PARSONS RESEARCH CENTER

Working Paper No. 330 April 1976

PERCEPTION OF BIOLOGICALLY MEANINGFUL SOUNDS BY DOGS

Henry E. Heffner

Perception of Biologically Meaningful Sounds by Dogs[1]

(Paper presented at the 90th meeting of the Acoustical Society
of America, November 1975)

Henry E. Heffner

Bureau of Child Research, University of Kansas, and

Parsons State Hospital and Training Center

Hearing allows an animal to obtain information about its environment on the basis of sound. Of the various ways in which hearing provides such information, probably the most common is the analysis of objects on the basis of the sounds which the objects produce. Such an analysis of sounds enables an animal to ascertain the presence, location, and in many cases the identity of sound-producing objects or "sound sources." For example, upon hearing a sound, an animal is instantly made aware of the presence of an object, usually another animal, and in most cases is able to ascertain its location. In addition, the animal may be able to determine whether the sound source is a predator, prey, conspecific, etc., on the basis of previous associations (innate or learned) between sounds and sound sources. This analysis of sound which enables an animal to detect, locate, and identify objects, provides a primary source of selective pressure for animal auditory systems (Masterton & Diamond, 1973). For this reason, any account of central auditory processes must include an analysis of the way in which sounds are used in obtaining information about sound sources.

Over the past years, a number of studies have been concerned with the neurological processes involved in detecting and localizing sound sources while little research has been concerned with the processes involved in identifying sound sources (c.f., Elliott & Trahiotis, 1972). This discrepancy is due to the fact that not only may detection and localization be considered to be more basic auditory processes than identification (i.e., conceptually simpler), but they are certainly more easy to test. However, the need to identify a sound source is crucial to an animal's survival in that it enables it to respond appropriately to its environment on the basis of sounds. Thus, although an animal is able to detect and locate a sound source, ultimately its behavior depends on its ability to identify the object.

Methods

Briefly, our procedure for assessing the ability of an animal to identify sound sources consisted of training dogs to touch one of two windows with their nose if a "dog sound" were presented, and to touch the other window if a "non-dog" sound were presented. The animals were then tested by recording their responses to additional sounds which they had never received during training. Evidence that the animals were responding on the basis of dog and non-dog was the touching of the dog and non-dog windows when the appropriate sounds were presented.

The choice of dogs as subjects and dog vocalizations as stimuli was based on the need to reduce the possibility that an animal could learn to discriminate the sounds on the basis of their physical characteristics (frequency, intensity, timbre, time, and so forth), rather than on the basis of their source. Since dogs produce a wide range of sounds which vary not only from one vocalization to another (e.g., barks vs whines) but from one dog to the next (e.g., German shepherd vs Chihauhau), it was possible to use a sound source whose sounds were fairly heterogeneous. As a result, sounds for both dog and non-dog categories could be chosen which overlapped in frequency and intensity (e.g., dog bark and seal bark, dog whine and sheep bleating). In addition, it was possible to set aside a subclass of dog vocalizations (howls) for use only as test stimuli to see if dogs trained to respond to dog barks, whines, whimpers, and growls would respond similarly to howls. Thus, our design was strongly influenced by the need to reduce the possiblity that the animals could learn the task on the basis of the physical characteristics of sounds rather than on the biological characteristics of sound sources.

Subjects

Eight mongrel dogs (2 male and 6 female) were used. They ranged from one to three years in age and 3.5 to 17 kg. in weight.

Stimuli

The dog and non-dog sounds were chosen from a collection of recordings which were either made by us or else obtained from sound effects and nature records. A frequency spectrum analyzer was used to insure that the frequency content of the two classes of sounds overlapped. Figures 1-4 are sound spectographs illustrating four of the sounds used.

Figures 1 - 4 appear about here

Apparatus

Details of behavioral apparatus. The animals were tested in a rectangular cage 90 cm long, 90 cm high, and 75 cm wide. The cage was constructed out of a wooden frame and except for the front, was covered with 12.7 mm (1/2 in.) hardware cloth. The front of the cage consisted of a plywood panel with three windows (12.7 cm x 12.7 cm) mounted side-by-side and a light and waterspout mounted 7.6 cm and 15.2 cm, respectively, below the center window as shown in Fig. 5. The windows were individually backlighted and were covered with a fine almost invisible wire mesh to which contact switches were connected. The waterspout was connected via tube to a water bottle and was interrupted by an electrically operated water valve.

Figure 5 appears about here

Details of stimulus-generating apparatus. Live recordings were obtained with a Nagra IV tape recorder and a Sony ECM-50 Electret condensor microphone. The sound effects and nature recorded were recorded with a Sony tape recorder, and a Dual 1229 turntable with Shure V15 Type III cartridge. Candidate sounds were then analyzed with a Tektronix 3L5 spectrum analyzer and 564B storage oscilloscope and in selected cases with a Kay 6061A sound spectrograph.

For experimental presentation, the sounds were rerecorded onto individual tapes using a 4-channel tape recorder (TEAC 3340S) and a Dolby noise reduction unit (Advent 100A). Each tape contained 16 sounds, 8 dog and 8 non-dog, with all dog sounds on channels 3 and 4, and all non-dog sounds on channels 1 and 2. However, to insure that the animals were not learning to discriminate differences between channels (e.g., variation in frequency response), four different tape recorders were used for playback. In addition, a duplicate of one of the tapes was made in which both the dog and non-dog sounds were recorded on all four channels. In no case could any indication be detected that the animals were using possible differences between channels as a cue.

On playback, the sounds were first led from the tape recorder to the Dolby unit, then to an amplifier and finally to a loudspeaker (Acoustic Research 3a). The loudspeaker was mounted over the testing cage which was located in a single-walled sound-proof chamber.

Procedure

The dogs were placed in the cage and trained to press the windows with their nose in order to receive a water reward (see Fig. 5). The animals were then trained to begin a trial by pressing the center window of the 3-window panel. This response caused a tape recorder to play one of the 16 sounds. Following presentation of the sound, the dogs were required to press the right window if a dog sound had been played and to press the left window if a non-dog sound had been played. A correct response was rewarded by making a small amount of water available at the water spout (signaled by the light above the spout as well as by a relay click) while an error was not rewarded and was followed by a short wait (5-15 sec) before another trial could begin.

Two separate tests were used: a "generalization" test; and, an "equivalence" test.

Generalization test. The dogs were first trained to classify 32 different sounds (16 dog and 16 non-dog). The animals were then presented with 16 new sounds on each of the next six sessions, thereby receiving a total of 96 new sounds (Table I). The *first* response of an animal to each novel sound was recorded and the total number of correct responses was summed to determine the degree of generalization to the new sounds. These sounds included barks, whines, whimpers, and growls, *but not howls*.

Table I appears about here

Equivalence test. The dogs were given additional training on the 96 sounds used in Test I using a schedule of partial reward. This procedure accustomed the animals to a situation in which responses on 40% of the trials were neither rewarded with water nor punished with a short wait before the next trial could begin. In other words, on 40% of the trials, the animals received no feedback as to whether their response was right or wrong. Once they had become accustomed to the partial feedback schedule, they were given an *equivalence* test in which new sounds were interspersed among the old sounds. Because the animals received no feedback on their responses to the new sounds, these sounds could be presented many times without the animal being trained to respond one way or another to them. A total of 24 different sounds were used in the equivalence test with two test sounds presented each session interspersed among 14 other sounds from Test I. Testing continued until each animal had accumulated about 30 trials per sound.

Results

Generalization Test

Figure 6 illustrates the ease with which dogs learn to discriminate dog sounds from non-dog sounds. Each letter in the figure indicates a different set of 16 sounds (8 dog and 8 non-dog). With the exception of early sessions (circled A), all 16 sounds of a particular set were presented within a session. All of the dogs successfully discriminated sounds on the first or second auditory session (in which two sounds were presented). The speed with which the animals learned the task suggests that the discrimination of dog vs non-dog sounds is a very easy one for them to make.

