JOURNAL OF THE EXPERIMENTAL ANALYSIS OF BEHAVIOR 2011, **96,** 177–189 NUMBER 2 (SEPTEMBER)

REVERSING THE COURSE OF FORGETTING

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Forgetting functions were generated for pigeons in a delayed matching-to-sample task, in which accuracy decreased with increasing retention-interval duration. In baseline training with dark retention intervals, accuracy was high overall. Illumination of the experimental chamber by a houselight during the retention interval impaired performance accuracy by increasing the rate of forgetting. In novel conditions, the houselight was lit at the beginning of a retention interval and then turned off partway through the retention interval. Accuracy was low at the beginning of the retention interval and then increased later in the interval. Thus the course of forgetting was reversed. Such a dissociation of forgetting from the passage of time is consistent with an interference account in which attention or stimulus control switches between the remembering task and extraneous events.

Key words: forgetting functions, remembering, short-term memory, retroactive interference, delayed matching to sample, pigeons

Over the last century, studies with a wide range of species have explored forgetting over both short and long times (Rubin & Wenzel, 1996; White, in press). Forgetting typically follows a systematically decreasing function in which performance gradually decreases as the retention interval lengthens (the ''forgetting function''). Various mathematical forms for the forgetting function have been proposed (Staddon, 1983; White, 1985, 2001; Wixted & Carpenter, 2007; Wixted & Ebbesen, 1991; Woodworth & Shlosberg, 1954), but their common characteristic is that accuracy decreases monotonically as time since the to-be-remembered event elapses. In addition, functions which best fit data from numerous studies indicate that the rate of forgetting is slower at longer retention intervals, consistent with what might be expected if memories consolidate with time (Wixted, 2004).

The systematic decrease in the accuracy of remembering with lengthening retention intervals suggests the conclusion that forgetting inevitably occurs with the passage of time. As noted by Roediger (2008), however, ''there is no general law that says forgetting always occurs in the time since presentation of information'' (p.245). Here, we describe forgetting functions that are nonmonotonic or irregular in time, and thus support Roediger's contention. Nonmonotonic forgetting functions are not consistent with a class of theories which attribute forgetting to mechanisms correlated with the passage of time. Such theories typically involve time-related organismic processes that might bridge the temporal gap between a prior event and subsequent behavior, and which are generally referred to as trace theories. The general aim of the present experiments, therefore, was to ask whether forgetting could be dissociated from the passage of time.

Over 50 years ago, Blough (1959) demonstrated short-term forgetting in pigeons in the delayed matching-to-sample task (DMTS). In this task, a to-be-remembered sample stimulus was presented at the beginning of each trial. After a retention interval that lasted for up to 5 or 10 s, the pigeon chose one of two comparison stimuli. Correct choices that matched the prior sample were reinforced with food. Blough observed the pigeons' behavior during the retention interval. Pigeons that developed different behavior patterns during the retention interval for each sample (e.g., bobbing up and down for one sample and a different behavior for the other sample, as though rehearsing) chose the comparison that matched the sample with high accuracy, even after 10 s. Accuracy for pigeons without such rehearsal-like behaviors, however, declined rapidly with increasing delay. The main theory of forgetting stemming from early research using the DMTS proce-

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doi: 10.1901/jeab.2011.96-177

dure with nonhuman animals assumed that, unless memory traces are maintained by rehearsal (Grant, 1981), traces decay with time (Roberts, 1972; Roberts & Grant, 1976). That is, forgetting is associated with the passage of time. An alternative account for forgetting which also links forgetting to the passage of time is consolidation failure—the strengthening of memories over time is retarded owing to interference (Wixted, 2004).

Nairne (2002) advanced a case for the dissociation of time and forgetting, largely based on the results of a study of short-term memory in humans reported by Turvey, Brick and Osborn (1970), with a replication by Greene (1996). Turvey et al. used the procedure originally described by Brown (1958) and Peterson and Peterson (1959) in a between-groups design. In this, participants were asked to recall letter trigrams after a short time of counting backwards from a given number (operationalized as rehearsal prevention or retroactive interference). In their first four recall trials, different groups of participants each experienced one retention interval—either 5, 10, 15, 20, or 25 s depending on the group. In the fifth recall trial, however, all groups experienced the same retention interval, 15 s. Two results are of interest. First, accuracy on the second trial for the different groups increased with increasing retention-interval duration—a reversed between-group forgetting function. Second, accuracy on the fifth trial with the 15-s retention interval was greatest for the groups who previously experienced the longest retention interval (20 s and 25 s). This second result is analogous to the result reported by Sargisson and White (2001) for pigeons in the DMTS task. Sargisson and White trained different groups of experimentally naive pigeons in a DMTS task with a single retention interval of 0, 2, 4, or 6 s from the very beginning of training. When tested with a range of retention intervals, remembering tended to be most accurate at the retention interval in original training, compared to shorter or longer retention intervals. For example, pigeons trained for many sessions in DMTS with only a 4-s delay, and then tested with a range of delays including 0 s, were most accurate at the 4-s delay and less accurate at both shorter and longer delays. This result contrasts with the typical forgetting function (and perhaps human intuition) in which accuracy is highest at the shortest delay. Reversal of the forgetting function was shown by higher accuracy at longer delays compared to lower accuracy at shorter delays.

The study by Turvey et al. (1970) is only one of two instances of human short-term memory studies, of which we are aware, in which the forgetting function reverses. That is, under certain conditions, remembering accuracy is greater at longer retention intervals than at shorter intervals. Like the study by Sargisson and White (2001) with pigeons, however, the training conditions with different retention intervals involved between-groups comparisons.

A forgetting function reversal was also demonstrated in humans by Unsworth, Heitz, and Parks (2008) who used the Peterson and Peterson (1959) procedure in a within-subjects design. Accuracy at a long-retention interval was greater than at a shorter retention interval when the trial with the long-retention interval was preceded by a long intertrial interval. Unsworth et al. interpreted this reversal in the forgetting function as evidence against trace decay and for a temporal-distinctiveness hypothesis in which, as a result of their increased temporal separation, the items to be remembered at the long retention interval are more easily distinguished from items on earlier trials.

