The direction of pitch change judged by Japanese monkeys

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ABSTRACT

A pair of tone bursts and/or harmonically structured complex tone bursts were sequentially presented on directional pitch change discrimination tasks for Japanese monkeys. Results show that monkeys may have similar sequential pitch perception as humans. However, both humans and monkeys may have common difficulty in judging the pitch direction when spectral cues and fundamental frequency cue are contradictory. Results implied that monkeys might have a prototype of human melody perception.

INTRODUCTION

We have neurophysiologically and behaviorally investigated pitch extraction system in the Japanese monkey [1, 2, 3, 4, 5, 6, 7, 8, 9]. Our behavioral studies have revealed that Japanese monkeys show similar pitch perception that humans do including the missing fundamental perception [2]. In this research perception of directional pitch change in monkeys is investigated. They could always discriminate the direction of pitch change but in one case [7]. The case was that the temporal sequence is made of a simple tone burst (ex. tone burst of 396 Hz) and a complex tone burst which was composed of the first five harmonics (ex. the complex tone of the fundamental of 264 Hz) with fundamental lower than 500 Hz. The frequency of the simple tone burst was in between the fundamental and the second harmonic frequencies of the complex tone burst. When the simple tone burst was followed by the complex tone without time lag, monkeys and some human subjects judged the pitch as increasing, although the fundamental frequency decreased [7]. Both may have common difficulty in judging the pitch direction depending upon the fundamental frequency cue. In a pilot study we found that human subjects could judge it when duration of tones or interval between tones were lengthened. We proposed a hypothesis that increasing duration of tones and/or interval between tones might eliminate the difficulty. This difficulty in monkeys was elaborated in Experiment 1. In Experiment 3 we tested the pitch directions in monkeys when the interval between two tones varied.

EXPERIMENT 1

Two Japanese monkeys were trained, on a Go-Nogo operant task, to discriminate between sequential pitch increment and decrement for a variety set of tone stimulus.

Methods

Subjects

Two Japanese monkeys (*Macaca fuscata*), Subjects M1 (4 years old)and M2 (5 years old) were used. M2 was used in the previous experiments of directional pitch change [1, 2, 3, 8, 9]. Both of them had experience in discrimination of coo sounds [10] and then were trained in pitch change discrimination of complex sounds for 15 months. They were deprived of water. One hour after the end of daily experimental session, 300 ml of water was given. They could freely drink water on weekends.

Apparatus

The tests and training took place within a sound attenuated chamber. The subject was sat in a monkey chair equipped with a stainless spout for water reward, an infrared sensor to confirm that both hands were on the table and a push button for response (Figure 1). Stimuli were presented from a loud speaker fixed in front of the animal at a distance of 84 cm.

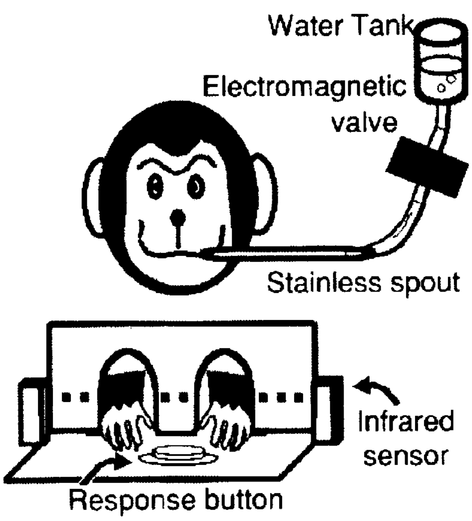


Figure 1. Experimental setups.

Stimuli

Stimuli were sequentially presented simple tone bursts and harmonically structured complex tone bursts. Figure 2 shows the envelope pattern of two sequential tones. The duration of a tone burst was 200 ms. The rise and fall times were 25 ms. For M1, S+ was defined by an increment of the fundamental frequency between the two tones while S- was defined by the opposite direction. Schematic spectrograms of a set of tones for M1 were indicated in Figure 3. For M2, S+ and S- were switched. T1 was a pair of simple tone bursts. T2 and T3 were pairs of complex tones. T4 and T5 were combination of a tone burst and a complex tone. The frequency of the simple tone burst was in between the fundamental frequency and the second

