DEVELOPMENT OF A SINGLE-CODE/DEFAULT CODING STRATEGY IN PIGEONS

Tricia S. Clement and Thomas R. Zentall
University of Kentucky

Abstract—We tested the hypothesis that pigeons could use a cognitively efficient coding strategy by training them on a conditional discrimination (delayed symbolic matching) in which one alternative was correct following the presentation of one sample (one-to-one), whereas the other alternative was correct following the presentation of any one of four other samples (many-to-one). When retention intervals of different durations were inserted between the offset of the sample and the onset of the choice stimuli, divergent retention functions were found. With increasing retention interval, matching accuracy on trials involving any of the many-to-one samples was increasingly better than matching accuracy on trials involving the one-to-one sample. Furthermore, following this test, pigeons treated a novel sample as if it had been one of the many-to-one samples. The data suggest that rather than learning each of the five sample-comparison associations independently, the pigeons developed a cognitively efficient single-code/default coding strategy.

An important goal of researchers in the area of animal cognition is to demonstrate that animals can develop active strategies for solving novel problems. The active role of the animal in developing such strategies is most convincing when the animal demonstrates a cognitively economical solution not readily predicted by noncognitive (e.g., stimulus-response) models of learning.

A versatile task used in cognitive research with animals is matching to sample (i.e., the two-alternative conditional discrimination). In this task, pigeons could be asked, for example, to choose a vertical rather than a horizontal comparison stimulus when the initial sample stimulus was a red light and to choose the horizontal comparison when the sample was a green light. Mastery of this task has traditionally been viewed as involving the development of two relatively simple stimulus-response chains, or “rules” (red \(\rightarrow\) vertical and green \(\rightarrow\) horizontal; see Skinner, 1950).

Alternatively, because of the symmetry of the task, subjects could learn a single rule involving the coding of a single sample, such as “if the sample was red, choose the vertical-line comparison,” and they could respond to the alternative comparison whenever there is no memory for having just seen a red sample (i.e., by default). Although it may be possible for an animal to use such a single-code/default strategy, rather than a strategy that requires the development of two sample-specific rules, given that the single-code/default strategy also requires learning a default rule, the use of such a strategy is not obviously more efficient.

However, if the task were modified so that a single-code/default strategy would be more cognitively efficient, one could ask if pigeons would adopt such a strategy. For example, if the task involved matching the red sample to one comparison and each of a number of other stimulus hues to the other comparison, then the development of a single-code/default strategy would be more efficient than learning a separate rule for each sample-comparison association.

There are two procedures that can be used to determine the strategy that has served as the basis for acquisition of this task. First, one can introduce various delays between the offset of the samples and the onset of the comparisons, and one can examine the slopes of the resulting retention functions for trials involving each sample stimulus. If the pigeons learned separate rules for each of the sample stimuli, one would expect that all of the retention functions would decline regularly with increasing retention interval, reaching about 50% correct (i.e., they all would look quite similar). However, if the pigeons developed a single-code/default coding strategy, one might see divergent retention functions. Consider, for example, the functions that might be found if the pigeons learned to choose vertical if there was a representation of the red sample in memory, and otherwise to choose horizontal: On red-sample trials, as memory for the red sample was lost, one would expect to see a sharply decreasing retention function that drops below chance with increasing retention interval (in the absence of memory for red, choose horizontal). On all other trials, however, there would be no memory for the red sample, and that would not change with the introduction of delays. Thus, on non-red-sample trials, the retention function would be expected to remain high and relatively flat with increasing retention interval.

A second test of the development of a single-code/default coding strategy would be to introduce a novel sample. If pigeons acquire the task by learning independent sample-comparison associations, then when they are presented with a novel sample, they should be equally likely to choose either comparison. However, if pigeons develop a single-code/default coding strategy, they should be more likely to choose the default-associated comparison.

In the present experiment, we used a 1:4 ratio of samples associated with the two comparison alternatives. To ensure generality of the findings, we included two groups of pigeons, one trained with hue samples and the other trained with shape samples.

METHOD

Subjects

The subjects were 12 White Carneaux pigeons, purchased as retired breeders from the Palmetto Pigeon Plant (Sumter, South Carolina). Both males and females were included, and they ranged from 5 to 8 years old. The pigeons were caged individually, with grit and water continually available to them in the home cage. Each was maintained at 80% of its free-feeding body weight throughout the experiment. The room in which the pigeons were housed was on a 12-hr:12-hr light:dark cycle. All the pigeons had previously served in unrelated studies involving delayed matching to sample.
Coding Strategies in Pigeons