Figure 6 appears about here

Figure 7 shows the percentage of correct classifications of the 96 novel sounds of Test I. These scores are based only on the response of the animals to the initial presentation of each sound and show that all of the animals generalized to the new sounds at a level greater than that expected by chance (the dashed line at 60% indicates the two-tailed 0.05 level of chance).

Figure 7 appears about here

Equivalence Test

While the generalization test allowed us to assess the degree to which the dogs generalized to new sounds, the equivalence test enabled us to determine a dog's classification of an individual sound. Before proceeding, however, it is important to note that there are three ways in which a dog could respond to a sound on an equivalence test. First, it could respond primarily to the "dog" window; second, it could respond primarily to the "non-dog" window; and, finally, it could respond about equally to both windows. These responses could be interpreted as indicating that the animal was labeling the sounds, respectively, as dog, non-dog, or ambiguous.

Figure 8 illustrates the classification of eight sounds by one of the dogs. Note that the animal correctly classified these sounds according to source even though it received no feedback over the 30 presentations of each of the sounds.

Figure 8 appears about here

The overall results of the equivalence test are summarized in Table II. Of the 24 stimuli, all of the animals correctly identified a high proportion of the test sounds. It is of interest to note that most of the errors tended to be a failure to respond consistently indicating that the animal was unsure as to which window was correct. In only three cases were sounds incorrectly identified.

Table II appears about here

These results, along with those of the generalization test, indicate beyond a doubt that the dogs were not responding randomly. Instead, the animals appear to have been effectively biased in their responding to new sounds by the initial training which they had received. However, it is possible that despite precautions to the contrary, the animals may have been responding on the basis of a cue or cues only correlated with the dog vs non-dog distinction. For this reason, the response of the dogs to the three howls used in the equivalence test is of special interest since it represents a physically different subclass of dog sounds on which the animals had received no previous training.

Figure 9 is a sonograph of one of the howls used in the equivalence test. Comparing this figure with Figures 1 and 3, it can be seen that the howl is a longer duration signal than the bark and tends to lack the higher harmonics of the whine. Indeed, we purposely chose the howl for the reason that it appeared to us to be the most unique dog sound in terms of its physical charactersitcs.

Figure 9 appears about here

In Figure 10 it can be seen that all of the dogs correctly classified at least two of the howls and that two of the dogs got all three of them correct. In addition, the three errors that did occur were not randomly distributed but occurred only in response to one of the howls indicating that that particular sound was more difficult to identify than the others. In this case, two of the animals (D-6 and D-8) failed to classify the sound one way or the other while only one dog (D-9) responded as though it were a non-dog sound. (This particular howl may have been more difficult to identify because it appears to lack the onset transients present in the other two howls and thus approximates a relatively clean tone throughout its entire duration--c.f., Figs. 9 and 11). Because of the physical differences between howls on the one hand and barks, whines, whimpers, and growls on the other, the response of the dogs to howls strongly suggests that the animals were not responding on the basis of similarities in the physical characteristics of the sounds, but were responding in terms of the biological similarities of their sources. Thus it is argued that the dogs responded appropriately to the howls not because they sounded like other dog sounds, but because howls, like barks, whines, whimpers, and growls, had all been previously associated with the single source of "dog."

Figure 10 appears about here

Discussion

The primary goal of this experiment was to determine the ease with which animals might be trained to respond to sounds on the basis of the sound source. To accomplish this goal it was necessary not only to give the animals the opportunity to discriminate sounds on the basis of source, but also to rule out the possibility that the animals might use some other cue to solve the task. Since it is impossible to completely rule out the use of another cue, our problem became one of reducing the possibility that the animals were using any cue other than the source of the sound.

Our first step in this direction was the choosing of a discrimination which the animals would naturally make themselves. The discrimination between members of one's own species as opposed to other species is one which all animals must make, if only to reproduce, and thus constituted an ideal choice for this experiment. Indeed, it is difficult to conceive of a more likely sound source discrimination. Thus, the extremely rapid learning of the dog vs non-dog discrimination should come as no surprise and, indeed, longer learning times would have suggested that a less natural cue was being used.

Our second step in reducing the possibility of the dogs using a different cue was to carefully analyze and select our sounds so that the discrimination could not be solved simply on the basis of frequency or intensity. Because we had access to a large number of recordings, we were able to choose sounds from both categories which not only overlapped in frequency, but which in some cases were quite similar (c.f., dog bark and seal bark). Thus, it is difficult to see how a simple frequency or intensity discrimination could have enabled the animals to perform so well.

While one cannot completely rule out the possibility that the animals were performing some sort of complex frequency-intensity-time discrimination only correlated with the dog vs non-dog categorization, it should be noted that such complex discriminations are generally quite difficult for animals to perform on artificial sounds (e.g., Dewson, Pribram & Lynch, 1969; Symmes, 1967). In contrast, our animals appeared to have had little difficulty discriminating the natural sounds used here. Not only did the dogs learn to perform the initial auditory discrimination (i.e., dog vs non-dog) almost immediately, but they learned to discriminate over 100 different physically complex (but biologically simple) sounds after only 15 or 20 training sessions (see Fig. 7). Thus the behavior of these animals does not appear to resemble the behavior of animals performing a discrimination of physically complex sounds, but is more like that of animals performing a very simple discrimination.

Third, we took steps to ensure that the animals were not using possible cues in our sound recording or reproducing system by changing between four different tape recorders from session to session. In addition, we tested the animals with a special tape in which the dog and non-dog sounds were recorded onto all of the channels. In no case did any variation in the sound system ever appear to have any effect on the dogs' performances. Thus, if the animals were using some sort of artifact it would have to have been one which was a) easily detected by the dogs, b) impossible for us to detect with either our ears or our instruments, and c) not disrupted by variations in the sound system. We feel that the existence of such an artifact is unlikely.

Turning to the results of the two tests, the ease and accuracy with which the dogs learned to discriminate the 96 sounds of the generalization test suggests that they were using an easily detectable cue. Not only did the animals generalize to these sounds as a whole, but an analysis of their final scores revealed that there were only three of the 96 sounds (2 dog and 1 non-dog) which any of the animals failed to learn to classify appropriately. These results along with those of the equivalence test indicate that the animals were relying on an easily perceived cue in order to discriminate physically complex, but biologically simple sounds.

The results of the equivalence test goes one step further. Here we found that the animals would classify together as dog or as non-dog sounds which were physically quite different from the ones with which the animals had been trained. Though some of the dogs had difficulty with the howl which lacked an appreciable onset cue, the overall results indicated that the animals responded to howls as they did to the other dog sounds.

On the basis of the evidence, we have concluded that the dogs were most likely making their discriminations on the basis of the sound source, i.e., dog vs non-dog. As a result, we have begun to use this procedure as a test of the ability to recognize objects on the basis of sound with the idea that a failure on this test would be an indication of auditory agnosia. At present this procedure is being used on nonverbal mentally retarded children as well as animals with bilateral lesions of auditory cortex.

References

Dewson, J. H., III, Pribram, C. K., & Lynch, J. C. Effects of ablation of temporal cortex upon speech sound discrimination in the monkey. *Experimental Neurology*, 1969, 24, 579-591.

Elliott, D. N., & Trahiotis, C. Cortical lesions and auditory discrimination. *Psychological Bulletin*, 1972, 77, 198-222.

Masterton, B., & Diamond, I. T. Hearing-central neural mechanisms. In E. C. Carterette & M. P. Friedman (Eds.), *Handbook of perception: Vol III*. New York: Academic Press, 1973, 407-448.

