

Obtaining acoustic similarity measures from animals: A method for species comparisons

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An efficient procedure has been developed for obtaining similarity measures for complex acoustic signals in small birds. Birds were trained using operant conditioning procedures to detect changes in the repeating background of an ongoing sound. Response latencies for detection were used to construct similarity matrices. Multidimensional scaling procedures were then used to produce spatial maps of these complex sounds reflecting perceptual organization. An example using contact calls from two avian species is described.

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INTRODUCTION

The study of acoustic communication in animals often involves testing strategies aimed at inferring the animal's perceptual organization for complex communication signals. In animal psychophysics, for instance, the study of complex stimuli such as species-specific vocalizations, speech, or tone patterns, typically relies on a classification task where learning rates for different classes of stimuli or responses to intermediate and extreme forms of stimuli are compared (see, for example, Burdick and Miller, 1975; Kuhl and Miller, 1978; Zoloth *et al.*, 1979; Sinnott, 1980).

Recently, in an effort to obtain a more direct measure of stimulus similarity among complex sounds, we trained budgerigars in a same/different task to discriminate among species-specific vocal signals. Response latencies from this task were taken as a measure of stimulus similarity and these similarity measures were then analyzed using multidimensional scaling techniques (MDS) (Dooling *et al.*, 1987b). The MDS produces a spatial representation or "perceptual map" of complex stimuli where perceived stimulus similarity is represented by spatial proximity. Subtle perceptual relations among complex stimuli can often be described and quantified from such spatial plots.

One problem with the auditory same/different paradigm, however, is that the task is very difficult for animals, often requiring several months of training (Shyan *et al.*, 1987; Dooling *et al.*, 1987a). We report here a much more efficient testing procedure for generating similarity data from animals suitable for analysis by multidimensional scaling and clustering routines. This procedure utilizes a repeating background or habituation paradigm rather than a same/different paradigm. With this procedure, we are able to train birds for testing in 2–4 weeks. This is much shorter than the 3–6 months required to train birds for the same/different task.

I. METHOD

A. Subjects

The subjects in this experiment were an adult male and female budgerigar (*Melopsittacus undulatus*) and an adult

male and female zebra finch (*Poephila guttata*) housed in aviaries at the University of Maryland.

B. Stimuli

The stimuli in this experiment were contact calls recorded in the laboratory from four adult budgerigars and four adult zebra finches. Sonograms of these eight stimuli are shown in Fig. 1. All stimuli were presented at a peak level of 72 dB SPL at the bird's head.

C. Apparatus

The birds were tested in wire cages mounted in sound-attenuated chambers. One wall of the wire test cage was modified by the addition of a custom-built response panel constructed of two sensitive microswitches with light emitting diodes (LEDs) attached. A bird could trip the microswitch by pecking at the LED. The left microswitch served as an observation key and the right microswitch served as a report key. Experimental events were controlled by an IBM AT microcomputer. Acoustic stimuli were stored on hard disk and output at a sampling rate of 20 kHz through D/A converters during a trial.

D. Training and testing procedures

The birds were food-deprived several hours prior to each training and testing session (Park *et al.*, 1985). The birds were trained to peck one key (observation key) repeatedly during the repetitive presentation of one sound (background) and to peck the other key (report key) when a new sound (target) was presented alternately with the background sound. A peck on the report key during this alternating stimulus pattern was defined as a correct response and was rewarded with a 4-s access to food. Two pure tones of 2 and 3 kHz were used as the two training stimuli and both served as a target and a background stimulus. Once the birds learned the task with pure tones, testing on a set of complex sounds began.