The aim of the present experiments was to demonstrate reversals in forgetting functions using a within-subject procedure, DMTS, with pigeons. Of the many conditions which influence performance in DMTS (White, in press; White, Ruske, & Colombo, 1996), illumination of the experimental chamber by a houselight during the retention interval results in a substantial reduction in accuracy at longer delays without affecting accuracy at a 0-s delay (Harper & White, 1997; Roberts & Grant, 1978; White, 1985).This effect is interpreted as retroactive interference, functionally defined as a performance deficit owing to a change in retention-interval conditions. Retroactive interference may occur when the experimental chamber is illuminated during a normally dark retention interval because the pigeon finds occasional spilt grain or engages in other behavior. Behavior extraneous to the task of remembering thus interferes or competes with the task of remembering (Brown & White, 2005a). In order to ask whether we could generate a reversal in the forgetting function, low accuracy was established at relatively short times in the retention interval by introducing retroactive interference. By withdrawing retroactive interference later in the retention interval, we asked whether accuracy would increase, thus yielding a forgetting function reversal. In the critical test conditions in the present experiment, therefore, the houselight was lit only for a limited time at the beginning of each retention interval. The experimental chamber was illuminated throughout short retention intervals, whereas it was illuminated only for the first few seconds of long retention intervals. According to theories in which forgetting is associated with the passage of time, such as trace decay and consolidation failure, once memory accuracy is reduced to a certain level in the retention interval as a result of high interference, it should not improve when the interference level is reduced, although the rate of forgetting might decrease. Demonstration of a reversal in forgetting would provide evidence for the dissociation of forgetting from the passage of time.

EXPERIMENT 1

METHOD

Subjects

Five adult homing pigeons with prior experience in DMTS lived in individual cages with free access to water and grit. The pigeons were maintained at between 80 and 85% of their free-feeding body weights by supplementary feeding of mixed grain at the end of the daily session.

Apparatus

The experimental chamber was 31 cm wide, 34 cm deep, and 32 cm high. On one wall were three 2-cm diameter response keys, 10 cm apart, and a central opening that allowed 3-s access to wheat as a reinforcer. Throughout the session, the chamber was dark, except when the keys were transilluminated red or green, the hopper was lit when wheat was available, or when the houselight was lit to provide interference. The houselight was mounted centrally at the top of a side wall and the experimental chamber was painted matte black. A ventilation fan at the rear of the chamber helped to mask extraneous sounds. Experimental events were controlled and recorded by a computer running MedPC 2.0 software and interfacing in an adjacent room.

Procedure

Each daily session lasted for 80 trials. Initially, the experimental chamber was dark. Each trial began when a red or green sample was presented on the center key. The fifth peck on the center key darkened it and initiated a retention interval which varied over values of 0.2, 1.5, 3, 6, and 12 s. During the retention intervals in baseline training, the experimental chamber was dark. The order of retention interval durations and red and green samples was randomized over trials with the constraints that the same sample could not occur on more than four consecutive trials, and that a retention interval could not be repeated until other retention intervals had occurred for a given sample. The retention interval terminated when red and green side-key comparisons were transilluminated. Left–right position of red and green comparisons varied randomly over trials. A correct choice of the comparison color that matched the sample was followed by 3-s access to grain and then by a dark 20-s intertrial interval. Incorrect choices were followed by a 3-s extension to the 20-s intertrial interval.

After approximately 90 sessions of training in the above procedure, a first interference condition (control) was conducted for eight sessions. In this condition, the experimental chamber was dark for the first 1.5 s, and after 1.5 s, the houselight was turned on for the remainder of the retention interval. At the end of the retention interval, the houselight was turned off and the comparison stimuli were presented on left and right keys. Thus the choice response was made when the chamber was dark. Following 22 additional sessions of baseline training with dark retention intervals, there were 8 sessions of a second interference condition in which the experimental chamber was illuminated for the first 1.5 s of the retention interval by turning on the houselight. That is, when a 1.5-s retention interval was arranged, the houselight was lit throughout. When a 3-s retention interval occurred, though, the houselight was lit for the first 1.5 s and the chamber was dark for the second 1.5 s, and so on for longer retention intervals. When the houselight was turned off at the end of any retention interval, the comparison stimuli

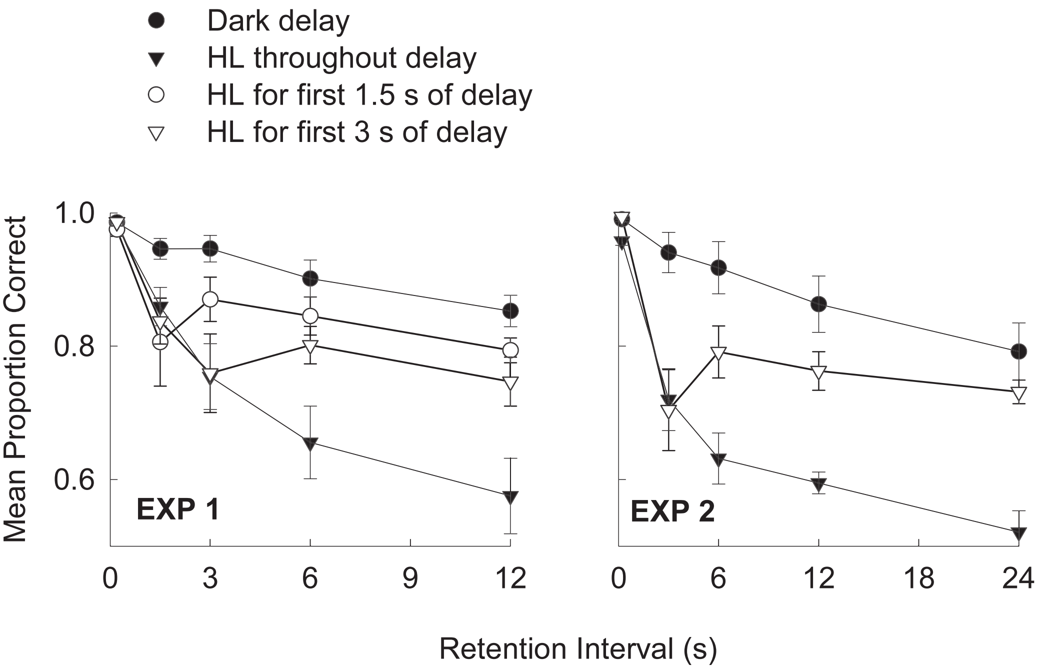

Fig. 1. Mean proportion correct as a function of retention interval for conditions with a dark retention interval (filled circles), the houselight (HL) lit throughout the retention interval (filled triangles), and the houselight lit for the first 1.5 s or 3 s of the retention interval (unfilled circles and triangles, respectively) in Experiment 1 (left panel, $n = 5$) and Experiment 2 (right panel, $n = 4$). Error bars are standard errors of the mean.

