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THE CHOOSE-SHORT EFFECT AND TRACE MODELS OF TIMING

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The tuned-trace multiple-time-scale (MTS) theory of timing can account both for the puzzling choose-short effect in time-discrimination experiments and for the complementary choose-long effect. But it cannot easily explain why the choose-short effect seems to disappear when the intertrial and recall intervals are signaled by different stimuli. Do differential stimuli actually abolish the effect, or merely improve memory? If the latter, there are ways in which an expanded MTS theory might explain differential-context effects in terms of reduced interference. If the former, there are observational and experimental ways to determine whether differential context favors prospective encoding or some other nontemporal discrimination.

Key words: delayed matching, choose-short, multiple-time-scale theory, prospective encoding, temporal control, rat, pigeon

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We thank Zentall (1999) for his thoughtful comment on Staddon and Higa (1999). His remarks are in the spirit of our paper, which was intended not just to criticize an old theory and propose a new one but also to encourage timing theorists to address a wider range of data.

Limitations of Multiple-Time-Scale Theory

As the title of our paper suggests, multiple-time-scale (MTS) theory is far from complete. Here are some of the omissions: (a) MTS has no explicit assignment-of-credit process. Hence, it cannot predict in an exact way just what stimulus or stimuli the animal will use as time markers. (b) It is not a comprehensive learning model; hence it cannot predict when an animal will develop a nontiming strategy, such as prospective or categorical encoding. (c) MTS treats remembered events as temporal points characterized at later times by a single trace value. Extended stimuli must be treated as pairs of start and stop points. A one-dimensional representation obviously cannot do justice to structural properties of remembered stimuli. In particular, the existing model does not deal with stimulus generalization. (d) The only kind of interaction we discuss in the paper is subtraction of traces. Hence, MTS cannot deal with proactive and retroactive interference among remembered events. (e) MTS has no assumptions to deal with context (i.e., nontemporal stimulus control). Yet there is evidence that context can limit interference effects such as the proactive temporal "overshadowing" involved in the reinforcement-omission effect. Zentall's comments highlight some of these limitations.

The Choose-Short Effect

The training procedure in choose-short-effect experiments is illustrated in Figure 1. The choose-short effect is just the finding that if the two choice stimuli are presented only after a delay (the retention interval: RI), rather than right after the sample (center diagram in Figure 2), pigeons continue to choose correctly after the short stimulus but begin to make errors after the long one, eventually responding less than 50% correct at long retention intervals, a puzzling asymmetry (Spetch & Wilkie, 1982).

MTS theory provides a simple explanation for the choose-short effect and for the complementary choose-long effect—a preference for the long choice after training at a long RI and testing at shorter RIs. But, because it lacks assumptions to deal with either context or interference effects, it does not deal with the results of Spetch and Rusak (1989, 1992a,

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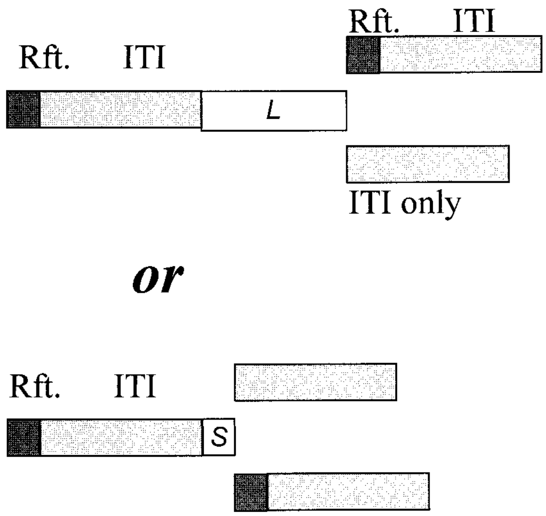

Fig. 1. Training procedure in the Sherburne et al. (1998) experiment. After a 10-s intertrial interval (ITI), either a long (L: 10 s, top) or a short (S: 2 s, bottom) sample stimulus is presented. Two choices (comparison stimuli) are presented at sample offset: One choice is correct (Rft.) if the sample was long; the other choice is correct if it was short. If the animal usually chooses correctly, the ITI usually begins with reinforcement.

