

*DIFFERENTIAL VOCALIZATION IN BUDGERIGARS:  
TOWARDS AN EXPERIMENTAL ANALYSIS OF NAMING*

KAZUCHIKA MANABE, TAKASHI KAWASHIMA, AND J. E. R. STADDON

MEISEI UNIVERSITY, NIHON UNIVERSITY,  
AND DUKE UNIVERSITY

In Experiment 1, 3 budgerigars (*Melopsittacus undulatus*) were trained with food reinforcement to make low- or high-frequency calls in response to different color stimuli, C1 and C2 (a color-naming task), using a gradual response-differentiation procedure and an automatic call-recognition system. Thus, a call within a certain frequency band was reinforced in the presence of C1 ("C1 call"), and a call within a different band was reinforced in the presence of C2 ("C2 call"). In Experiment 2, all 3 budgerigars were trained in a form-to-color matching-to-sample task, alternating trial by trial with either the color-naming task (2 birds) or an identity color matching-to-sample task (1 bird). Sample stimuli for the new matching-to-sample task were forms (F1 or F2) and comparisons were the same two colors (C1 and C2). Given Sample F1 or F2, birds had to make a call to produce Comparison Pair C1 and C2. With F1 as the sample, a peck on C1 was reinforced; with F2 as the sample, a peck on C2 was reinforced. Although no particular call was specified in the presence of F1 and F2, 2 birds made the C1 call in the presence of F1 and the C2 call in the presence of F2. In Experiment 3, the bird that failed to match form and color calls in Experiment 2 and another bird were first trained in a color-to-form matching-to-sample task: C1 to F3 and C2 to F4. In this task, to produce the comparison pair of forms, a high call (or low for the other bird) was required in the presence of C1, and a low call (or high) was required in the presence of C2. Both birds were then trained with an identity matching-to-sample task in which sample and comparison stimuli were the same two forms, F3 and F4. Trials on the identity task alternated with the color-to-form trials. Although no particular call was required in the presence of Samples F3 and F4, both birds came to make the C1 call in the presence of F3 and the C2 call in the presence of F4. Our technique promises to be useful for the study of emergent vocal relations in budgerigars and other animals.

*Key words:* vocal operant, automated technology, real-time signal processing, differential reinforcement, stimulus control, vocal naming, transfer of naming, stimulus equivalence, functional equivalence, budgerigars

The vocal behavior of many bird species is modifiable by experience. Perhaps the most common route is through mimicry: The calls of many adult passerines and psittacines are partly determined by their auditory and social environment (e.g., Farabaugh, Linzenbold, & Dooling, 1994; Kroodsmas, 1982). A smaller set of birds have been shown to be capable of operant vocal learning; their calls can be modified by reinforcement and punishment. For example, West, King, and Eastzer (1981) have shown that male cowbirds will modify their courtship song to elicit responses from females with different song preferences, an effect of reinforcement. Under other conditions, birds

attacked by the dominant bird in a flock will modify their songs to make them less effective, an effect of punishment. Pepperberg (1981) has shown how a combination of food and social reinforcement can produce extensive elaborations of the vocal behavior of an African grey parrot. We have not been able to find any experimental examples in which bird vocalizations have been modified through automated (i.e., entirely nonsocial) reinforcement procedures. Developing such a procedure was the objective of the first experiment in the present series. In the second and third experiments we used the method to study emergent relations involving vocal behavior.

This research was supported by a Grant-in-Aid for Developmental Scientific Research from the Ministry of Education, Science and Culture of Japan and also by grants from the NIMH and NSF to Duke University and a NATO grant to J. Staddon. We thank Mark Cleaveland for comments on an earlier version of the manuscript. Correspondence and reprint requests should be sent to Kazuchika Manabe or J. Staddon, Department of Psychology: Experimental, Duke University, P.O. Box 90086, Durham, North Carolina 27708-0086.

**EXPERIMENT 1:  
STIMULUS CONTROL OF  
DIFFERENTIAL VOCALIZATION**

In the laboratory, an African grey parrot has been taught to show not just naming but a variety of more complex types of vocal behavior (Pepperberg, 1981, 1987, 1988). My-

nah birds have been taught to mimic words spoken by a human trainer, although this method is apparently rather slow (Turney, 1982). In both Pepperberg's and Turney's studies, training was under explicitly social conditions, and "correct" vocalizations had to be identified by a human observer. There is obviously some risk of "clever Hans" effects (i.e., inadvertent cuing by the human experimenter) under these conditions, although recent studies seem to be free of this problem. But this approach is unavoidably labor intensive and difficult to quantify.

It would be desirable to develop an automatic method for the study of vocal operants in animals. The budgerigar (parakeet), a small, tractable bird in the parrot family with a substantial vocal repertoire, is a natural subject for the study of vocalization (cf. Brockway, 1964; Ginsburg, 1960; Okanoya & Dooling, 1991). We describe in Experiment 1 a simple, efficient, and reliable automated technique for training budgerigars to emit sounds of different frequencies in the presence of different visual stimuli.

## METHOD

### *Subjects*

Three adult male budgerigars (*Melopsittacus undulatus*) were maintained at 90% of their free-feeding weights. The birds were obtained from a local pet supplier and were maintained in an aviary at Meisei University under a 12:12 hr light/dark cycle. They were kept in cages bought from a local pet shop. The birds were fed once a day and had free access to grit and water in their home cages. Budgerigars are hardy and long-lived, and we had no difficulty maintaining our birds in good health.

### *Apparatus*

*Experimental chamber.* The birds were trained in a small experimental chamber (14 cm wide by 12 cm high by 17 cm deep) situated in a sound-attenuated room (approximately 35 dB attenuation). A rectangular window (7 cm wide by 2.5 cm high) was on the front wall 7 cm above the floor. The window was split horizontally into three panels (2.3 cm wide by 2.5 cm high; we will refer to these panels as left, center, and right response panels). Pecks to each panel were detected by photocells. Various visual stimuli could be presented on a TV monitor visible through the panels. A food

hopper containing millet seed was mounted on the floor 3 cm below the front panel. The reinforcer was 2-s access to the seed. The birds' vocalizations were recorded with a 1.5-cm electret condenser microphone (Sony® ECM-44B) attached to the ceiling of the chamber 5 cm from the front panel.

*Recognition of calls.* The output of the microphone was fed into an audio mixer (Sony® MU-X051). The amplified output of the audio mixer was low-pass filtered at 10 kHz and sent to a 12-bit analog-to-digital converter (Canopus® ADX-98E) with a trigger controller (Canopus® ADT-98E). When sound intensity exceeded a preset value, the analog signal was converted to digital at a sampling rate of 20 kHz. The digital signal was sent to random-access memory on a 32-bit personal computer (NEC® PC-9801RA21) using direct memory access for a 256-ms overall sampling period. A digital signal-processor board (Canopus® Flash-16) on the personal computer calculated peak-energy spectra with a Hamming window (sampling interval) of 12.8 ms. The calculation of the first 12.8-ms data point was carried out while the second 12.8 ms of data was sent to random-access memory, and so on.

Twenty successive peak-energy spectra were computed for each call, but only the initial six (76.8 ms) were used in recognition, for two reasons. First, Park and Dooling (1986) have shown that budgerigars can discriminate calls based on only the first 70 ms. Second, calls vary in length, and the end of each call generates noise that is more or less independent of the spectral composition of the rest of the call.

If all six 12.8-ms initial peak-energy spectra fell between a lower and upper limit, the signal was recognized as a "correct" call. The computer completed this recognition analysis within 8 ms after the first 76.8-ms call segment. The computer reinforced correct calls after the 256-ms sampling period, which meant that there had to be some delay between the end of a correct call and reinforcement. The maximum possible delay between the end of a correct call and the delivery of food reinforcement was 200 ms. But because most calls were 150 to 250 ms long (so-called *contact calls* that are typically emitted when budgerigars are separated from their neighbors or mates; cf. Brockway, 1964; Okanoya & Dooling,

