, green, or white and required a force of at least 0.15 N to be operated. A hopper situated behind an aperture 12.5 cm below the center key provided access to wheat when raised. The hopper was illuminated with a 1-W white bulb when raised.

The custom-built chambers had internal dimensions of 28.5 cm high, 32 cm wide, and 50 cm deep. Three translucent plastic response keys, 3 cm in diameter, were located flush on one wall of each chamber, 20 cm from the grid floor and 7.5 cm apart. The keys could be illuminated red, green, or white and required a force of at least 0.15 N to be operated. A hopper situated behind an aperture 8.5 cm below the center key provided access to wheat when raised. A light inside the aperture was illuminated when the hopper was raised.

Both types of chamber contained a houselight, but this light was never illuminated during the experiment.

Procedure

Shaping and fixed-ratio (FR) 1 training. Each bird was trained to eat wheat from a raised hopper, and then to peck a white center key. Ten of the 13 pigeons were trained using an autoshaping procedure. For the remaining 3, which required additional training, successive approximations to pecks at the white center key were followed by wheat delivery. Once center-key pecking was established, 24 sessions were conducted for each bird, in which in random order the left, center, or right key was lit white and a single peck to the lit key on each trial produced 3-s access to wheat. Each session was terminated after 50 min or after 80 reinforcer deliveries, whichever came first. Sessions were conducted 7 days per week.

Initial-delay phase. Following FR 1 training, each bird was introduced to the DMTS task with a single delay of 2, 4, or 6 s from the outset. Birds T2, P1, C1, and C4 were assigned a 2-s delay, Birds T3, P2, P4, C2, and C5 were assigned a 4-s delay, and Birds T1, T4, P3, and C3 were assigned a 6-s delay. Birds T1 and T4 (both initially assigned a 6-s delay) did not respond during the first 43 training sessions and the accuracy of the responses of Bird T2 (assigned a training delay of 2 s) had remained at chance. After 43 sessions at their assigned delay, the training delay was changed to 0 s for Birds T1, T2, and T4.

Sessions were terminated after either 50 min or a maximum of 82 trials had been completed. The first two trials of each session were treated as warm-ups, and the data were not used in the analyses. Trials began with the center key lit either red or green (the sample stimulus). Five responses to the center key turned the center keylight off and initiated the delay (0, 2, 4, or 6 s). After the delay, one of the side keys was lit red and the other green (the comparison stimuli). Over the last 80 trials in each session equal numbers of red and green sample stimuli were combined with red and green comparison stimuli on the left and right keys. The quasirandom order of trials was constrained so that two consecutive trials had same or different samples equally often. A peck to the red comparison key was deemed correct following presentation of the red sample, and a peck to the green comparison key was correct following presentation of the green sample. Initially, every correct response was reinforced by 3-s access to wheat. Incorrect responses produced a 3-s blackout. Each trial was followed by a 12-s intertrial interval, during which all keys were dark.

The probability of reinforcement for a correct choice was changed for each bird individually to .5 following five consecutive sessions in which the proportion of correct responses was greater than .8. Correct, nonreinforced responses produced a 3-s blackout followed by the intertrial interval. The blackout conditions did not differ from those of the intertrial interval. The 3-s blackouts were added to make the time between trials equal on both reinforced and nonreinforced trials.

Test sessions. Following five consecutive sessions with a reinforcer probability of .5 in which accuracy was maintained at a proportion correct greater than .8, a single test session was conducted. Test sessions consisted of 108 trials, with 12 trials at probe delays of 0, 2, 4, 6, 8, and 10 s and 36 trials at the original training delay. Test sessions were terminated after 108 trials or 1 hr, whichever came first. All choices following probe delays resulted in a 3-s blackout followed by the 12-s intertrial interval. Each correct choice response on the 36 training-delay trials resulted in 3-s access

Table 1

The number of training sessions required for each bird to reach the criterion for halving the reinforcer probability and before conducting each test.

Training delay	Bird	Sessions						
		Halving	Test 1	Test 2	Test 3	Test 4	Test 5	Total
0 s	T1	7	5	5	5	5	5	32
	T2	17	5	5	5	6	5	43
	T4	10	5	5	5	5	5	35
2 s	P1	20	5	7	14	5	5	56
	C1	15	22	5	5	5	5	57
	C4	13	5	5	5	5	5	38
4 s	T3	11	5	9	5	5	5	40
	P2	28	5	5	5	5	5	53
	P4	29	5	42	21	5	5	107
	C2	25	5	11	5	5	5	56
	C5	32	14	5	5	10	6	72
6 s	P3	53	5	6	5	5	5	79
	C3	35	5	49	5	17	23	134

to wheat. In each block of nine trials, each probe delay occurred once, and the training delay occurred three times. This meant that the training delay appeared four times in each block of nine trials, once without any scheduled reinforcement. Probe sessions were repeated following each block of five consecutive sessions in which proportion correct exceeded .8.

