JOURNAL OF THE EXPERIMENTAL ANALYSIS OF BEHAVIOR VOLUME 9, NUMBER 5 SEPTEMBER, 1966

SERIAL DISCRIMINATION–REVERSAL LEARNING WITH AND WITHOUT ERRORS BY THE CALIFORNIA SEA LION[1]

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A sea lion under water performed virtually without errors on a series of three form-discrimination reversals. Significant training requirements were the combining of a previously well-established size cue preference with the nonpreferred form cue, followed by the gradual reduction of the size cue until it was completely eliminated. Orienting responses reached a peak and then decreased during progressive-dimensional-change training, suggesting critical stages in the transition of attention from the size dimension to the form dimension. Further experimentation revealed that intensive training during these critical stages obviated the need to reduce very gradually the size cue. Without special training sea lions make perseverative errors on a series of form-discrimination reversals. "Emotional" or nontest-oriented behavior was associated only with the occurrence of successive errors.

Stimulated by Terrace's (1963*b*) demonstration that pigeons can be transferred without errors from a previously well-learned color discrimination to a more difficult line-orientation discrimination, Schusterman (1965*a*) trained a California sea lion to reverse a previous habit on a form discrimination task virtually without errors. The significant training requirements were the combining of a previously well-established size cue preference with the nonpreferred form cue, followed by gradual reduction of the size cue until it was eliminated. Thus, after a significant form preference was established, training consisted of presenting compound stimuli with positive and negative cues congruent in both the size and form dimensions. During form-reversal training, the sea lion would make orienting responses of the head and body (Schusterman, 1965*a*, 1965*b*) which reached a peak at size difference ratios of 1.43 : 1 to 1.20 : 1 and then decreased.

The present study attempted to repeat these findings (Schusterman, 1965*a*) with a second sea lion on a *series* of discrimination reversals. Additional experiments in errorless learning of a discrimination-reversal task were undertaken to yield information regarding the length and gradualness of the progressive training stages and to determine whether there was a relationship between errorless reversal learning and reversal learning with errors.

EXPERIMENT I

Subject

A feral female sea lion (Bibi) (*Zalophus californianus*) judged to be approximately 26 to 29 months old, had previously been tested on size-discrimination tasks with both circular- and triangular-shaped stimulus targets (Schusterman, Kellogg, and Rice, 1965). In addition, the animal had been tested in turbid water, predominantly with circular-shaped targets of different size and sound-reflection characteristics, in attempts to demonstrate its echo-ranging capabilities (Schusterman, 1966). During the latter stages of these tests, training was instituted to reverse the previous preference for the smaller of two identically-shaped stimuli; when the present experiments were initiated the animal was consistently responding to the larger of two stimuli (for which it was reinforced), despite changes in relative size and form. Before this study Bibi had never been confronted with stimuli differing in the form dimension.

Apparatus and Procedure

All testing was conducted outdoors in an oval tank constructed of redwood, painted white, measuring 15 ft by 30 ft, and 6 ft deep.

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[1]Supported by NSF grants GB-1437 and GB-4349. I gratefully acknowledge the assistance of Tom Thomas and Garth Rader who helped in testing the animals. Reprints may be obtained from the author, Stanford Research Institute, Menlo Park, California 94025.

Pictures of the testing conditions and apparatus have previously been published (Schusterman *et al.*, 1965). Target stimuli were presented simultaneously so that they projected below the opaque screen and were at least 15 in. below water level. At the beginning of a trial, a stimulus panel located behind the opaque screen was lowered to the water level. Attached to the side of the stimulus panel facing the experimenter were two rods, each 45 in. in length and .25 in. in diameter. The targets were cut from 20-gauge sheet metal and were attached to the lower portion of each rod by set screws. Deflection of either rod activated a microswitch and produced a light signal behind the stimulus panel. Activation of the microswitch defined the indicator response by the sea lion. The distance between the centers of any two targets was 22.5 in.

The animal had previously been trained to remain almost motionless at a starting position 16 to 20 ft in front of a testing platform until it was signaled to approach by the sound of the stimulus display being lowered into the water. The animal's task was to strike one of two target stimuli to obtain a small piece of herring (*Clupea pallasi*) weighing approximately 5 g. The experimenter immediately reinforced a correct response by dropping a piece of herring through a 6-in. gap between the opaque screen and the testing platform. The stimulus display was immediately withdrawn after either a correct or incorrect response. The position of the targets was randomly determined. A perpendicular divider made of mesh wire projected 4 ft outward between the targets and down to the floor of the tank, thus preventing the animal from swimming laterally from one target to another.