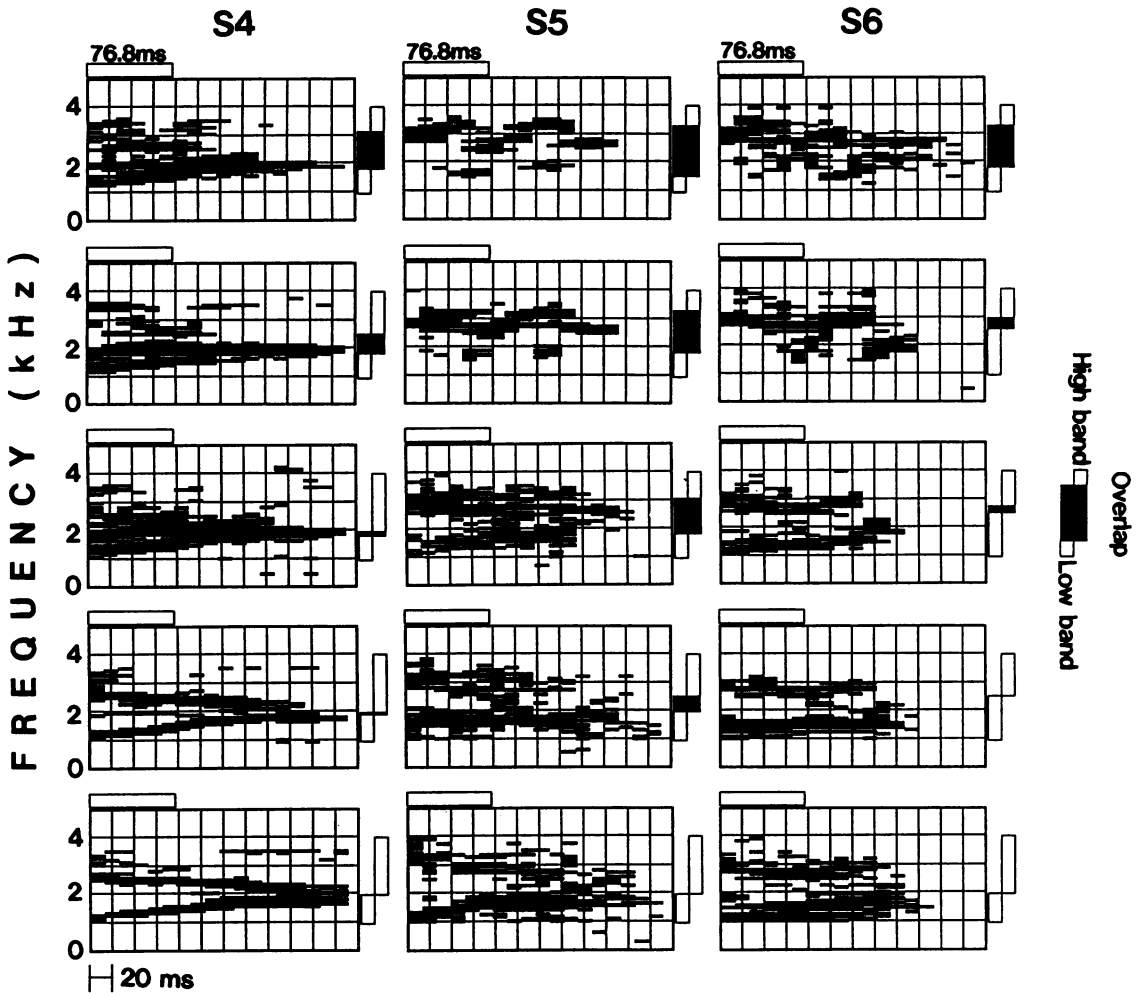


Fig. 1. Experiment 1: Average peak-energy spectra traces of 50 calls in the last session meeting the reinforcement criterion at five criterion levels (rows) for each of the 3 budgerigars (columns). Each criterion is shown on the right as two rectangles.

1991), in practice the delay between the end of a call and reinforcement was never more than 90 ms (see Figure 1). This delay is obviously too short to diminish the effect of reinforcement.

Programs for experimental control and data collection were written in Microsoft® C. This system was calibrated using natural calls and noises that had been recorded in the aviary prior to the experiment. We chose our criteria so that the system could discriminate reliably between calls and noises.

#### Procedure

The procedure involved three steps. First, we shaped undifferentiated calling by provid-

ing food reinforcement. Second we differentiated calling: In a quasi-random series in each session, either a "high" or a "low" call was required for reinforcement. No stimuli were involved at this stage. In the final step, the high and low calls were brought under the control of red and green stimuli. The details are as follows.

*Shaping of calls.* After all birds were habituated to the chamber, they were trained to eat grain from the food hopper. We first tried to shape a vocal operant with an autoshaping procedure in which a digitally stored natural call 256 ms in duration was presented as a signal for food presentation. However, the birds did not call but came to insert their heads into

Table 1

Experiment 1: Criteria for reinforcement and number of sessions used to differentiate high- and low-frequency calls. Conditions shown in order, from top to bottom.

Bird	Phase	High band (kHz)	Low band (kHz)	Sessions
S4	1	1.0-4.0	1.0-4.0	3
	2	1.8-4.0	1.0-3.2	4
	3	1.8-4.0	1.0-2.5	3
	4	1.8-4.0	1.0-2.0	6
	5	1.9-4.0	1.0-2.0	10
	6	2.0-4.0	1.0-2.0	7
S5	1	1.0-4.0	1.0-4.0	3
	2	1.5-4.0	1.0-3.3	3
	3	1.8-4.0	1.0-3.3	3
	4	1.8-4.0	1.0-3.1	5
	5	2.0-4.0	1.0-2.9	1
	6	2.0-4.0	1.0-2.5	1
	7	2.0-4.0	1.0-2.0	17
S6	1	1.0-4.0	1.0-4.0	3
	2	1.8-4.0	1.0-3.3	4
	3	2.5-4.0	1.0-3.1	2
	4	2.5-4.0	1.0-2.9	24
	5	2.5-4.0	1.0-2.8	1
	6	2.5-4.0	1.0-2.5	1
	7	2.0-4.0	1.0-2.0	8

the opening of the food hopper as soon as the natural call was presented; the autoshaping approach was unsuccessful.

We succeeded in getting the birds to call by playing tape recordings of typical sounds in the aviary, which included calls as well as noises (cf. Ginsburg, 1960). Because the automatic system could not perfectly discriminate between the bird's call and the played call, calls by the bird were reinforced by the experimenter during this period. When birds began to emit calls reliably in the absence of played calls, the calls were reinforced automatically. In Phase 1 of the experiment proper, calls were reinforced only when all of the first six 12.8-ms peak-energy spectra were between 1 kHz and 4 kHz.

*Differentiation of calls.* In Phase 2, two types of calls were differentiated using the auditory signal-processing system. The criterion peak-energy spectrum for reinforcement was changed in several steps from the wide band to two nonoverlapping narrow bands according to the progress in vocal differentiation of each bird. The criteria were shifted in subsequent phases when a substantial number of calls met the criterion in a given session. There were small differences in the criteria used for different

birds in different phases. The exact criteria and number of sessions for each bird are shown in Table 1. During a session, the high and low requirements were alternated according to a Gellerman (1933) series. A requirement remained in force until a call that met the criterion was emitted. A white square was presented on the middle response panel except during reinforcer presentations and 2-s inter-trial intervals (ITIs) after reinforcement (during these 2 s, digitized call waveforms were sent from random-access memory to disk). Each time a bird made a call or a noise during the ITI, the ITI was prolonged by 2 s.

We adopted this differentiation method for the following reasons. At first, budgerigars usually make only contact calls; it is very difficult to get the birds to make different types of calls right at the beginning. If we had begun with the final criteria, the birds would soon have ceased to call at all. The initial contact calls do nevertheless show some variation in frequency as well as in duration and amplitude. It is important during differentiation to make sure that a sufficient number of calls are effective in producing reinforcement; hence our method of slowly adjusting the frequency criteria according to individual performance.

*Stimulus control of calls.* After the two calls were successfully differentiated, each call was brought under the control of a different stimulus. When a red square was presented at the TV window (center response panel), high calls (from 2 kHz to 4 kHz) were reinforced for Subject S6, and low calls (from 1 kHz to 2 kHz) were reinforced for Subjects S4 and S5. When a green square was presented, low calls were reinforced for Subject S6, and high calls were reinforced for S4 and S5. When the bird made the correct call, the color disappeared and a reinforcer was presented. After a 2-s ITI, the next trial began. If subjects made an incorrect call, the color disappeared and a 5-s timeout plus the 2-s ITI followed. After an "error" trial, the same color was re-presented until subjects made a correct call. During a session, the two colors were alternated according to a Gellerman (1933) series.

All experimental sessions were terminated after 50 reinforcers or 20 min, whichever came first. All subjects received one or two sessions daily, 7 days per week. (Because of the high rate at which their food is metabolized, it is possible to conduct two sessions a day with

small birds like budgerigars.) A second session on the same day occurred 6 hr after the first session.

### RESULTS

The birds made sounds in the following five categories: (a) *correct*: calls meeting either the high-band criterion or the low-band criterion for the first 76.8 ms, but not both; (b) *overlap*: calls meeting both criteria, when this was possible (overlap calls were not possible in the last phase of training, when the criterion bands no longer overlapped); (c) *wide*: calls meeting the wide-band criterion from 1 kHz to 4 kHz, but were not in categories (a) or (b); (d) *other*: calls meeting none of these criteria; and (e) *noise*: including scratching, pecking, and so on. Other calls were emitted infrequently; noise calls, often generated by sounds outside the apparatus, were also infrequent. We describe correct, overlap, and wide calls in the following sections.