Zero-delay phase. After each bird had completed five test sessions, the training delay was changed to 0 s, with a reinforcer probability of .5. The exception was Bird P3 (trained at a 6-s delay), which completed seven test sessions before being trained with a 0-s delay, because this bird completed only 56 trials on average during each test session. During the zero-delay phase, test sessions occurred following five consecutive sessions in which proportion correct exceeded .8. In these test sessions, the same probe delays were used, with reinforcement available for every correct choice on the 36 trials with a 0-s delay.

All-delay training. Following five test sessions after training in the zero-delay phase, the training procedure was changed to include delays of 0, 2, 4, 6, 8, and 10 s (as in the test sessions). Every correct response at every delay was reinforced. The six delays occurred in a random order in each session, equally often with each combination of sample stimulus and comparison stimulus location. For each bird 20 sessions were conducted.

RESULTS

The number of training sessions each bird required during initial-delay training to reach the first stability criterion, that is, the number of sessions completed prior to the halving of the reinforcer probability, is shown in Table 1. The criterion (five consecutive sessions with proportion correct greater than .8) was reached after a mean of 11, 16, 25, and 44 training sessions for birds trained with 0-, 2-, 4-, and 6-s delays. A one-way analysis of variance on the data in Table 1 showed a significant effect of the training delay on the number of sessions required to reach stability, $F(3, 9) = 8.55$, $p < .05$. As the training delay increased, the number of training sessions required to reach the same level of accuracy increased. Table 1 also shows the number of sessions required for each bird before each test session. Total training sessions for birds trained with 0-, 2-, 4-, and 6-s delays averaged 37, 50, 66, and 107. Analysis of variance indicated that more training sessions were required with increasing delay, $F(3, 9) = 4.27$, $p < .05$.

A three-way analysis of variance was conducted to assess order effects across test sessions during the initial-delay phase. For each training group, the proportion correct was compared at each probe delay across test sessions. No significant effect of test session on proportion correct was found, $F(4, 36) = 1.79$, $p > .05$, and no interaction effects be-

