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DISCRIMINATION OF MUSICAL STIMULI BY RATS (*Rattus norvegicus*)

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ABSTRACT: Rats were trained under go–no go conditions to discriminate among complex acoustic stimuli (short musical sequences). In order to investigate the role of different stimulus attributes in discriminative performance, two short musical excerpts differing in their melodic pattern, but maintaining the number, pitch, and duration of notes constant were provided in two different timbres, to obtain four different complex auditory stimuli. According to the experimental condition, the discriminative stimuli were, therefore, different in structure, in timbre or in both aspects.

The animals were able to discriminate efficiently among the musical sequences only when cues furnished by timbre were available, whereas melodic differences made no difference. In the experimental setting used, the rat's discrimination of complex auditory stimuli appears, therefore, to be based neither on the melody nor on a compound of melody and timbre, but simply on the properties of the timbre of the stimuli.

RIASSUNTO: Dei ratti sono stati addestrati con una procedura go–no go a discriminare tra stimoli acustici complessi (brevi brani musicali). Al fine di valutare il ruolo di attributi diversi di uno stimolo complesso nell'acquisizione di una discriminazione condizionata, sono stati sintetizzati su personal computer due brevi brani musicali, identici nel numero di note costituenti, nella frequenza media, nella durata e nel ritmo, ma sensibilmente diversi sotto l'aspetto melodico. Le due melodie sono state poi realizzate in due diversi timbri "strumentali" in modo da ottenere quattro diversi stimoli complessi. A seconda della condizione sperimentale, gli stimoli discriminativi differivano o per le loro caratteristiche melodiche, o per quelle timbriche, o per entrambi questi aspetti.

I risultati ottenuti indicano che, nella situazione sperimentale da noi utilizzata, i ratti sono in grado di discriminare tra stimoli acustici relativamente complessi, ma suggeriscono che la discriminazione non è basata tanto sulla struttura melodica quanto sulle caratteristiche timbriche dello stimolo utilizzato.

INTRODUCTION

Although most studies of conditioned discrimination learning and of stimulus control in animals have been carried out with simple stimuli such as colored lights or tones of different intensity or pitch, a growing body of ethological data gathered both in the laboratory and in the field

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and derived mainly from studies on animal communication point out that for many species of birds and mammals the stimuli controlling behavior are often quite complex, and that animals are endowed with sophisticated abilities for their recognition (Cheney & Seyfarth, 1980, 1988; Falls, Dickinson, & Krebs, 1990; Falls, Horn, & Dickinson, 1988; Harrington, 1986).

Moreover, the recent and increasing interest in cognitive processes in animals (Hulse, Fowler, & Honig, 1978; Roitblat, Bever, & Terrace, 1984; Weiskrantz, 1988) makes it necessary to devise more complex experimental situations, better suited to investigate the integration of complex information. A number of studies have recently been performed in such a cognitive framework using complex visual stimuli varying along several dimensions at the same time. For example, natural-concept discrimination in pigeons has been investigated using photographs representing open-ended categories such as people, individual persons, alphanumeric characters, fishes, etc. (Herrnstein, 1984; Honig and Stewart, 1988 and Wilkie, Willson, and Kardal, 1989). Others have shown that nonhuman primates can acquire high-order abstract visual concepts (Schrier, Angarella, & Povar, 1984; Schrier & Brady, 1987; Rosenfeld & Van Hoesen, 1979; Yoshikubo, 1985).

Laboratory studies based on complex acoustic stimuli have been less frequent, but some interesting studies have been performed to assess the way animals analyze complex auditory information. It has been shown that both birds and mammals can be trained to discriminate synthetic and naturally produced speech stimuli (Hienz, Sachs, & Sinnott, 1981; Kluender, Diehl, & Killeen, 1987; Kuhl, 1981, 1986; Kuhl & Miller, 1975, 1978; Waters & Wilson, 1976), thus suggesting that the perception of speech sounds is not necessarily a uniquely human ability. A number of studies showed that starlings and other songbirds can manage structured information and respond differentially to organized computer generated sequences of tones (Hulse, Cynx, & Humpal, 1984a,b, 1985; Hulse & Cynx, 1985, 1986). Shy, McGregor, and Krebs (1986) using operant techniques demonstrated that great tits categorize natural song types in the same way as humans do, at least to some extent.