*Differentiation of calls.* By the end of training almost all the birds' calls were within the high or low bands. Figure 1 summarizes the acquisition process beginning with Phase 2. Each panel shows peak spectra for all 50 calls in the last session at five different reinforcement criteria, from early in training (top) to the end of the response-differentiation phase (bottom), for each of the 3 birds. Data from the fifth phase for Subject S5 and the third phase for Subject S6 (Table 1) are not shown, because their performances changed little over this period. The two criteria in each phase are shown by the two more or less overlapping rectangles on the right of the figure. Look at the first 76.8 ms in each display (first four columns in each plot), the criterion period. Early in training (top row) peak spectra occurred at all frequencies between 1 and 4 kHz (S4 and S6) or within a band (S5). At the end of training (bottom row), all 3 birds showed a more or less bimodal distribution of frequencies, with almost no calls in the border region (2 kHz).

With the exception of calls emitted by S5 at the outset of differentiation training (top panel of Figure 1), the calls rarely resembled typical budgerigar calls. The early calls of S5 resembled contact calls. The sonagrams of calls meeting the low-band criterion (low calls) in the last phase show increasing lines (an upward frequency sweep) from about 1 to 2 kHz for all subjects (bottom panels of Figure 1).

These calls first appeared under the first pair of differential criteria for S4, in the third pair for S5, and in the second pair for S6. On the other hand, the sonagrams of calls meeting the high-band criterion in the last phase varied across the 3 subjects. The high calls emitted by S4 covered a narrower frequency range than the high calls of the other 2 subjects. The amplitude of low calls was lower than the amplitude of high calls for all subjects. The sonagrams of both high and low calls changed greatly from early to late in training.

Figure 2 shows the numbers of overlap calls and wide calls made by Subject S4 in Phases 2 through 6. In the first two phases shown in the figure, frequency of overlap calls increased across sessions, going from 6% to 24% of all correct calls. Overlap calls fell to zero in later phases. The number of wide calls decreased over the last three phases.

Overlap calls were of almost constant frequency, whereas the frequency of other correct calls varied considerably within each call. As the region of overlap between the two criteria was reduced across phases, the number of overlap calls declined to zero, presumably because the band of overlap had vanished or become too small.

*Stimulus control of calls.* Figure 3 shows a measure of discrimination accuracy across stimulus-control training. The y axis shows the ratio of the number of correct calls (e.g., high in the presence of red plus low in the presence of green for Subject S6) divided by total calls (comprising correct calls, overlap calls, and wide calls). The learning curves for all 3 subjects were similar. Percentage correct for all 3 subjects was usually better than 90% after about 20 sessions.

### DISCUSSION

These results show that budgerigar vocal topography is sensitive to differential food reinforcement and can be brought under the control of visual stimuli. All the birds eventually satisfied the low and high criteria. In addition, when the response criteria overlapped, 1 subject, S4, made many calls that satisfied both criteria (overlap calls), and the frequency of these calls changed systematically as the overlap region changed.

The birds satisfied the criteria in different ways. Although the final form of the low calls was similar for all birds, the final form of the

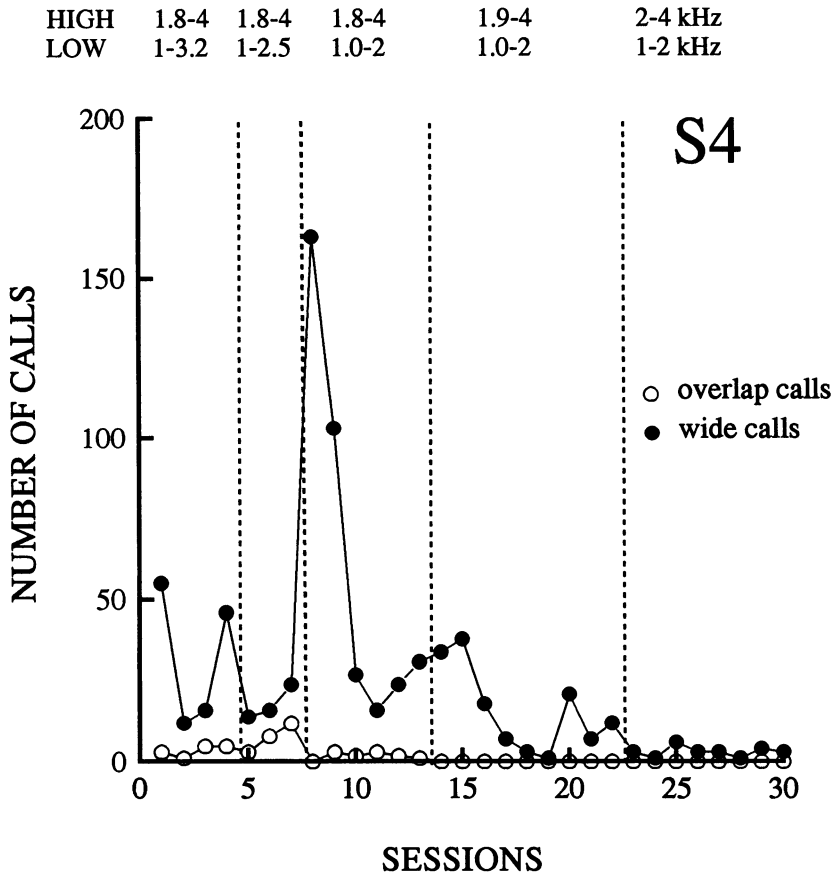


Fig. 2. Experiment 1: The frequencies of overlap calls (open circles) and wide calls (closed circles) emitted by S4. The reinforcement criteria are shown at the top. See text for details.

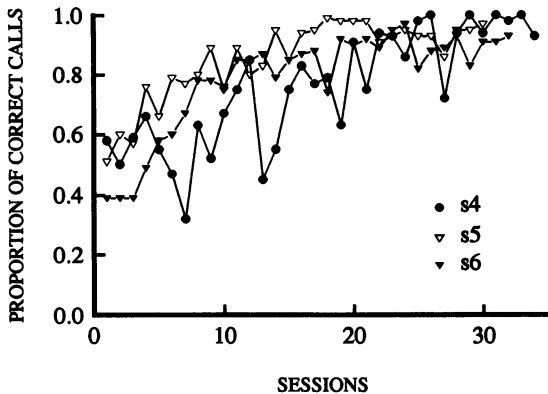


Fig. 3. Experiment 1: The proportion of total correct calls to the two visual stimuli across sessions for each of the 3 birds.

high calls differed from bird to bird. These calls are clearly not “instinctive” or food related in some preprogrammed way. Both the calls and their links to the red and green stimuli were shaped by our training method. The birds’ calls are “arbitrary” in the sense we describe below (see the Introduction to Experiment 2). Our results add budgerigars to the list of species shown to be capable of associating arbitrary vocal signals with visual stimuli.

We used peak frequency (detected by a fast-fourier-transform technique) as the relevant auditory dimension for shaping calls, but there are other possibilities. For example, zero-crossing displays, which compute frequency in a very simple way, from the time period between successive negative-going zero crossings of the sound wave, capture much of the same information as a fast-fourier-transform, but

require less computation. The zero-crossing method has been used to analyze a wide range of bird songs (Okanoya & Kimura, 1993; Staddon, McGeorge, Bruce, & Klein, 1978), and we have used it to train budgerigars to make vocalizations that are more or less dissimilar to their previous vocalizations.

If we use frequency distribution rather than peak-energy spectrum, our system is applicable to vocalization in many other species, mammals as well as birds. Guinea pigs, for example, make broad-spectrum sounds (cf. Burnstein & Wolf, 1967) that should be recognizable with this system.

There are also ways to shape vocalization that do not prescribe in advance the relevant auditory dimension. For example, a real-time method that allows a call to be compared with earlier calls would allow selective reinforcement of highly variable vocal behavior. Current technology makes real-time comparison possible.

Our training method was relatively rapid. In Turney's (1982) experiment with mynah birds, for example, mimicry was used to elicit vocalizations, and shaping took about half a year. On the other hand, the present procedure needed only from 30 to 40 sessions of 20 min or less (15 to 20 days) to shape two different vocalizations. It took under 20 sessions to bring the vocalizations under stimulus control. The rapid training method and automated reinforcement make the method useful for studying more complex types of vocal learning in budgerigars, as we show in the next two experiments.

## EXPERIMENT 2: SPONTANEOUS TRANSFER OF DIFFERENTIAL VOCALIZATIONS

The task in Experiment 1 is sometimes termed *color naming*, but naming, as it occurs in human language, obviously involves much more than the control of vocal responses by discriminative stimuli. The use of names by human speakers has three properties. Two (stimulus-response connections and arbitrariness of responses) are shared with all operant behavior, but the third—"emergent" use—is, if not unique, at least especially well developed in naming. Naming is thus a natural starting point for the comparative study of emergent

relations (cf. Bernstein, 1987; Kent, 1987; Terrace, 1985).