1992b) and Sherburne, Zentall, and Kaiser (1998) that Zentall (1999) describes.

Explanations for the Choose-Short Effect

Spetch and Rusak (1992a), in their relative-duration hypothesis, propose that the choose-short effect arises because the animal is reacting not to a single stimulus but to the sample duration in a temporal context that includes the intertrial interval (ITI): "Manipulations that decrease the temporal background (i.e., decreases in the delay or ITI) should make the sample seem longer, whereas manipulations that increase the temporal background (increasing the delay or ITI) should make the sample seem shorter" (p. 119). This idea is qualitatively consistent with the data of Spetch and Rusak (1989), who found that on test trials preceded by a longer-than-normal ITI pigeons are more likely to choose short, whereas following a shorter-than-normal ITI they are more likely to choose long.

Zentall favors the hypothesis that the choose-short effect results from confusion (generalization) between the ITI and the retention interval: Compare the upper and center diagrams in Figure 2, which show the same stimulus present during the ITI and RI. When the choice stimuli appear at the end of the RI, therefore, the animal is likely to respond as if the RI were the ITI, and is more likely to do so the longer the RI. The animal then chooses short because no sample is more similar to a short sample than a long one. Kraemer, Mazmanian, and Roberts (1985) did a choose-short experiment with three sample durations, 2, 10, and 0 s, and three choice responses. After training with zero RI they found both a choose-short effect and an increasing tendency to respond on the 0-s key at longer RIs, just as Zentall's confusion hypothesis predicts. However, neither of these theories accounts easily for the choose-long effect.

According to the confusion hypothesis, "during 0-s delay training, pigeons learn the *meaning* of the ITI. When, in a test, the RIs are similar to the ITIs used *in training*, confusion results" (Sherburne et al., 1998, p. 517). Less anthropomorphically, the issue is one of stimulus control, in this case temporal control. Each reinforced choice occurs in a certain temporal context. When offered a choice in a novel temporal context (i.e., after a nonzero RI), choice will presumably be determined by similarity. The more similar the temporal context in testing to the temporal context in training, the more similar the response is likely to be. The choose-short effect results because at choice time the events in the immediate past after a long RI are more similar to those that occurred during training just after the short sample than just after the long one. From this point of view, the confusion and relative-duration hypotheses are in fact quite similar. They differ chiefly in how specific they are about what makes one temporal context similar to another, about what stimuli will acquire temporal control.

The MTS approach accepts that the choose-short result is a problem of temporal control; but we would like to identify the processes that make one temporal context more or less similar to another, rather than rely on intuition, like the confusion hypothesis, or a static rule, like the relative-duration hypothesis. According to current MTS theory, the controlling stimulus in the choose-short experiment is the difference in strength between the traces for sample onset and offset. Intertrial interval does not figure in this com-