There is evidence that, despite a rich vocal communication system, primates are much more efficient in acquiring visual than auditory discriminations (Segal & Harrison, 1978; Thompson, 1980). It has been suggested that this reduced discriminative ability might be related to the very limited patterning of the stimuli employed in most studies (Beecher, Petersen, Zoloth, Moody, & Stebbins 1979). Primates would not attend to unpatterned sounds, usually unimportant in their natural habitats. To test this hypothesis, D'Amato and Salmon (1982) trained both monkeys (*Cebus apella*) and rats to a similar auditory discrimination task, where S+ was a short and very simple computer generated structured six-note melody, while S− was a simple "glissando." Both stimuli were presented for a very short time (slightly more than one second). Although all the primtes eventually learned the task, they always proved markedly less efficient than the rats, which were consistently faster in learning the auditory discrimination and more efficient in generalizing it to other stimuli. Moreover, the performance of the rats was very poor when the discriminative stimuli were constant tones rather than interrupted tones or patterned melodies. These experiments seemed, therefore, to confirm the importance of auditory stimulus patterning for both rats and primates.

However, in a later study with a different setup, the same authors (D'Amato & Salmon, 1984) found that neither rats nor monkeys appeared to make great use of structural cues, but seemed to base their discriminations on more local aspects of the stimuli, such as overall frequency differences. They concluded that the ability of the rats and monkeys to discriminate between patterned auditory stimuli displayed in their previous study had been overestimated. The local feature responsible for discrimination learning in the 1982 paper was apparently the frequency of the initial notes of the melody.

On the other hand, Porter and Neuringer (1984) have argued that their pigeons were not only able to discriminate among complex melodic patterns, but also skillful in generalizing to other stylistically similar musical pieces in almost the same way as people do. To rule out the possibility that the rats would respond to some simple attribute to the stimuli, they employed long and complex musical excerpts: The stimuli differed, therefore, along several dimensions, pertaining, for example, to instrumentation, tempo, timbre, richness of sound, pitch, etc. As the exact nature of the music varied considerably from trial to trial, Porter and Neuringer (1984) concluded that pigeons were attending to some rather complex attribute of the musical stimuli. However, the stimuli employed in the study were extremely complex and it was, therefore, impossible to tell which auditory cue or pattern of cues was responsible for the results.

These findings clearly show that nonhuman animal responses to auditory events may be more complex than is usually assumed, and suggest that at least some species can respond to the pattern of the acoustical stimuli rather than to limited local features. However, without a complete and detailed analysis of the controlling features of the acoustic signals, either natural or artificial, this latter possibility cannot be ruled out. In particular, the possibility that discriminative behaviour could be based on the complex stimulus "in toto" rather than on other structural elements (i.e., rhythmic, tonal or timbric patterns) has not been fully investigated.

The aim of the present study was to extend D'Amato and Salmon's study of rats to a more complex auditory domain. By the use of forward and backward versions of a short melody, we were able to keep constant both the rhythmic patterns and the mean frequencies of the two tunes.

Our situation was in this respect somewhat similar to the one used by D'Amato and Salmon (1984). Furthermore, to allow for a meaningful patterning of the melody, we chose a longer lasting melody. Finally, to avoid the possibility pointed out by D'Amato and Salmon (1984) that the discrimination would be based on the frequency of the initial notes, in our study the onset of the stimulus presentation was randomly chosen at different points of the melody. The purpose of the experiment was, therefore, first, to ascertain whether rats would acquire an operant discrimination based on relatively complex and structured musical sequences and, second, if they succeeded in doing so, to evaluate whether the discrimination was based on the melody as a whole, or on other stimulus attributes, such as timbre.