Two experimenters were always present. One presented the stimulus display and reinforced appropriate responses while the other observed the animal from the testing platform, recording correct responses and the presence of orienting responses. An orienting response was defined as postural changes of the head or body occurring within 7 ft of the stimulus display. In most instances the response was a lateral movement or change in swimming direction away from one stimulus and toward the other at a point 1 to 3 ft in front of the perpendicular divider. Occasionally two or three such reversals of head and body orientation occurred before the indicator response (striking the target and activating the microswitch).

Progressive dimensional change. The sequence of progressive training stages, stimulus dimensions, reinforcement values, and the number of trials per training stage are outlined in Table 1. Performance was quite stable throughout the three series of training stages instituted to obtain the three form reversals. To avoid unnecessary repetition, Table 1 presents information regarding only the first two series. The first stage of training was designed to reveal which of the stimulus forms the animal preferred. Subsequently, Stage 2 was begun with the aim of "forcing" Bibi to respond to the nonpreferred form on the basis of its previous size preference (large). Thus, from Stages 2 through 13 the nonpreferred form (triangle) and the preferred size constituted the positive compound stimulus, and the nonpreferred size and the preferred form (circle) constituted the negative compound stimulus. The size cue was progressively diminished until Stage 14, at which point Bibi was confronted with targets differing only in the form dimension. Training Stages 15-27 essentially replicated Stages 2-13 except that the circle and the preferred size constituted the positive compound stimulus and the triangle and the nonpreferred size constituted the negative compound stimulus. A form reversal with its associated training stages was undertaken on each of three consecutive days. On the second and third days testing was begun, with Bibi being given 10 trials on the same form-discrimination task which had terminated testing on the previous day.

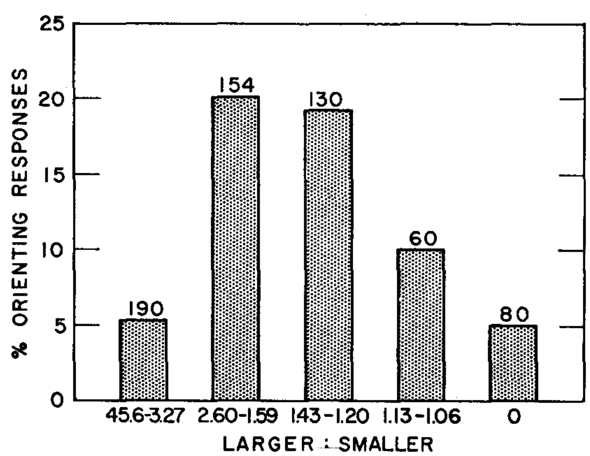

Fig. 1. Orienting responses as a function of size-difference ratios. Numerals at each data point represent number of trials.

Table 1

Description and Results of Training

Training Stages	Stimuli[a]: Triangle Area (cm.²)	Stimuli[a]: Circle Area (cm.²)	Size-Difference Ratio: Larger: Smaller	No. of Trials	Errors or Responses to Circle
1	108.7	108.7	1.00 : 1	12	11
2	456.7	16.1	28.37 : 1	20	0
3	456.7	25.9	17.63 : 1	10	0
4	283.2	41.9	6.76 : 1	10	0
5	175.5	41.9	4.19 : 1	10	0
6	175.5	67.6	2.60 : 1	10	0
7	175.5	86.6	2.03 : 1	10	0
8	137.9	86.6	1.59 : 1	20	0
9	137.9	96.5	1.43 : 1	30	0
10	122.9	96.5	1.27 : 1	30	0
11	122.9	102.4	1.20 : 1	10	0
12	115.3	102.4	1.13 : 1	10	0
13	115.3	108.7	1.06 : 1	10	0
14	108.7	108.7	1.00 : 1	25	0
	Circle	Triangle			Errors (or Responses to Triangle)
15	736.1	16.1	45.72 : 1	20	0
16	736.1	41.9	17.57 : 1	10	0
17	456.7	41.9	10.90 : 1	10	0
18	456.7	67.6	6.76 : 1	10	0
19	283.2	67.6	4.19 : 1	20	0
20	283.2	86.6	3.27 : 1	10	0
21	175.5	86.6	2.03 : 1	30	2
22	137.9	86.6	1.59 : 1	10	0
23	137.9	96.5	1.43 : 1	10	0
24	122.9	96.5	1.27 : 1	10	0
25	122.9	102.4	1.20 : 1	10	0
26	115.3	102.4	1.13 : 1	10	0
27	115.3	108.7	1.06 : 1	10	0
28	108.7	108.7	1.00 : 1	35	0

