

*SUPPORT FOR A THEORY OF
MEMORY FOR EVENT DURATION MUST
DISTINGUISH BETWEEN TEST-TRIAL
AMBIGUITY AND ACTUAL MEMORY LOSS*

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Staddon and Higa's (1999) trace-strength theory of timing and memory for event duration can account for pigeons' bias to "choose short" when retention intervals are introduced and to "choose long" when, following training with a fixed retention interval, retention intervals are shortened. However, it does not account for the failure of pigeons to choose short when the intertrial interval is distinct from the retention interval. That finding suggests that stimulus generalization (or ambiguity) between the intertrial interval and the retention interval may result in an effect that has been attributed to memory loss. Such artifacts must be eliminated before a theory of memory for event duration can be adequately tested.

Key words: temporal discrimination, delayed matching, conditional discrimination, instructional failure, confusion, key peck, pigeons

As others have elegantly noted in response to Staddon and Higa's (1999) provocative pacemaker-free theory of interval timing (Killeen, 1999; Shimp, 1999), the development of an alternative theory to account for a finding, be it transposition (Spence, 1937, in reaction to Kohler, 1929), transitive inference (Fersen, Wynne, Delius, & Staddon, 1991, in response to Gillan, 1981), or timing (Staddon & Higa, 1999, in response to Gibbon, 1977), will inevitably advance our understanding of the phenomenon. It will do so because it tends to shift the focus of research from the examination of data consistent with the theory to the search for critical tests of each theory. But even when this approach does not yield a clear answer as to which theory is correct (because inevitably both theories survive enough critical tests to maintain their credibility), it can stimulate creative research that often reveals much about behavior.

Staddon and Higa's (1999) pacemaker-free model of timing is just such a theory. By substituting strength of memory trace for accumulation of pulses, this clock-free model appears to be able to account for much of the data for which it was assumed that a clock was

necessary. As Shimp (1999) has noted, parsimony is not always easy to define, but Staddon and Higa's model clearly has fewer "moving parts." Furthermore, this trace-strength theory can be applied to other phenomena associated with timing for which it would be difficult to imagine a clock-based explanation.

The application of the trace-strength notion to memory for event duration has also resulted in an elegant and simple account of the so-called choose-short effect (Spetch & Wilkie, 1983). Pigeons can easily learn to choose one comparison stimulus following the presentation of a short-duration (2-s) light but to choose the alternative comparison following a long-duration (8-s) light. If pigeons are trained with no delay between the end of the duration event and the comparison stimuli and then delays are introduced, the resulting retention functions show a clear bias. On short-event trials, matching accuracy is high and remains high over extended delays, whereas on long-event trials, matching accuracy drops rapidly with increasing retention interval, often to a point well below chance (see, e.g., Spetch & Wilkie, 1983, Figure 2). This quite counterintuitive finding is easily predicted from a trace-strength model if one assumes that the trace of a long-duration stimulus (or, more accurately, the difference in trace between the onset and offset of a long-duration stimulus) is of greater magnitude than the trace of a

Preparation of this commentary was supported by Grant MH59194 from the National Institute of Mental Health.

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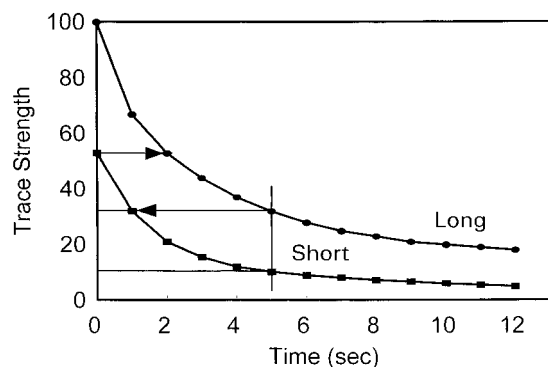