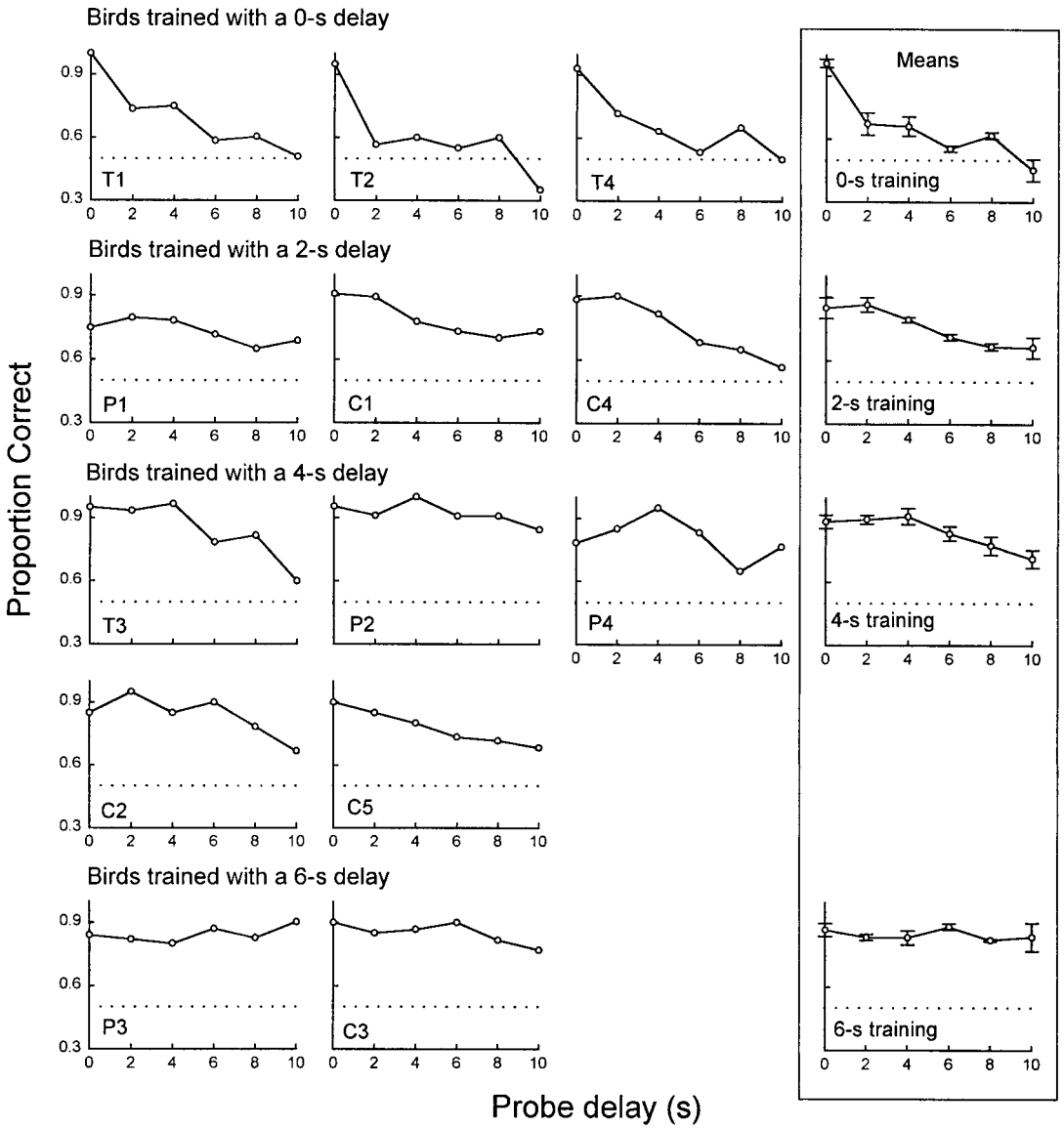

Fig. 2. Proportion of correct choice responses at each probe delay produced by pooling the data from all probe sessions for each bird. The boxed right panel shows mean proportion correct (and standard errors of the means) for each training group as a function of probe delay.

tween test session and training delay, $F(12, 36) = 0.69$, $p > .05$, or test session and test delay, $F(20, 180) = 0.97$, $p > .05$, were found. Because the mean accuracies did not change across test sessions, data from the individual test sessions were pooled for each bird.

Figure 2 shows the proportion of correct responses at each probe delay for each bird based on responses pooled over all probe test sessions. It shows that for birds trained with a 0-s delay, accuracy peaked at 0 s and decreased as the delay increased. All birds responded at chance levels at the longest delay (10 s). For birds trained with a 2-s delay, accuracy was higher across all delays and the functions were flatter, with accuracy never falling to chance levels. Accuracy at the 2-s delay was higher for birds trained with this delay than for birds trained with the 0-s delay. For birds trained with a 4-s delay, only Bird

Table 2

Mean proportion correct for the last 5 days at each bird's training delay and the proportion correct for the first session with a 0-s delay.

Training delay	Bird	Last 5 days	0-s delay
2 s	P1	.86	.63
	C1	.94	.81
	C4	.98	.95
4 s	T3	.97	.74
	P2	.96	.91
	P4	.94	.93
	C2	.90	.86
	C5	.92	.93
6 s	P3	.87	.49
	C3	.85	.71
M		.92	.80

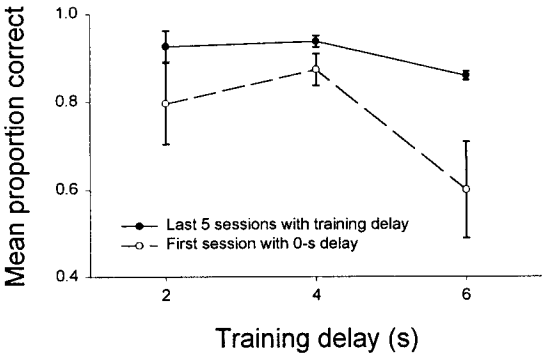

Fig. 3. Mean proportion correct for birds trained with delays of 2, 4, or 6 s from the last five sessions of the initial-delay phase and the first session of the zero-delay phase.

C5 showed the highest accuracy at the 0-s delay, whereas the other 4 birds responded accurately at delays up to and including 4 s, with Birds T3, P2, and P4 responding most accurately at 4 s. Accuracy for the birds trained with a 4-s delay remained above chance for all birds at all delays. For birds trained with a 6-s delay, accuracy did not decrease with increasing delay for either bird. Accuracy peaked at 10 s for P3 and at 6 s for C3.

The right panel of Figure 2 shows test-probe data averaged for each training group. The mean functions show that in every group, accuracy was highest at the training delay. A three-way analysis of variance showed a significant effect of training delay, $F(3, 9) = 13.95$, $p < .001$, and delay interval, $F(5, 45) = 20.76$, $p < .001$, on proportion correct. The interaction between training delay and delay interval was also significant, $F(15, 45) = 5.23$, $p < .001$. A Duncan's multiple-range test showed that mean accuracy for the 4-s and 6-s training groups was significantly higher than that of the 0-s and 2-s training groups. However, the two long-delay training groups (4 s and 6 s) and the two short-delay training groups (0 s and 2 s) did not differ significantly from each other in mean accuracy. The means of proportion correct across all delays for birds trained at 0, 2, 4, or 6 s were .65, .73, .84, and .85. As the training delay increased, overall accuracy increased.

