The acquisition of three types of auditory pattern discrimination in the cat*

JACK B. KELLY

Carleton University, Ottawa, Ontario, Canada K1S 5B6

This study compared the learning ability of cats in shock-avoidance discrimination with temporally patterned sounds. The three discriminations used involved detection of rising vs falling frequency-modulated tones, low-high vs high-low pairs of pure tones, and rising-falling vs falling-rising pairs of frequency-modulated tones. The discrimination of rising vs falling frequency-modulated tones was more easily learned than the other two discriminations.

Although temporal patterns constitute an important part of the auditory environment, relatively little attention has been paid to the ability of animals to discriminate patterned auditory stimuli. Temporal patterns composed of pure tones have been used with monkeys and cats (Jerison & Neff, 1953; Diamond & Neff, 1957; Elliott & Trahiotis, 1972) but have proved to be relatively difficult discriminations to learn (Cowey, 1968). On the other hand, Kelly and Whitfield (1971) have used temporal patterns composed of frequency-modulated tones and have found that cats easily learn to discriminate rising from falling tones. These results suggest a basic difference between FM patterns and pure tone patterns, although comparison is complicated by differences in intensity, duration, and frequency range of different patterns. In the following study, a direct comparison is made among three pattern discriminations involving frequency-modulated tones and pure-tone bursts.

METHODS

Twelve male adult cats were involved in pattern-discrimination tests. Each of the animals was first trained in a double-grill box to make an avoidance response to the onset of a buzzer. In this, and in subsequent tasks, a daily training session consisted of five warning trials presented at random intervals between 60 and 300 sec. Each buzzer-warning trial was 10 sec long, and the cats were trained to cross during this period from one side of the box to the other to avoid a shock. When a cat reached a criterion of 9 out of 10 correct responses over 2 days, training with patterned stimuli was begun.

Three different pattern discriminations were employed. Four cats were assigned to each of the discriminations. With the exception of the stimulus configuration, the training procedure was the same for the three discriminations. A patterned safe signal was presented in the background at a rate of 1/sec. During a training trial, the safe signal was replaced by a warning signal. The cats were expected to respond to this signal within 10 sec in order to avoid a shock. In addition to the number of correct responses, the number of spontaneous responses was estimated from the number of 10-sec periods between trials during which a response occurred. A discrimination score for each session was

based on the difference between percentages of correct responses and spontaneous responses.

The differences of the three temporal pattern discriminations are illustrated in Fig. 1. In the first discrimination (FM), the safe signal consisted of a series of rising frequency-modulated tones and the warning signal was a series of falling frequency-modulated tones. The range of frequencies covered was between 3,780 Hz and 4,220 Hz. In the second discrimination (TONE PAIRS), the safe signal was a series of low-high tone pairs. The warning signal was a series of high-low pairs. The two tones were 4,220 Hz and 3,780 Hz, separated by an 80-msec silent interval. In the third discrimination (FM PAIRS), the safe signal was a series of paired frequency-modulated tones, rising then falling. The rising component was separated from the falling component by 80 msec. The warning signal was a series of paired frequency-modulated tones in which the falling component preceded the rising component. The terminal frequencies of these modulated tones were 4,220 Hz and 3,780 Hz. As can be seen in Fig. 1, the total duration of each stimulus configuration

Fig. 1. Illustration of the three discriminations used. The stimulus configuration for the safe signal is shown on the left. The warning signal is shown on the right. Notice that the frequency excursion from f_1 to f_2 is the same for each configuration, i.e., 3,780 to 4,220 Hz. Also, the duration, 350 msec, is the same for each stimulus. (Onset and offset times were 15 msec for all stimulus presentations.)

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was 350 msec. The sound pressure level was the same for each as was the rate of presentation (1/sec). The safe signal and warning signal for each discrimination were identical in frequency content and therefore could be distinguished only on the basis of temporal order.

RESULTS

The ease of learning the three pattern discriminations was not the same. The four cats trained to discriminate rising from falling FM patterns reached a criterion of 9 out of 10 correct responses over 2 days in 11, 16, 18, and 19 sessions. None of the animals on the other two pattern discriminations reached this criterion. Training was continued for 20 sessions with pure-tone pairs and 15 sessions for FM pairs and, during these sessions, performance remained at a very low level. The level of spontaneous responses was generally quite low for each of the three discriminations. Means were 6.8% for the FM task, 7.0% for the tone pairs, and 9.7% for FM pairs. Therefore, differences in performance were not due simply to large differences in spontaneous activity. Performance levels for each of these discriminations are shown as average discrimination scores in Fig. 2. The FM pattern discrimination was more rapidly acquired than the other two discriminations. Statistical analysis of performance levels was carried out separately for sessions 1-5, 6-10, and 11-15 using the Kruskal-Wallis test (Siegel, 1956). Differences in performance were statistically significant ($p < .05$) for the second and third five-trial blocks.