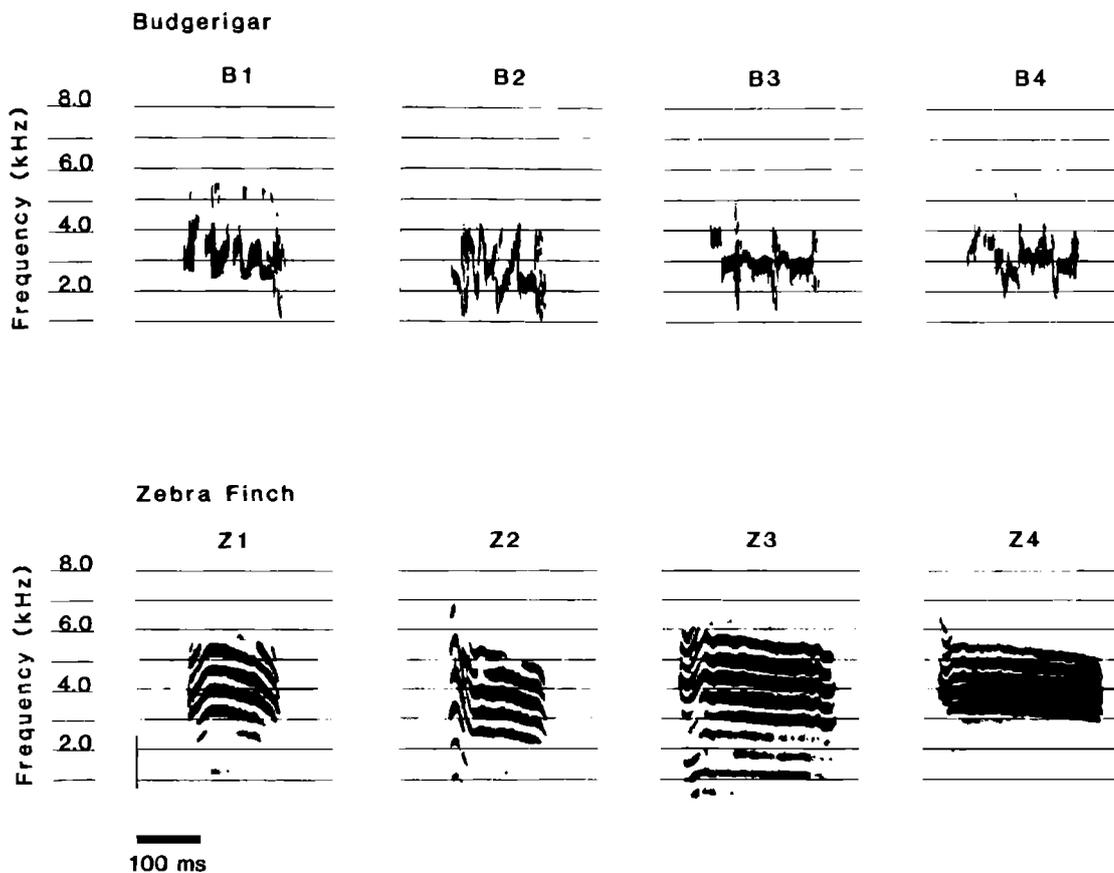


FIG. 1. Sonograms of contact calls from four budgerigars (B1–B4) and four zebra finches (Z1–Z4). Frequency markers are at 1 kHz. Time scale is 100 ms.

The procedure consisted of two distinct phases; a habituation phase and a testing phase. During the initial habituation phase, the background sound was repeated at the rate of 2/s. If the bird did not respond within 10 s, the LEDs on both observation and report keys were illuminated and the testing phase began. On the other hand, if the bird pecked the report key during this habituation phase, a new habituation interval of 10 s was initiated.

The same background stimulus continued during the testing phase. A peck on the observation key initiated a random interval of 1–7 s. Following this interval, a peck on the observation key initiated an alternation of the target stimulus with the background stimulus. A response on the report key within 3 s of the beginning of this alternating pattern was reinforced with a 4-s access to food. About 20% of the trials were sham trials in which the target stimulus was the same as the background stimulus. A response on the report key during a sham trial or during the waiting interval was punished with a 16-s timeout period during which lights in the test chamber were extinguished but the repeating sound continued.