Naming involves at a minimum the emission of topographically different responses in the presence of different stimuli (stimulus-response connections). Names are also usually arbitrarily related to the things named and to one another. Nonvocal responses (such as hand signs or responding to keyboard symbols) share the arbitrary quality of vocal naming, but arbitrariness is obviously easier to achieve in the vocal modality. These two properties, which were demonstrated for budgerigars with colored stimuli in Experiment 1, do not differentiate naming from other operant behavior.

*"Emergent" use.* The most distinctive and least well-understood property of naming is that the name for something may be used in its absence. Indeed, without this referential property, naming would be no more than vocal pointing. Emergent use is not the same as stimulus generalization, a term that is usually applied to an effect of physical resemblance. Things that look quite different may nevertheless have the same name (e.g., "tools"), the same name may apply to quite different things (e.g., the several meanings of "pool" or "beam"), and a name may be extended to new referents for reasons other than physical resemblance (e.g., similar function). Moreover, a name may be emitted under a variety of circumstances to do with the history and motivational state of the namer, as in "requesting," "describing," "relating," and so on. An experimental route to understanding naming from the point of view of the speaker, therefore, is to map out the conditions under which a set of responses trained to one set of stimuli comes to occur in their absence.

Using matching-to-sample (MTS) tasks, Sidman and his colleagues (e.g., Sidman, 1971; Sidman & Cresson, 1973; Sidman & Tailby, 1982) have carried out numerous studies on a class of emergent relations that Sidman terms *stimulus equivalence*. Experiments 2 and 3 explored the possibilities of applying our technique to demonstrate spontaneous transfer of "names" by these budgerigars after training on MTS tasks.

In Experiment 1, we trained 3 budgerigars to emit low- and high-frequency (high and low for 1 bird) calls in the presence of the colors red and green. In the present experiment, we trained birds on an alternating MTS task in

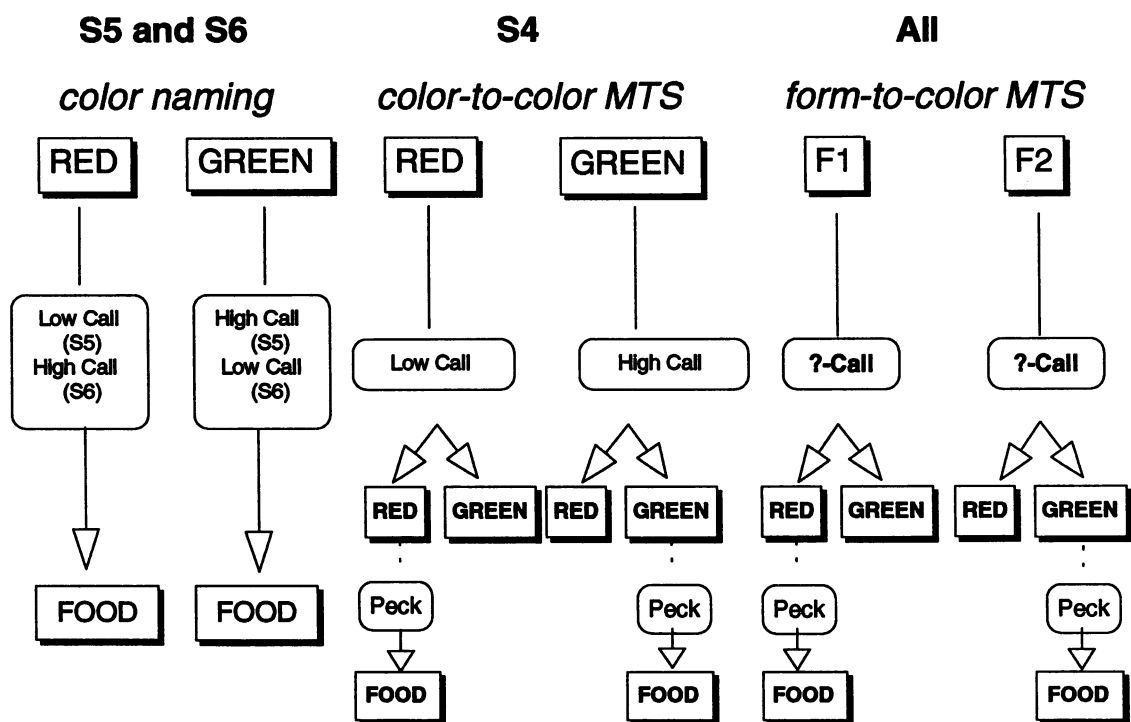


Fig. 4. Experiment 2: Trial types. Two tasks were alternated within each session: a color-naming task (left: Birds S5 and S6) or a color-to-color matching-to-sample (MTS) task (center: Bird S4) with a form-to-color MTS task (right: all birds). The color-to-color MTS task required high or low calls to the green and red samples to produce the comparison color pair. The form-to-color MTS task required no particular call to the form samples. Both MTS tasks required a peck to the correct comparison to produce food reinforcement. See text for details.

which forms (a circle and a cross) were the samples and red and green were the comparisons: Circle signaled red as the positive stimulus and cross signaled green. The birds were required to call to produce the comparison pairs, but no stimulus-specific constraints were placed on the call. Nevertheless, some birds consistently made the low call in the presence of the circle (which signaled green as the correct comparison) and the high call in the presence of the cross (which signaled red).

#### METHOD

The subjects and apparatus were the same as in Experiment 1. By the end of Experiment 1, all 3 birds had been trained to emit different vocalizations to the colors red and green (see Figure 4, left). When red was presented in the center response panel, high vocalizations (from 2 kHz to 4 kHz) were reinforced for S6, and low vocalizations (from 1 kHz to 2 kHz) were reinforced for S4 and S5. When green was presented, low vocalizations were reinforced

for S6, and high vocalizations were reinforced for S4 and S5.

In addition, S4 was subsequently trained in an identity color MTS task using high (in the presence of the green sample) and low (red) vocalizations as sample responses (Figure 4, middle). That is, after a correct vocalization, the comparison colors appeared on left and right response panels, and the color on the center response panel disappeared and was replaced by a dark screen. When the bird pecked the correct comparison color, both colors disappeared and a reinforcer was presented. Thus, although S4 was required to emit the correct vocalization to the sample stimulus (to produce the two comparison stimuli), a peck to the correct comparison color was required for food. After a 2-s ITI, the next trial began. The two comparison colors alternated randomly between the left and right response panels from trial to trial. If S4 pecked the incorrect comparison color, both comparisons went dark and a 10-s timeout plus the 2-s ITI followed. After



an "error" trial, the same sample was re-presented until the bird vocalized correctly and chose the correct comparison color. S4 achieved high accuracy on this task. Both correct choice ratio and correct naming were 100% in the last three sessions. The total number of sessions was 27.

Our method in this experiment was to present the birds with two types of discrimination in the same experimental session. For S5 and S6, one discrimination was the original color-naming task from Experiment 1; for S4, it was the identity color MTS task. For all 3 birds, the second task was a new, form-to-color MTS task. Thus, in the final phase of Experiment 2, all 3 birds experienced four different trial types during each experimental session (see Figure 4).

Subjects S5 and S6 were introduced to the new MTS task by a shaping procedure. Pecking responses to left and right response panels were shaped by reinforcing successive approximations. One of the two color stimuli was present at a time, randomly assigned to left and right panels. When a colored stimulus (2 cm by 2 cm) was presented on the center response panel, the appropriate high or low vocalization was reinforced with food; a pecking response was reinforced when the appropriate color appeared on one of the two side panels. After some training sessions, subjects called only to color stimuli on the center panel and pecked only the two side panels.

After this training, the form-to-color MTS procedure was introduced (Figure 4, right). In this task two unfamiliar forms (F1 and F2) were presented as sample stimuli and the two colors, red and green, were used as comparison stimuli. When one of the two forms was presented on the center response panel, subjects had to vocalize to produce the two color comparisons on the left and right response panels, but the type of vocalization was irrelevant. When the comparison colors appeared on the left and right response panels, the form on the center response panel disappeared and was replaced by a dark screen. When the bird pecked the correct comparison color, both colors disappeared and a reinforcer was presented. After a 2-s ITI, the next trial began.