[a]Except for the first training stage, in which responses to either stimulus were reinforced, the positive stimulus for each pair appears in column 2 and the negative stimulus appears in column 3.

Results

Table 1 shows that the subject initially preferred the circular stimulus ($p < .01$, binomial test) but was able to reverse this original form preference without any errors. Furthermore, two additional errorless or nearly errorless reversals were accomplished.

The results dealing with orienting responses occurring throughout the entire experiment are presented in Fig. 1. They show that orienting responses reached a peak at size-difference ratios ranging from 2.60 : 1 to 1.20 :1 and subsequently decreased.

EXPERIMENT II

On the assumption that orienting responses may reflect a shift of attention from one stimulus dimension to another, it was reasoned that intensive training primarily with compound stimuli, in which orienting responses are frequently displayed, may be critical in obtaining errorless form reversal by means of progressive dimensional change. A second experiment compared intensive training with only a few pairs of those compound stimuli which had previously produced the most frequent display of orienting responses with less

Table 2

Phase 1 (Intensive Training Series)

Training Stages	*Stimuli*[a] *Circle Area (cm.²)*	*Triangle Area (cm.²)*	*Size-Difference Ratio Larger: Smaller*	*No. of Trials*	*Errors or Responses to Circle*
1	175.5	67.6	2.60 : 1	5	0
2	175.5	86.6	2.03 : 1	15	0
3	137.9	86.6	1.59 : 1	50	0
4	122.9	96.5	1.27 : 1	50	1
5	108.7	108.7	1.00 : 1	20	0

[a]Except for the first training stage, in which responses to either stimulus were reinforced, the positive stimulus for each pair appears in column 2 and the negative stimulus appears in column 3.

intensive training on a more extensive series of compound stimulus pairs. The first training series was designated Phase 1 and the second Phase 2.

The apparatus and procedure were essentially the same as those in Exp I. Tables 2 and 3 present the sequence of training stages, stimulus dimensions, reinforcement values, and the number of trials per training stage for both phases of training.

Terrace (in press) has found that once responses to the negative stimulus persist under one set of conditions, they tend to characterize performance under a related set of conditions despite gross changes in values of the discriminative stimuli. In order to perform additional experiments on errorless learning with the same animal (Bibi), Terrace's results suggested that it would be advisable to minimize the occurrence of errors during the experiment. Thus, if the animal made either two consecutive errors or committed a total of three errors during the first five trials of any training stage, it was considered to have failed that training series, and was returned to the previous stage of training for five additional errorless trials before proceeding to the next stage.

Table 3

Phase 2 (Extensive Training Series)

Training Stages	*Stimuli*[a] *Circle Area (cm.²)*	*Triangle Area (cm.²)*	*Size-Difference Ratio Larger: Smaller*	*No. of Trials*	*Errors or Responses to Circle*
1	283.2	25.9	10.93 : 1	10	0
2	283.2	41.9	6.76 : 1	10	0
3	175.5	41.9	4.19 : 1	10	0
4	175.5	67.6	2.60 : 1	10	0
5	137.9	67.6	2.04 : 1	10	0
6	137.9	86.6	1.59 : 1	10	0
7	122.9	86.6	1.42 : 1	2	2*
6	137.9	86.6	1.59 : 1	5	0
7	122.9	86.6	1.42 : 1	10	0
8	122.9	96.5	1.27 : 1	10	1
9	115.3	96.5	1.21 : 1	10	0
10	115.3	102.5	1.13 : 1	10	0
11	108.7	102.5	1.06 : 1	10	0
12	108.7	108.7	1.00 : 1	20	0

[a]Except for the first training stage, in which responses to either stimulus were reinforced, the positive stimulus for each pair appears in column 2 and the negative stimulus appears in column 3.