A matrix of stimuli (background by target) was constructed and one row of background was randomly selected for testing from this matrix (Fig. 2). The testing phase continued until the background stimulus was paired with every other stimulus in the set three times. A session proceeded a row at a time (i.e., same background stimulus) until all possible combinations within the row were exhausted. Another

row was then randomly selected and a new habituation phase began with a new background sound. This procedure continued until all rows were tested. Thus the same sound served both as a background and as a target stimulus. Since each stimulus combination was tested three times, a total of three response-latency matrices were available for analysis at the conclusion of testing. Generally, between two and six

Target \ Background	A	B	C	D
A	S	*	*	*
B	*	S	*	*
C	*	*	S	*
D	*	*	*	S

FIG. 2. A schematic example of a stimulus matrix consisting of four sounds. In this example, row B is selected for the testing. Stimulus B continues as a repeating background sound and detection latencies for the sounds A, C, and D are measured. Here, S refers to the sham trials and responses to these trials are used to calculate false alarm rates. After row B is exhausted, one of the rows from A, C, or D is then randomly selected for testing. The "upper half" of the matrix refers to the upper half elements from the diagonal. The "lower half" is the lower half-elements from the diagonal.

sessions, each lasting about 30 min, were required to complete three matrices.

E. Data analysis

A median-latency matrix was constructed from the three raw-latency matrices. The upper and lower halves of the matrix were averaged to produce a single latency half-matrix. This half-matrix was log transformed to compensate for the positively skewed distribution of reaction times and then analyzed by a multidimensional scaling (MDS) procedure, SINDSCAL (Shepard, 1980; for a tutorial, see Arabia *et al.*, 1987). The MDS places points in multidimensional space such that interstimulus distances correspond as closely as possible to stimulus similarities. (For a detailed mathematical discussion on MDS, see Borg and Lingoes, 1987.) If the latency to detect the change from background A to target B is short, then the separation between A and B in a multidimensional plot will be large. On the other hand, if the latency to detect the change from A to B is long, then the separation between A and B will be small. In other words, stimuli having similar perceptual properties are in close proximity to each other in multidimensional space whereas stimuli having different perceptual properties are far apart. The data for the two budgerigars and the two zebra finches were analyzed separately to produce separate solutions for each species.

II. RESULTS

The two-dimensional spatial representation generated by SINDSCAL of the perceptual similarity among the eight contact calls is shown for the two budgerigars and the two zebra finches in Fig. 3(a) and (b), respectively. The variance in response latency accounted for by the MDS solution was 66.9% for budgerigars with the first and second dimen-

sion accounting for 41.0% and 26.0%, respectively. For zebra finches, the variance accounted for by the MDS solution was 69.8% with the first and second dimensions accounting for 50.0% and 19.8%, respectively. These eight stimuli are clearly split into two groups for both species with budgerigar calls on the left and zebra finch calls on the right. This grouping of stimuli was confirmed with a complete linkage, hierarchical cluster analysis (Aldenderfer and Blashfield, 1984).

The first dimension accounts for the largest amount of variance in response latencies for both species. In other words, the most salient aspect of these stimuli for both budgerigars and zebra finches is the species difference in calls. Humans listening to these calls report that budgerigar calls sound high-pitched and whistled while zebra finch calls sound low-pitched and buzzy. This suggests that budgerigars, zebra finches, and humans may be using similar features to discriminate between species calls—an idea that could be tested with synthetic stimuli.

But these data also reveal other, more subtle, species differences. The cluster of conspecific (same species) calls in each plot is larger (more scattered) than the cluster of calls from the other species (less scattered). In other words, the differences among budgerigar calls are more salient for budgerigars than the differences among zebra finch calls while the converse is true for zebra finches. A measure of this dispersion D can be obtained by taking the average weighted distances from the centroid of the cluster where the weight for each dimension is the variance accounted for by that dimension. The degree of conspecific advantage can then be obtained by taking the ratio between D for conspecific calls and D for the other-species contact calls. A value of 1.0 would indicate no conspecific advantage. The conspecific advantage calculated in this way is 2.59 for budgerigars and 1.67 for zebra finches. We conclude that each species has a larger perceptual representation for conspecific vocal signals.