Symmes, D. Discrimination of intermittent noise by macaques following lesions of the temporal lobe. *Experimental Neurology*, 1967, 16, 201-214.

Footnote

[1] This work was supported by NICHHD grant HD 02528, Bureau of Child Research, University of Kansas.

Table I. Representative Sample of the 96 Sounds Used in the Generalization Test

"Non-Dog"	"Dog"
LION SNARLING	BRITTANY SPANIEL BARKING
MOOSE BELLOWING	COLLIE (MONGREL) BARKING
PIGS GRUNTING	GERMAN SHEPARD BARKING
SEALS BARKING	SCHNAUZER BARKING
CHICKADEE SINGING	8 MONGREL DOGS BARKING
OWL HOOTING	DOBERMAN PINSCHER GROWLING
CRICKETS CHIRPING	SPANIEL (MONGREL) YELPING
CREAKING DOOR	TERRIER (MONGREL) WHINING

Table II. Results of Equivalence Test

	Number of Sounds		
Dog	Correctly Identified	Incorrectly Identified	Failed to Identify
D-5	24	0	0
D-6	20	1	3
D-7	22	0	2
D-8	22	0	2
D-9	19	2	3

Note: An identification occurred when an animal responded to a given sound by consistently touching one of the windows over successive presentations of that sound ($p < 0.05$, 2-tailed). Failure to identify a sound indicates that the animal responded randomly when that sound was presented.

Figure Captions

Fig. 1. Sound spectrum of three consecutive barks produced by an adult female German Shepherd. All spectrograms in this paper were made on a Kay 6061A sound spectrograph using a 45 Hz band width. The line at the top right of the figure indicates 0.1 sec.

Fig. 2. Sound spectrogram of two consecutive seal barks.

Fig. 3. Sound spectrogram of a whine produced by a small mongrel dog.

Fig. 4. Sound spectrogram of the bleating of a lamb.

Fig. 5. Response panel. The dogs touched the center window to initiate a trial and turn on the tape recorder. After the tape recorder had played a sound the animal would respond by touching one of the two side windows. A crorect response was immediately followed by clicking a relay and turning on the light located above the water spout. A water reward was delivered when the animal made contact with the spout.

Fig. 6. Illustration of the ease with which dogs learn to discriminate dog from non-dog sounds. Each letter indicates a different set of 16 sounds (8 dog and 8 non-dog). With the exception of early sessions (circled A), all 16 sounds of a particular set were presented within a session. Dogs trained so far have successfully discriminated sounds on the first auditory session (in which 2 sounds were presented) and have rapidly transferred to new sounds. Initial visual training was used to accustom the animal to the apparatus. Sessions 15 to 27 were devoted to adapting the animal to partial reward.

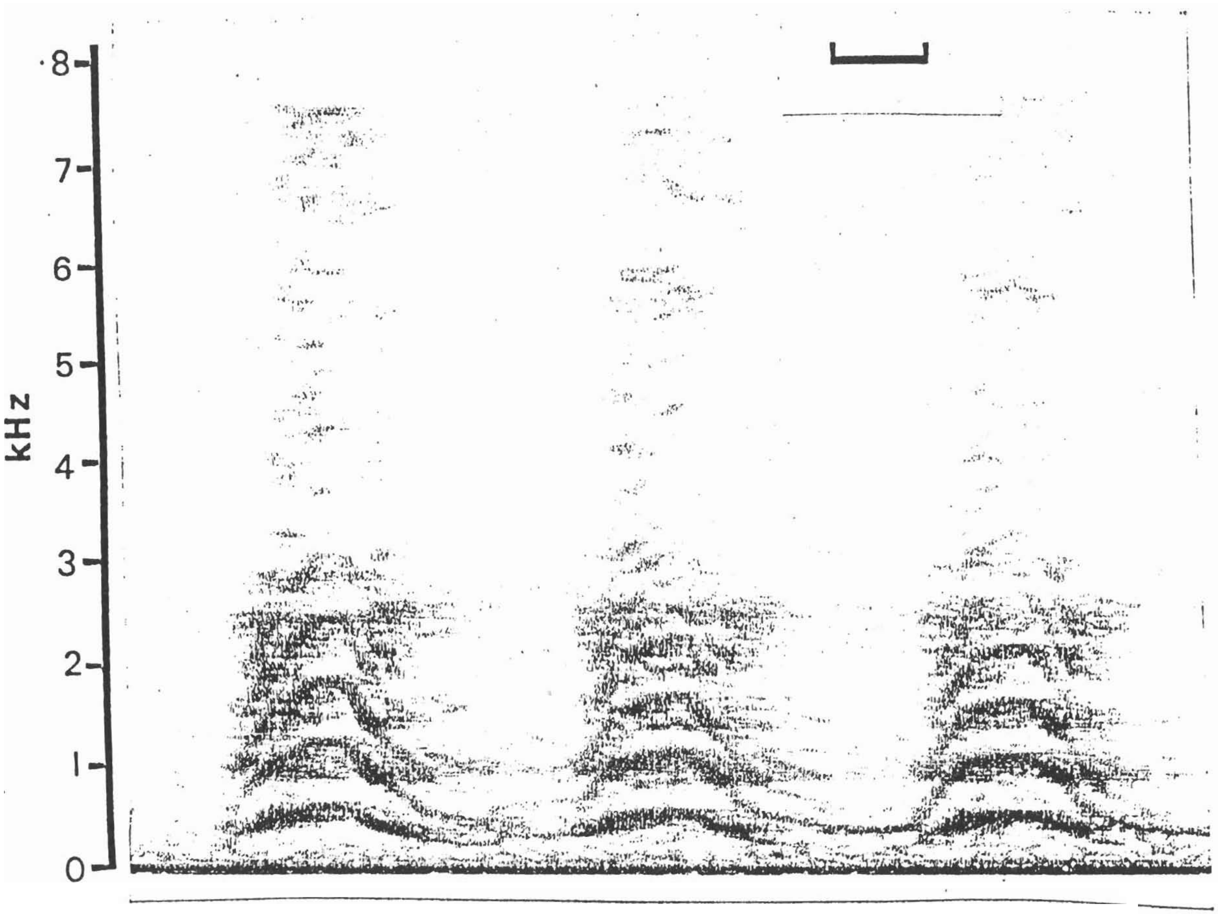
Fig. 7. Percentage of correct responses to the first presentation of each of the 96 sounds of the generalization test. Dashed line indicated the 0.05 two-tailed level of chance.

Fig. 8. Example of the response of dogs to animal sounds in the absence of reward (i.e., feedback). The dog correctly classified these sounds into the categories of dog and non-dog without receiving feedback as to whether its responses were correct or incorrect. Each score is based on a minimum of 30 trials.

Fig. 9. Sound spectrogram of a howl produced by a spaniel.

Fig. 10. Response of dogs to 3 howls in which the animals received no feedback as to whether or not their responses were correct. Dashed line indicates 0.05 two-tailed level of chance.