Apparatus

The experiment was conducted in a BRS/LVE (Laurel, Maryland) pigeon test chamber. The chamber measured 30 cm (front to back) × 36 cm (across the response panel) × 36 cm (high). The three circular response keys (2.5 cm in diameter) were centered horizontally on the response panel. Mounted behind the center response key was a 12-stimulus inline projector that projected five hues (yellow, red, green, blue, or white; Kodak Wratten Filters Numbers 9, 26, 60, and 38a, and no filter, respectively), as well as five shapes (a white plus sign, 13 mm long and 3 mm wide; a white outline circle with an outside diameter of 16 mm and inside diameter of 13 mm; a white dot 5 mm in diameter; a solid equilateral triangle with the apex pointing down and with 1-cm sides; or a white outline square with 1.5-cm sides outside and 1.0-cm sides inside). Behind each of the left and right response keys was a similar projector that was equipped to show three white vertical or three white horizontal lines (2.4 cm long, 0.3 cm wide, 0.3 cm apart) on a black background. A rear-mounted grain feeder was centered horizontally on the response panel. When operated, the lit feeder was accessible through an aperture measuring 5.0 × 5.5 cm. Reinforcement consisted of 1.5-s access to Purina Pro Grains. A shielded house light located 3 cm from the top of the panel, above the center response key, provided general illumination for the chamber. White noise and an exhaust fan mounted on the outside of the chamber masked extraneous noise. The experiment was controlled by a microcomputer located in an adjacent room.

Procedure

The experiment was conducted in two replications of 6 subjects each. For each replication, the pigeons were randomly assigned to either the hue group or the shape group.

Training

All pigeons were placed directly on 0-s-delay matching-to-sample training. For each pigeon, training consisted of a hybrid task in which one comparison was correct following presentation of one sample (one-to-one matching) and the other comparison was correct following any of four different samples (many-to-one matching). The one-to-one portion of the task involved either the yellow or plus-sign sample (yellow for the hue group, plus sign for the shape group). The comparison stimuli were vertical lines and horizontal lines. The many-to-one portion of the task involved red, green, blue, and white samples (hue group) or circle, dot, triangle, and square (shape group). For half the pigeons, vertical was designated as the correct comparison choice following the one-to-one sample and horizontal was the correct choice following the many-to-one samples. For the remaining pigeons, this designation was reversed.

Each trial began with the onset of the sample on the center key. Ten responses were required to extinguish the sample and to initiate the comparison stimuli on the left and right response keys. One response to either side key constituted a choice and extinguished both comparison stimuli. If a response was made to the comparison designated as correct, food was made available for the first 1.5 s of the 10-s intertrial interval. If a response was made to the comparison designated as incorrect, only the intertrial interval was initiated.

Each session comprised 96 trials, 48 trials involving the one-to-one sample and 48 trials involving the many-to-one samples (12 trials with each sample). Sessions were conducted 6 days a week. Training continued for 20 sessions beyond a single-session criterion of 90% correct or higher matching accuracy for each sample. In the first replication, any pigeon that had not reached a performance criterion of 80% correct on all sample types after 200 training sessions was switched to a correction procedure in which an incorrect comparison choice caused the trial to repeat. A particular trial could be repeated a maximum of five times. All animals in the second replication began this correction procedure from the start of training.

Retention Test

One 96-trial test session followed the completion of the training. Retention intervals during which the chamber was darkened were inserted between the sample offset and the comparison onset. Intervals of 0, 1, 2, and 4 s were intermixed in each session. Each of the many-to-one samples was presented equally often at each retention interval, and the total number of trials with the many-to-one samples equaled the total number of trials with the one-to-one sample at each retention interval.

Novel-sample test

Following the retention test, pigeons in the second replication were returned to original training. Once they recovered a criterion of 90% correct on all training-trial types, 16 novel-sample probe trials (purple for the hue group and the letter X for the shape group) were inserted in each session for two sessions. Choice of comparison on these probe trials was randomly reinforced (50%) regardless of the comparison chosen.

RESULTS

Acquisition

One pigeon in the first replication (in the shape group) died during the acquisition phase. Data from this pigeon were not included in any of the data summaries. The mean number of sessions for the pigeons to reach criterion was 177.6 in the first replication and 82.0 in the second replication.

Retention Test

Pigeons’ matching accuracy was high at the 0-s retention interval for both the many-to-one and the one-to-one portions of the task. At longer retention intervals, accuracy on the many-to-one portion of the task remained relatively high; however, accuracy on the one-to-one portion of the task declined rapidly as the retention interval increased. The retention-test data appear in Figure 1.

A three-way repeated measures mixed-model analysis of variance was performed on the retention data, with group (hue vs. shape) as the between-subjects factor and sample type (one-to-one vs. many-to-one) and delay (0 vs. 1 vs. 2 vs. 4 s) as the repeated measures. (In all the analyses reported, the .05 significance level was adopted.) Overall, the effect of sample type was significant, $F(1, 9) = 38.96$, as was the effect of delay, $F(3, 27) = 16.45$, but the effect of group was not, $F < 1$. Most important, there was a significant Sample Type × Delay interaction, $F(3, 27) = 3.76$. None of the other interactions was statistically significant.
the matching task.