were transilluminated and the choice response was made in the otherwise dark chamber. Owing to the random order of retention intervals within a session, the duration of a particular interval could not be predicted by the pigeon at the beginning of the trial.

Following a further 22 sessions of training with dark retention intervals, 8 sessions of a third interference condition occurred. In this, the experimental chamber was illuminated by the houselight only for the first 3 s of each retention interval. Another 22 sessions of training with dark retention intervals were followed by 8 sessions of a fourth interference condition, in which the houselight was lit for the entire retention interval.

Data Analysis

Because we planned to compare performance in each of the interference conditions to performance in baseline sessions in which the retention interval was always dark, an important element of the present design was repeating the blocks of baseline sessions so that stable performance could be assessed. Data analysis was based on the total correct and error choices following red and green samples for each delay. Correct and error choices were summed over all eight sessions of each interference condition or the last eight sessions of each of the three blocks of baseline sessions with dark retention intervals conducted between the interference conditions. Across the three dark baseline conditions there were no statistically significant differences in overall accuracy or interactions with delay according to a repeated-measures analysis of variance. That is, performance in baseline conditions was stable across the experiment, and there was no effect of continued training. Accordingly, the forgetting functions for dark retention intervals were based on averages over the three baseline conditions.

RESULTS AND DISCUSSION

In order to summarize the main result, Figure 1 (left panel) shows mean proportion correct (averaged across pigeons) plotted as a function of retention interval for the baseline conditions with dark retention intervals and the last three interference conditions with the houselight lit throughout the delay, the houselight lit for the first 1.5 s of the delay, and the houselight lit for the first 3 s of the delay. Error bars are standard errors of the mean. Consistent with many previous demonstrations of retroactive interference in the DMTS procedure (Cook, 1980; D'Amato, 1973; Harper & White, 1997; Roberts & Grant, 1978; White, 1985), illumination of the houselight throughout the retention interval produced a substantial reduction in accuracy compared to the effect of a dark retention interval, particularly at longer delays. Longer houselight durations produced greater reductions in accuracy as previously shown by Roberts and Grant (1978) and Harper and White (1997).

The main question of interest is whether accuracy changed when the normally dark retention interval was reinstated after a short period of houselight illumination. In the condition with the houselight lit for the first 1.5 s of the delay, average accuracy at 3 s was higher than at 1.5 s. In the condition with the houselight lit for the first 3 s, accuracy at 6 s was higher than at 3 s. In both conditions, accuracy at 6- and 12-s retention intervals was substantially higher than the corresponding levels of accuracy when the chamber was illuminated by the houselight throughout the retention interval. At 6- and 12-s retention intervals, accuracy did not differ systematically when the houselight was lit for the first 1.5 s of the retention interval and when the retention interval was dark throughout. In other words, the function for the condition with the houselight lit for the first 1.5 s of the delay was initially consistent with the function obtained when the houselight was lit throughout the delay, but reversed to become consistent with the function for the completely dark retention interval. Although the function for the condition with the houselight lit for the first 3-s of the delay showed a similar reversal, it remained below the function for the dark retention interval at 6- and 12-s retention intervals. Nonetheless, it did not differ systematically at 6- and 12-s retention intervals from the function for the condition with the houselight lit for the first 1.5 s of the delay.

Figure 2 shows that there were marked individual differences in the extent of change in the partial houselight-illumination conditions. In Figure 2 the same functions for the conditions with a dark retention interval and with the houselight lit throughout the retention interval are plotted in all three panels for each pigeon. For the condition with the houselight lit for the first 1.5 s of the retention interval, for Pigeons L4 and L5, recovery from retroactive interference occurred immediately by the 3-s retention interval (Figure 2, left panels). For Pigeons L1 and L2, such recovery did not occur until the 6- or 12-s retention interval. For Pigeon L3 the forgetting function did not reverse, perhaps because accuracy was overall high in all conditions. Nonetheless, Pigeon L3 was overall more accurate in the condition in which the houselight was lit for the first 1.5 s than in the condition in which the houselight was lit throughout the retention interval, a feature common to all pigeons.

In the condition with the houselight lit for the first 1.5 s of the retention interval, there appeared to be almost full recovery of accuracy after reinstatement of the dark delay by the 6- and 12-s retention intervals. At these retention intervals, proportion correct was not systematically different than it was during baseline conditions. In the condition with the houselight lit for the first 3 s (Figure 2, right panels), recovery of accuracy from retroactive interference when the dark retention interval was reinstated was only partial. Average accuracy at the 6- and 12-s retention intervals was lower than in the baseline condition with dark retention intervals, but higher than when the houselight was lit through the entire retention interval. Clear reversals in the forgetting functions for this condition are evident for Pigeons L2 and L5, but less so for the other pigeons.