METHOD

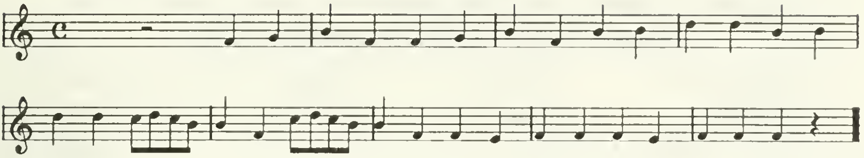
Rats

Twenty-four female Long-Evans rats, obtained from Charles River Inc. were studied. They were about five months old at the start of the study and had no previous experimental experience. During the experiment, they were housed in pairs in 56.5 × 35 × 18 cm plastic cages under an artificially reversed light cycle (light on from 9 p.m. to 9 a.m.). While dry food was constantly available in the home cages, water was available only for 1 hr after each daily session; therefore, all rats were water deprived for approximately 23 hr before each experimental session.

Apparatus

The apparatus used consisted of two Grason-Stadler operant chambers, housed in custom-built sound attenuating enclosures, each consisting of two laminated wood boxes one inside the other and separated by a 5 cm thick layer of expanded styrene. Each chamber measured 23 × 20 × 29 cm. The side walls of the chambers were clear Plexiglas; the front and the rear walls were aluminium; and the floor was formed of 3 mm steel bars. A response lever was located on the left side of the front panel, 8.5 cm from the grid floor, and extended 2 cm from the wall. Reinforcement consisted of .4 ml of water presented for 4 sec through a Gerbrands liquid dipper positioned in the middle of the lower part of the front wall.

Diffuse illumination was provided by a 25-W bulb positioned behind the front wall of the chamber. A Philips wide-range two-way speaker (model PRO 602 with a rated response of 20 to 20,000 Hz) was located 10 cm behind the front panel. The musical stimuli were presented with a Marantz/Superscope Model CD-330 tape recorder (rated frequency

Tune 1: Normal

Tune 2: Modified

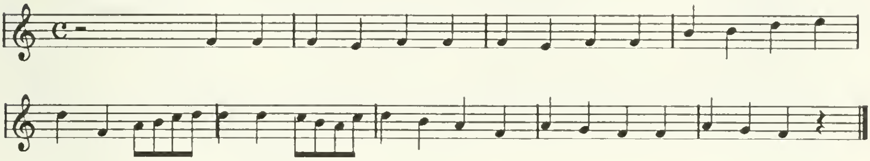



FIGURE 1. Scores of the discriminative stimuli.

response 40 to 15,000 Hz ± 3 dB; S/N ratio with Dolby B on, 55 dB), and their intensity was held constant at approximately 85 dB throughout the experiment. All aspects of the experiment were controlled by conventional relay equipment.

The auditory stimuli were two 37-note tunes synthesized with the Instant Music program running on an Apple II GS personal computer. One of the tunes, referred to as Tune 1, was the well-known folk melody "Frère Jacques" while the other, Tune 2, was obtained by arranging the component notes of "Frère Jacques" in a reversed sequence without altering the rhythmic structure (the scores are presented in Fig. 1). The two tunes were therefore identical with respect to their mean frequency, note duration and rhythm, but noticeably different in their melodic patterns.

Both tunes were synthesized in two different "instrumental" timbres, namely trumpet and guitar, and recorded on cassettes. The three different experimental conditions were, therefore, characterized by differences in the melodic and timbre features of the tunes. In the *Timbre-Melody* condition, the two stimuli differed both in structure (sequence of the individual notes) and in timbre; in the *Melody* condition the sequence of the notes was different, but the timbre was maintained constant; in the *Timbre* condition the same sequence of notes was presented in the two different timbres; finally, the *Control* rats were always presented the same sequence of notes with the same timbre. In principle, there were 16 different possibilities (4 in each of the four conditions). However, for practical reasons, the study has been carried out with only four groups, each given one condition.