The inability of the animals trained on patterns of tone pairs and FM pairs to perform these discriminations does not mean that the discriminations are impossible for cats. Indeed, the four animals trained originally to discriminate rising from falling tones were able to learn the discrimination of low-high vs high-low tone pairs in an average of 10 additional sessions. Furthermore, the four cats which failed initially to learn the discrimination of tone pairs did learn to discriminate rising from falling FM tones in an average of 8.25

sessions and were subsequently able to discriminate low-high pairs in an average of 8.50 sessions.

DISCUSSION

Rising vs falling frequency-modulated patterns are more easily learned by cats than are patterns of tone pairs or FM pairs, even when the procedures used in training the cats are the same and the methods of stimulus presentation, the intensity, frequency range, duration, and repetition rate are identical. The difference in difficulty under these testing conditions must, therefore, be related to the temporal configuration of the stimuli. Also, the ease of learning the FM pattern task is not due simply to the use of frequency-modulated tones, although the complexity of such stimuli and their relevance to environmental sounds or the animal's past experience are possible factors. Pattern discriminations with paired FM tones are not so easily learned.

Kelly and Whitfield (1971) have suggested that the ease of learning to discriminate rising from falling FM sounds is related to the way in which these stimuli are processed by the central nervous system. Neurons at several levels of the auditory pathway are sensitive to directional properties of frequency-modulated stimuli (Erulkar, Butler, & Gerstein, 1968; Fernald & Gerstein, 1972; Nelson, Erulkar & Bryan, 1966; Whitfield & Evans, 1965). Indeed, at the level of the auditory cortex, some cells respond vigorously to modulation in one direction but not at all to modulation in the other direction (Whitfield & Evans, 1965). Thus, within the central nervous system, a somewhat different population of cells will respond to rising and falling frequency-modulated tones, even though the same frequency range is covered by both stimuli. This type of response suggests an interaction between the elements excited by different frequency components of the stimulus (Erulkar, Nelson, & Bryan, 1968; Whitfield, 1969). The opportunity for this kind of interaction

Fig. 2. The average discrimination scores for animals tested under the three stimulus conditions. Solid circles represent FM patterns, solid triangles represent tone pairs and open circles represent FM pairs. Because training was discontinued when an animal reached criterion, the later sessions for FM patterns represent fewer than the normal four cases per group.

would be less when a temporal gap is introduced between the elements which make up a pattern. In the case of paired pure tones, low-high vs high-low, a temporal gap of 80 msec separates the two frequency components. Similarly, with paired FM patterns a temporal gap exists between the rising and falling components of the stimulus configuration. In both these pattern discriminations, there is a different requirement for temporal integration than in the case of rising and falling FM stimuli.

The suggestion that differences in central processing exist for FM and pure-tone patterns is confirmed by studies of the effect of central nervous system lesions. In behavioral-discrimination tasks with cats, auditory cortical lesions result in severe impairments in discriminations of pure-tone patterns (Diamond & Neff, 1957; Goldberg, Diamond, & Neff, 1957). Comparable lesions have a much less pronounced effect in discriminations of rising and falling FM patterns (Kelly & Whitfield, 1971). Following insular-temporal lesions, cats can learn discriminations of rising vs falling FM patterns, but fail to learn low-high vs high-low pure-tone patterns (Kelly, 1973). Thus, differences exist in the cortical dependency of these two types of discrimination. Differences in central processing have also been proposed by Nabelek et al (1973) to explain perceptual features of continuous and discontinuous frequency changes in humans.

SUMMARY

Twelve cats were trained in a shock-avoidance task to discriminate temporally patterned sounds. The discriminations used were rising vs falling frequency-modulated tones, low-high vs high-low pairs of pure tones, and rising-falling vs falling-rising pairs of frequency-modulated tones. Comparison of the rate of acquisition of animals on these discriminations showed

that rising vs falling FM pattern was more easily learned than the other two discriminations.

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