The results of the retroactive interference conditions described in Figures 1 and 2 generally involved a reversal of the forgetting function. When the experimental chamber was illuminated by the houselight for the first 1.5 or 3 s of the retention interval, accuracy was virtually identical to accuracy at 1.5 and 3 s when the houselight was lit for the entire retention interval. Once darkness was reinstated later in the retention interval, accuracy increased toward the level associated with the condition in which the retention interval was always dark. The results of the first interference condition in which the houselight was lit after 1.5 s of each retention interval showed the opposite pattern (Figure 2, center panels). This condition served to control for the possible effects of general disruption. The

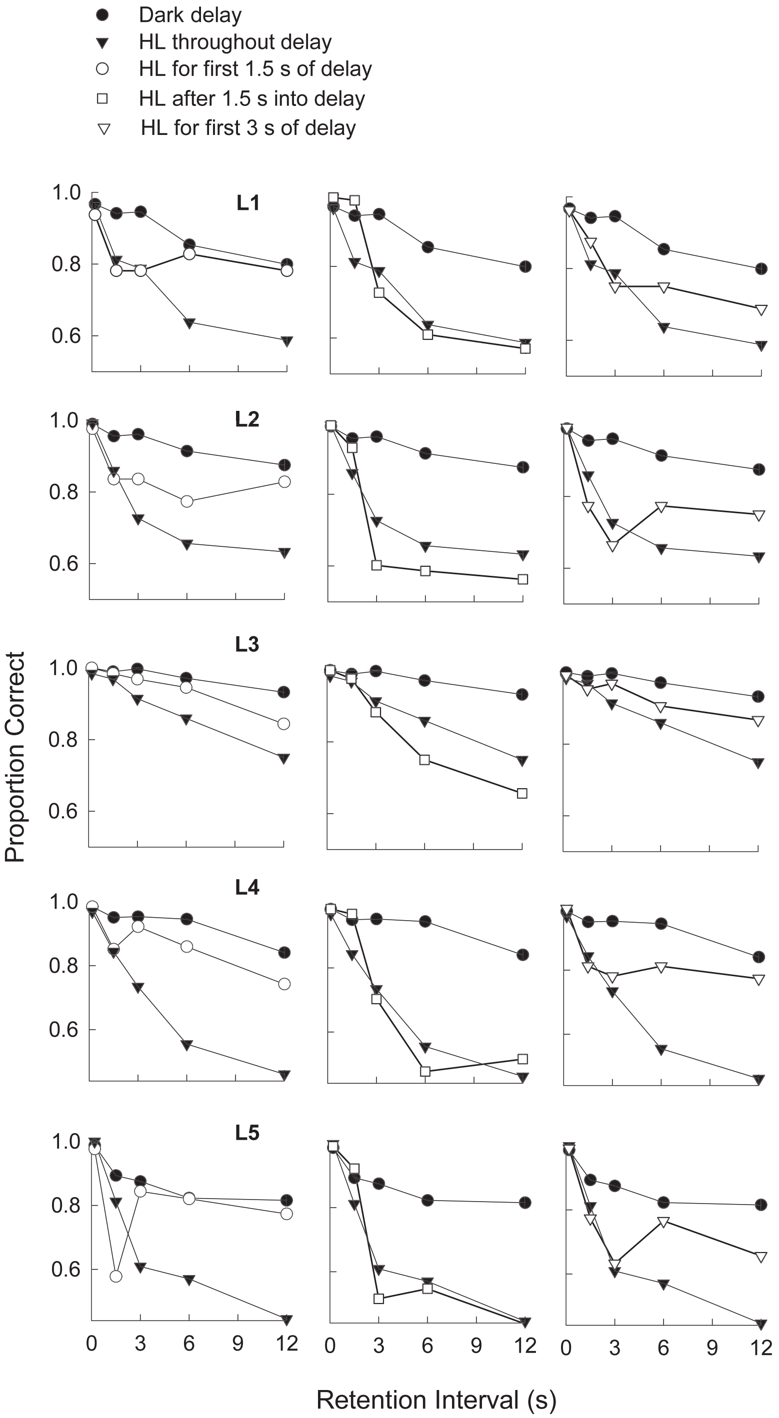

Fig. 2. Mean proportion correct as a function of retention interval for conditions with a dark retention interval (filled circles), the houselight lit throughout the retention interval (filled triangles), and the houselight lit for the first 1.5 s (left panels, unfilled circles) or the first 3 s (right panels, unfilled triangles) of the retention interval, or from 1.5 s into the retention interval (center panels, unfilled squares), for individual pigeons in Experiment 1. Mean proportions correct were based on eight sessions for each condition and were averaged over replications of the baseline condition with dark retention intervals. *Note.* The same functions for the dark retention interval and with the houselight lit throughout the retention interval are plotted in all three sets of panels.

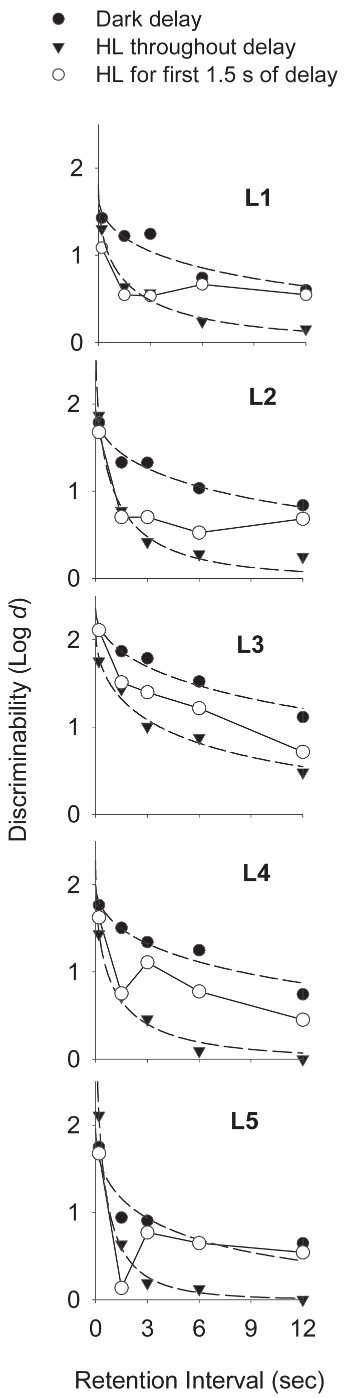

Fig. 3. Measures of discriminability, Log *d*, as a function of retention-interval duration for individual pigeons in Experiment 1, for the condition with the houselight lit for the first 1.5 s of the retention interval (unfilled circles), and with exponential functions in the square root of time fitted to the data for conditions in which the retention interval was dark (upper, filled circles)

←

or in which the houselight was lit throughout the retention interval (lower function, filled triangles).

result was a reduction in accuracy to the same level as that when the houselight was lit for the entire retention interval. The same result was reported by White (1985), but in the present experiment, the symmetry between the increase and decrease in accuracy as a result of changing the level of interference partway through the retention interval is remarkable.