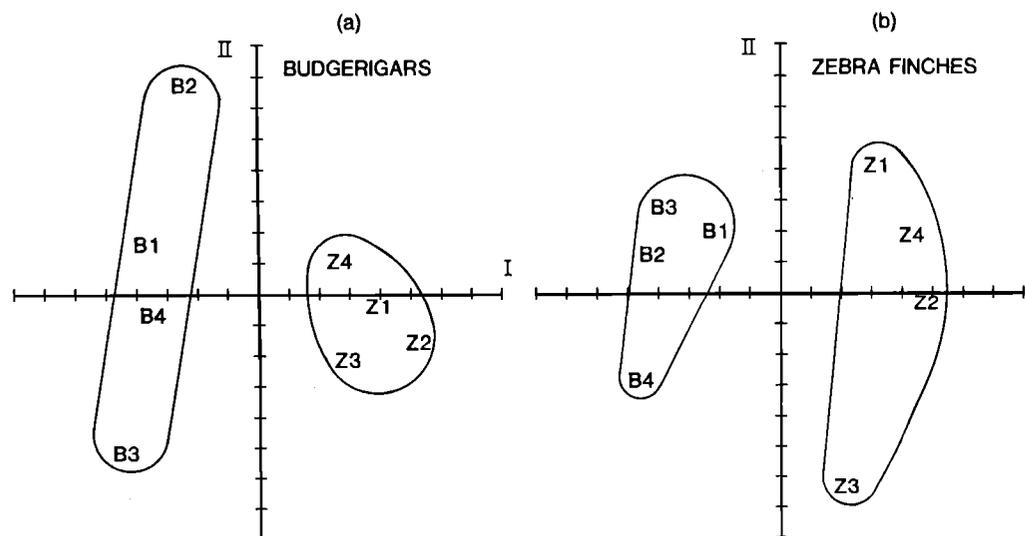


FIG. 3. (a) Two-dimensional spatial representation by SINDSCAL of the perceptual similarity among budgerigar and zebra finch contact calls by budgerigars. (b) Two-dimensional plot of the same stimuli as perceived by zebra finches.

III. CONCLUSION

Multidimensional scaling techniques have proven especially useful in understanding human perception of complex sounds such as speech and music where the physical correlates of the perceptual experience are often unclear (see, for example, Shepard, 1980; Murry and Singh, 1980). When studying perception in animals, it is always the case that the physical correlates of the perceptual experience are unknown, thus providing an ideal situation for the application of MDS. The present experiment demonstrates that MDS techniques can be used to study the perception of complex acoustic signals by animals without the laborious requirement of having to train animals to the concept of same/different.

The habituation or repeating background paradigm has been used extensively in psychophysical tests with animals and human infants (see, for review, Gottlieb and Krasnegor, 1985). Here, we applied this habituation paradigm to two avian species using operant techniques. In the experiment we report, both species show an advantage for conspecific calls. This advantage suggests that each species might somehow be specialized for the perception of species-specific contact calls. If these species-specific results are indeed due to perceptual specializations, the extent to which these specializations are innate, or due to experience, remains to be determined but might be addressed using isolate-reared and devocalized birds.

The procedures described above should prove generally useful in a variety of other auditory testing situations especially those involving species comparisons and complex vocal signals. While we have applied these procedures to small birds, these same procedures should prove equally valuable for testing other species commonly used in auditory research (e.g., chinchillas, cats, monkeys) and, of course, human infants.

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An investigation of voided PVdF after exposure to high-pressure pulses

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The effect of high-pressure (0-75 MPa) pulses on the piezoelectric properties of voided PVdF film has been investigated. The SEM micrographs show that microvoids still exist in the material after exposure to many such pressure pulses. The measured decrease in the piezoelectric coefficient reported by other workers would appear to require a new explanation.

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INTRODUCTION

In a recent article,¹ Meeks and Ting investigated the behavior of 0.5-mm-thick voided PVdF film with pressure. In the article they reported the response of the PVdF film to

pressure pulses with peak pressure in the range 0-75 MPa and with rise times of 1-3 μ s. They found that the measured value for the piezoelectric coefficient d_h initially decreased as the number of pressure pulses to which the material was