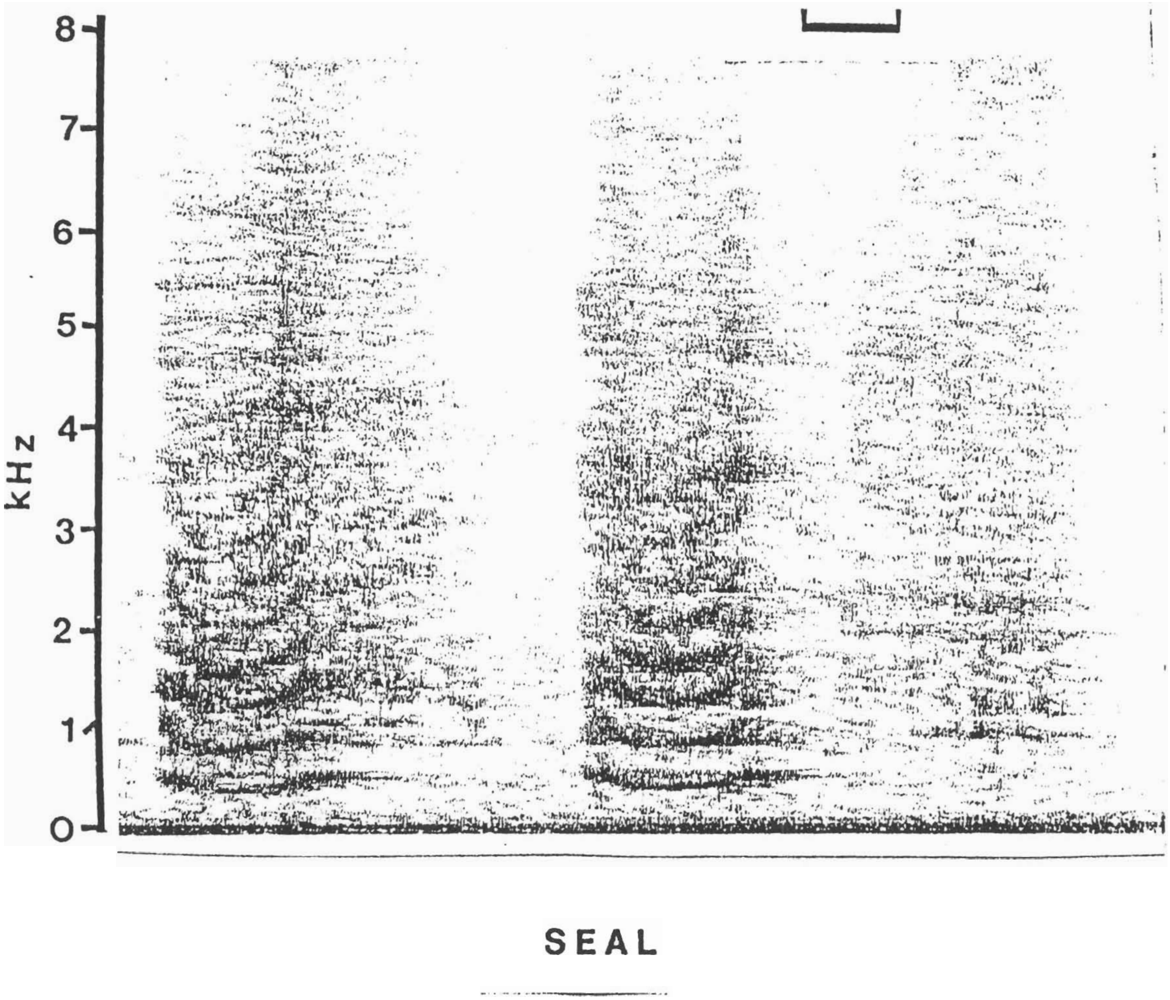
Fig. 11. Sound spectrogram of a howl produced by a small mongrel. Note the lack of a definite onset as compared to the howl shown in Fig. 9 (vertical spike in the left section of the figure is an artifact produced during the spectrum analysis and was not present in the taped version of the sound).

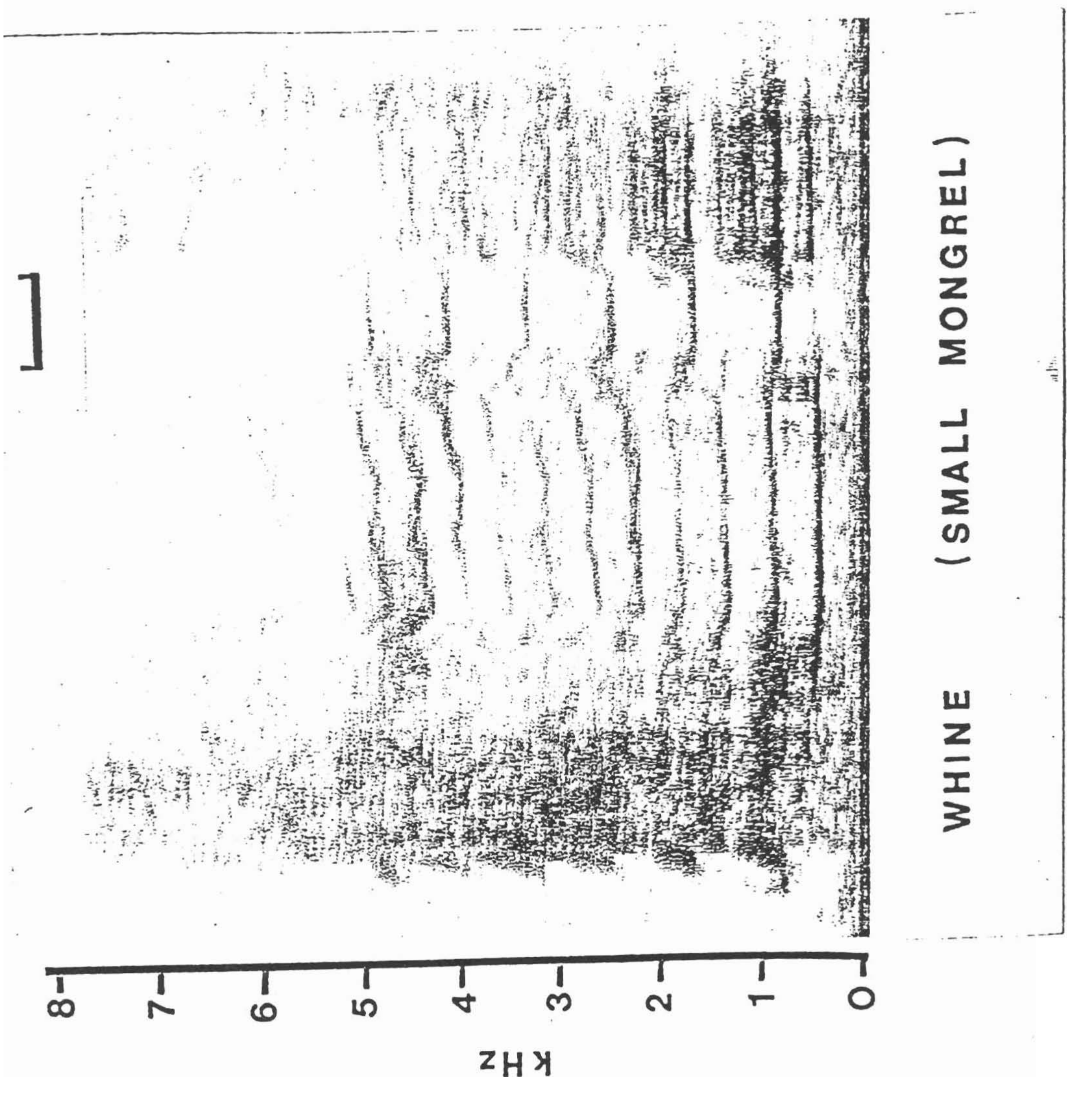


BARK (GERMAN SHEPHERD)