The two comparison colors alternated randomly between the left and right response panels from trial to trial. If the subject pecked the incorrect comparison color, both comparisons

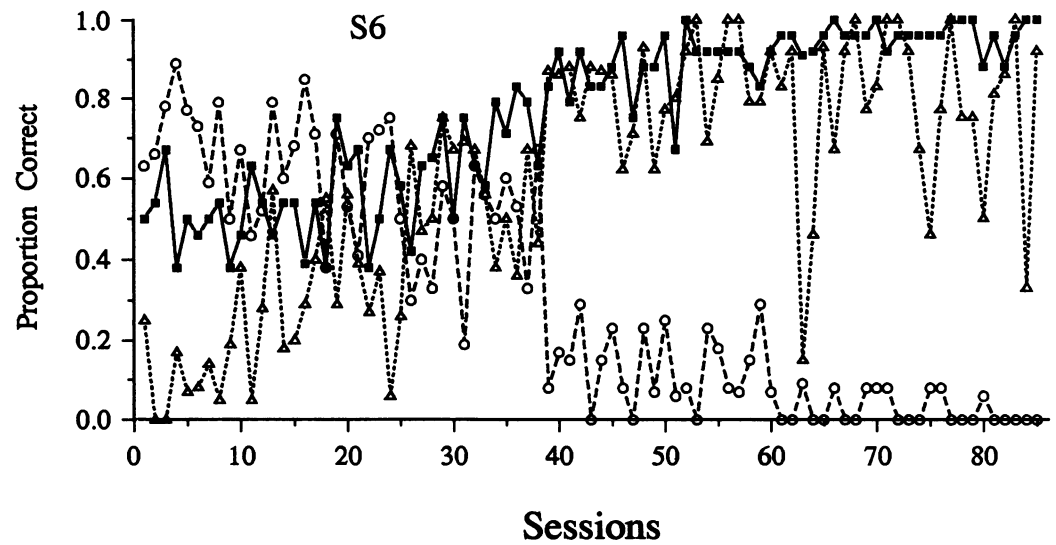
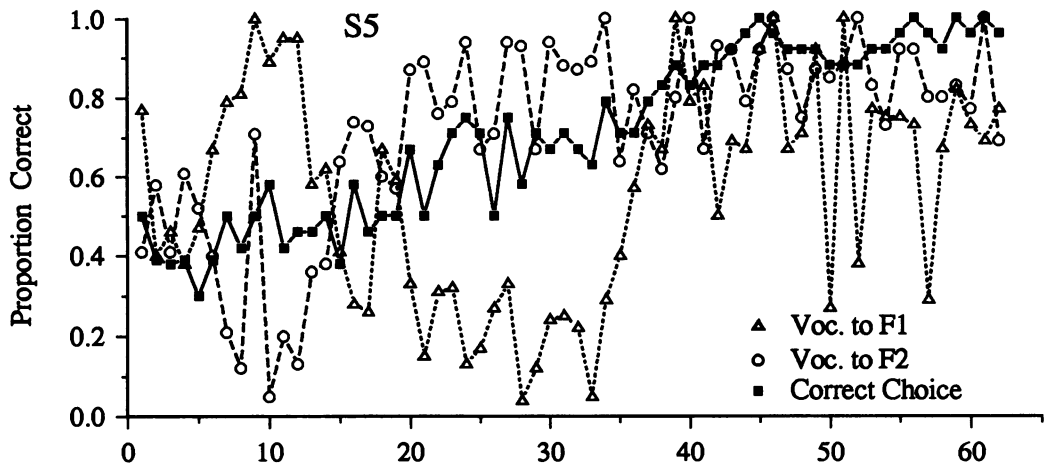
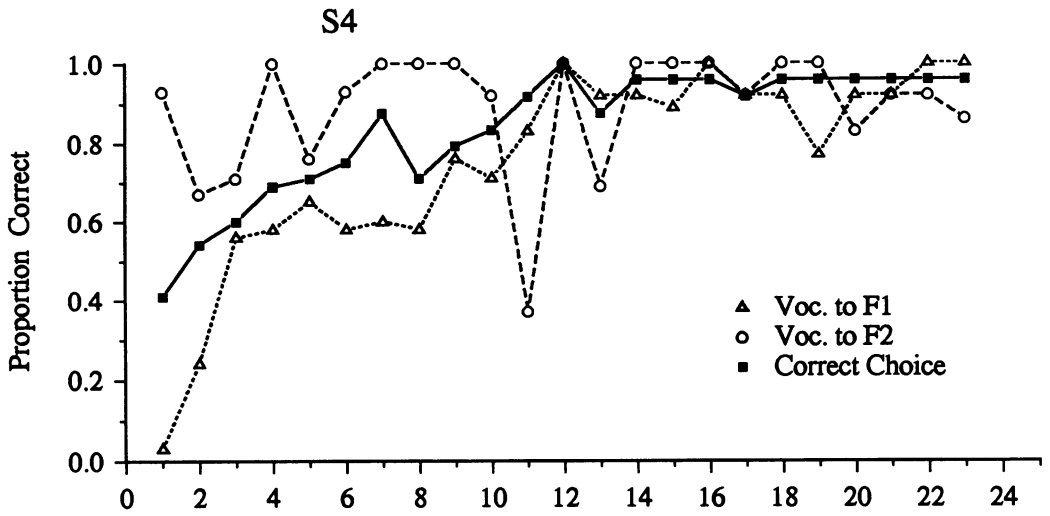
went dark and a 10-s timeout plus the 2-s ITI followed. After an "error" trial, the same sample was re-presented until the subject chose the correct comparison color. The data presented below exclude these correction trials.

For S5 and S6, the F1 sample was a filled white circle and F2 was a white cross; for S4, F1 consisted of three vertical lines and F2 was three horizontal wavy lines. For all birds, the correct comparison was red for the F1 sample and green for F2. All experimental sessions were terminated after either 48 reinforcements or 20 min, whichever came first. All subjects received one or two sessions daily, 6 days per week. For S5 and S6, the color-naming task and the MTS task alternated randomly within each session, 24 trials on each. For S4, the color identity MTS task took the place of the color-naming task.

## RESULTS

Performance of the 3 birds on the form-to-color MTS task is shown in Figure 5. Filled squares connected with a solid line show the proportion of correct color choices. Open triangles connected with a dotted line and open circles connected with a dashed line show the proportion of "correct" vocalizations to the sample forms. For S4, for example, the open circles show that by the end of training, between 70% and 100% of the time, the bird made a low vocalization to the F1 sample, the stimulus signaling red as the correct comparison choice. The low call was required in response to red in the color-naming task for this bird. Initially, S4 made the low call to both the F1 and F2 samples; it always made the low call to F1 (open circles) but also made it to F2 (hence the low initial value for the open-triangle line). The call was of course effective in producing the comparison pair. But as training progressed, the high call (the call to green in the color-naming task, hence "correct" for F2, which signaled the green comparison) came to predominate in the presence of F2, as shown by the rise in the open-triangle line.

Subject S5 began by making high and low calls more or less indiscriminately to the two samples (open circles and triangles both close to 50%). He eventually came to make the same call to the sample as to the signaled comparison color, but the change was sudden, after Session 35, with three subsequent partial reversions to



the previous pattern, rather than gradual as with S4. S6 began by making both high and low calls, but after Session 38, he settled on a high call, appropriate for red, and thus "correct" for F1 (which signaled the red comparison) in the presence of both samples. Thus, 2 of 3 subjects eventually made the same call to the sample form as to the comparison color in the color-related task. The transfer was from vocal color naming for S5 and from color identity MTS, with vocal naming as the sample response, for S4.

Choice of the correct comparison stimulus in the form-to-color MTS task was unrelated to the proportion of correct vocalizations for S5 and S6: Choice performance improved more or less steadily, but the proportion of correct vocalizations varied erratically for both birds. Choice performance and proportion of correct vocalizations improved together for S4. Although there was little day-by-day correlation between discrimination performance and the proportion of correct vocalizations (especially for S5 and S6), S4, which learned the task most rapidly overall, also showed the cleanest correlation between call type and correct comparison.

Performances on the color identity MTS task for S4 and the color-naming task for S5 were stable and almost 100% correct. On the other hand, performance on the color-naming task for S6 was not as stable, and some errors occurred especially for red (which was matched to the circle sample). The ratio of correct responses on the red color-naming task in the initial 42 sessions was 96.6%, whereas the percentage in the last 43 sessions was 82.7%. The ratios on the green color-naming task were 93.6% and 91.8%, respectively.

#### DISCUSSION

This experiment shows that budgerigars will spontaneously transfer a call associated with a color from either a color-naming task (S5) or a color identity MTS task (S4) to a form-to-color MTS task. Similar results have also been reported in retarded children (cf. Sidman, 1971; Sidman & Cresson, 1973). Nevertheless, S6 failed to make the correct color calls to the two form stimuli. Why did S6 not match his

calling to the correct color? We can eliminate one possibility: that S6 was simply incapable of spontaneous call-to-stimulus matching. This was the purpose of Experiment 3, in which we trained S6 and S5 on a new MTS task.