TABLE 1
Experimental Design and Discriminative Stimuli. Tune 1: Frère Jacques; Tune 2: Frère Jacques Reversed

	Timbre-Melody Condition (T-M group)	*Melody Condition (M group)*	*Timbre Condition (T group)*	*Control Condition (C group)*
S+	Tune 1	Tune 2	Tune 2	Tune 1
	Guitar	Guitar	Trumpet	Trumpet
S−	Tune 2	Tune 1	Tune 2	Tune 1
	Trumpet	Guitar	Guitar	Trumpet

Procedure

The animals were first magazine-trained and hand-shaped to press the lever on a continuous reinforcement schedule (CRF). After acquisition of the operant response, they were gradually introduced to a fixed-ratio 5 schedule of reinforcement (FR 5), that was maintained for a few sessions (2–4) in the absence of auditory stimuli.

The experiment was then carried out as follows:

Phase 1. After shaping was completed, a Mult. FR 5/Ext schedule was introduced. The subjects were then assigned at random to one of the four groups (Table 1). For the six rats in the TM group, the stimuli to be discriminated differed both in melody and in timbre. For those in the M group, S+ and S− differed in melody but were presented in the same timbre. For those in the T group, the only difference between S+ and S− was timbre. For the C group no acoustic discriminative information was available as the same tune (i.e., Tune 1, Trumpet) was played repeatedly in both contingencies. This group served to evaluate to what extent the behaviours of the experimental groups were controlled simply by fixed ratio schedule cues. The possibility of introducing a negative contingency during extinction was considered, but we decided that the advantages of such a procedure would have been overridden by its perturbing effect.

Acquisition training consisted of 50 consecutive daily sessions. Each session lasted 20 min and consisted of randomly intermixed 15 sec periods of either S+ or S−. The sequence of S+ and S− periods was randomized through a Campden Instrument random event generator so that in each session the average number of S+ equated that of S−. Therefore, the exact sequence of S+ and S− was unpredictable and varied from day to day. During each session the total number of responses emitted during S+ and S−, the number of S+ and S− presented, and the number of reinforcements obtained were recorded for each rat.

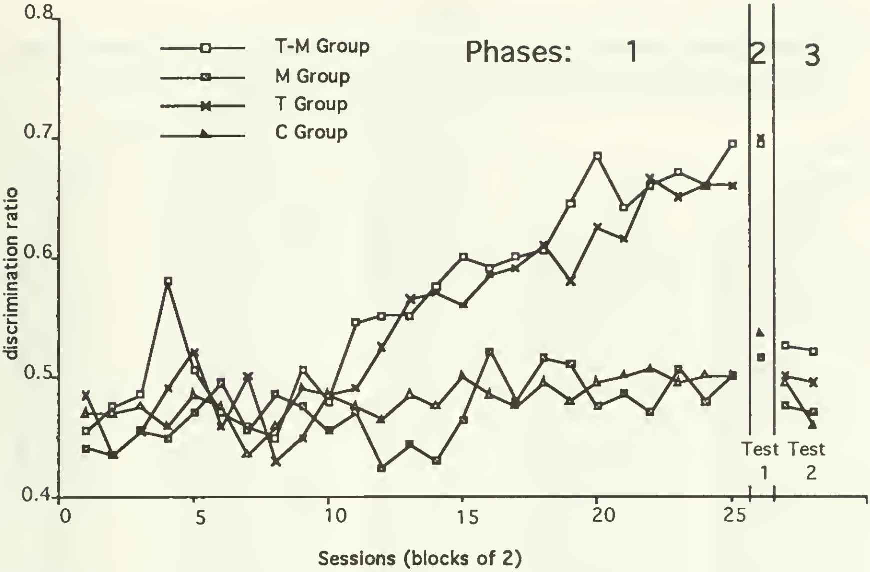


FIGURE 2. Performance curves for each group during the three phases.

Discriminative behavior was measured by a discrimination ratio (DR) defined by the following formula: $DR = R^+/(R^+ + R^-)$, *where:* $R^+ = Rs^+/S^+$ *and* $R^- = Rs^-/S^-$.

This formula was introduced to compensate for the effects of the variable number of stimuli introduced by the randomization over sessions of relatively short duration.

Phase 2. To test whether the regular alternation of the two stimuli and their longer duration affected the performance of the rats, Phase 1 was followed by two 20 min test sessions in which periods of S^+ and S^- lasting 1 min each were regularly alternated.