Fig 1

Fig 2

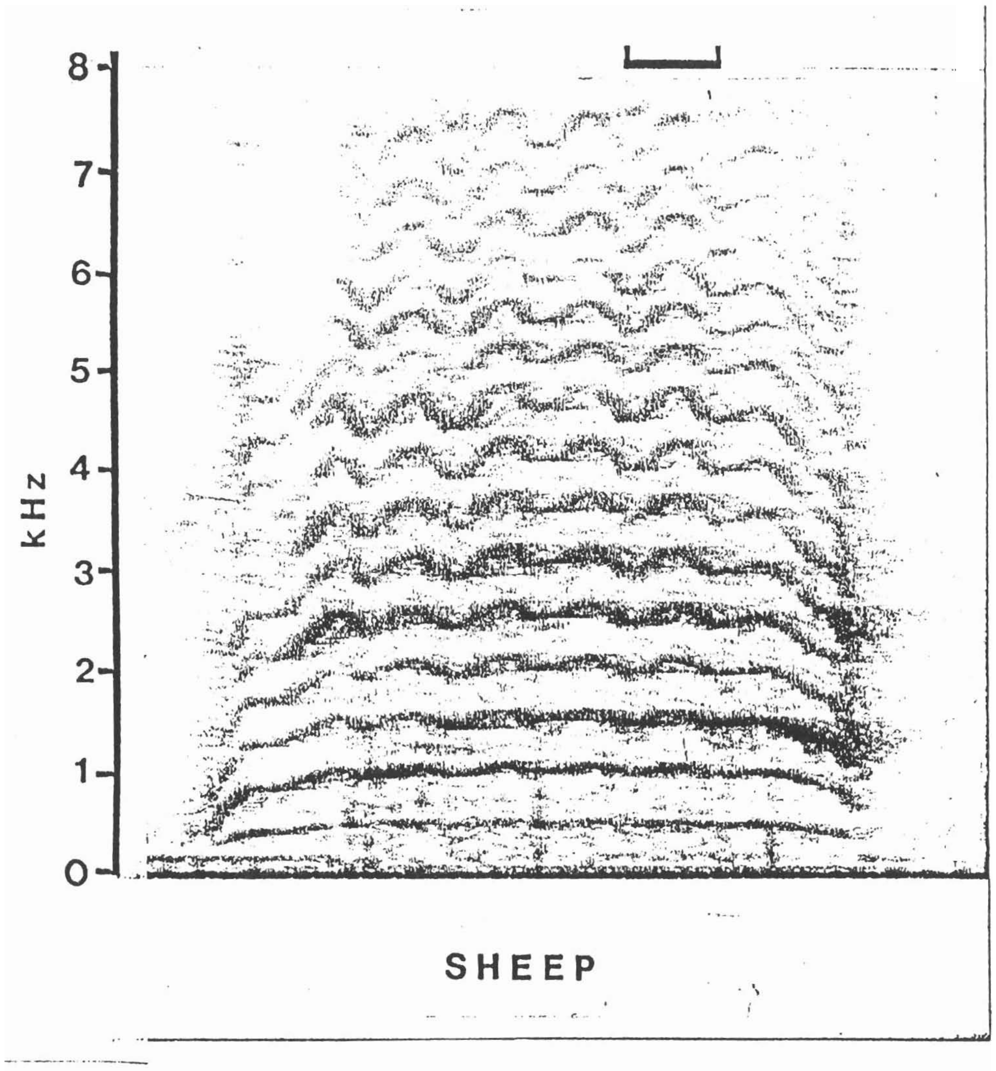


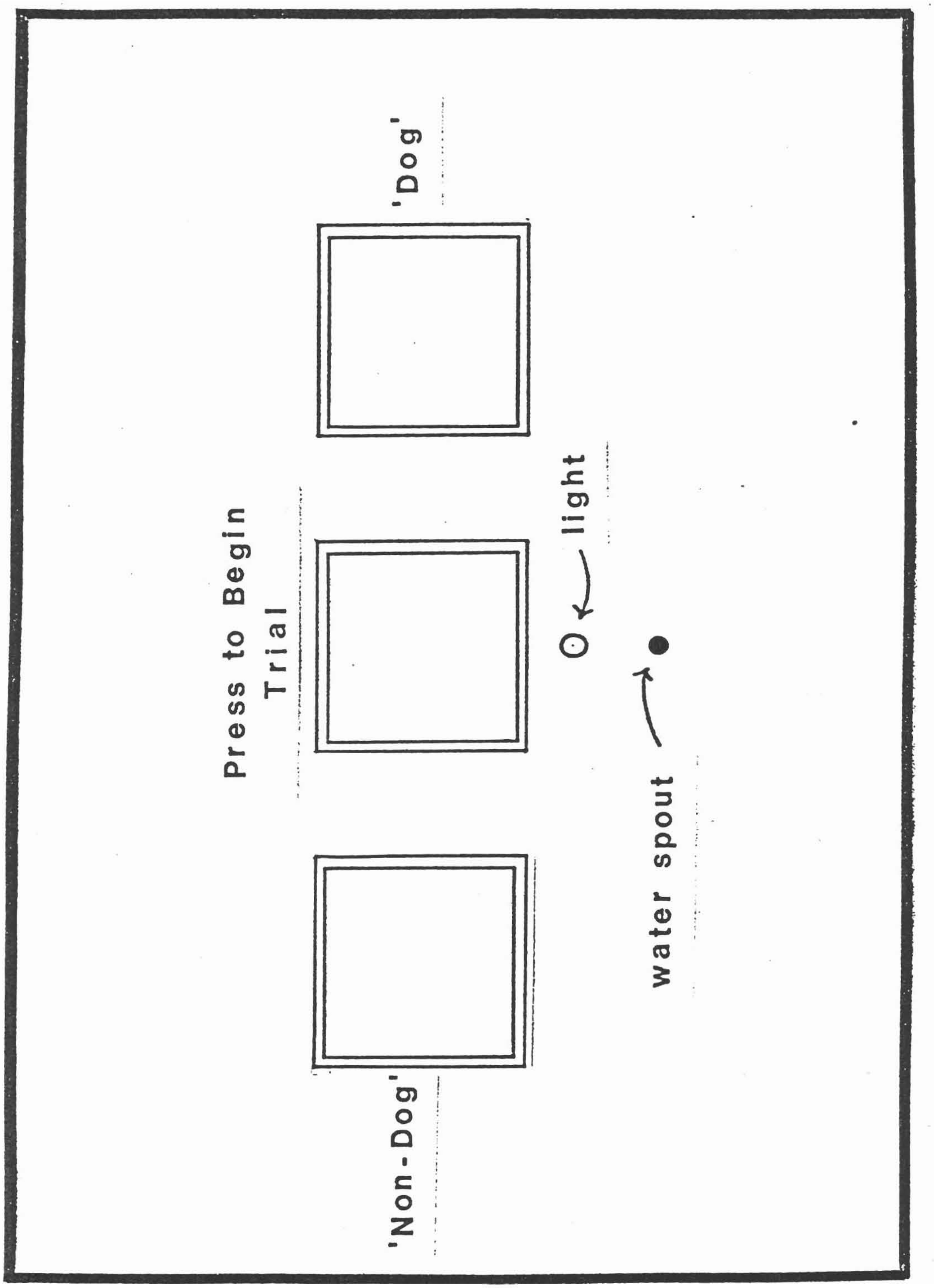


WHINE (SMALL MONGREL)