#### EXPERIMENT 3: TRANSFER OF NAMING FROM SAMPLE TO COMPARISON STIMULI

In this experiment we further explored the ability of S5 (who showed spontaneous naming in Experiment 2) and S6 (who did not) to transfer "names" spontaneously from colors to forms. In Experiment 3, the birds were first trained on a color-to-form MTS task (instead of color naming). In this task, to produce the comparison pair of forms, one of two calls was required in the presence of one of two sample colors, and the other call was required in the presence of the other sample color. Then, we trained the birds on an identity MTS task in which sample and comparison stimuli were the same two forms. The birds produced the comparison pairs by calling, but no constraints (other than a minimum intensity and a broad frequency band) were placed on the call.

#### METHOD

The subjects were S5 and S6 from Experiment 2, maintained under the same conditions. The apparatus was the same as in Experiments 1 and 2. Both birds were by now well trained to make different calls in the presence of the red and green stimuli: red  $\rightarrow$  low (S5) or red  $\rightarrow$  high (S6), and vice versa for green. (We use the notation "S  $\rightarrow$  R" to mean "S was the stimulus for R.") In this experiment, they were introduced to two new tasks: color-to-form MTS (Figure 6, left) and form-to-form MTS (Figure 6, right). Form F3 consisted of three horizontal wavy lines, and F4 consisted of three vertical lines. Thus, on color-to-form trials, in the presence of a red sample, a high call (low for S5) was required to produce the comparison forms; in the presence of a green sample, a low call (high for S5) was required. On form-to-form trials, in the presence of either form, any call sufficed to produce

←

Fig. 5. Experiment 2: Proportion of correct MTS choices (closed squares) and "correct" vocalizations to the sample stimuli (F1 and F2).

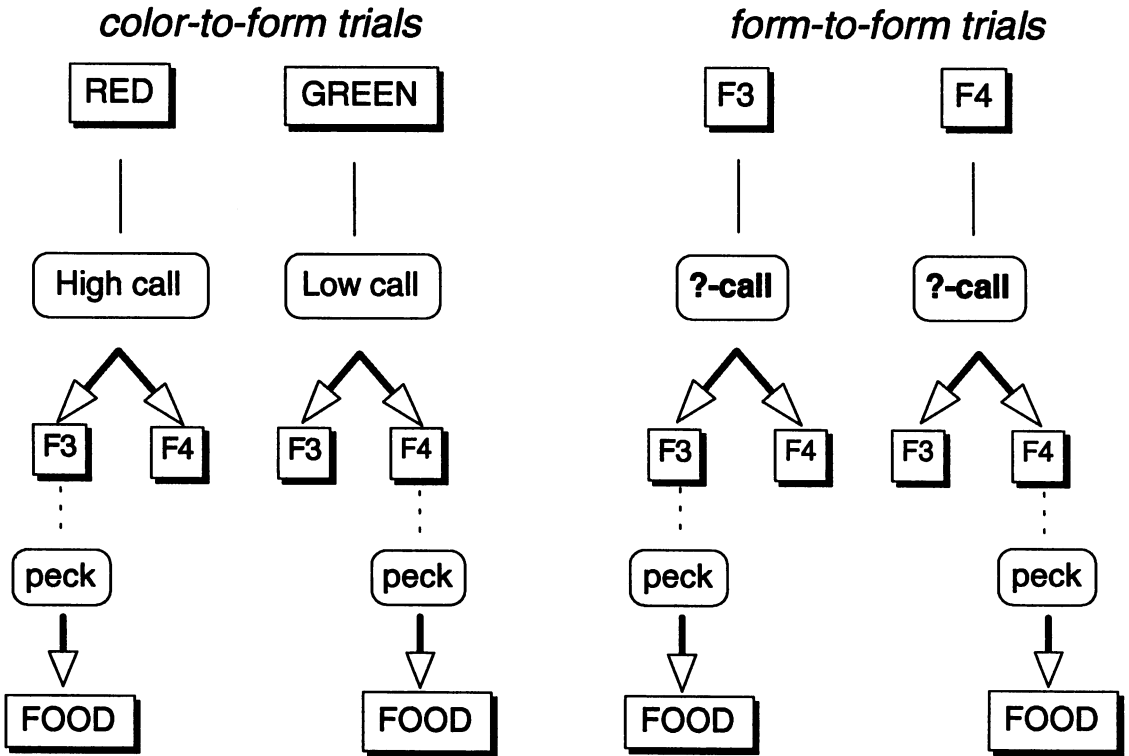


Fig. 6. Experiment 3: Trial types for Bird S6. Conditions for S5 were the same, except that a low call was required in the presence of red, and a high call was required in the presence of green. See text for details.

the sample forms. On all four trial types, a peck on the correct comparison form was required for food reinforcement.

Figure 6 shows the conditions for S6; the conditions for S5 were the same except that the calls were reversed. The form-to-form MTS task was introduced after both correct-choice ratio and correct-sample naming on the color-to-form MTS task were over 90% in three successive sessions. The correct-choice ratio in the last session was 95.8% for both subjects; the correct-sample naming in the last session was 100% for S5 and 98.1% for S6. S5 was trained for 13 sessions, and S6 was trained for 20.

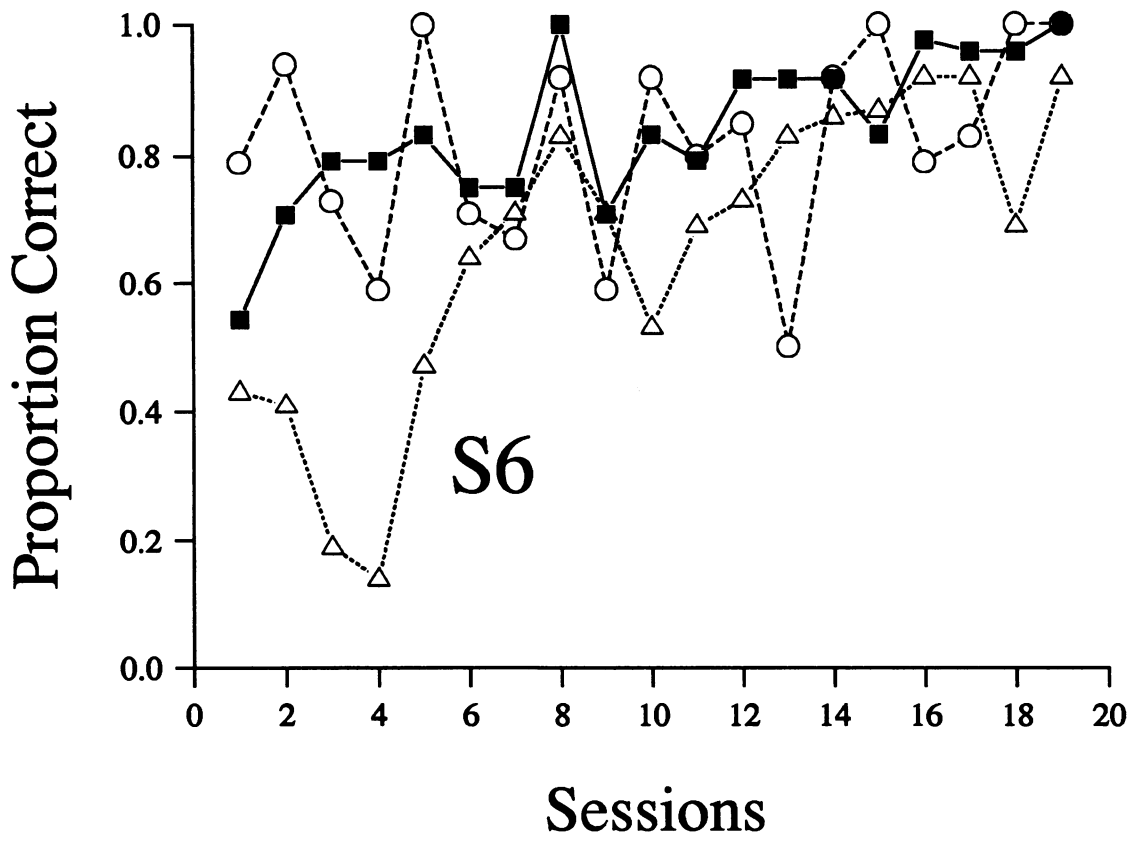
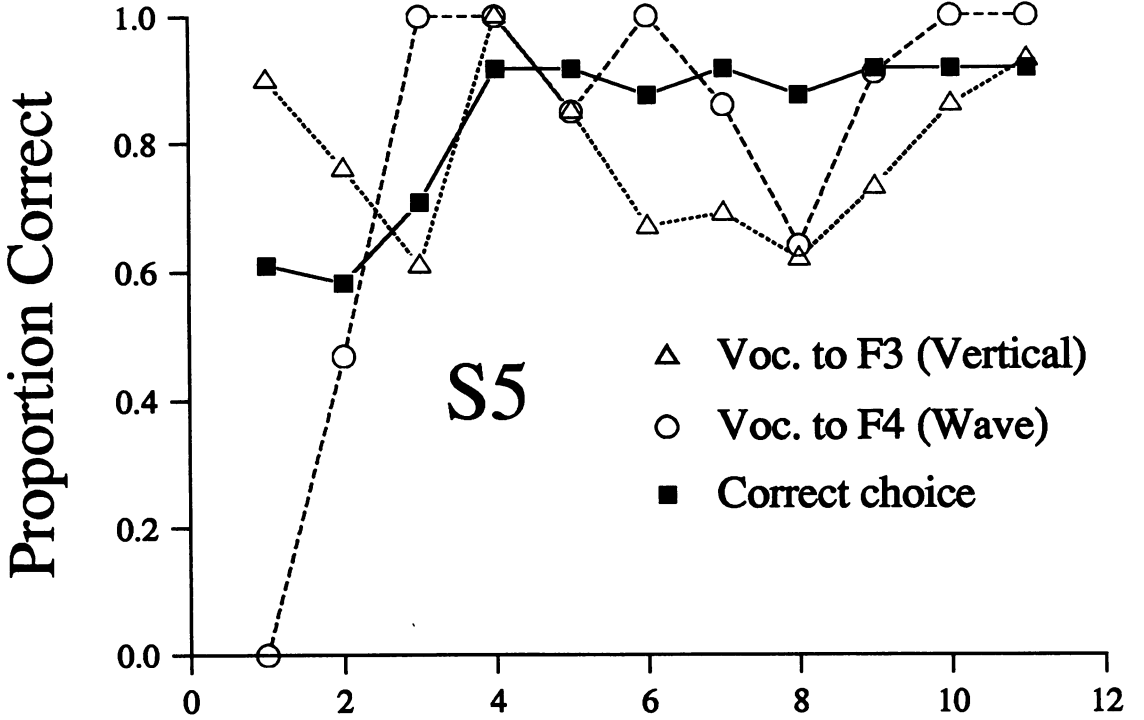
#### RESULTS AND DISCUSSION