Phase 3. Four 20 min control sessions in the absence of the musical stimuli were performed to test whether to the discrimination obtained was based on the physical properties of the auditory stimuli or was due to some artifact. During these sessions blank tapes replaced the music, so that only an unstructured noise approaching white noise was presented, while all other contingencies were the same as during acquisition (Phase 1).

RESULTS

The main results of the experiment are reported in Fig. 2, showing for each group, in two session blocks, the mean discrimination ratios during the different phases. Table 2 reports the discrimination ratios of the

TABLE 2
Discrimination Ratios (2 Session Blocks) of Individuals in Each Group During Testing and at the End of Training (Last Four Sessions)

Session		*Phase 1*		*Phase 2*	*Phase 3*	
(Blocks)	*Rat*	*47–48*	*49–50*	*51–52*	*53–54*	*55–56*
T-M group	1	.56	.70	.67	.46	.54
	2	.57	.59	.66	.49	.48
	3	.63	.66	.66	.56	.57
	4	.75	.75	.74	.54	.57
	5	.71	.68	.74	.52	.46
	6	.70	.77	.75	.55	.50
M group	1	.47	.43	.57	.46	.48
	2	.49	.49	.50	.48	.45
	3	.40	.45	.42	.43	.41
	4	.51	.55	.56	.53	.52
	5	.47	.56	.61	.53	.57
	6	.43	.51	.47	.41	.42
T group	1	.73	.70	.69	.51	.51
	2	.69	.72	.71	.50	.50
	3	.54	.56	.62	.45	.40
	4	.60	.57	.68	.46	.53
	5	.64	.68	.65	.54	.44
	6	.74	.74	.79	.55	.54
C group	1	.53	.58	.59	.44	.42
	2	.51	.56	.58	.57	.51
	3	.53	.46	.53	.43	.52
	4	.42	.43	.48	.43	.43
	5	.52	.48	.49	.51	.42
	6	.48	.48	.52	.52	.47

individual rats of each group at the end of training (sessions 47–50) and during testing.

These results clearly indicate a difference in discriminative performance between the two groups that could make use of timbre differences (T-M and T) and both the M and the C groups. None of the rats in the last two groups showed any sign of learning the discrimination, whereas three of the six rats in the T-M and T groups were clearly responding above chance at the end of training (Table 2). The statistical significance of these differences in performance was assessed using a between subject two-way ANOVA based on the mean discrimination ratio of the indi-