The present result does not depend on the measure of performance adopted. Here we used proportion correct, consistent with the majority of previous studies of DMTS. Our own preference is a measure of discriminability, Log *d*, especially in the context of fitting mathematical functions to the data (White, 2001). As an example, Figure 3 shows that the data for the baseline conditions and conditions in which the houselight was lit throughout the delay were well fitted by exponential functions in the square root of time. The log *d* values in Figure 3 (log of the geometric means of the ratios of correct to error responses) included a 0.5 correction to all response totals, as recommended by Brown and White (2005b). As in the left panel of Figure 2, the function for the condition in which the houselight was lit for the first 1.5 s of the retention interval tended to move from the lower fitted function to the higher function, consistent with the notion discussed in the General Discussion that there may be different time-independent *levels of interference* during the retention interval.

EXPERIMENT 2

In Experiment 1, reversal of the forgetting function was obvious only for some pigeons and was less clear in the condition in which the houselight was lit for the first 3 s of the retention interval. A marked difference between the pigeons was in the overall level of accuracy in DMTS performance. The pigeon (L3) that did not show recovery of accuracy was highly accurate; that is, recovery may have been masked by a potential ceiling effect. Experiment 2 repeated the procedure of Experiment 1 with the same pigeons. The difference, however, was in the set of retention intervals, which were generally doubled in duration in order to generate overall lower levels of accuracy. An additional reason for conducting Experiment 2 was that the lower likelihood of reversed forgetting functions, in the condition with the houselight lit for the first 3 s of the retention interval, may have been the result of a greater reduction in accuracy over the first few seconds of the retention interval than in the condition with the houselight lit for the first 1.5 s. Arguably, and contrary to the notion that remembering is delay-specific (White, 2002), this might have been the case if control by the sample stimuli later in the retention interval depended on the extent of control early in the interval. Therefore, lengthening the retention intervals in Experiment 2 also could be associated with a lower likelihood of reversing the forgetting function.

Method

Four pigeons from Experiment 1 were trained in exactly the same apparatus and procedure as in Experiment 1. The 5th pigeon, L1, became ill and was retired from the experiment. The single difference in the procedure was that the retention intervals were varied within sessions over durations of 0.2, 3, 6, 12, and 24 s. After the completion of Experiment 1, 80 sessions were conducted with the set of longer delays, in order to ensure stable DMTS performance. Following this preliminary training, another 22 baseline sessions were conducted with dark retention intervals, followed by 8 sessions in which the experimental chamber was illuminated by the houselight for the first 3 s of each retention interval. Next, after a further 22 baseline sessions with dark retention intervals, 8 sessions were conducted in which the houselight was lit throughout the retention interval. Finally, an additional 22 sessions in the baseline procedure with dark retention intervals was followed by 8 sessions in a repetition of the condition where the houselight was lit for the first 3 s of each retention interval.

Results and Discussion

As in Experiment 1, the important comparisons were between the training conditions in which the retention intervals were dark throughout, and the interference conditions which included houselight illumination. Performance remained stable across the three baseline conditions. Accuracy was averaged over these three conditions, and also averaged over the two conditions in which the houselight was lit for the first 3 s of each delay. The overall level of accuracy did not differ between these two conditions.

Figure 1 (right panel) shows the mean proportion correct for the three different conditions. Accuracy in the first 3 s in the condition in which the houselight was lit for the first 3 s of the retention interval was the same as in the condition in which the houselight was lit for the entire retention interval. This is expected because the houselight was lit for first 3 s of the retention interval in both cases. In the condition with the houselight lit for the first 3 s, however, accuracy increased from the 3- to the 6-s retention intervals. This increase occurred for all 4 pigeons. Figure 1 also shows that by the 24-s delay, accuracy reached a similar level as in the baseline condition with dark retention intervals.

Figure 4 shows that each of the 4 pigeons exhibited reversed forgetting functions. The function for Pigeon L2 is of particular interest. Although the function for the condition with the houselight lit for the first 3 s of the retention interval did not reach the highly accurate level of baseline performance at 24 s, the forgetting function for this condition increased monotonically from 3 to 24 s.

Recovery of accuracy was observed in Experiment 2 in two ways. First, accuracy increased from the 3- to the 6-s delay. Second, despite the houselight being turned on and reducing accuracy near the start of the retention interval, accuracy recovered to a similar level to that found in dark baseline conditions when the houselight was turned off after 3 s. This latter result was not the case for Pigeon L2, despite its monotonically increasing forgetting function from the 3-s retention interval.

GENERAL DISCUSSION

In the present experiments, a high level of accuracy in a DMTS task was established when the retention interval was dark, and a marked reduction in accuracy with increasing retention-interval duration resulted from illuminating the experimental chamber during the retention interval. This result is well estab-

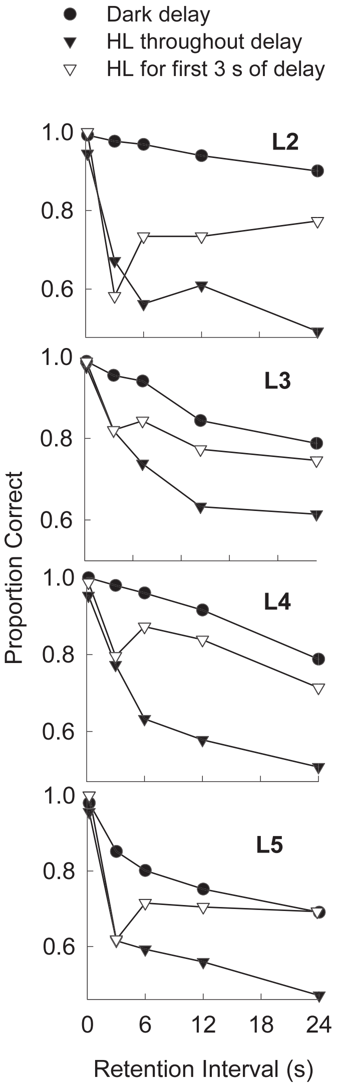

Fig. 4. Proportion correct as a function of retention interval for conditions with a dark retention interval (filled circles), and with houselight lit for the first 3 s of the retention interval (unfilled triangles), or throughout the retention interval (filled triangles), for individual pigeons in Experiment 2.