Figure 7 shows how well the birds chose the correct comparison, and the proportion of

correct calls to F3 and F4 in the form-to-form task. Choice performance and the proportion of correct calls increased together across sessions. In the first session, the high call was dominant for both subjects, but both rapidly transferred the appropriate call from the color-to-form task to the appropriate form in the form-to-form task. Acquisition of accurate choice performance was faster in this experiment than in Experiment 2. On the color-to-form task, both correct-choice ratio and correct-sample naming were stable and close to 100% for both birds.

Both birds in this experiment showed emergent matching of calls to the to-be-reinforced form stimuli. Both birds transferred the call signaling the to-be-reinforced form in the color-to-form MTS task to the form in the identity form-to-form MTS task. Thus, the failure of S6 to show matching of call type to sample

Fig. 7. Experiment 3: Proportion of correct MTS choices and "correct" vocalization to the sample stimuli (F3 and F4).



## Experiment 2

## Experiment 3

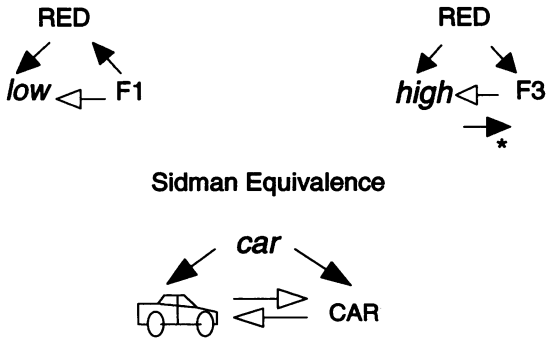


Fig. 8. Top: Trained (solid arrows) and emergent relations (open arrows) established in Experiments 2 and 3. Bottom: Trained and emergent relations described by Sidman (1990) for stimulus equivalence given two sets of training experiences. See text for details.

stimuli in Experiment 2 does not seem to reflect any general deficiency in this animal.

## GENERAL DISCUSSION

The emergent relations demonstrated in Experiments 2 and 3 are diagrammed at the top of Figure 8. In Experiments 1 and 2, the color red became a discriminative stimulus for the low call for S4 and S5 (see Figure 4). This trained relation is indicated by the solid red  $\rightarrow$  low arrow in the left diagram at the top (the parallel link acquired between high and green is omitted for simplicity). In the MTS task in Experiment 2, Form F1 also became a discriminative stimulus for a peck response to the color red. This relation is indicated by the filled F1  $\rightarrow$  red arrow in the diagram. The open arrow from F1  $\rightarrow$  low shows the emergent relation between F1 and the low call that was shown spontaneously by S4 and S5 in the MTS task.

The relations in Experiment 3 are shown in the upper right diagram. A discriminative relation between the color red and the high call and between red and F3 was established by the color-to-form MTS trials (see Figure 6). It might be said that a second relation between the high call and F3 ("\*" in Figure 8) was indirectly established once the birds learned the required high call to produce F3 (and F4) and learned to peck F3. An emergent relation between F3  $\rightarrow$  high, shown on the form-to-form MTS trials, developed spontaneously.

The three-way relations between color and

form stimuli and call type that the birds showed in Experiments 2 and 3 can be compared with the relations studied under the rubrics of functional and stimulus equivalence. For example, de Rose, McIlvane, Dube, Galpin, and Stoddard (1988) carried out a series of experiments very similar to ours but with human subjects. They noted that "Functional equivalence requires merely a demonstration that two or more stimuli control the same behavior" (p. 18). Our results can be more or less fitted to this pattern. For example, in Experiment 2, red  $\rightarrow$  low and F1  $\rightarrow$  red (for S4, see Figure 4); in the form-to-color MTS task, S4 came to respond with the low call to F1, implying that red and F1 formed a functionally equivalent stimulus class. Similarly, in Experiment 3, red  $\rightarrow$  high and high  $\rightarrow$  F3 were established (see Figure 6), and the birds spontaneously formed the relation F3  $\rightarrow$  high, implying that F3 and red again formed a functionally equivalent class.

On the other hand, it is hard to see what is gained by this classification beyond a redescription of the data: F3 and red (and F4 and green) form a functionally equivalent class, but labeling the experimental outcome in this way gives no clue as to why or where the behavior of the budgerigars differs from the behavior of human subjects. The comparison with the relations studied by Sidman and his coworkers under the rubric of stimulus equivalence seems to be more interesting. Sidman (1990) recently gave an example that approximately parallels our study. The experiment was in two parts: training followed by testing. The training phase involved two MTS tasks, as follows: In Task 1, in the presence of form comparison stimuli (pictures of a car, dog, etc.) the sample is spoken (by the experimenter): if the subject picks the car picture in the presence of the spoken "car" (and the dog picture in the presence of the spoken "dog"), a reinforcer is presented. In Task 2, the sample is again the spoken "car," and the comparison stimuli are the written words *car*, *dog*, and so on. The subject's choice of *car* is reinforced. These two trained relations, spoken "car"  $\rightarrow$  written word *car* and spoken "car"  $\rightarrow$  picture of a car, are illustrated by the solid arrows in the diagram at the bottom of Figure 8. In the test phase, the subject is presented with the written word *car* (as sample) and is asked to choose between the car picture and other stimuli (dog picture, etc.). The subject chooses the car picture. In another test, the subject is confronted with a car picture (as sam-

ple) and chooses the written word *car*. These two emergent relations are illustrated by the two horizontal open arrows. Thus, although trained on only two relations, the subject shows four, a "multiplier" (ratio of emergent relations to trained relations) of one. In other experiments, with more transfer tests, Sidman and others have shown as many as four emergent relations (e.g., car picture  $\rightarrow$  spoken "car," written *car*  $\rightarrow$  spoken "car," etc.) plus the three reflexive relations (*car*  $\rightarrow$  *car*, etc.).

What is the relation between our results and stimulus equivalence results like this? (a) We believe that we have shown emergent relations of the same general type. (b) We have shown only a small "multiplier": in Experiments 2 and 3 we trained two (or three) relations and found one emergent relation, a multiplier of 1/2. We might have found more, of course, had we given the appropriate tests, such as presenting a recording of a low call or the color red in Experiment 2 and asking the bird to choose between F1 and F2. It remains to be seen whether budgerigars will show the large number of emergent relations that human subjects show in stimulus equivalence experiments. (c) The subjects in our experiments made overt naming responses, rather than responding to spoken words or recorded calls. Active naming may encourage the emergence of new relations, but this is not yet proven (but see Mandell & Sheen, 1994).