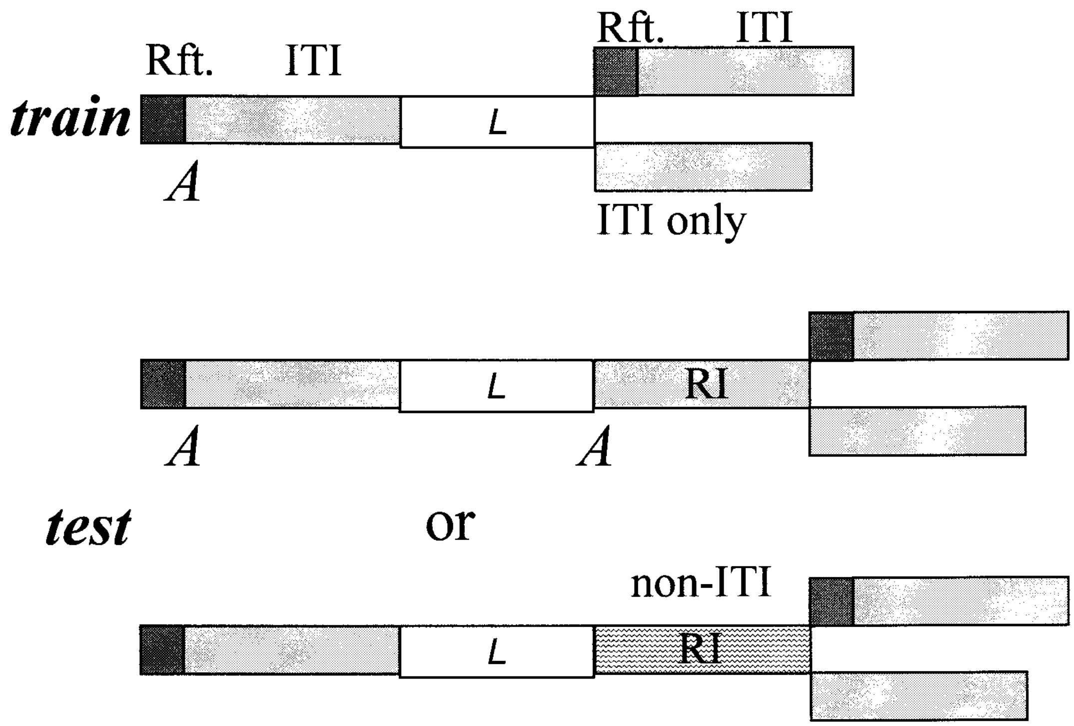

Fig. 2. Top: training procedure in the choose-short experiments (long-stimulus trial: same as the upper diagram in Figure 1). Center: testing procedure that yields the choose-short effect. Comparison stimuli are presented after a nonzero retention interval (RI). Retention-interval stimulus condition is the same as the ITI. Bottom: Testing procedure that abolishes the choose-short effect: Retention-interval stimulus condition is different from ITI.

putation. But suppose we add to the MTS theory an assumption to handle proactive interference. The simplest assumption is that trace strength of an event is diminished by preceding occurrences of the event, and the closer the preceding event, the greater the suppression (proactive inhibition). It is easy to see that this assumption is consistent with both primacy and recency effects in serial learning. Primacy is handled because the first event in a series has no preceding event to suppress it. Recency is handled by the fact that newer traces are stronger (Staddon, 1998). In the choose-short experiment, the proactive inhibition assumption means that the trace of RI onset (which is identical with ITI onset: the points labeled A in Figure 2) will be weaker following a short ITI than a longer ITI because it will be closer to the preceding trial when the ITI is shorter. Traces of all other trial events will be similarly affected. If all traces are reduced at short ITIs, then the differences between traces will also be reduced and discrimination will be worse at short ITIs than at long ones, as Spetch and Rusak (1989) found. We have not yet implemented this suggestion in a quantitative way, but it seems that an appropriately chosen inhibitory assumption would lead to the results described.

Temporal Control: What Is the Stimulus

As Zentall suggests, looking at the choose-short effect as a problem of temporal stimulus control relates it to so-called "gap" timing experiments, in which timeouts or some other kind of stimulus change are introduced into a to-be-timed interval (e.g., Cabeza de Vaca, Brown, & Hemmes, 1994; Hopson, 1999; Roberts, 1981). Regarded in these terms, the issue is not the resetting or stopping of a hypothetical clock, but rather the degree of temporal control exerted by the novel temporal context created by inserting the gap. If the gap is effectively identical to the controlling context during the RI, the animal behaves as if the clock is "reset." Con-