lished (Cook, 1980; Harper & White, 1997; Roberts & Grant, 1978; White, 1985) and is interpreted as retroactive interference. Because behavior during the retention interval is not associated with a specific task that is similar to the main task, the retroactive interference is *nonspecific*, to use Wixted's (2004, 2010) term. The result of main interest in the present experiments, however, is the increase in accuracy from an early stage in the retention interval in which accuracy was reduced by retroactive interference, to later times in which the dark retention interval was reinstated. Only for some individual pigeons was the reversal complete in that accuracy recovered to the level of the forgetting function for baseline conditions in which retention intervals were dark. In both experiments, however, there were many individual instances in which accuracy at the point of interference reduction (when the houselight was turned off) was lower than later in the retention interval. Such reversals of the forgetting function suggest a dissociation of forgetting from the passage of time.

In studies of human short-term memory, reversals have been reported by Turvey et al. (1970) and Unsworth et al. (2008), as noted above. Reversed forgetting functions have also been reported in the context of several prior studies of DMTS in nonhuman animals and are generally consistent with the present result. In an experiment in which five retention intervals were included within sessions of a DMTS task, White (2001) reinforced correct matching responses of pigeons at all retention intervals except one. Accuracy decreased at that retention interval, relative to shorter and longer intervals. The reverse version of this study was reported by Nakagawa, Etheridge, Foster, Sumpter, and Temple (2004), who reinforced correct responses of hens at a 4-s retention interval in a DMTS task, but not at 0-s or 16-s retention intervals. Accuracy was higher at the 4-s retention interval than at the shorter or longer retention intervals. That is, remembering can be more accurate at one time than at other shorter or longer times, despite the fact that retention-interval duration is varied unpredictably within the experimental session. Reversals in the forgetting functions reported by Sargisson and White (2001) in which highest matching accuracy tended to occur at the retention interval with which pigeons were trained, can be construed as instances of generalization along the temporal dimension of the retention interval (Rayburn-Reeves & Zentall, 2009; White, 2001). These are nonetheless instances of reversed forgetting functions which are nonmonotonic or irregular in time.

Reversed forgetting functions are also evident in two earlier studies. In these, each of two retention intervals was accompanied by a specific cue or signal. Wasserman, Grosch, and Nevin (1982) used different line orientations, or different auditory stimuli, to signal short and long retention intervals within sessions. Following training with the signalled retention-interval procedure, tests were conducted in which the relation between the signals and retention intervals was reversed. In their Experiment 2, accuracy was lower at the long retention interval during training, but during testing when the cues signaling retention-interval duration were reversed, accuracy was higher at the long retention interval than at the short retention interval. The same result was reported by McDonald and Grant (1987); low accuracy that was specific to the long delay during training transferred to the short delay when the cue was reversed.

In the studies by Wasserman et al. (1982) and McDonald and Grant (1987), it is perhaps not surprising that the cue gained such strong stimulus control, as shown by the effect of reversing it. In the experiments reported by White (2001) and Nakagawa et al. (2004), the duration of the retention interval itself could serve as a discriminative stimulus to signal the differential consequences of correct responding. Nevertheless, it is of interest that accuracy can improve from a shorter retention interval to a longer interval given the usual assumption that a decline in accuracy with increasing time is inevitable. In the present experiments, there were no explicit cues or differential reinforcement. Illumination of the experimental chamber by houselight at the beginning of a retention interval led to a reduction in accuracy, but interestingly, performance recovered within a retention interval when the source of interference was removed or reduced.

In the seminal short-term memory studies with pigeons (Blough, 1959) and humans (Brown, 1958; Peterson & Peterson, 1959), the passage of time was emphasized as the main determinant of forgetting. Time was supposed to generate forgetting, either through trace decay or through an inability to maintain rehearsal behaviors. Well before then, McGeoch (1932) had dismissed trace decay as a cause of forgetting. His grounds were that forgetting may be caused by a time-related process, but not directly by the passage of time. Despite continued support for versions of trace-decay theory (Barrouillet, Bernardin, & Camos, 2004; Cowan, Saults, & Nugent, 1997; Portrat, Barrouillet, & Camos, 2008) there are now strong arguments against trace decay (Berman, Jonides, & Lewis, 2009; Brown & Lewandowsky, 2010; Lewandowsky, Oberauer, & Brown, 2009; Nairne, 2002; Surprenant & Neath, 2009). The main strategy has been to show that remembering does not necessarily worsen with time, and that forgetting can occur even when rehearsal is not prevented. Laming and Scheiwiller (1985) had pointed out earlier that any demonstration of an increase in remembering accuracy with increasing time would constitute evidence for a dissociation of forgetting from the passage of time and would thus contradict the notion of trace decay as a cause of forgetting. The present results seem to provide strong evidence for this view.

Can the present result be accounted for in terms of influences that seem unrelated to the memory task? Roberts and Grant (1978) reported a ''beginning–end effect'' in which accuracy in a DMTS task with a single delay was lower when a houselight was lit for a certain time at the end of the retention interval than for the same time at the beginning of the retention interval. They considered and rejected three hypotheses for reduced accuracy when the houselight was lit until the time of choice. Two hypotheses related to attenuated or altered perception of the comparison stimuli compared to the samples as a result of illuminating the chamber. The third related to continued random pecking of side keys during the illuminated delay interval. Although these hypotheses were rejected by Roberts and Grant, they could potentially account for reduced accuracy in the present experiment when comparison-stimulus choice immediately followed short delays when the experimental chamber was illuminated. A more general version of these hypotheses is ''generalization decrement'' in which choice responses after short delays following houselight illumination are made under relatively novel conditions, compared to the familiar conditions of dark delays. In other words, illumination of the experimental chamber resulted in a general disruption of stimulus control.

