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Delayed matching-to-sample: A tool to assess memory and other cognitive processes in pigeons

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ABSTRACT

Delayed matching-to-sample is a versatile task that has been used to assess the nature of animal memory. Although once thought to be a relatively passive process, matching research has demonstrated considerable flexibility in how animals actively represent events in memory. But delayed matching can also demonstrate how animals fail to maintain representations in memory when they are cued that they will not be tested (directed forgetting) and how the outcome expected can serve as a choice cue. When pigeons have shown divergent retention functions following training without a delay, it has been taken as evidence of the use of a single-code/default coding strategy but in many cases an alternative account may be involved. Delayed matching has also been used to investigate equivalence learning (how animals represent stimuli when they learn that the same comparison response is correct following the presentation of two different samples) and to test for metamemory (the ability of pigeons to indicate that they understand what they know) by allowing animals to decline to be tested when they are uncertain that they remember a stimulus. How animals assess the passage of time has also been studied using the matching task. And there is evidence that when memory for the sample is impaired by a delay, rather than use the probability of being correct for choice of each of the comparison stimuli, pigeons tend to choose based on the overall sample frequency (base-rate neglect). Finally, matching has been used to identify natural color categories as well as dimensional categories in pigeons. Overall, matching to sample has provided an excellent methodology for assessing an assortment of cognitive processes in animals.

1. Introduction

Delayed matching-to-sample is a versatile task that can be used directly to study various aspects of animal memory including what animals remember, how they remember it, and what strategies they use to remember. But it can also be used as a tool to assess other comparative cognition phenomena. For example it can be used to examine how animals represent the passage of time and how animals naturally categorize stimuli. It can also be used as a means of degrading memory to examine how decisions are made in the absence of information.

Matching-to-sample can be described as a conditional discrimination in which the correct response in the presence of two simultaneously presented stimuli depends on the nature of a third stimulus, the sample (see Fig. 1). For example, on some trials a pigeon may be presented with a red stimulus on the center response key and a response to that stimulus (or the passage of time) may illuminate a stimulus on each side key one red the other green. Choice of the red side-key stimulus would be reinforced but not the green. On other trials, a green stimulus is presented on the center response key and choice of the green side-key stimulus would be reinforced. This task became popular after Skinner (1950) described the task as "the discriminative response of striking-red-after-being-stimulated-by-red" and suggested that it "is apparently no easier to establish than striking-red-after-being-stimulated-by-green" (p. 214). The implication of this statement is the identity relation between the sample and the correct comparison is not important, and furthermore it suggests that the incorrect alternative plays little role in the learning.

In response to this challenge, several investigators have asked whether the tendency to choose the stimulus that is the same or the one that is different involves the same/different concept that could be shown to generalize to new stimuli. The results have been variable. Although early reports suggested that there was no evidence for the development of a generalized same/different or identity concept (Carter and Eckerman, 1975; Cumming and Berryman, 1961), when the novelty of the transfer stimuli is controlled evidence for concept formation has been found following training with

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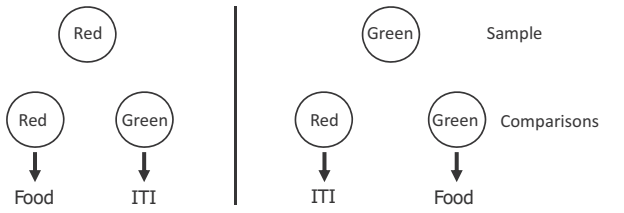

Fig. 1. Example of identity matching to sample. If there is a delay between the offset of the same and the onset of the comparison stimuli it is a delayed matching to sample procedure.

simple colors or shapes (Cook et al., 1997; Wright et al., 1988; Young and Wasserman, 1997; Zentall et al., 1981; Zentall and Hogan, 1974, 1976).

Perhaps the most extensive use of matching-to-sample has been as a measure of short-term memory. Short-term memory can be examined following training in which the choice or comparison stimuli appear immediately following termination of the conditional stimulus or sample (0 s delay matching) by inserting a delay between the offset of the sample and the onset of the comparison stimuli. In one of the earliest reports of pigeons' memory performance, Blough (1959) trained pigeons to match a steady or flickering light. Surprisingly, although the pigeons matching accuracy was above 90% correct when the comparison stimuli appeared immediately after termination of the sample (0 s delay), matching accuracy fell rapidly to about 62% as the delay increased to 5 s.