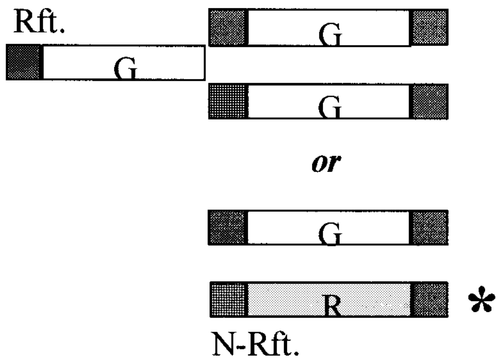

Fig. 3. Top: sequence of events in a reinforcement-omission experiment (Staddon, 1974). Successive pairs of 120-s fixed intervals began with food reinforcement (Rft.) and ended with either reinforcement or a neutral stimulus of equal duration (N-Rft.). During the interval, the key stimulus was green (G). Bottom: a modification that eliminates the reinforcement-omission effect. Intervals that began with food had a green key stimulus, as before, but intervals that began with nonreinforcement always had a red stimulus (R). Temporal control by Rft. was always good. But under the conditions in the top diagram, temporal control by N-Rft. was poor. Under the conditions in the bottom diagram, temporal control by N-Rft. was usually good (*). Apparently Rft. interferes with N-Rft. only when they occur in the same stimulus context.

versely, if the gap is ignored, the clock will continue to "run." If the gap creates a context that is merely similar to the RI, an intermediate result may look like "stop-retain-restart." Again, the problem for theory is to define just what makes one temporal context more or less similar to another.

The Effects of Stimulus Context

Separating two events by a longer time reduces interference between them. There is another way to reduce interference between two situations, and that is to identify them by different contextual stimuli. Figure 3 shows an old example from a fixed-interval (FI) reinforcement-omission experiment with pigeons. In this experiment each fixed interval ended in either food or an equal-duration neutral stimulus. Typically, temporal control after the neutral stimulus is not as good as after food: The postevent pause is shorter and there is no FI "scallop" (the reinforcement-omission effect: Staddon & Innis, 1969). But Staddon (1974) found that if intervals beginning with the neutral stimulus always had a different key stimulus than intervals beginning with food, interference is reduced and temporal control in intervals with the novel stimulus is relatively good—comparable to food-initiated intervals.

Spetch and Rusak (1992b) and Sherburne et al. (1998) report something similar for the choose-short experiment. When the context of recall is different from the ITI (e.g., houselight on vs. houselight off; Figure 2, bottom diagram), temporal control is good: Choice accuracy after short and long sample stimuli is comparable at delays up to 10 s (Sherburne et al., Figure 2; Spetch & Rusak, Figure 3.6), and the choose-short effect is abolished. Thus, the effect of stimulus context in the reinforcement-omission situation and in the choose-short experiment appear quite similar.

But there are differences between the two situations that may be critical. The reinforcement-omission experiments typically use much longer intervals than the choose-short experiments: FIs on the order of 60 to 120 s, versus samples on the order of 10 s. At long intervals, food reinforcement is a much more effective time marker than any neutral stimulus, and the omission effect seems to reflect proactive interference from reinforcement as a dominant time marker. But there is no evidence that reinforcement plays any role as a time marker in the choose-short experiment, and there is some evidence that it does not. For example, Spetch and Rusak (1992a) found similar discrimination performance with fixed ITIs, which makes postfood time a reliable temporal predictor, and variable ITIs, for which postfood time is not a reliable temporal predictor. Most important, the fact that separate stimulus contexts improve temporal control on FIs cannot account for the fact that separate contexts for recall and ITI in the choose-short experiment not only improve choice performance but also abolish the asymmetry between performance after long and short samples, as the Sherburne et al. data, using RIs up to 4 s, seem to show. The Spetch and Rusak (1992b, Figure 3.6) data, using up to 10-s RIs, do in fact show some signs of divergence between the post-long-sample and post-short-sample error curves. New experiments with even longer RIs are needed to confirm this tendency. We need to know whether differential context abolishes the choose-short effect completely or simply slows forgetting following both sample stimuli.

There is also the possibility that context difference per se is not sufficient for abolition of the choose-short effect, that specific stimuli make a difference (Marcia Spetch, personal communication). Perhaps some differential contexts abolish the effect and some do not. This variable also awaits exploration.

