APPLICATION OF BOWER'S ONE-ELEMENT MODEL TO PAIRED-ASSOCIATE LEARNING BY PIGEONS

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Bower's (1961) all-or-none model of human paired-associate learning was applied to individual data supplied by three pigeons. When the center one of three keys was illuminated with red light or with three white dots in a vertical array on a black ground, pecking on the left key was reinforced. When the center key was lighted green or with a horizontal array of three white dots on a black ground, pecking on the right key was reinforced. The left and right keys were illuminated with white light. The task was considered to be analogous to learning a paired-associate list of four pairs involving four stimulus items and two response items. The model was evaluated by comparing the following model predictions with values obtained from each animal: trials-to-criterion, standard deviation of trials-to-criterion, standard deviation of errors-to-criterion, mean error runs, mean error runs of lengths one to four, and autocorrelations of errors of lags one to three. Most of the predictions based upon the model were in close agreement with the obtained data.

The present experiment investigated whether or not pigeons acquired stimulus control in an all-or-none manner. To make explicit the meaning of "all-or-none", a mathematical model with this characteristic was chosen. There is a rather large field from which to choose (see Atkinson, Bower, and Crothers, 1965), and the present decision was based on the model's simplicity. Bower (1961) developed a model that requires the estimation of only two parameters and makes explicit the relations between correct guessing and actual conditioning. Bower's treatment of the model and its predictions were developed in detail by him, and a general treatment of the class of models to which his belongs has been given by Bernbach (1966).

Bower proposed to account for learning in a paired-associate task in which the subject is shown the stimulus member of a pair and is required to produce the appropriate response member. Several such pairs are presented, and the subject continues to work at the task until he can supply the appropriate response in the presence of each stimulus. He is told the correct response to each stimulus after he has made his own response. In other words, the subject's responding is brought under stimulus control.

The model was developed from a set of axioms (Bower, 1961, p. 256) paraphrased as follows. An item is represented by a single stimulus element, which is observed on each presentation of the pair. On a particular trial, the element is in either a conditioned state, C , or an unconditioned state, $\bar{C}$. On each trial, the probability of changing from state $\bar{C}$ to C is a constant, c . Once state C is entered, no more errors are made on that S-R pair. If an element is in $\bar{C}$, the probability of a correct response occurring is $g = 1/N$, where N is the number of response alternatives. Since it is assumed that the process starts in $\bar{C}$, the first correct response may move the element to state C . It is further assumed that c is independent of the trial number and the outcomes of prior trials. The model can thus be described as a Markov chain with C as an absorbing state.

The model makes some strong predictions about behavior during presolution trials. The expected values of the numbers of correct responses in the first half and second half of the presolution trials for a pair, trials before entering state C , are equal. This is a statement of stationarity of responding. Second, the probabilities of a correct response following an error and of a correct response following a correct response are equal. This is the condition of independence of presolution responding.

Other predictions about the acquisition of S-R pairs are possible as a result of the application of mathematics of the Markov chain. The

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ones employed in the present study are as follows.

Average trials-to-criterion:

$$L = (1/c) (1/(1 + (cg/(1 - g))))$$

Standard deviation of trials-to-criterion:

$$\sqrt{L((2/c) - 1 - L)}$$

Standard deviation of errors-to-criterion:

$$\sqrt{u(1 + (1 - 2c)u)},$$

where u is the mean errors-to-criterion.

Mean number of error runs:

$$u(1 - \beta),$$

where $1 - \beta = c + (1 - c)g$.

Mean number of error runs of length j :

$$\beta^j - {}^1(1 - \beta)^2u$$

Mean autocorrelations of lag k :

$$((1 - g)^2/c) (1 - c)^k$$

The first three predictions are common to learning data. Mean number of error runs is based on a count of the times the subject engages in a string of any length of incorrect responding on a pair. Mean number of error runs of length j is a count of the occurrence of error runs of a particular length: a correct response followed by three incorrect responses, followed by a correct response on a pair is a run of length $j = 3$. Autocorrelations of lag k are counts of the number of times an error on trial n is followed by an error k trials later for a pair. The trials between n and $n + k$ may contain errors or correct responses in any mixture.