There are three arguments against the generalization-decrement hypothesis. First, if delayed control by the sample stimulus was disrupted early in the retention interval, the disruption might be expected to generalize to later times in the retention interval. A loss of stimulus control on either a certain proportion of the trials or in a certain proportion of the retention interval cannot account for recovery because the loss would place a ceiling on accuracy of performance. Second, illumination of the chamber by the houselight did not constitute a novel situation because in 8 of the 28 sessions of many conditions the experimental chamber was illuminated by the houselight in each session, for all or part of the retention interval. Third, Harper and White (1997) showed that a fixed duration of houselight illumination resulted in a proportionally constant reduction in accuracy, independent of the point in the retention interval at which the houselight was introduced. An appeal to generalization decrement to account for the temporary reduction in accuracy does not seem plausible. A possible way to test the generalization-decrement hypothesis might be to reverse the training and testing conditions so that the pigeons are trained under conditions in which the experimental chamber is illuminated throughout the retention interval and tested in conditions in which the chamber is dark. Cook (1980) did just this (but without the novel conditions of the present experiments), and showed that darkening the normally illuminated chamber resulted in reduced accuracy. The extent of the reduction, however, was not as great as when a normally dark chamber was illuminated during the retention interval. A general disruption of stimulus control might only partly account for the present result, and as discussed below, a more likely source of interference is from behaviors influenced by extraneous reinforcement which compete with task-related behaviors (Brown & White, 2005a).

In nonhuman memory tasks, nonspecific interference is the likely cause of forgetting. In DMTS tasks with pigeons, illumination of the experimental chamber results in an increased rate of forgetting, as in the present experiments, and the pigeons are likely to engage in behaviors extraneous to the remembering task. The negatively accelerated decrement in accuracy can be accounted for in terms of the increasing duration of the houselight over the course of the retention interval—when the duration for which the houselight is lit is held constant at different points in the retention interval, the forgetting function shows only a reduction in intercept without an increase in rate of forgetting (Harper & White, 1997). There is also considerable evidence that interference is the major cause of human forgetting (Jonides et al., 2008; Nairne, 2002; Wixted, 2004) although ''interference'' has been construed theoretically from a variety of viewpoints (Lewandowsky et al. 2009).

An appeal to interference has the advantage that it can apply to forgetting over both short and long times (Melton, 1963). In the DMTS procedure, interference is generated by several sources, including prior trials (White, Parkinson, Brown, & Wixted, 2004) and extraneous stimuli during the retention interval (Jans & Catania, 1980; Brown & White, 2005a, 2009), particularly when the houselight is lit. As more time passes, the likelihood increases that control by extraneous stimuli increases. Accuracy therefore declines with increasing retention-interval duration. With less interference, stimulus control by the DMTS task increases. Thus there may be different *levels of interference* during a retention interval. Normally, the levels increase systematically as the retention interval proceeds, with the nature of the increase determining the form of the forgetting function. When the retention interval is dark, the interference level is generally low. When the experimental chamber is illuminated by the houselight during the retention interval, the level of nonspecific interference is high. By switching from one level to another, accuracy of remembering can switch from low to high or vice versa, thus generating a dissociation of forgetting from the passage of time. According to the discrimination hypothesis for remembering (White, 2001, 2002), because the discrimination at a long delay following a period of darkness in the retention interval is independent from the discrimination at a short delay in which the retention interval is accompanied by houselight illumination, it is possible for accuracy at the long delay to be higher than at the short delay, especially if control by the DMTS task is strong. One early result supports this interpretation. By manipulating the conditions for reinforcement, Heinemann, Chase and Mandell (1968) demonstrated that pigeons' attention to a discrimination could be turned on or off by a contextual cue that indicated whether the discrimination was relevant or not. Such an attentional or stimulus control account of performance in DMTS is consistent with both the discrimination hypothesis for remembering (White, 2002) and with the reinforcement-based theory proposed by Nevin, Davison, Odum, and Shahan (2007). Application of their theory to the present result would require the plausible assumption that in the partial houselight conditions, reinstating the dark retention interval would be associated with a decrease in the level of reinforcement from sources extraneous to the DMTS task. A test of this assumption would require variation in the relative reinforcer probability for correct matching responses along with a repetition of the present partial-interference conditions. Such an experiment is yet to be conducted, but might show different effects of varying the reinforcer probability on accuracy in light and dark periods of the retention interval.

REFERENCES

Barrouillet, P., Bernardin, S., & Camos, V. (2004). Time constraints and resource sharing in adults' working memory spans. *Journal of Experimental Psychology: General, 133*, 83–100.

Berman, M. G., Jonides, J., & Lewis, R. L. (2009). In search of decay in verbal short-term memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 25*, 317–333.

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

Brown, J. (1958). Some tests of the decay theory of immediate memory. *Quarterly Journal of Experimental Psychology, 10*, 12–21.

Brown, G. D. A., & Lewandowsky, S. (2010). Forgetting in memory models. In S. D. Salla (Ed.), *Forgetting* (pp. 49–75). Hove, Sussex: Psychology Press.

Brown, G. S., & White, K. G. (2005a). Remembering: The role of extraneous reinforcement. *Learning & Behavior, 33*, 309–323.

Brown, G. S., & White, K. G. (2005b). The optimal correction for estimating extreme discriminability. *Behavior Research Methods, 37*, 436–449.

Brown, G. S., & White, K. G. (2009). Reinforcer probability, reinforcer magnitude, and the reinforcement context for remembering. *Journal of Experimental Psychology: Animal Behavior Processes, 35*, 238–249.

Cook, R. G. (1980). Retroactive interference in pigeon short-term memory by a reduction in ambient illumination. *Journal of Experimental Psychology: Animal Behavior Processes, 6*, 326–338.

Cowan, N., Saults, J. S., & Nugent, L. D. (1997). The role of absolute and relative amounts of time in forgetting within immediate memory: The case of tone–pitch comparisons. *Psychonomic Bulletin & Review, 4*, 393–397.

D'Amato, M. R. (1973). Delayed matching and short-term memory in monkeys. In G. H. Bower (Ed.), *The psychology of learning and motivation: Advances in research and theory* (pp. 227–269). New York: Academic Press, *7*.