*Designates failure.

Results

The main results are shown in Column 6 of Tables 2 and 3. Although the animal proceeded through Phase 1 essentially without errors (Table 2) it failed to do so with Phase 2 training despite the fact that the size dimension was reduced more abruptly during the first phase. However, when the animal was returned to Stage 6 of Phase 2 for only five additional training trials, it completed the rest of the series with only one error. The greatest number of orienting responses on the first phase of training occurred during Stage 3. There was a total of 14 orienting responses during the 50 trials of this stage, 86% of which occurred during the first 25 trials.

EXPERIMENT III

This sought to determine whether the animal could reverse its previous form perference with a minimal amount of progressive-dimensional-change training. The procedure was similar to that of the previous experiment, and is outlined in Table 4.

Results

The results presented in the last column of Table 4 show that the sea lion failed to reverse its previous form preference during the present training series. Furthermore, persistent errors during Stages 3 and 2.5 apparently had an adverse effect on performance when the animal was returned to a former discrimination (Stage 2) which had previously been perfected. It should be noted, however, that these effects may be reversible. After this experiment, the animal was given progressive training comparable to that received during the first phase of the second experiment. Under these training conditions, it succeeded in reversing its form preference with only a few errors.

EXPERIMENT IV

Two sea lions were tested with the triangle and circle on a series of discrimination-reversal problems presented in the usual manner. In this paradigm the reinforced member of the stimulus pair is repeatedly alternated after each problem is learned to a criterion. Since there was no attempt to train these discriminations without errors by progressively eliminating the size cue, this experiment served as a control for the previous experiments.

Subjects

Two California sea lions (Bibi and Cathy) were used. Bibi had been previously trained to reverse a form preference on six occasions by means of a progressive-dimensional-change technique. Cathy's previous form-discrimination training had been limited to a single form reversal by means of this technique (Schusterman, 1965*a*). Before such training, Cathy, like Bibi, had been tested on size-discrimination tasks with circular- and triangular-shaped targets (Schusterman *et al.*, 1965) in both clear and turbid water (Schusterman, 1965*b*).

Table 4

Description and Results of Training

Training Stages	*Stimuli*[a] *Circle Area* $(cm.^2)$	*Triangle Area* $(cm.^2)$	*Size-Difference Ratio* *Larger: Smaller*	*No. of Trials*	*Errors or Responses to Circle*
1	175.5	67.6	2.60 : 1	5	0
2	137.9	86.6	1.59 : 1	15	0
3	108.7	108.7	1.00 : 1	2	2*
2	137.9	86.6	1.59 : 1	5	0
3	108.7	108.7	1.00 : 1	2	2*
2.5	122.9	96.5	1.27 : 1	2	2*
2	137.9	86.6	1.59 : 1	3	2*

[a]Except for the first training stage, in which responses to either stimulus were reinforced, the positive stimulus for each pair appears in column 2 and the negative stimulus appears in column 3.

*Designates failure.

Apparatus and Procedure

The testing conditions and apparatus were essentially the same as those in the previous experiments. The stimuli were a triangle and a circle 108.7 cm^2 in area. During the first 20 reversals, each problem was presented until solved to a criterion of either 10, 12, or 14 consecutive correct responses. During the next 40 problems, the learning criterion was either 8, 10, or 12 consecutive correct responses. The animals received 89 to 100 trials per session. A session was terminated when either an error or problem solution occurred during the last 12 trials. Generally, each animal received one test session per day. On the original form-discrimination, the circle was the positive stimulus for Bibi and the triangle was the positive stimulus for Cathy.

Results

The main results are presented in Figure 2 which depicts the course of the inter-reversal learning curves for both animals. Since the original problem was the last trained form discrimination by the progressive-dimensional-change technique, both animals learned this problem with a minimum of errors. The first reversal, however, produced a large number of errors by both animals. Errors decreased rapidly after the first or second reversal and there was relatively little inter-reversal improvement after the fifth reversal.

"Emotional" or nontest-oriented behavior was frequently displayed when subjects persistently responded ot the negative stimulus during the initial stages of most reversal problems. This nontest-oriented behavior took the form of biting parts of the apparatus and attempting to escape from the testing tank. Frequently the animals would attempt to bite the negative stimulus immediately after a series of consecutive nonreinforced responses.