A further assessment of whether training delay influenced the shape of the relations in Figure 2 treated them as frequency distributions. We calculated the mean of each function in seconds. This method is often used to assess the central tendency of stimulus generalization gradients (Honig & Urcuioli, 1981). If the function was very steep the mean would be closer to zero delay, and if the function was perfectly flat the mean would be the average of the testing delays (5 s). Mean delays were 1.74, 2.84, 2.99, and 3.35 s for birds trained with delays of 0, 2, 4, and 6 s, reflecting the changing location of the maximum of the forgetting function as a function of training delay.

When the training delay was changed to 0 s for birds trained with 2-, 4-, or 6-s delays, for all birds but 1 (C5), accuracy decreased in the first session with a 0-s delay. Table 2 shows the mean proportion of correct responses for the last five sessions at each bird's initial training delay (2, 4, or 6 s) along with the proportion of correct responses for the first session with a 0-s delay. Accuracy decreased for Birds T3, P1, P3, C1, and C3 on moving to the 0-s delay training. A dependent measures *t* test showed that the mean proportion correct obtained in the first session of the zero-delay phase was significantly lower than the mean of the previous five sessions at the initial training delay, $t(9) = 3.11$, $p < .05$. The means in Figure 3 show that accuracy decreased when the training delay was changed to 0 s relative to the stable performance that had been achieved at 2, 4, or 6 s.

For 6 of the 10 birds trained with a nonzero delay, accuracy in the first session of the zero-delay phase was lower than it had been with

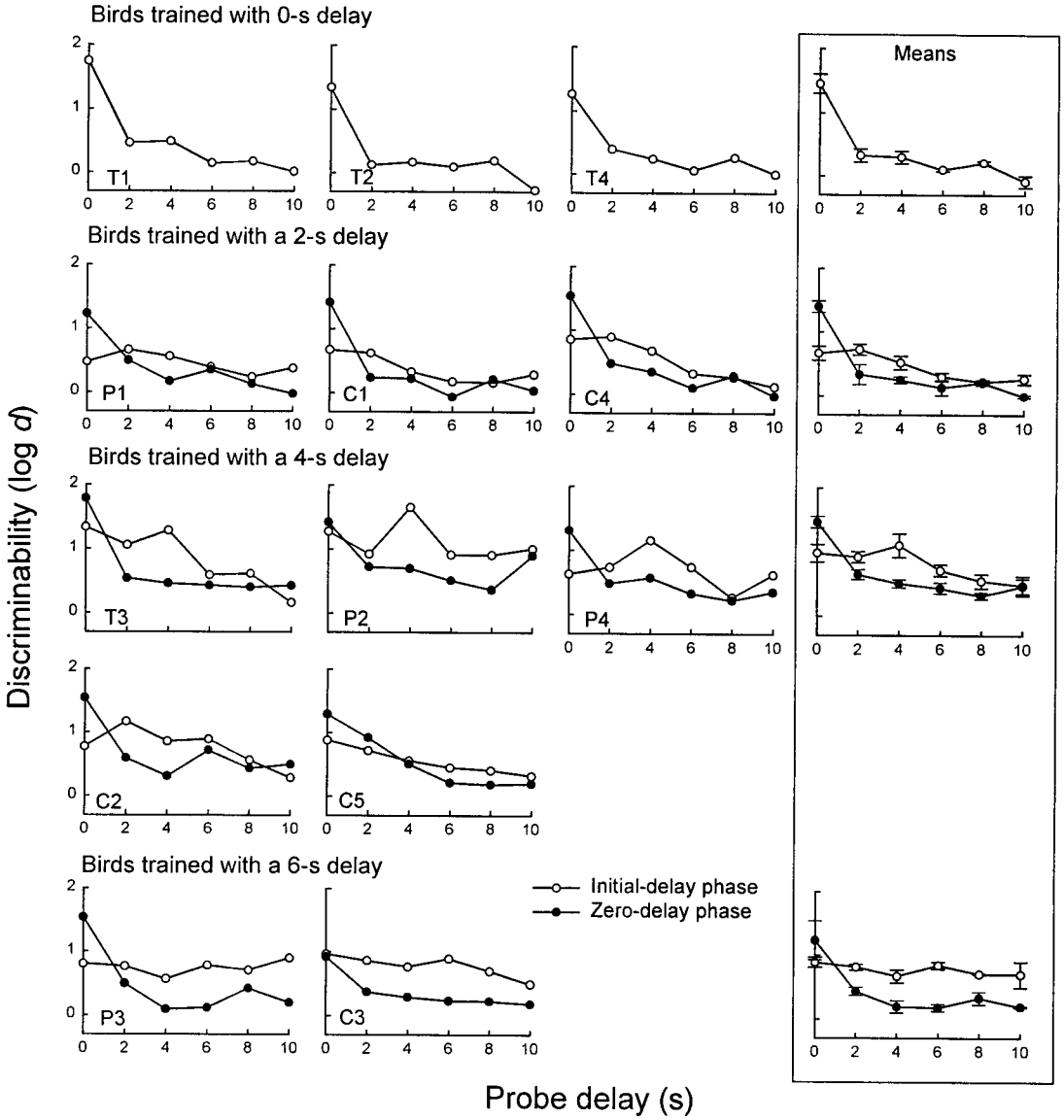

Fig. 4. Log d measures of stimulus discriminability plotted as a function of probe delay for each bird, for test probe sessions following the initial-delay phase (open circles) and following the zero-delay phase (filled circles). The right panel shows log d (and standard errors of the means) averaged across birds trained with the same initial delay.