Fig. 3

Fig 4





Response Panel

5

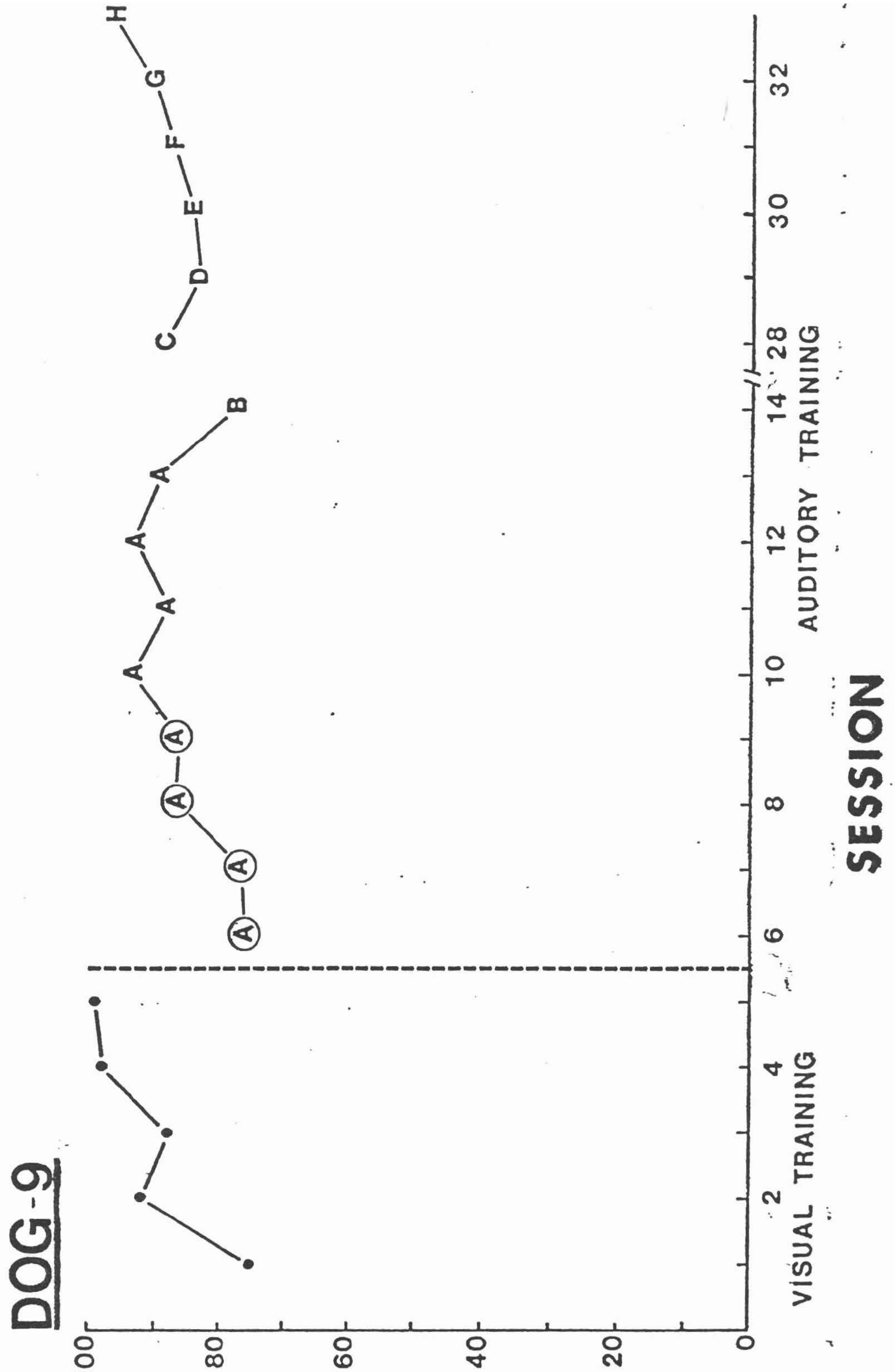

DOG-9
PERCENT CORRECT
100
80
60
40
20
0
2
4
6
8
10
12
14
28
30
32
VISUAL TRAINING
AUDITORY TRAINING
SESSION
Ⓐ
A
B
C
D
E
F
G
H