Fig. 1. Staddon and Higa's (1999) trace strength model of memory for event duration. The model can account for the choose-short effect because, following training with no retention interval, the trace strength of a long-duration event after a 2-s retention interval is approximately the same as that of a short-duration event during training. The model can also account for the choose-long effect because, following training with, for example, a 5-s retention interval, the trace strength of a short-duration event after about a 1-s retention interval is approximately the same as that of a long-duration event during training.

short-duration stimulus and that both traces decay with time (see Figure 1; after Staddon & Higa, 1999, Figure 11). A useful metaphor for this model is that of a water bucket that is filled during event presentation (the longer the event, the more water is poured into the bucket). But this bucket has a hole in it that allows water to leak out with time. Thus, the performance established during training can be described by the rules: If the "water level" is high, choose one alternative, if the "water level" is low, choose the other. As the retention interval increases, the water level following a long event becomes more similar to what it was in training following a short event. In Figure 1, after about a 2-s retention interval, the trace strength of a long sample would be about the same as the trace strength of a short sample in training with no retention interval.

Although the assumption of event-duration/retention-interval trade-off is not unreasonable, it is also not obvious why it should be true. After all, one could just as easily assume that event duration is coded "categorically" as "short" and "long," and that trace strength is dependent only on the time since event termination.

For reasons unrelated to tests of the differential trace-strength account of the choose-

short effect, we asked recently whether the choose-short effect might result, at least in part, from the similarity between the novel retention intervals and the familiar intertrial interval, because these events are typically very similar, dark intervals (Sherburne, Zentall, & Kaiser, 1998). If on test trials involving novel retention intervals, pigeons "confuse" the retention interval with the intertrial interval, then they may behave as if the retention interval is an end-of-trial event, and the appearance of the comparison stimuli is the start of a new trial. Such confusion or stimulus ambiguity would result in a choose-short effect because on these apparently eventless trials, the absence of an event (or an event that was presented for such a short duration that it was missed entirely) should functionally be more similar to a short event than to a long event. Furthermore, the magnitude of the choose-short effect should be proportional to the similarity between the retention interval and the intertrial interval (both in appearance and in duration).

To test this hypothesis, we trained two groups of pigeons on a 0-s-delay event-duration matching task (Sherburne et al., 1998). For one group, the intertrial intervals were dark during training, and for the other group they were lit. On test trials, for both groups, we introduced retention intervals that were sometimes dark and sometimes lit. Furthermore, for both groups, on some trials the intertrial intervals were dark and on other trials they were lit. According to the ambiguity hypothesis, if divergent retention functions result from confusion (or generalization) between the intertrial interval experienced during training and the retention interval encountered on test trials, then divergent retention functions should be found on test trials only when the ambient light conditions during the retention interval matched the ambient light conditions during the intertrial interval *during training*. That is exactly what we found (see Spetch & Rusak, 1992, for similar results).

Evidence that ambiguity between the intertrial interval and the retention interval can account for the divergent retention functions known as the choose-short effect does not argue against the notion of trace decay. It just argues against the differential-trace-strength model, proposed by Staddon and Higa

(1999), in which long events at long retention intervals may be functionally equivalent to short events at short retention intervals.

According to the trace-strength hypothesis proposed by Staddon and Higa (1999), there is no reason why the similarity between the intertrial interval and the retention interval should affect the relative slopes of the retention functions because trace strength should not be affected by illumination of the intertrial interval (the only procedural difference between groups). Furthermore, it is hard to imagine how any modification of this trace-strength theory might account for the elimination of the choose-short effect.

Staddon and Higa (1999) address this problem by suggesting that the parallel retention functions found by Sherburne et al. (1998) represent the development of a different coding process—one in which the event durations are represented by codes having similar trace strengths. According to Staddon and Higa, when the ambient light conditions during the intertrial interval and the retention interval do not match, then the pigeons encode the event durations *prospectively*. That is, they code the events in terms of the appropriate comparison stimulus to which a response will be reinforced, rather than code them retrospectively in terms of the event durations themselves. Thus, if after a short-duration event, a response to the red comparison stimulus is reinforced, then short events are coded as (and remembered as) red. Similarly, long events are coded as green. If the coding process is of this form, parallel retention functions would be expected because the strengths of the red or the green code are presumed to be similar and thus they would be expected to decay at comparable rates.