Second, when a novel sample was introduced, the pigeons tended to trials involving the sample from the one-to-one portion of the task, whereas matching accuracy declined rapidly with increasing delays on trials involving samples from the many-to-one portion of the task, between the offset of the samples and the onset of the comparisons. Functions were found when delays of different durations were inserted this strategy comes from two sources. First, clearly divergent retention exerts significant control over comparison choice (Weaver, Dorrance, Honig, 1980). Furthermore, we have recently found that in the case of novel stimulus replaced the correct comparison on probe trials, matching accuracy remained high, but when the novel stimulus replaced the incorrect comparison, there was a substantial drop in matching accuracy. Thus, with this single-incorrect-comparison/multiple-correct-comparison task, the pigeons learned to use the identity of the incorrect alternative as a basis for comparison choice.

It has been suggested elsewhere that animals can develop a single-code/default coding strategy (Colwill, 1984; Grant, 1991; Sherburne & Zentall, 1993; Wilson & Boakes, 1985); however, that conclusion was based on the finding of divergent retention functions following training on a matching task in which comparison choice was based on whether a sample stimulus had been presented or no sample had been presented (e.g., pigeons learned to choose the vertical comparison if a red sample was presented but to choose the horizontal comparison if no sample was presented; this task is often referred to as present/absent-sample matching). The problem with such a task is that the retention interval is very similar to the absent sample (Zentall, 1997). Both typically are periods of darkness. Furthermore, when present/absent samples are used, the behavior during the retention interval (typically the absence of pecking) is similar to the behavior in the presence of the absent sample (also the absence of pecking) but not to the behavior in the presence of the present sample (pigeons typically peck at a lit sample stimulus even when such behavior is not required).

It is well known that when differential sample responding occurs, that sample responding itself can control comparison choice (Urcuioli & Honig, 1980). Furthermore, we have recently found that in the case of present/absent-sample matching, although no behavior toward either sample is required, the differential sample behavior that does occur exerts significant control over comparison choice (Weaver, Dorrance, & Zentall, 1999; Zentall, Kaiser, Clement, Weaver, & Campbell, in press). Thus, the results of prior research on single-code/default coding strategies using present/absent-sample matching are likely to have been influenced by stimulus- and response-related confounds. The present research (together with the results of Zentall et al., 1981) may

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Fig. 1. Performance on the retention test (percentage correct, with standard error bars) following training with one-to-one matching (OTO) and many-to-one matching (MTO). Performance was tested at four different retention intervals. The horizontal line at 50% correct indicates indifference between the two comparison stimuli.

**DISCUSSION**

When pigeons were trained on a matching task in which a response to one comparison was correct following the presentation of one sample and a response to the other comparison was correct following the presentation of each of four different samples, the pigeons appeared to develop a single-code/default coding strategy. That is, they learned to respond to one comparison if they remembered having recently seen the one sample associated with it; otherwise, they responded to the other comparison. Evidence for the development of this strategy comes from two sources. First, clearly divergent retention functions were found when delays of different durations were inserted between the offset of the samples and the onset of the comparisons. Matching accuracy remained relatively high with increasing delays on trials involving samples from the many-to-one portion of the task, whereas matching accuracy declined rapidly with increasing delays on trials involving the sample from the one-to-one portion of the task. Second, when a novel sample was introduced, the pigeons tended to choose the comparison that was correct for the many-to-one portion of the matching task.

One point that should be noted is that, by its nature, the hybrid one-to-one/many-to-one task used in the present research requires that the amount of training associated with each of the samples is not equal. Specifically, samples involved in the one-to-one portion of the task received four times as many presentations during training as those involved in the many-to-one portion of the task. Although the training criterion of 90% correct for each of the samples ensured that there would be comparable performance on trials with each sample by the end of training, it is generally true that the considerably greater experience with one of the samples than with the four others meant that the one-to-one sample-comparison association was overtrained. However, this overtraining could not have been responsible for the divergent retention functions found during test because if it were, matching accuracy on one-to-one trials would be expected to have been higher than matching accuracy on many-to-one trials, but the reverse was found.

The present results are compatible with earlier findings indicating that pigeons are capable of flexible cognitively efficient learning (Zentall, Edwards, Moore, & Hogan, 1981). Skinner (1950) proposed that when pigeons acquire a matching task, the only relation that they learn is between the sample and the correct comparison. We (Zentall et al., 1981) asked if pigeons could be encouraged to base their choice instead on the incorrect comparison by increasing the number of correct comparisons associated with each sample (there were still only two comparisons presented on a trial, but, over trials, the correct comparison could have been one of four different stimuli). When a novel stimulus replaced the correct comparison on probe trials, matching accuracy remained high, but when the novel stimulus replaced the incorrect comparison, there was a substantial drop in matching accuracy. Thus, with this single-incorrect-comparison/multiple-correct-comparison task, the pigeons learned to use the identity of the incorrect alternative as a basis for comparison choice.

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provide the only clear evidence for the development of a flexible single-code/default coding strategy in animals.

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REFERENCES


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