There is another way to look at our data. In both experiments, the results can be interpreted as an example of what Honig and Thompson (1982) and others have called *prospective coding* (e.g., Gaffan, 1977; Grant, 1981; Urcuioli, Zentall, Jackson-Smith, & Stein, 1989). The idea is that in a delayed MTS task, during the delay period when the sample is off and the comparison stimuli are yet to appear, the animal can "remember" (in Skinnerian language, "its behavior can come under the control of") either the identity of the sample (retrospective coding) or the identity of the correct comparison stimulus (prospective coding). By studying the pattern of errors in particular experiments, we can get some idea which of these two admittedly vague possibilities is more likely. In our experiment, there is no delay, of course. But the birds in Experiment 2 that made the low call to F1 provide some evidence for prospective coding, because the low call was effectively the name for red, and red was the color to peck given F1 as

sample. The results of Experiment 3 are ambiguous, because the identity MTS task (form-to-form trials in Figure 6) had the same stimulus as sample and comparison, so that the emergent high call in the presence of F3 can be interpreted as either prospective or retrospective coding.

Additional experiments can answer questions about emergent relations (in the stimulus or functional equivalence sense) and about coding, but something more than these accounts will still be needed for full understanding. The diagrams in Figure 8 and the coding hypothesis are both static, descriptive explanations. They give no hint of the processes that allow these new relations (or codings) to emerge. What we really need is some idea of the learning processes that bring about the "spontaneous" matching of call type and comparison stimulus.

The first question is: Are the relations we found truly "emergent," or can they perhaps be reduced to one or more familiar conditioning processes? We did not train the apparently emergent relations shown by the budgerigars in Experiments 2 and 3 directly. Did we nevertheless train them in an indirect way? There are some possibilities. Look first at the procedure in Experiment 2 (Figure 4). All 3 birds were well trained on the relation between color and call type (e.g., red  $\rightarrow$  low for S4 and S5). In the common MTS task (Figure 4, right), they were well trained on the relation F1 signals red. Two of the 3 birds then developed the "transitive" relation F1  $\rightarrow$  low. This pattern is of course almost the same as the pattern in classical conditioning. Step 1: US  $\rightarrow$  UR; Step 2: CS  $\rightarrow$  US; Step 3: CS  $\rightarrow$  UR (CR). The only difference is that the first step (US  $\rightarrow$  UR) is "innate" in the case of classical conditioning, but was acquired through operant conditioning (red  $\rightarrow$  low) in our experiment. Nevertheless, the resemblance suggests experiments to determine whether this kind of transfer is a general effect.

The fact that only 2 of the 3 birds in Experiment 2 showed the effect indicates that transfer of this sort is not universal, however. And this argument cannot be extended to the results of Experiment 3. The only possibility here seems to be some kind of association-by-contiguity argument. Given the trained relation red  $\rightarrow$  high and the programmed relation high produces F3 (see Figure 6), an association may form between F3 and high, so that given

F3 in the MTS task (Figure 6, right), the high call occurs. But the association must be bidirectional, because it is formed through the high-produces-F3 pairing (Figure 6, left), but emerges as an F3 → high controlling relation (Figure 6, right). Bidirectional associations (what Sidman terms *symmetry*) do not follow from standard conditioning principles. It is hard to avoid the conclusion that something more than standard conditioning processes underlies the emergent relations demonstrated in these experiments. We will have a better idea of what that might be when we know more about the experimental limits of these emergent effects.

Finally, we should point out that the present experiments are concerned with the behavioral precursors of naming from the point of view of the speaker. Additional studies will be needed to study the equally important problem of naming from the standpoint of the listener.

## REFERENCES

- Bernstein, E. (1987). "In the beginning was the 'name'": Response to Terrace. *American Psychologist*, 42, 272-273.
- Brockway, B. F. (1964). Ethological studies of the budgerigar (*Melopsittacus undulatus*): Nonreproductive behavior. *Behaviour*, 22, 192-222.
- Burnstein, D. D., & Wolf, P. C. (1967). Vocal conditioning in the guinea pig. *Psychonomic Science*, 8, 39-40.
- de Rose, J. C., McIlvane, W. J., Dube, W. V., Galpin, V. C., & Stoddard, L. T. (1988). Emergent simple discrimination established by indirect relation to differential consequences. *Journal of the Experimental Analysis of Behavior*, 50, 1-20.
- Farabaugh, S. M., Linzenbold, A., & Dooling, R. J. (1994). Vocal plasticity in budgerigars (*Melopsittacus undulatus*): Evidence for social factors in the learning of contact calls. *Journal of Comparative Psychology*, 108, 1-11.
- Gaffan, D. (1977). Response coding in recall of colours by monkeys. *Quarterly Journal of Experimental Psychology*, 29, 597-605.
- Gellerman, L. W. (1933). Chance orders of alternating stimuli in visual discrimination experiments. *Journal of Genetic Psychology*, 42, 207-208.
- Ginsburg, N. (1960). Conditioned vocalization in the budgerigar. *Journal of Comparative and Physiological Psychology*, 53, 183-186.
- Grant, D. S. (1981). Short-term memory in the pigeon. In N. E. Spear & R. R. Miller (Eds.), *Information processing in animals* (pp. 227-256). Hillsdale, NJ: Erlbaum.
- Honig, W. K., & Thompson, R. K. R. (1982). Retrospective and prospective processing in animal working memory. In G. H. Bower (Ed.), *The psychology of learning and motivation* (Vol. 16, pp. 239-283). Orlando, FL: Academic Press.
- Kent, T. C. (1987). "In the beginning was the 'name'": Comment on Terrace. *American Psychologist*, 42, 273.
- Kroodtsma, D. E. (1982). Learning and ontogeny of sound signals in birds. In D. E. Kroodtsma & E. H. Miller (Eds.), *Acoustic communication in birds* (Vol. 2, pp. 1-23). San Diego: Academic Press.
- Mandell, C., & Sheen, V. (1994). Equivalence class formation as a function of the pronounceability of the sample stimulus. *Behavioural Processes*, 32, 29-46.
- Okanoya, K., & Dooling, R. J. (1991). Perception of distance calls by budgerigars (*Melopsittacus undulatus*) and zebra finches (*Poephila guttata*): Assessing species-specific advantages. *Journal of Comparative Psychology*, 105, 60-72.
- Okanoya, K., & Kimura, T. (1993). An automated procedure to measure responsiveness for distance calls in Bengalese finches. *Bioacoustics*, 5, 117-122.
- Park, T. J., & Dooling, R. J. (1986). Perception of degraded vocalizations by budgerigars (*Melopsittacus undulatus*). *Animal Learning & Behavior*, 14, 359-364.
- Pepperberg, I. M. (1981). Functional vocalizations by an African grey parrot (*Psittacus erithacus*). *Zeitschrift fuer Tierpsychologie*, 55, 139-160.
- Pepperberg, I. M. (1987). Evidence for conceptual quantitative abilities in the African grey parrot: Labeling of cardinal sets. *Ethology*, 75, 37-61.
- Pepperberg, I. M. (1988). An interactive modeling technique for acquisition of communication skills: Separation of "labeling" and "requesting" in a psittacine subject. *Applied Psycholinguistics*, 9, 59-76.
- Sidman, M. (1971). Reading and auditory-visual equivalences. *Journal of Speech and Hearing Research*, 14, 5-13.
- Sidman, M. (1990). Equivalence relations: Where do they come from? In D. E. Blackman & H. Lejeune (Eds.), *Behaviour analysis in theory and practice: Contributions and controversies* (pp. 93-114). Hillsdale, NJ: Erlbaum.
- Sidman, M., & Cresson, O. (1973). Reading and cross-modal transfer of stimulus equivalences in severe retardation. *Journal of Mental Deficiency*, 5, 515-523.
- Sidman, M., & Tailby, W. (1982). Conditional discrimination vs. matching to sample: An expansion of the testing paradigm. *Journal of the Experimental Analysis of Behavior*, 37, 5-22.
- Staddon, J. E. R., McGeorge, L. W., Bruce, R. A., & Klein, F. F. (1978). A simple method for the rapid analysis of animal sounds. *Zeitschrift fuer Tierpsychologie*, 48, 306-330.
- Terrace, H. S. (1985). In the beginning was the "name." *American Psychologist*, 40, 1011-1028.
- Turney, T. H. (1982). The association of visual concepts and imitative vocalizations in the mynah (*Gracula religiosa*). *Bulletin of the Psychonomic Society*, 19, 59-62.
- Urcuioli, P. J., Zentall, T. R., Jackson-Smith, P., & Stein, J. N. (1989). Evidence for common coding in many-to-one matching: Retention, intertrial interference, and transfer. *Journal of Experimental Psychology: Animal Behavior Processes*, 15, 264-273.
- West, M. J., King, A. P., & Eastzer, D. H. (1981). The cowbird: Reflections on development from an unlikely source. *American Scientist*, 69, 57-66.

Received December 29, 1993  
Final acceptance August 16, 1994