Must of the research on delayed matching has been done with pigeons. Research on delayed matching with rats has shown very poor transfer from 0 s delayed matching training to longer retention intervals (Herremans and Hijzen, 1997). Although rats do show better delayed matching accuracy on a delayed matching to spatial location in which one sample indicates that choice of the left lever will be reinforced and a different sample indicates that choice of the right level will be reinforced (Dunnett, 1985), rats will often circumvent the memory task by standing in front of the correct comparison position until the lever appears. For this reason, when the effects of drugs or neurological intervention has been studied using this procedure one can argue that the disruptive effects of the manipulation on delayed matching accuracy likely result from interference with the rats' lever-orienting response rather than from the loss of short-term memory (see e.g., Herremans et al., 1994). Thus, most of the research described in the present review involves pigeons.

There are two purposes of the present review. The first is to explore how the delayed matching task has been used to investigate what is remembered during the interval between sample offset and comparison onset. That is, to what extent might animals develop strategies to facilitate memory? In much of this research it will be important to ask if there are alternative interpretations of the absolute or relative decline in matching accuracy as the sample-comparison delay increases. The second purpose of this review is to demonstrate how delayed matching can be used as a tool to assess other cognitive processes. That is, the decline in matching accuracy with increasing delay can provide an indirect means of identifying potential underlying processes. The objective of this paper is not to review all of the literature on delayed matching but only to touch on research suggesting the nature of the underlying processes.

2. Working memory

In the field of animal research, working memory is used synonymously with short-term memory. It refers to the short-term storage of information without necessarily implying the manipulation or organization of material held in memory, as it often does when referring to human working memory (Cowan, 2008).

2.1. Parameters affecting working memory

Early research on delayed matching focused on parameters of the delayed matching task including delay duration, responses to the sample, and duration of the intertrial interval. The typical procedure involves training pigeons on 0 s delayed matching (the offset of the sample precedes the onset of the comparison stimuli) and then testing with delay trials that vary duration from trial to trial. When treated this way, pigeons often show a relatively rapid decline in matching accuracy with relatively short delays (3–5 s). The rationale for training with 0 s delays and testing with longer delays is that training with multiple delays from the start results in rather slow acquisition (Perkins et al., 1973) but if delays are trained from the start it may avoid the detrimental effect on matching accuracy of the novelty of the delays on working memory (see Zentall, 1997).

2.1.1. Sample duration

Matching accuracy can be improved considerably by requiring the pigeon to peck at the sample (Roberts, 1972): 5 pecks are better than 1 and 15 pecks are better than 5. Similar results have been found when sample duration is manipulated without required pecking (Grant, 1976; Nelson and Wasserman, 1978). These results have suggested to Roberts (1998) that sample memory is analogous to a leaky bucket. The bucket fills during sample presentation but it leaks out when the sample is removed.

2.1.2. Intertrial interval

One hypothesis for the relatively poor delayed matching accuracy by pigeons with even short delays is that memory for the sample from previous trials interferes with sample memory from the current trial. This hypothesis has been supported by the finding that increasing the time between trials improves matching accuracy. One can think of the effect of the prior trial as either a masking effect (proactive interference; Grant and Roberts, 1973) or the loss of temporal order (the failure to remember which sample was the last to have been seen; Worsham, 1975). However, there also appears to be a general disruptive effect of short intertrial intervals that is independent of the identity of previous sample because short intertrial intervals can have a negative effect on delayed matching accuracy even when the previous sample is the same as the current sample (Edhouse and White, 1988; Roberts, 1980).

2.1.3. Differential sample behavior

Differential behavior required to the two sample stimuli, such as a low rate of responding to one sample and a high rate to the other, has been found to result in more accurate delayed matching than when the same number of responses are required to both samples (Cohen et al., 1976; Urcuioli, 1985; Urcuioli and Honig, 1980). Furthermore, there is evidence that differential sample behavior alone can serve as an effective cue for comparison choice (Urcuioli and Honig, 1980). Thus, paradoxically, although the identity of the sample must be determined before the differential behavior can be produced, memory of the response to the sample may be a sufficient cue for comparison choice.

2.1.4. Differential behavior during the delay

If differential behavior during the delay is required as signaled by the sample, there is evidence that matching accuracy can be quite good even at long (70 s) delays (Tsai et al., 1980). But because one can think of differential sample behavior as a kind of rehearsal activity, it is interesting to consider reported cases in which differential delay behavior emerges spontaneously. In an early experiment on delayed matching already cited, Blough (1959) reported that two pigeons developed different stereotypic behaviors during the delay following presentation of each of the two sample stimuli and that those pigeons showed enhanced delayed