Bower's (1961) experimental test employed 29 subjects and a list of 10 pairs. The stimulus members were pairs of consonant letters and the responses were either the number 1 or 2. Half the pairs required a "1" and half a "2" response. The criterion of mastery was two consecutive, errorless runs through the list. The model was tested by comparing some predicted statistical properties of the data with those actually observed. The model accounted adequately for the observed values.

The present experiment extended Bower's study by utilizing an analogue of human paired-associate learning with pigeons. Whereas Bower had 10 stimuli and two responses available, here there were four stimuli and two responses. A further variation is made

in order to simulate the explicit correction or feedback aspect of human paired-associates tasks: If an error is committed, the trial for that S-R pair is repeated until a correct response is emitted. The procedure also allows continuous random presentation of pairs as compared with the presentation of all S-R pairs before repetition of the list in the usual human setting. The reason for the modification is that the list is short by comparison with human lists. Were a list procedure employed, every fourth response would be determined by the previous three responses. In fact, if two "1" responses were emitted and reinforced, the last two responses would be determined. The modified procedure thus establishes a firmer basis for the assertion that stimulus control has been achieved.

There are two objectives in the present study. One is to test the model against data supplied by single organisms. Bower averaged data over 29 subjects. A second objective is to extend the model to the learning of a simulated paired-associate task by a new species, the pigeon. Assuming adequate simulation, the data could serve to delimit the generalizability of the model or to extend it greatly.

METHOD

Subjects

Three racing pigeons obtained from a local pigeon fancier were maintained at 80 to 85% of their free-feeding weights. The free-feeding weights were 307, 330, and 349 g.

Apparatus

A Lehigh Valley Electronics pigeon chamber supplied with three key positions was housed in an acoustical chamber (Industrial Acoustics Company, Model 102311). Behind each key was an in-line projector (Industrial Electronics Engineering, one-plane readout, Model 0010-01-xxxx-1820) also supplied by Lehigh Valley. Control of the projectors, schedules and data retrieval was accomplished by a Lehigh Valley Interact System employing a PDP 8/I 8k computer. The floor of the pigeon chamber was raised about 2 in. (5 cm) to accommodate the relatively small racing pigeons.

Procedure

Preliminary training. The animals were not experimentally naive. They had served in an

experiment in which the four stimulus members of the present study served as discriminative stimuli. The desirability of this history is explained in the final section of this report.

Preliminary training resulted in responding to either side key under the condition in which the key was illuminated with white light. This was accomplished by illuminating the keys singly according to a randomized schedule. If the animal pecked the lighted key, 3-sec access to grain occurred immediately. A 5-sec blackout followed reinforcement. After this blackout, the probability of the other key being illuminated was 0.5. If the animal pecked a dark key, a 10-sec blackout was started, and pecks occurring during the blackout held it in effect for additional 10-sec periods. A correction procedure was employed to prevent perseveration of responding to only one key. The animal had to make a correct response before the illuminated-key position could be changed.

All experimental sessions consisted of the presentation of 100 reinforcers. The preliminary training lasted three sessions.