The fact that separate stimulus contexts for ITI and recall seem to eliminate the choose-short asymmetry suggested to us (Staddon & Higa, 1999, Footnote 7) that perhaps some completely different process is operating under these conditions. What might that process be, and how can it be tested? Prospective encoding (see Grant, Spetch, & Kelly, 1997, for a review in the context of the choose-short effect)—defined noncommittally as a state of the animal corresponding to the anticipated response rather than the experienced stimulus—is an obvious possibility. This idea is not quite as vague as it sounds, because pigeons, budgerigars, and other animals in delayed-choice situations often show distinctive anticipatory motor patterns that are highly correlated with the upcoming choice response (e.g., Manabe, Staddon, & Cleaveland, 1997; Urcuioli & DeMarse, 1997). These observations suggest that prospective encoding is likely to occur in situations in which anticipatory responding is possible (and perhaps not otherwise). The possibility that the "code" corresponds to an anticipatory response unrelated to the physical properties of the sample durations provides an answer to Zentall's objection that "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" (p. 469).

Do pigeons show anticipatory patterns during the RI under differential-stimulus conditions but not under nondifferential ones? What is the effect of using place (e.g., left vs. right) rather than color (e.g., red vs. green) choices in the nondifferential choose-short paradigm? Granted that place favors the development of distinctive anticipatory behavior (and thus a prospective code), will the choose-short effect disappear if choice responses are defined spatially rather than in terms of key color? Relevant data would be helpful.

Zentall argues against prospective encoding in general, discounting the apparent demonstration of prospective encoding in a successive version of the choose-short experiment by Grant and Spetch (1993), writing that "there are many ways in which retrospective coding processes may result in parallel retention functions (e.g., nonanalogical or categorical coding)" (p. 469). We agree; our point is simply that the Sherburne et al. result is consistent with *some kind* of nontemporal discrimination process.

The question nevertheless remains: Why should differential ITI and RI stimuli favor prospective encoding? We are not sure, but one possibility is competition among anticipatory activities. In the nondifferential condition, different behavior occurs during ITI and RI, but because of the ambiguous stimulus situation, there will always be some tendency for the ITI behavior to intrude during the RI (this is a behavioral version of Zentall's confusion hypothesis). In the differential condition, on the other hand, the ITI behavior can come under the control of (or "become conditioned to") the unique ITI stimulus, and so is less likely to compete with whatever differential anticipatory behavior normally occurs during the RI. Again, direct observations would be interesting.

There is a direct test for prospective encoding, in the form of a conditional version of the differential-context choose-short experiment. The experimental design would be the same as that of Sherburne et al. (1998), but the choice responses would be different. Instead of red versus green (say), the choice would be left or right, depending upon the color of the choice keys. If both are red, the correct responses would be short → left, long → right; if both are green, the reverse. This procedure does not allow the animal to anticipate the correct location response, because it is not known until choice time. If the choose-short effect is restored under these conditions, we have indirect support for some kind of prospective encoding in the original differential-context experiments. If not, we are left with some version of the confusion hypothesis, or categorical encoding, or something else. In any event, it would be interesting to see experimental answers to all these questions.

Finally, a minor cavil. Zentall (1999) writes that the choose-short effect "has been attributed to memory loss" but may in fact reflect stimulus generalization decrement. "Such artifacts must be eliminated before a theory of memory for event duration can be adequately tested" (p. 467). There is no consensus on what "memory" means, in a scientific sense. It is surely premature, therefore, to label any of these effects "artifacts." The point is not to separate "memory" from "nonmemory" but to understand the processes that produce all these effects.

The choose-short and choose-long effects are the strongest evidence in favor of a trace theory of time discrimination. Zentall has put his finger on a key problem not just for MTS theory but for all timing and memory models. No explanation for context effects in the choose-short experiment is as yet conclusive. Perhaps this discussion will stimulate additional experimental work that can help to resolve this intriguing problem.

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