DISCUSSION

These experiments have shown that a sea lion can, by means of a "progressive" training procedure, repeatedly reverse well-established habits on a form-discrimination task virtually without error. These results support and extend previous findings on errorless reversal learning in the sea lion (Schusterman, 1965*a*), and further extend the use of progressive training techniques for minimizing the occurrence of errors in discrimination tasks (Hively, 1962; Terrace, 1962, 1963).

Although the present data are far from sufficient, in both sample size and experimental design, to yield any definitive conclusions about the techniques necessary to yield errorless reversal learning, a theoretical account of the techniques that generated repeated errorless reversals, and of the process itself, may prove helpful. This account is drawn primarily from the theoretical discussions of Terrace (in press) and Mackintosh (1965) who have recently attacked the problem of stimulus control and attention in animal discrimination learning.

In extending a *single* errorless form reversal to a *series* of errorless form reversals, the critical elements of training appeared to depend on the *repeated* combining of a previously well-learned size cue preference with the nonpreferred form cue, followed by a relatively gradual reduction of the size cue. The fact that the sea lion performed without error at the beginning of each new reversal training series, which began with a recombination of positive size—previously negative form (S+), and negative size—previously positive form (S−), suggests that size is the primary controlling stimulus dimension (or the stimulus to which the sea lion attends) during the early stages of each training series. Certainly, if this were not the case, *i.e.*, if both the size and form dimensions had equal control over responding during initial reversal training (as would be predicted by continuity theory [Spence, 1940]), or if form were the primary controlling stimulus dimension, then responses to the previously positive form would occur rather frequently, as they did during the fourth experiment when "progressive" training was not used. The question then arises as to when and in what manner the animal shifts its attention from the size dimension to the form dimension. If the shift occurred abruptly, *i.e.*, the animal suddenly eliminated size as a cue and attended solely to the form cue as would probably be predicted by noncontinuity theory (Krechevsky, 1938), then it would be expected that since S− contains the previously positive form cue, numerous errors or responses to S− would occur. On the other hand, if the shift in stimulus control (from size to form) occurred gradually as the size discrimination became