0-s delay in the probe sessions. However, a dependent measures t test showed no significant difference between accuracy at the 0-s delay during probe sessions and in the first session of zero-delay training, $t(9) = 1.59$, $p > .05$.

Correct (c) and error (e) response frequencies following red (r) and green (g) samples were pooled across probe tests during the initial-delay phase and during the zero-delay phase for each bird, and were transformed into log d measures of discriminability at each test delay. Log d is a bias-free measure of discriminability described by Davison and Tustin (1978), and is calculated according to $\log d = \frac{1}{2} \log[(c_r/e_r)(c_g/e_g)]$.

Figure 4 shows log d from test sessions following the initial-delay phase. The functions resemble those for proportion correct in Figure 2. Following retraining with a delay of 0

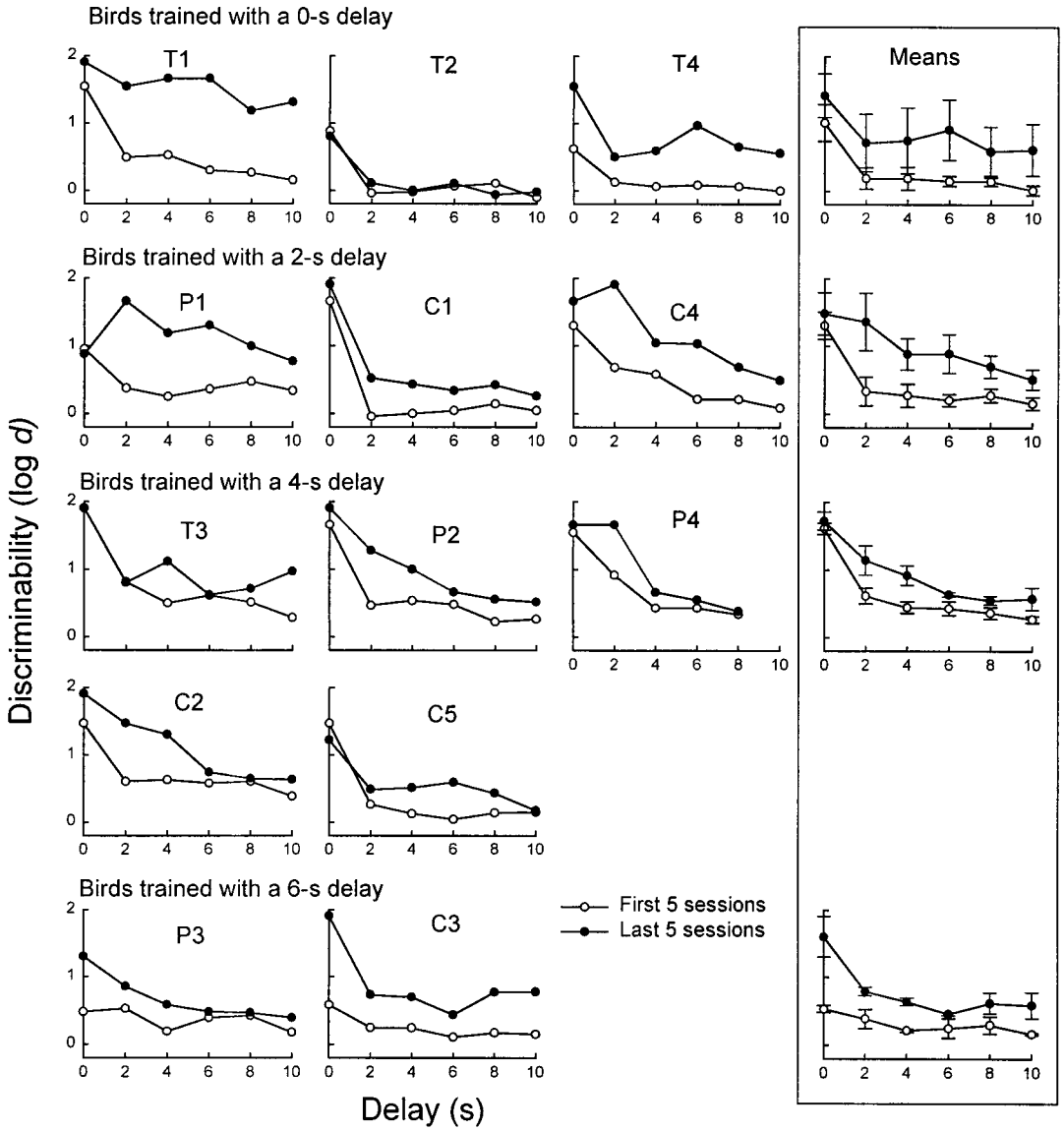

Fig. 5. Discriminability (log *d*) for the first five sessions of all-delay training (open circles) and for the last five sessions of the 20 sessions of all-delay training. The right panel shows log *d* averaged across birds in each training group.