Although it is true that parallel retention functions are consistent with a prospective coding account, it is not obvious why short and long events of different trace strengths would be converted into prospective red and green codes having equal trace strengths. More important, Staddon and Higa (1999) fail to explain why a mismatch between the ambient light conditions during the intertrial interval and the retention interval should result in a shift from the retrospective coding of the event durations to the prospective coding of the red and green comparison stimuli.

Finally, the direct evidence for prospective coding of comparison stimuli in matching procedures is rather weak.

Indirect evidence for prospective coding comes from findings such as those reported by Sherburne et al. (1998) and Grant and Spetch (1993) in which a particular manipulation results in parallel retention functions when divergent retention functions otherwise would be expected. But parallel retention functions provide an insufficient basis upon which to conclude the involvement of prospective coding processes because there are many ways in which retrospective coding functions may result in parallel retention functions (e.g., nonanalogical or categorical coding).

Other evidence for prospective coding has been attributed to the finding of differences in retention functions between one-to-many matching (when either of two pairs of comparison stimuli are possible) and one-to-one matching (when only one pair of comparisons is possible; Zentall, Jagielo, Jackson-Smith, & Urcuioli, 1987). The argument is that if the pigeons are prospectively coding the comparison stimuli, then they must remember twice as many comparison stimuli in a one-to-many task than in a one-to-one task. But it is also the case that in a one-to-many task, the particular pair of comparisons presented on a given trial is less predictable than in a one-to-one task, because in a one-to-many task either pair of comparisons may follow each sample. Both the prospective-coding hypothesis and the comparison-predictability hypothesis predict poorer matching accuracy for one-to-many matching than for one-to-one matching, but the prospective-coding hypothesis attributes the difference to increasing memory load; thus, it predicts that the difference in matching accuracy will increase with increasing delays. The comparison-predictability hypothesis, on the other hand, attributes the difference in retention between one-to-many matching and one-to-one matching to a constant effect that would not be expected to change with increasing delay. In fact, Zentall et al. (1987) found better matching accuracy over delays on the one-to-one task than on the one-to-many task, but they found no evidence of divergent retention functions as predicted by the prospective-coding hypothesis. Thus, there is no strong evi-

dence for the prospective coding of comparisons following matching-to-sample training. And in the absence of prospective coding of comparison stimuli, parallel retention functions following event-duration matching pose a considerable problem for a trace-strength theory of memory for time of the type proposed by Staddon and Higa (1999).

In all fairness to trace-strength accounts of the choose-short effect, the ambiguity hypothesis does not easily predict results obtained when pigeons are trained on event-duration matching with a fixed delay between the initial duration event and the comparison stimuli and they are then tested with shorter delays. Under these conditions, a choose-long effect has been reported (Spetch & Rusak, 1989, i.e., matching accuracy on long-event trials is generally higher than on short-event trials). However, these results are directly predicted from the multiple trace decay model proposed by Staddon and Higa (1999). In Figure 1, if training occurs with a 5-s retention interval, for example, and testing occurs with shorter intervals, the trace strength of a short-duration sample at the 1-s retention interval will be approximately the same as that of a long-duration sample during training.

To account for the shortened-retention-interval choose-long effect, Sherburne et al. (1998) proposed that when shorter than expected retention intervals are introduced, it not only results in a shorter time between event presentation and test but it also results in a shorter time between the prior trial and test. Thus, shortening the intertrial interval may result in an increase in intertrial interference. In support of this notion, there is evidence that stimuli presented on preceding trials (as well as responses made to them) can be associated with a decline in matching accuracy (Overman & Doty, 1980; Roitblat & Scopatz, 1983). Furthermore, there is evidence that shortening the intertrial interval can also lead to poorer matching accuracy (Roberts, 1972).