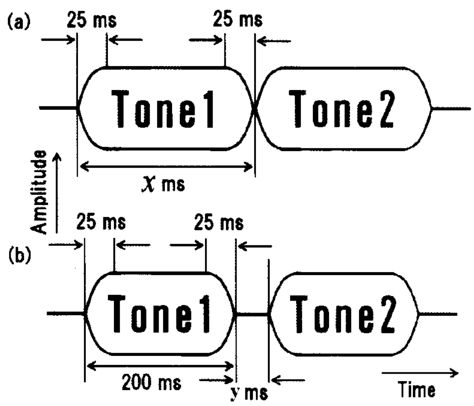
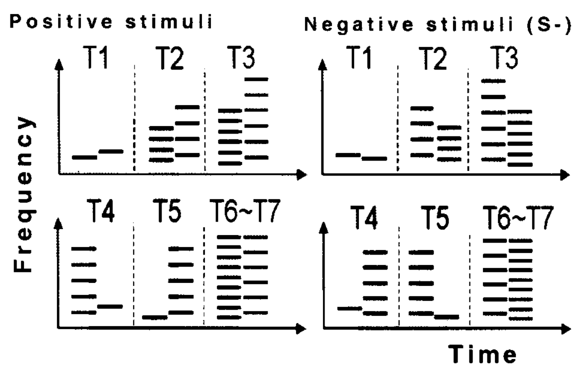


Figure 2. Envelope pattern of sequential tones. a: Duration of both tone bursts was always 200 ms. b: The pattern used in Exp. 2. The interval between two tones was varied.



Fugure 3. Schematic spectrograms of a set of tones for Subject M1.

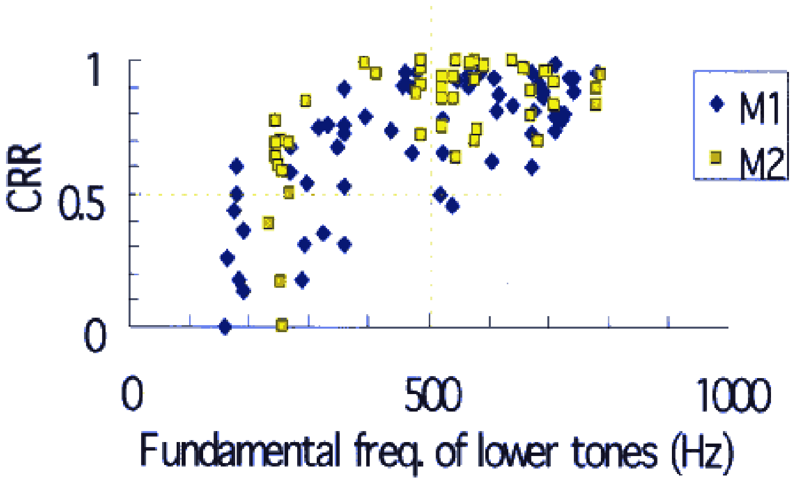


Figure 4. Relation between fundamental frequency of lower tone and CRR .

harmonic of the complex tone burst for T4, where the directions of the change in the fundamental frequency of the complex tone burst and the simple tone frequency were opposite. The fundamental frequency of the complex tone burst was higher than the frequency of the simple tone burst for T5. T6 and T7 were a pair of complex tone bursts where the highest harmonics were the same frequency. The fundamental frequency was selected randomly from 150 to 1000 Hz. The frequencies of the highest harmonics were lower than 9000 Hz. The ratio between the fundamental frequencies of the first and the second tones in a sequence was 1.25 - 1.89. The stimulus set was replaced by an unfamiliar set in each session. These pair of tone bursts were presented repeatedly 6 times at 1.5-s intervals. Amplitudes of successive harmonics were the same. Sound pressure level was randomly varied between 30 and 50 dB SPL.

Training

Each session lasted about 1.5 h and took place 6 days a week. We repeatedly presented seven pairs of S+ and S- randomly within a session. Trials started only when the subject inserted hands into the frontal opening over 1 s. If the subject pushed the button while positive stimulus (S+) was presented, water was given from the spout at variable interval. So, the subjects could not always receive water for correct response. When M1 responded to S-, the response was always followed by vocalized Japanese warning word "kora", and timeout for 10 or 15 s as a punishment. When M2 responded to S-, the response was always followed only by timeout for 10 or 15 s.