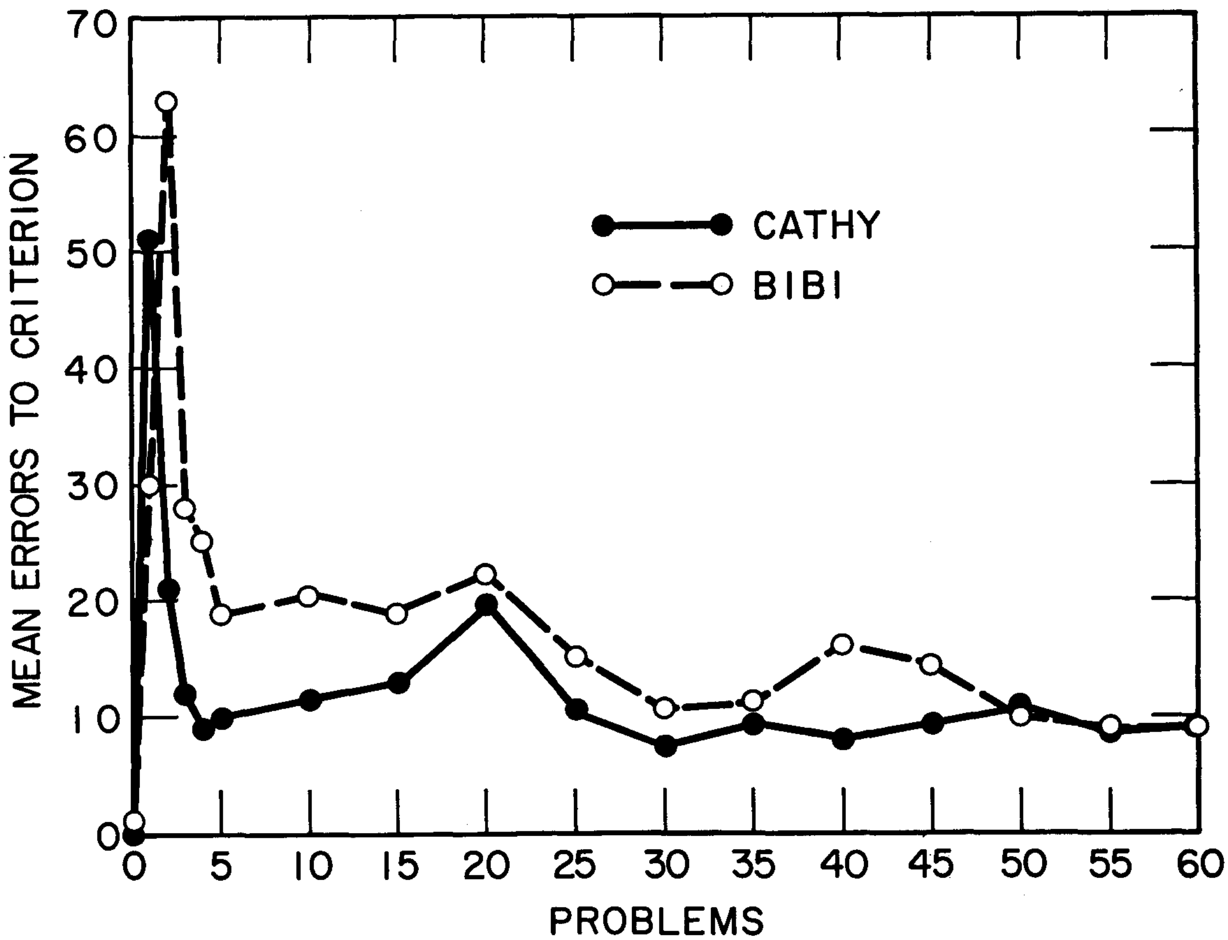

Fig. 2. Inter-reversal learning by two California sea lions following errorless reversal learning by means of progressive-dimensional-change training.

difficult the animal on any given trial might attend to both cues. The previous reinforcement values of the size and form cues are opposed during each succeeding training phase. It has, therefore, been my contention (Schusterman, 1965*a*, 1965*b*) that the sea lion's vacillation between the target stimuli as it approached the stimulus display area reflects a shift in the controlling stimulus dimension.

Experiments by Terrace (1963*a*, 1963*b*) and Mackintosh (1965) have clearly shown that the more difficult the original discrimination the more the subjects learn about a second relevant cue. Thus, in the present context, as the prominence of the size cue is progressively diminished, a peak in the occurrence of orienting responses appears to suggest a shift in stimulus control at size-difference ratios ranging from approximately 2.60 : 1 to 1.20 : 1. During the early stages of this transition, although the conflict may be resolved at the last moment in favor of the size cue, responses involved in attending to the form cue may gradually become conditioned. Although such conditioning would be facilitated by gradually eliminating the size cue, an abrupt shift in stimulus control would result in responses to S–, as was the case in the third experiment.

Although not a precise account of the technique and process of errorless reversal learning, this description seems to be consistent with the following brief statement by Guthrie: "What is being noticed becomes a signal for what is being done." (Guthrie, 1959, p. 186.) According to Guthrie, "what is being noticed" is that aspect of the organism's own activity which is involved in selective attention to physical stimuli.

Since Cathy's performance during the fourth experiment was at least as proficient as Bibi's, the results suggest that previous experience with successive reversals trained by a technique resulting in errorless performance has little or no relevance to the learning with errors which normally occurs on a series of successive discrimination-reversal problems. Moreover, observation of the animals' behavior during testing supports Terrace's contention that the "negative stimulus" acquires aversive properties following discrimination learning with errors (Terrace, in press). Whereas the sea lions showed no "emotional" or nontest-oriented behavior during errorless reversal training, such behavior was frequently displayed during the fourth experiment.

Despite differences in procedure, apparatus, and deprivation schedules, comparative studies of serial discrimination-reversal learning and interproblem learning have resulted in what some view as a fairly systematic phyletic trend toward an increasingly greater learning capacity within the vertebrate series (Warren, 1965). Comparison of the inter-reversal learning curves of the sea lion (see Fig. 2) with those of other mammalian species suggests this marine mammal's proficiency on a series of visual discrimination reversals, although superior to rats and squirrels (data by A. R. Rollin as cited by Warren, 1965) is within the range of proficiency achieved by cats, rhesus monkeys, and chimpanzees (Schusterman, 1964; Warren, 1965).

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Received February 14, 1966