s, the functions for each bird peaked at 0 s and generally decreased as the probe delay increased. For 9 of the 10 birds, accuracy was higher at 0 s after retraining. For every pigeon, accuracy at the initial training delay was lower in test sessions conducted after the zero-delay phase than it was after the initial-delay phase.

Figure 5 shows the results of the all-delay training in which each session included the same six delays as the test sessions (0, 2, 4, 6, 8, and 10 s). It shows discriminability (log *d*) for each bird plotted against delay. Each open point was calculated by pooling responses from the first five sessions in the all-delay phase. Each filled point was calculated by pooling responses from the last five sessions of the 20 sessions.

Figure 5 shows that for all birds, except P3 and C3 (initially trained with a 6-s delay), dis-

criminability was high during the first five sessions at 0 s, and decreased rapidly at longer delays. Birds P3 and C3 showed equally poor discrimination at all delays during the first five sessions. After a further 10 sessions, discriminability had increased across all delays for 10 of the 13 birds. Three of the birds (P1, C4, and T3) showed peaks of discriminability at their initial training delays compared to that obtained at other delays.

DISCUSSION

The results demonstrate that it is possible to train pigeons in DMTS tasks with delays of up to 6 s from the outset of training. Following initial training in which responses on any of three white keys were immediately reinforced, we introduced the delayed matching procedure with red and green sample stimuli and delays of 0, 2, 4, or 6 s between sample and comparison presentations at the outset. Consistent with the belief that DMTS performance is difficult to train if delays greater than 0 s are employed at the beginning of training (Roberts & Kraemer, 1982), more sessions were required to reach a criterion level of performance as the delay increased. It seemed remarkable, however, that a level of accuracy comparable to that with 0-s DMTS could be achieved with 4-s and 6-s delays.

The effect of training delay on the results of the generalization tests with varying delays was confounded with the number of sessions of training. The confounding effect was inevitable because if we had trained for a fixed number of sessions before the test, accuracy in training would have been confounded with training delay. Indeed, we followed the standard procedure for testing postdiscrimination generalization in which training continues until a performance criterion is reached before generalization tests are conducted (Honig & Urcuioli, 1981). Further, when we continued to train and test, there was no order effect in consecutive tests, suggesting that once the performance criterion had been achieved, the number of sessions of continued training did not influence performance in the test.

Three main features characterized the functions obtained following training with fixed delays from the outset. First, the maximum accuracy tended to occur at the value of the training delay (Figure 2). The influence of the training delay was verified when all birds were shifted to training with a 0-s delay. In the first session of 0-s delay training, accuracy was significantly lower at 0 s than at the initial training delays of 2, 4, or 6 s for the same birds (Figure 3). Second, with longer training delays the functions became flatter, and third, overall accuracy increased with longer training delays (Figures 2 and 4). The within-bird comparison also showed that accuracy at long delays was higher when birds had been trained with longer delays than when they had been trained with the 0-s delay. This latter result is consistent with the finding reported by Steirn, Zentall, and Sherburne (1993). They trained one group of pigeons with a 0-s delay and another with a 0.5-s delay in a DMTS task. They found that when tested at delays longer than the training value, the 0.5-s group responded more accurately at longer test delays than did the 0-s group.

The tendency for the maximum accuracy to occur at the training delay is similar to the result of testing for generalization along physical stimulus dimensions (Honig & Urcuioli, 1981). Hence the decrement in accuracy with increasing delay in standard forgetting functions following initial training that included a 0-s delay is at least in part the result of training with a 0-s delay. That is, the forgetting function is a generalization gradient along the temporal dimension of delay duration. In other terms, delay is an important aspect of the sample. Our conclusion is consistent with the temporal coding hypothesis for Pavlovian conditioning, which assumes that ''the temporal relationship between the events that prevailed during training is encoded as part of the association'' (Savastano & Miller, 1998, p. 148). But instead of assuming that delay is ''encoded'' along with other features of the sample stimulus, we prefer the ''direct remembering'' interpretation (White, 1991) that delay is a dimension of the sample that may exert discriminative control in conjunction with other dimensions of the sample stimulus.