Paired-associate training. The center key was used to present the four stimulus members of the pairs. There were red or green lights or three white dots on a black background; the dots were oriented in either a vertical or a horizontal array. The two side keys were illuminated with white light and were both "on" together. The animal was required to peck the left key when the center one was illuminated with red or the vertical array and to peck the right key when the center showed green or the horizontal array. A correct response resulted in immediate access to grain for 3 sec. Following presentation of grain, all keys were black for 5 sec. The center key was then illuminated with one of the four stimuli on an equi-probable basis. Three seconds after the center key was illuminated, the two side keys (white) were illuminated. Staging of the presentation of center and side keys was used to encourage an observing response to the stimulus member, but no overt observing response was required. If a side-key response occurred while only the center key was illuminated, the illumination of the side keys was delayed 3 sec. This contingency further encouraged the observing response and discouraged pecking a dark key. When an error occurred (red center, peck right white, etc.) the keys immediately went black for 10 sec. Responses during the

last 7 sec of error-blackout periods caused the blackout to remain in effect another 7 sec. Upon completion of the blackout contingency, the stimulus was repeated. The use of the correction procedure encouraged the establishment of stimulus control of the response. Without correction, the animal could perseverate on one of the keys and receive a reinforcer for half of its responses, since half of the trials would require a response to that key.

The stimulus conditions and the responses were recorded each time the three keys were illuminated. Errors of perseveration were treated as any other error by the schedule. However, for the purposes of data analysis, errors of perseveration were counted as a single error; an error consisted of a behavioral episode that was initiated by an incorrect response and was terminated by the crossover response. Similarly, the occurrence of the crossover correct response was not considered to be a true correct response, even though it was reinforced according to the schedule in effect. Correct responses were those that occurred without preceding errors on a given trial.

Paired-associate training was continued until each animal had produced runs of at least 12 consecutive correct responses for each center-key stimulus. All these sessions involved the four stimuli. An animal's training was terminated when it reached criterion on its most difficult pair. This typically resulted in much over-training on some pairs.

RESULTS

Since the training sessions were defined completely by the delivery of 100 reinforcers, many post-criterion trials were presented. The post-criterion performance can be used to check the adequacy of the arbitrarily chosen criterion of mastery. For Animals 1, 2, and 3, the probabilities of correct responding following the start of the criterion run were 0.86, 0.90, and 0.92, respectively. These values were obtained by dividing the total number of post-criterion correct responses on all four pairs by the total number of post-criterion presentations.

Stationarity of pre-criterion responding was evaluated for each animal by subtracting the number correct in the first half from the number correct in the second half for each of the four pairs. A paired *t*-test (Hays, 1963, p. 335) was used to evaluate these differences. With

$df = 3$, the obtained values of t for Animals 1, 2, and 3 were 1.13, -0.99 , and 2.79, respectively. All three values fall short of significance at the 0.05 level, two-tailed. Thus, the null hypothesis of no difference between first- and second-half correct responding cannot be rejected (see Atkinson *et al.*, 1965, p. 44).

The independence of responding on successive trials was evaluated by a χ^2 test (see Atkinson, *et al.*, 1965, p. 48). With $df = 1$, the obtained values of χ^2 for Birds 2 and 3 were 0.0769 and 1.5136, respectively. These are short of significance at the 0.20 level. Data for Animal 1 produced a $\chi^2 = 17.26$, which is significant at the 0.001 level. Independence held for two of the animals and was violated by the third.

Two parameters must be fixed to provide the other predictions based on Bower's model. The first, g , is an estimate of the probability of a correct response occurring as a pure guess. Bower argued that this value was the reciprocal of the number of response alternatives, $\frac{1}{2}$. This seems to be a strong assumption here since animals can exhibit response biases. Since, according to the all-or-none aspects of the model, correct responses before criterion are assumed to be guesses, g could be estimated by dividing the number of correct responses before criterion by the number of trials to

criterion, summed over the pairs for each animal. The values of g for Animals 1, 2, and 3 were 0.4050, 0.3457, and 0.6711, respectively.

The second parameter, c , is the probability of an element moving from an unconditioned state on trial n to the conditioned state on trial $n + 1$. Bower's estimate was used here:

$$c = (1 - g)/u.$$

For Animals 1, 2, and 3 the values were 0.0112, 0.0494, and 0.0133, respectively.

The remainder of the predictions and their corresponding observed values are shown in Table 1.