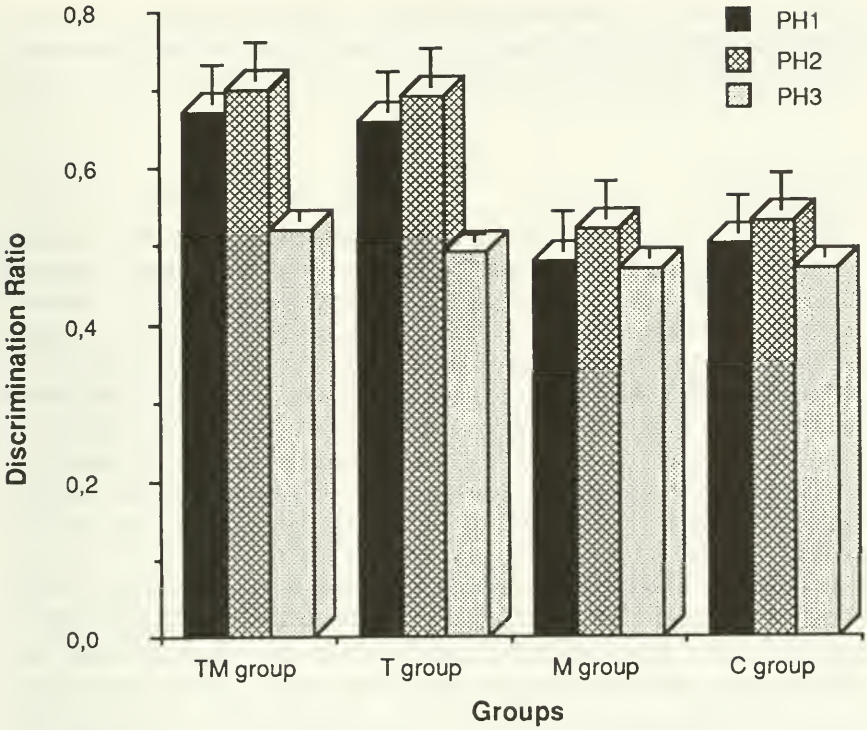


FIGURE 3. Mean discrimination ratios of the four groups in the last four sessions of Phase 1 and in Phases 2 and 3.

vidual subjects over the last four sessions of Phase 1. The test revealed a significant effect of timbre (F(1, 20) = 43.503, p = .0001), but not of melody or of timbre × melody interaction. These results seem to indicate that rats are able to discriminate among fairly complex artificial acoustic stimuli, but they also suggest that the discrimination is based on simple and general properties of the tune stimuli, such as timbre, rather than on the melodic structure.

The effect of Phase 2, consisting of the regular alternation of the two stimuli, was assessed with the Wilcoxon matched-pairs test, but no significant effect was revealed in any of the groups (for all of them, $p >$ .05, two-tailed test).

However, when, in Phase 3, blank tapes were substituted for the musical stimuli, discriminative performance in the T-M and T groups was clearly disturbed (Figs. 2 and 3). The Wilcoxon matched-pairs test, employed to evaluate the effects of the withdrawal of the acoustic stimuli, showed no significant effects of this procedure, either in the C group (p = .7, two-tailed test) or in the M group (p = .2). Both the T-M and the

T groups showed a significant disruption of performance ($p = .02$), indicating that the discrimination was not an artifact but was really controlled by the experimental stimuli.

DISCUSSION

The results of the present experiment do, therefore, partly confirm those obtained in previous studies (D'Amato & Salmon, 1982, 1984), in that rats are shown to be able to discriminate among auditory stimuli more complex than those usually used in laboratory studies. Although the discrimination ratios reached by the T-M and T rats were relatively low in comparison with those reported by D'Amato and Salmon, due to the differences in procedure, exact comparisons are, however, difficult to make. The consistent differences in performance between the sessions, in which the musical stimuli were present (Phase 1) and the Control sessions (Phase 3) clearly indicate that discrimination was based on the musical stimuli.

As noted by D'Amato and Salmon (1982), rats are nocturnal animals and apparently rely more on olfactory and acoustic stimuli than on visual ones. It is, therefore, not surprising that they are able to respond appropriately to auditory stimuli of some complexity. Furthermore, these rodents make large use of infra- and ultra-sounds in their social interactions (Sales & Pye, 1974; Nyby & Whitney, 1978; Thomas & Barfield, 1985). The ability to efficiently analyze the auditory information in a large range of frequencies could at least partly explain this capacity. However, in the present study discriminative behaviour appears to be based more on general properties of the stimulus (i.e., timbre) rather than on its melodic pattern. This suggests that in the rat the recognition of complex auditory stimuli is based mainly on immediately detectable features, rather than on the detection of the structured organization of the stimulus. Although timbre is very complex to define from a physical point of view, it is usually quite easy to recognize, and is generally perceived as a "unitary" feature. On the other hand, the melodic structure is easily described in physical terms, but its apprehension as a structured whole may be less immediate.

The possibility that the differences in the performance of Melody and Timbre groups could be an artifact either of the particular samples of melody and timbre selected or of the procedure cannot be ruled out. Different melodic patterns or timbres and a different training procedure could conceivably have been more or less effective.

Moreover, the experimental stimuli used in this study were artificially synthesized and arguably devoid of any particular ecological meaning. It is possible that more natural and meaningful signals could have been discriminated more easily. As already suggested for other species (Marler, 1983; Snowdon, 1983), the possibility that the rat's ability to detect structural differences among complex auditory stimuli might be restricted to a limited range of biologically relevant acoustic signals needs further investigation.

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