Most theories of remembering refer to temporally related processes. For example, in trace decay and competition theory (Grant, 1975; Roberts & Grant, 1976), the trace has maximal strength at 0-s delay and decays as a monotonic function of time since presenta-

tion of the sample. Maintenance-rehearsal theory (Grant, 1981), drift theory (Roitblat, 1983), and the temporal discrimination hypothesis (D'Amato, 1973) also rely on temporally related processes. Because of the diminishing effect of the sample on the conditional discrimination with increasing temporal distance between sample and choice, a delay-dependent reduction in discriminability is expected to contribute to the form of the forgetting function. The nonmonotonic functions obtained in the present experiment, however, suggest that a process of generalization also contributes to the form of the function relating accuracy to delay. In addition, the finding that the delay-interval functions flattened with longer training delays suggests that generalization is greater with longer training delays, following Weber's law (Weber, 1834/1978).

Figure 2 shows that the decrement in accuracy with delays longer than the training delay was greater than the decrement with shorter delays. That is, the birds responded accurately with delays up to and including the training delay and less accurately with longer delays. This result may be explained by the idea that forgetting functions consist of two components, generalization and an effect of temporal distance of the sample (White, in press). The generalization component applies Shepard's (1958, 1987) exponential law of generalization to the temporal dimension of delay. The present result suggests that remembering is specific to the delay at which remembering has been trained but may generalize to delays of similar duration. In Shepard's law, the dimension for generalization is psychological distance, and the exponential decrement in discriminability with increasing psychological distance between stimuli holds for a wide range of continua (Shepard, 1987). In the present case, the simplifying assumption is made that the temporal dimension of the delay equates to psychological distance. Hence the generalization component is given by $g_2 = c \cdot \exp(d|t - T|)$, for delay interval t and training delay T. The equation for g_2 predicts a symmetrical gradient along the dimension of delay, with a peak at T and an exponentially decrementing curve from each side of the peak.

The temporal distance component follows the perception-memory continuity assumption of the theory of direct remembering, which requires that the effect of the sample decreases exponentially with increasing temporal distance (White, 1985, 1991, 1996). That is, $g_1 = a \cdot \exp(-b \cdot t)$. The sum of the two components g_1 and g_2 produces a double exponential function:

$$\log d = a \cdot \exp(-b \cdot t) + c \cdot \exp(-d \cdot |t - T|). \quad (1)$$

The forgetting function described by Equation 1 has an intercept that represents initial discriminability (White, 1985) and is influenced by the constant a in the temporal distance component and the value of the generalization component when $t = 0$. The rate of forgetting of the composite function is influenced by both the rate of decrement b of the temporal distance component and the rate of generalization decrement d. When the training delay (T) is 0 s, the temporal distance and generalization components cannot be separated, although they may occur at different rates to yield a function that may appear hyperbolic and corresponds very closely to the function defined by $y = a \cdot \exp(-b \cdot \sqrt{t})$, which is one of the best fitting functions to the data from a large number of studies reanalyzed by Rubin and Wenzel (1996). When the training delay T differs from 0 s, it is possible to separate the generalization component that extends from a nonzero delay from the temporal distance component that extends from 0 s. The present experiment therefore allowed the two effects to be separated.

Figure 6 illustrates the functions predicted by Equation 1, with the same values chosen for the parameters a, b, c, and d, for each of the functions predicted for the different training delays, T. These values approximated the means of the parameter values reported below. The four illustrative functions in Figure 6 differ only in terms of the value of the training delay. This was arranged by assuming, consistent with Weber's law, that the extent of generalization was greater with longer training delays, and with d set at $d/(T + 1)$. The illustrative functions have the same three features of the present data: They peak at the training value, they are flatter for longer training delays, and accuracy at long delays is overall higher for longer training delays.

The composite function given by Equation 1 was fitted to the mean log d data for each

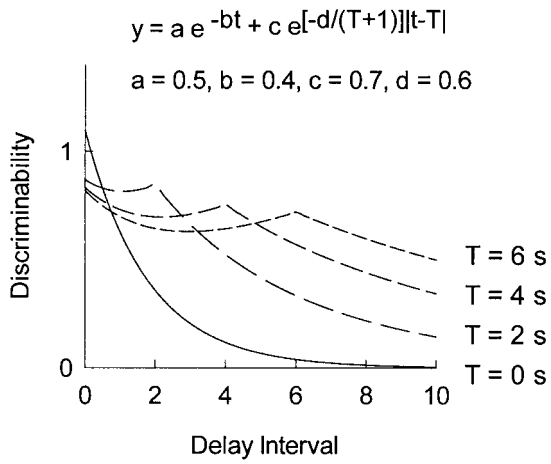

Fig. 6. Predicted functions from Equation 1 with d replaced by $d/(T + 1)$, for four values of training delay T, and with parameters a, b, c, and d fixed at the same values for all four functions.