But intertrial-interference effects, as they are described in the literature, would be expected to result in a general decrease in matching accuracy rather than more specifically in a tendency for short events to be coded as long. Data reported by Spetch and Sinha (1989) suggest how such a selective intertrial-interference effect might come

about. Spetch and Sinha trained pigeons on event-duration matching and then presented them with double duration-event trials. When the second event was a long duration, there was no decrement in matching accuracy relative to single-event trials, and it did not matter whether the first event was short or long. On the other hand, when the second event was of short duration, matching accuracy was poorer than on single-event trials, but again it did not matter whether the first event was short or long. Spetch and Sinha concluded that the pigeons tended to sum the durations of the two events (rather than code them categorically as short and long), and they did so even when the interval between events was relatively long (e.g., 10 s, comparable to the intertrial interval used in many event-duration studies). Consistent with the hypothesis that the shortened-retention-interval choose-long effect results from an increase in intertrial interference is the fact that a similar choose-long effect can be obtained by decreasing the duration of the intertrial interval (Spetch & Rusak, 1989).

The problem with this account of the choose-long effect is that it requires resurrection of the assumption that long and short events are represented by similar codes that differ only in strength. This is true because if those events had been coded solely in terms of their category (short vs. long), one would have expected symmetrical interference effects. Thus, to account for all of the results of event-duration experiments, it appears that some form of differential trace strength may be needed. But the problem remains that differential trace strength cannot account for the parallel retention functions found by Sherburne et al. (1998).

The notion of ambiguity of stimulus conditions on test trials has further implications for the study of memory for time. Even when the intertrial interval and the retention interval are made distinct for the pigeon, the "meaning" of the novel retention interval may not be clear (see Zentall, 1997). If one objects to the term *meaning*, one can think of the novel retention intervals as producing a generalization decrement, a novelty effect, or a failure of instructions to maintain memory over the retention interval. In any event, the loss in matching accuracy with increasing delay may not be attributable to trace decay or

actual memory loss if those retention intervals are novel.

We are currently investigating this possibility by training pigeons on an event-duration matching task with mixed-duration delays. If differential similarity of the delays to the samples is responsible for the typically found choose-short effect, then such training should result in parallel retention functions. Furthermore, to the extent that retention functions assessed following zero-delay training are attributable to a generalization decrement that increases with increasing delay rather than to a true loss of memory, the resulting retention functions should show little decline with increasing delay (at least over relatively short delays).

In contrast to event-duration matching experiments, the assessment of timing using the peak procedure ordinarily does not suffer from ambiguity at the time of the test because probe trials (i.e., extended-duration trials without reinforcement) are inserted among the reinforced (fixed-interval) trials throughout training. However, ambiguity effects may be present in some of these experiments as well. Specifically, investigators who have studied the effect of break periods inserted for various durations and at various times within a trial may have introduced ambiguity with their manipulation because, in general, the break-period stimuli have had characteristics that have been different from the trial-signaling stimuli but have been similar to the intertrial interval (Cabeza de Vaca, Brown, & Hemmes, 1994; Roberts, Cheng, & Cohen, 1989). Under such conditions, the pigeons often appear to “reset their clocks” during these break periods. However, such results also would be expected if the pigeons treated the break as if it were an intertrial interval. We are currently testing this hypothesis by making the break period distinctive from the intertrial interval. Under such conditions, we expect that the pigeons will not “reset” but instead will show timing behavior that is better described as “stop-retain-restart” behavior. We expect that they will simply stop timing during the break, and they will pick up where they left off when the break is over.

Although the ambiguity hypothesis does not describe an alternative timing mechanism, it should force one to consider its contribution to effects found when tests are con-

ducted using novel stimulus conditions. Furthermore, ambiguity effects are likely to be present whenever animals are tested with retention intervals but they were not trained with them.

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