Inspection of Table 1 indicates probable failure for Animal 1 at four places: Standard Deviation (S.D.) Trials, Mean Error Runs, Mean Error Runs of Length 3 and 4. Predictions for Animal 2 are good except for Mean Error Runs of Length 3 and 4. Two large failures occur at S.D. Trials and S.D. Errors for Animal 3. The common dependent variable, trials to criterion, is predicted by the model in all cases.

DISCUSSION

While there are a few discrepancies, the model gives a good fit to the data. The finding of stationarity for all animals is strong support

Table 1
Statistics Predicted (P) by Bower's Model and Those Obtained (O) for Each Pigeon

Statistic	Animal					
	1		2		3	
	O	P	O	P	O	P
Mean Trials	89.50	88.82	20.25	19.74	75.25	73.26
Standard Deviation						
Trials	68.17	88.99	24.38	19.75	25.59	74.74
Mean Errors	53.25	—	13.25	—	24.75	—
Standard Deviation						
Errors	54.55	53.15	16.17	13.09	9.50	24.92
Mean Error Runs	16.25	21.92	4.00	5.01	14.75	16.72
Mean Error Runs						
of Length:						
1	8.50	9.02	2.00	1.89	9.25	11.29
2	2.50	5.31	1.25	1.18	3.75	3.66
3	2.50	3.12	0.25	0.73	1.25	1.19
4	0.50	1.84	1.25	0.46	0.50	0.39
Autocorrelations						
of Lag:						
1	35.00	31.32	8.25	8.24	9.00	8.03
2	34.75	30.98	8.25	7.83	7.50	7.93
3	33.75	30.63	8.00	7.45	7.50	7.82

for an all-or-none principle. Independence is also a rather stringent test of the principle, and it was upheld in two of the three cases. Why it was not supported in all instances is not suggested by the data.

The statistical predictions of Table 1 are well confirmed. However, when only four values are used to establish a statistic, sampling error is likely to be great. In this context, one can evaluate the goodness of fit for the present model by a comparison with another potentially useful one.

The single-operator linear model is an analogue of Hull's incremental learning theory. In this model, the occurrence of a reinforcer is assumed to reduce the probability of an error on a particular S-R pair. The all-or-none principle states that a reinforcer produces learning on a trial or it does not; there is no gradual growth in the probability of a correct response. The computational equations involved in the predictions considered here for the linear model can be found in Atkinson, *et al.*, (1965, pp. 111-115), and in Restle and Greeno (1970, pp. 64-65). Predictions were made for S.D. Errors, Mean Error Runs, and Autocorrelations of Lag 1, 2, and 3. These predictions were typically about one-half the values of the obtained data. The exceptions were with respect to Mean Error Runs; the linear model predicted about twice as many runs as were observed. The single-operator model required estimation of only one parameter, while two were estimated in this treatment of Bower's model. On the basis of that difference, Bower's model is expected to yield somewhat better predictions.

Several special considerations must be taken into account in applying the model (Bower, 1961). The stimuli must be easily discriminable. For this reason, animals were chosen that had demonstrated discriminative behav-

ior in the presence of the four stimuli. The responses must be in the subject's repertoire. Preliminary training provided the necessary repertoire. Therefore, the model is actually an account of the so-called "hook-up" phase of paired-associate learning. The present study required the establishment of stimulus control.

Stimulus control involves relations among many more variables than the model proposes to explicate. However, in view of the apparently good fit of an all-or-none model and the violations of the predictions of an incremental, linear-operator model, it is reasonable to conclude that there is strong evidence for an all-or-none process in the development of stimulus control. Bower (1961) was also able to reject the linear model for his data on human learning. It would be interesting to evaluate the model in a matching-to-sample situation.

In summary, the analysis leads to the conclusion that Bower's model performs well in areas that seem at first inspection to be quite different from his original application in human paired-associate learning. It is important to recognize the potential utility of models in dealing with experiments that have formal or structural characteristics in common.

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