Fig. 6

6

Fig. 7

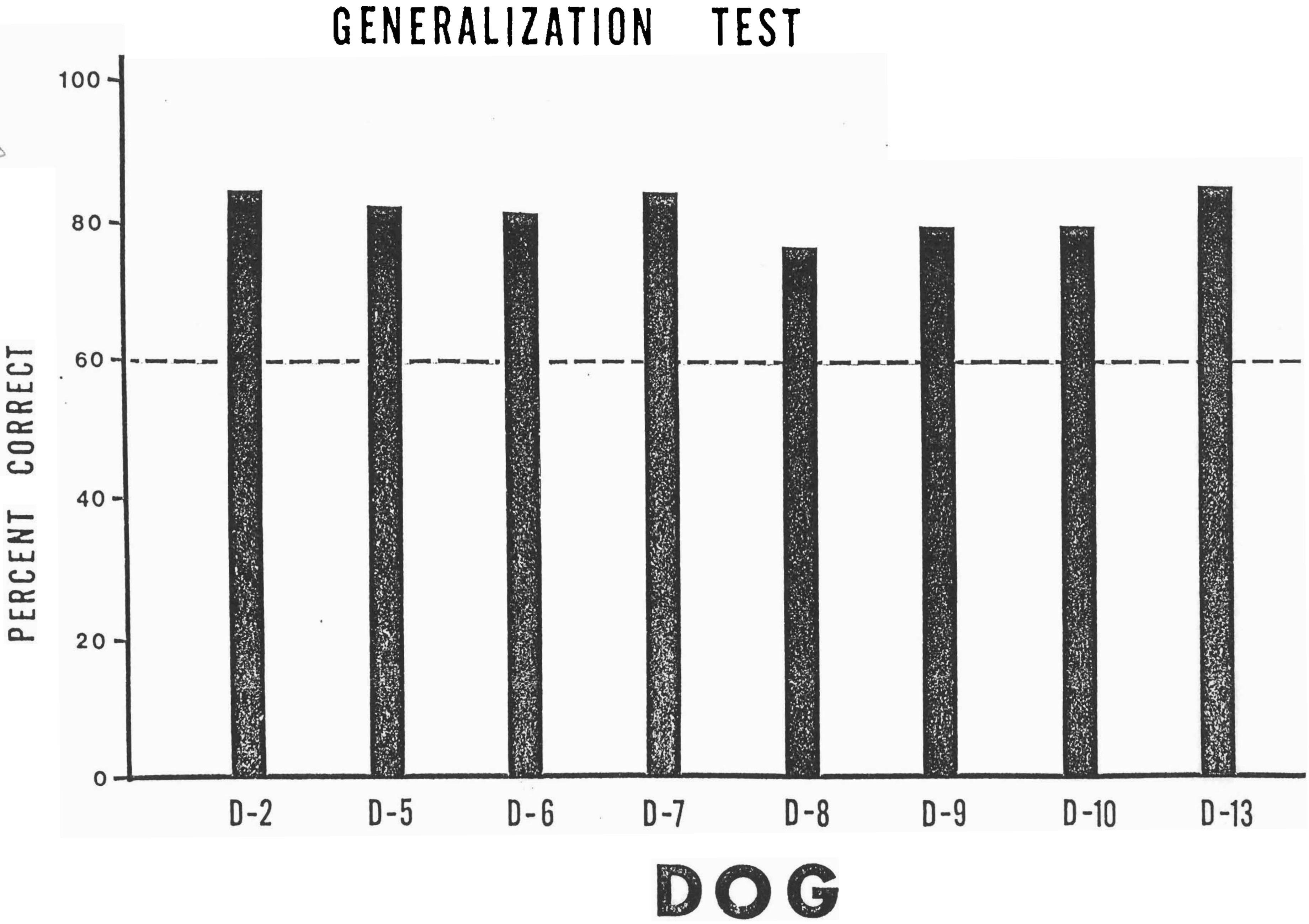
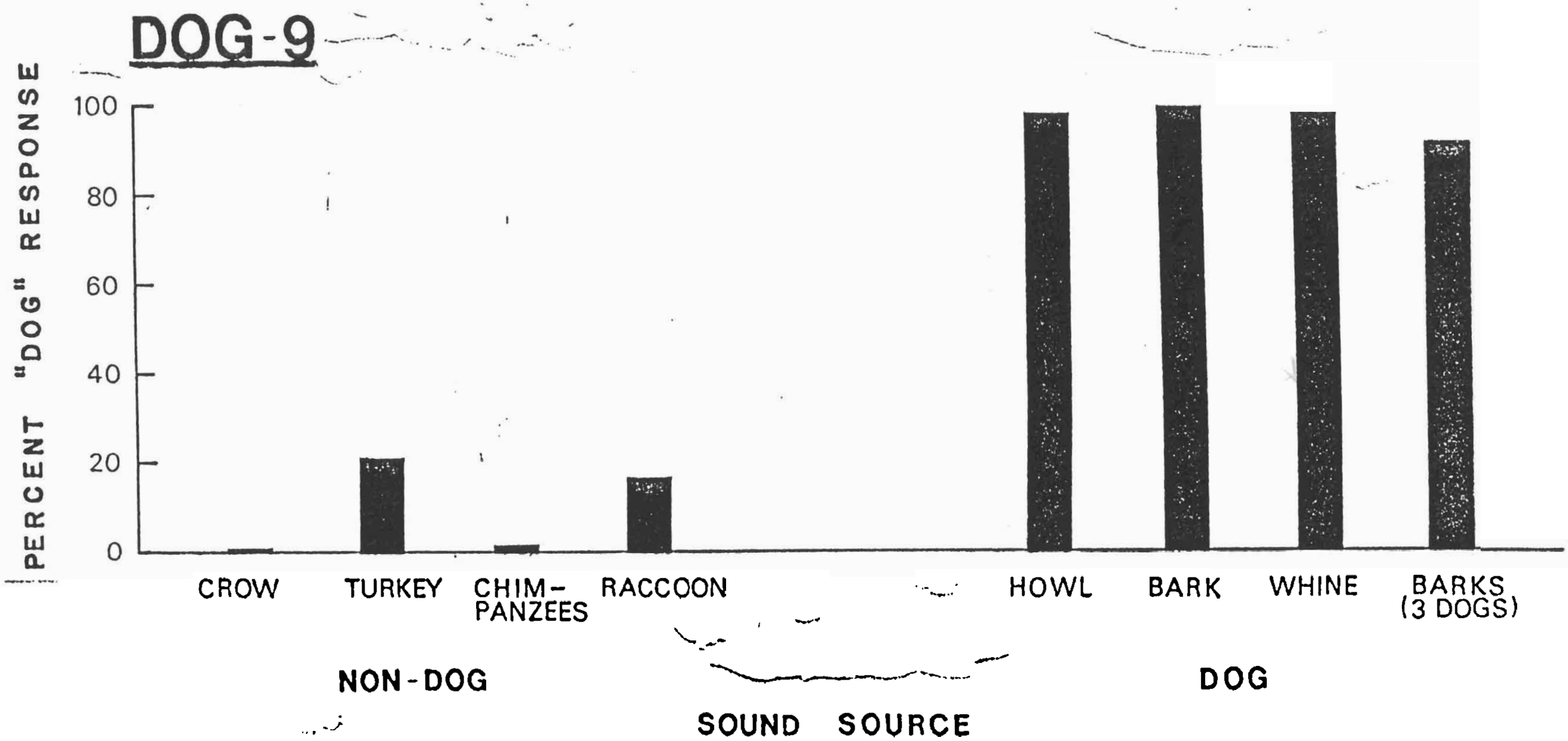
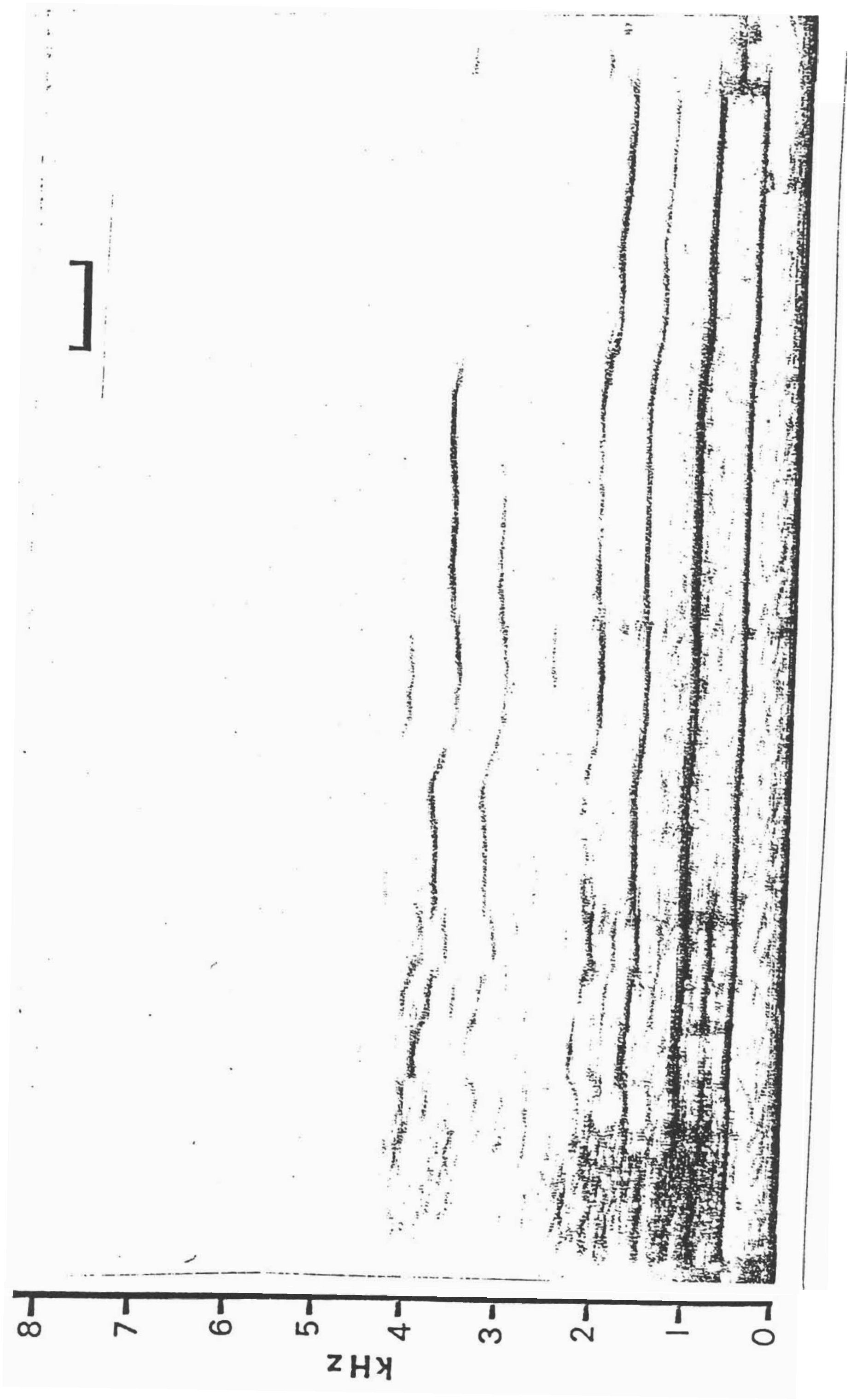

GENERALIZATION TEST
PERCENT CORRECT
100
80
60
40
20
0
D-2
D-5
D-6
D-7
D-8
D-9
D-10
D-13
DOG

Fig. 8

Fig. 8


DOG-9
PERCENT "DOG" RESPONSE
100
80
60
40
20
0
CROW
TURKEY
CHIM-PANZEES
RACCOON
HOWL
BARK
WHINE
BARKS (3 DOGS)
NON-DOG
DOG
SOUND SOURCE