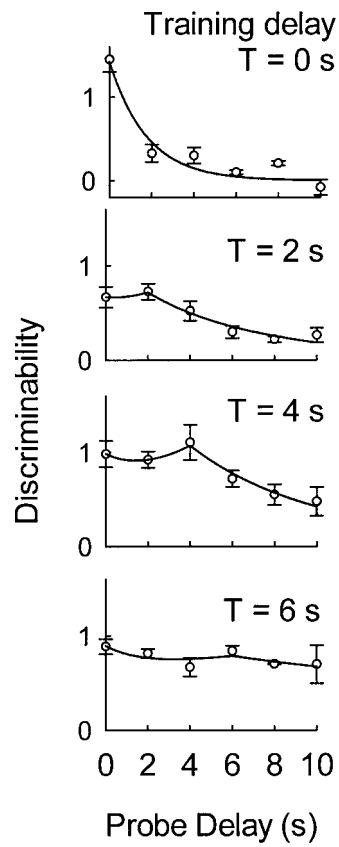

Fig. 7. Functions for best fits of Equation 1, with all four parameters free to vary, to mean discriminability at each probe delay for each training-delay group. When parameters a and b were held constant at the means of the values for the four-parameter fits, the best fitting functions were virtually identical to those shown.

training group (Figure 7), using the fitting routine in Sigmaplot 2000©. Table 3 gives the values of the four parameters, the variance accounted for by the fits, and the standard errors of the estimate. The means of the a, b, and c parameters were used for the illustrative functions in Figure 6. When values of d for best fits of Equation 1 to mean discriminability measures were plotted as a function of training delay, the function $d = .56/(T + 1)$ accounted for 98% of the variance. Accordingly, a value of $d = .6$ was used for the illustrative functions in Figure 6. Note that the illustrative functions differ from Equation 1 in that they include the term $1/(T + 1)$. The parameters for the generalization component are expected to vary with training delay, and in particular, d (in Equation 1) should increase with training delay in a way that is consistent with Weber's law. Indeed, our assumption that d is inversely related to $T + 1$ was sufficient in that it accounted for 98% of the variance in d obtained by fitting Equation 1.

There is no reason to expect the temporal distance component to vary with training de-

Table 3

Parameter values, variance accounted for (VAC), and standard errors of the estimate (*SE*) for fits of Equation 1 to mean discriminability measures for each condition.

Training delay (T)	*a, b, c, d* free						*c, d* free; $a = 0.4$, $b = 0.5$			
	a	*b*	*c*	*d*	VAC	*SE*	*c*	*d*	VAC	*SE*
0 s	0.71	0.57	0.71	0.57	.94	.21	1.03	0.62	.94	.15
2 s	0.20	0.47	0.64	0.16	.95	.08	0.52	0.14	.86	.09
4 s	0.43	0.45	1.0	0.15	.97	.06	1.02	0.15	.97	.05
6 s	0.27	0.52	0.78	0.04	.66	.08	0.80	0.06	.51	.07

lay. Accordingly, the values of the *a* and *b* parameters should not change. Equation 1 was therefore fitted again to the discriminability measures, but with the values of *a* and *b* fixed at .4 and .5 for each function. These were the means of the parameter values in Table 3. Table 3 shows the results of fits of Equation 1 with parameters *c* and *d* free to vary. The variance accounted for by the two-parameter fits did not differ appreciably from that for the four-parameter fits except for the 2-s training-delay function for which the variance accounted for dropped from 95% to 86%. Nevertheless, the graphical depiction of the two-parameter fits was virtually indistinguishable from the four-parameter fits shown in Figure 7. The conclusion that the *a* and *b* parameters in the temporal distance component should not vary with training delay is therefore supported by our analysis.

In conclusion, the present data are well described by a model that assumes that accuracy is influenced both by the temporal distance of the sample stimulus from the comparison stimulus and by generalization of performance from the delay used in training to other delays. The combined effect of these factors is shown in the nonmonotonic functions in Figure 2, in which accuracy decreases faster at delays longer than the training delay but is maintained at shorter delays. The emphasis on remembering as discriminative behavior at the time of remembering (Catania, 1979; White, 1985, 1991) suggests that performance is specific to training delays and may generalize to other delays. The present study provided evidence for generalization. Lack of generalization was reported by White and Cooney (1996), who differentially reinforced choices at a short delay and observed a strong bias towards choice of the more frequently reinforced comparison stimulus. That bias did not generalize to the nondifferentially reinforced choices at a longer delay. Similarly, biased choice at a long delay did not generalize to choice at a short delay. Generalization was possible if the delays were close, but for the delays in the DMTS procedure used by White and Cooney, behavior at one delay was independent of behavior at another. Although remembering is specific to the delay at which it is trained, the present study provides strong evidence to suggest that generalization along the temporal dimension of delay may be an important component of forgetting functions.

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