Grant, D. S. (1981). Short-term memory in the pigeon. In N. E. Spear, & R. R. Miller (Eds.), *Information processing in animals: Memory mechanisms* (pp. 227–256). Hillsdale, NJ: Erlbaum.

Greene, R. L. (1996). The influence of experimental design: The example of the Brown-Peterson paradigm. *Canadian Journal of Experimental Psychology, 50*, 240–242.

Harper, D. N., & White, K. G. (1997). Retroactive interference and rate of forgetting in delayed matching-to-sample performance. *Animal Learning & Behavior, 25*, 158–164.

Heinemann, E. G., Chase, S., & Mandell, C. (1968). Discriminative control of attention. *Science, 160*, 553–555.

Jans, J. E., & Catania, A. C. (1980). Short-term remembering of discriminative stimuli in pigeons. *Journal of the Experimental Analysis of Behavior, 34*, 177–183.

Jonides, J., Lewis, R. L., Nee, D. E., Lustig, C. A., Berman, M. G., & Moore, K. S. (2008). The mind and brain of short-term memory. *Annual Review of Psychology, 59*, 193–224.

Laming, D., & Scheiwiller, P. (1985). Retention in perceptual memory: A review of models and data. *Perception & Psychophysics, 37*, 189–197.

Lewandowsky, S., Oberauer, K., & Brown, G. D. A. (2009). No temporal decay in verbal short-term memory. *Trends in Cognitive Sciences, 13*, 120–126.

McDonald, 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.

McGeoch, J. A. (1932). Forgetting and the law of disuse. *Psychological Review, 39*, 352–370.

Melton, A. W. (1963). Implications of short-term memory for a general theory of memory. *Journal of Verbal Learning and Verbal Behavior, 2*, 1–21.

Nairne, J. S. (2002). Remembering over the short-term: The case against the standard model. *Annual Review of Psychology, 53*, 53–81.

Nakagawa, S., Etheridge, R. J. M., Foster, T. M., Sumpter, C. E., & Temple, W. (2004). The effects of changes in consequences on hens' performance in delayed-matching-to-sample tasks. *Behavioural Processes, 67*, 441–451.

Nevin, J. A., Davison, M., Odum, A. L., & Shahan, T. A. (2007). A theory of attending, remembering, and reinforcement in delayed matching to sample. *Journal of the Experimental Analysis of Behavior, 88*, 285–317.

Peterson, L. R., & Peterson, M. (1959). Short-term retention of individual items. *Journal of Experimental Psychology, 58*, 193–198.

Portrat, S., Barrouillet, P., & Camos, V. (2008). Time-related decay or interference-based forgetting in working memory? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 34*, 1561–1564.

Rayburn-Reeves, R., & Zentall, T. R. (2009). Animal memory: The contribution of generalization decrement to delayed conditional discrimination retention functions. *Learning & Behavior, 37*, 299–304.

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., & Grant, D. S. (1976). Studies of short term memory in the pigeon using the delayed matching-to-sample procedure. In D. L. Medin, W. A. Roberts, & R. T. Davis (Eds.), *Processes of animal memory.* Hillsdale, N.J.: Erlbaum.

Roberts, W. A., & Grant, D. S. (1978). An analysis of light-induced retroactive inhibition in pigeon short-term memory. *Journal of Experimental Psychology: Animal Behavior Processes, 4*, 219–236.

Roediger, H. L. (2008). Relativity of remembering: Why the laws of memory vanished. *Annual Review of Psychology, 59*, 225–254.

Rubin, D. C., & Wenzel, A. E. (1996). One hundred years of forgetting: A quantitative description of retention. *Psychological Review, 103*, 734–760.

Sargisson, R. J., & White, K. G. (2001). Generalization of delayed matching-to-sample performance following training at different delays. *Journal of the Experimental Analysis of Behavior, 75*, 1–14.

Staddon, J. E. R. (1983). *Adaptive behavior and learning.* Cambridge, England: Cambridge University Press.

Surprenant, A. M., & Neath, I. (2009). *Principles of memory.* NY: Psychology Press.

Turvey, M. T., Brick, P., & Osborn, J. (1970). Proactive interference in short-term memory as a function of prior-item retention interval. *Quarterly Journal of Experimental Psychology, 22*, 142–147.

Unsworth, N., Heitz, R. P., & Parks, N. A. (2008). The importance of temporal distinctiveness for forgetting over the short term. *Psychological Science, 19*, 1078–1081.

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.

White, K. G. (2001). Forgetting functions. *Animal Learning & Behavior, 29*, 193–207.

White, K. G. (2002). Psychophysics of remembering: The discrimination hypothesis. *Current Directions in Psychological Science, 11*, 141–145.

White, K. G. (in press). Remembering and forgetting. In G. Madden (Ed.), *Handbook of behavior analysis.* New York: APA Books.

White, K. G., Parkinson, A. E., Brown, G. S., & Wixted, J. T. (2004). Local proactive interference in delayed matching to sample: The role of reinforcement. *Journal of Experimental Psychology: Animal Behavior Processes, 30*, 83–95.

White, K. G., Ruske, A. C., & Colombo, M. (1996). Memory procedures, performance and processes in pigeons. *Cognitive Brain Research, 3*, 309–317.

Wixted, J. T. (2004). The psychology and neuroscience of forgetting. *Annual Review of Psychology, 55*, 235–269.

Wixted, J. T. (2010). The role of retroactive interference and consolidation in everyday forgetting. In S. D. Salla (Ed.), *Forgetting* (pp. 285–312). Hove, Sussex: Psychology Press.

Wixted, J. T., & Carpenter, S. K. (2007). The Wickelgren Power Law and the Ebbinghaus Savings Function. *Psychological Science, 18*, 133–134.

Wixted, J. T., & Ebbesen, E. B. (1991). On the form of forgetting. *Psychological Science, 6*, 409–415.

Woodworth, R. S., & Schlosberg, H. (1954). *Experimental psychology: Revised edition.* New York: Holt, Rinehart and Winston.

Received: March 21, 2011
Final Acceptance: June 24, 2011