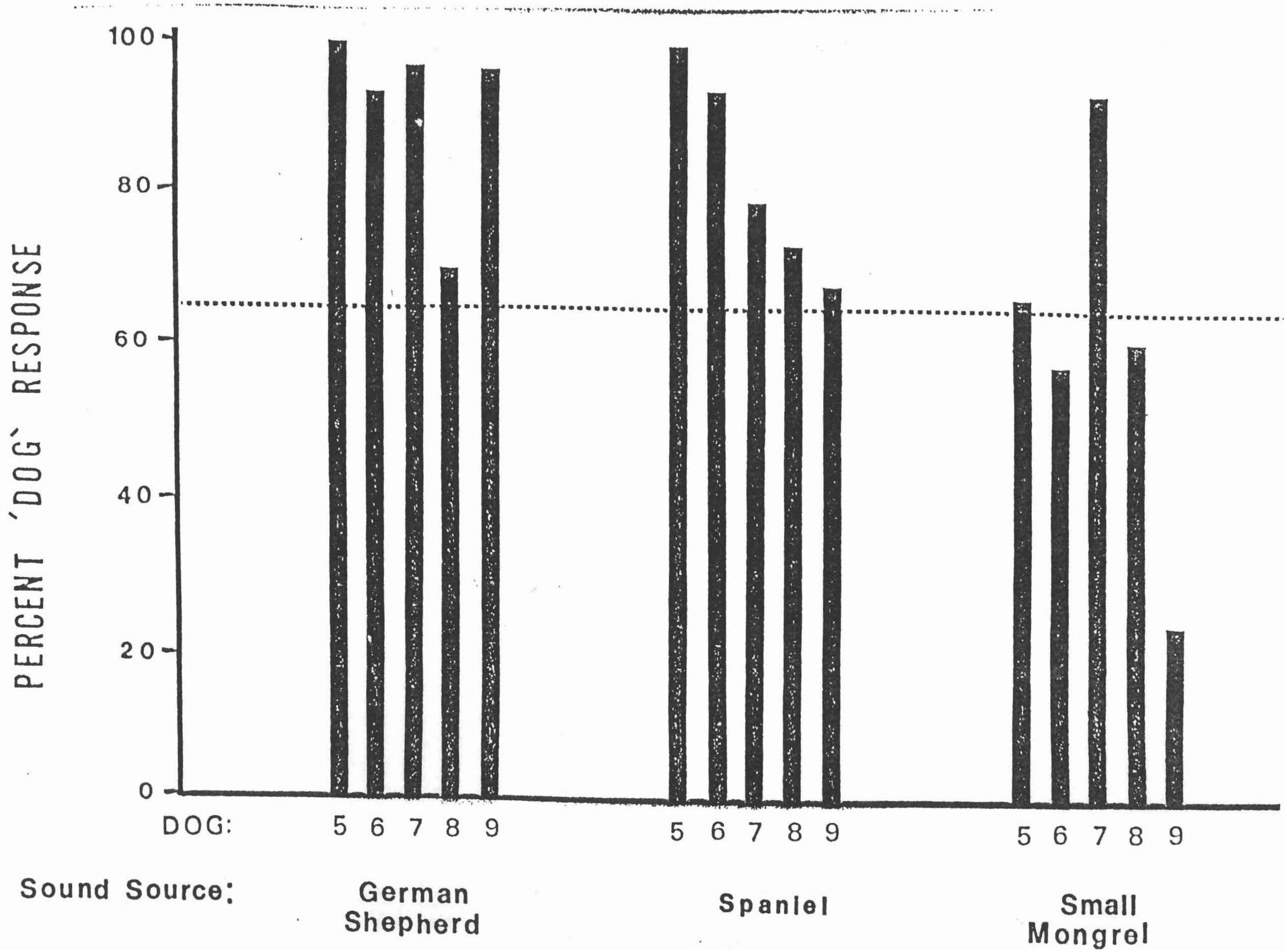


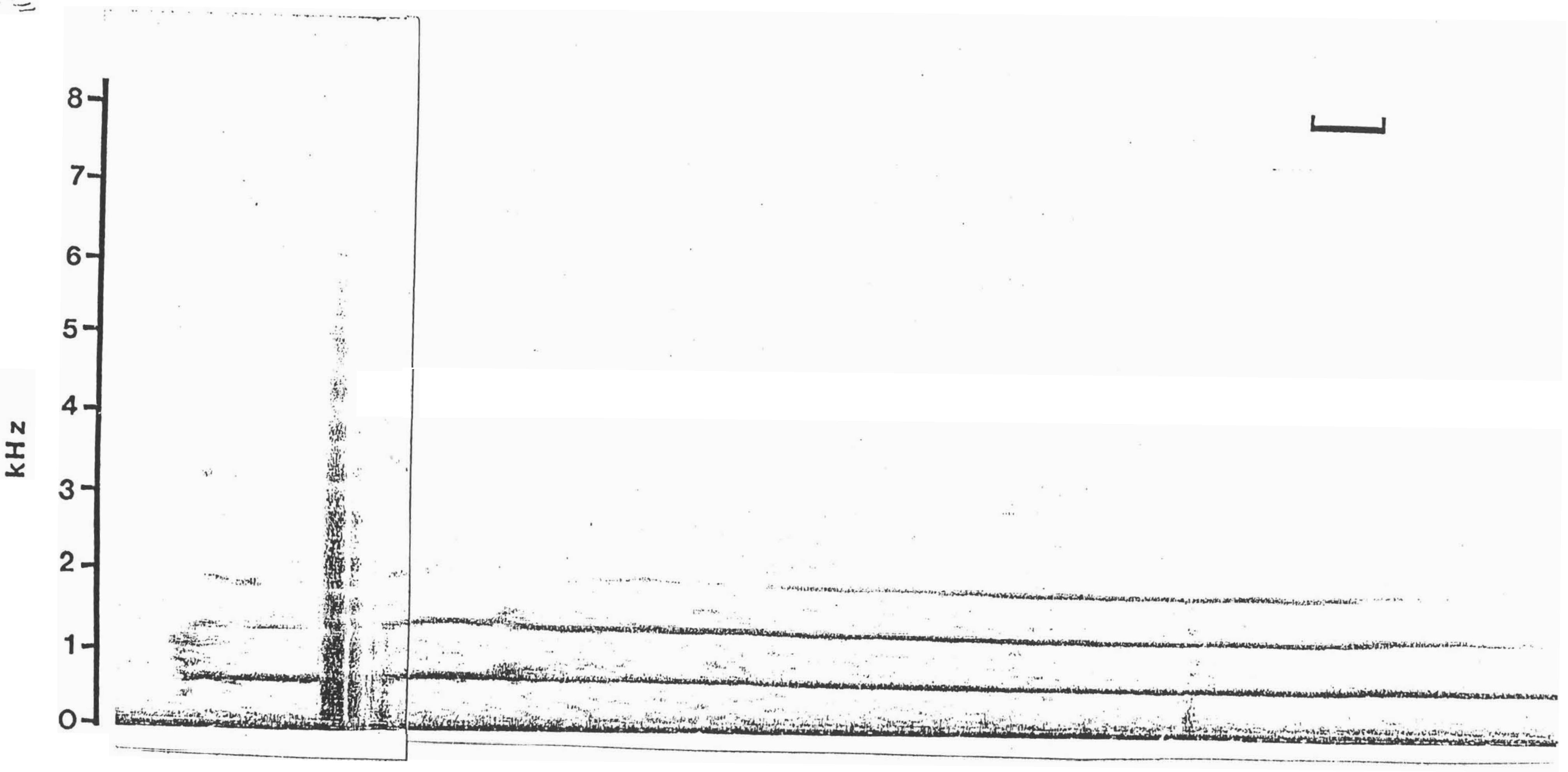
HOWL (SPANIEL)

Fig. 9.

Fig. 10

EQUIVALENCE TEST: HOWL





HOWL (SMALL MONGREL)