Correct response ratio (CRR) was conveniently calculated by the next equation (1).

$$CRR = Rp/(Rp + Rn) \qquad (1)$$

where Rp is the number of responses to S+; Rn is the number of the responses to S-.

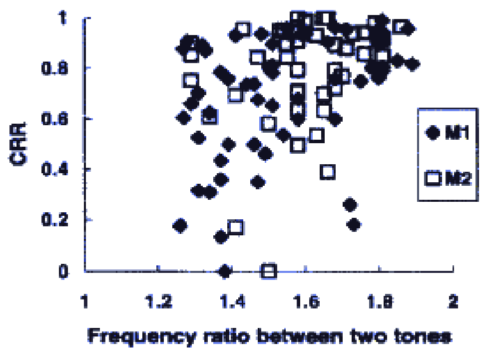


Figure 5 . Relation ship between frequency ratio between two tones and CRR.

Results

CRR for T4 pattern (0.7 for M1 and 0.8 for M2) was lower than that for the other patterns. **Figure 4** indicates CRRs for T4 pattern as a function of the fundamental frequency of lower tones. CRR increased with the fundamental frequency. CRR was below 0.5 when the fundamental frequencies of lower tones were less than 300 Hz, showing that the subjects persisted in responding to S- in spite of the fact that the response was followed by time out. **Figure 5** indicated CRRs for T4 pattern as a function of the fundamental frequency ratio between the first and the second tones. Reversal responses (CRR < 0.5) were often found when the fundamental frequency ratio between the first and the second tones was lower than 1.5. **We performed additional experiments and analyses, revealing relationships between the fundamental frequency and the directional pitch perception shown in Figure 6. When the fundamental frequency of the lower tone was 150 Hz, both animals demonstrated consistent reversal responses. The number of harmonic component also wound affect the directional pitch perception. The more the number of harmonics, the less influential the fundamental frequency (Figure 7).**

EXPERIMENT 2

In Experiment 2 we investigated direction of pitch change in monkeys, varying intervals between tones. At first the interval between tones varied from 0 up to 150 ms. However, it was difficult to maintain discrimination with such a short interval for monkeys. For human it was easy to discriminate pitch other than pattern T4 even if the interval of tones was 800 ms. So, interval

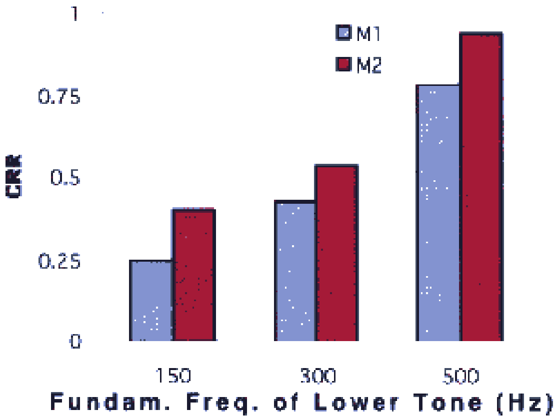


Figure 6 Relationship between fundamental frequency and CRR. F0 ratio: 1.5

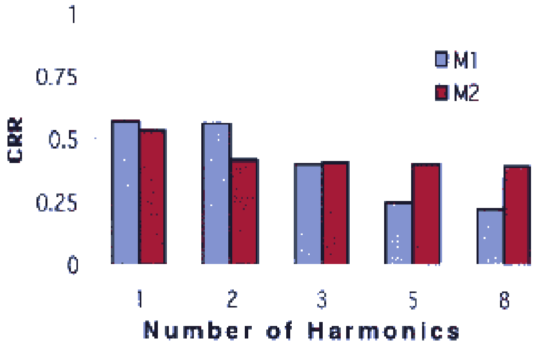


Figure 7 Relationship between number of harmonics and CRR.

between tones was gradually lengthened with training. As training progressed, generalization was investigated by presenting reward and timeout.

Methods

Subjects
The same Japanese monkeys used in Experiment 1 were employed. They were deprived of water.

Apparatus
The same as in Experiment 1.

Stimuli
The same as in Experiment 1 except for the matters described below. Interval between tones was 0, 50, 100, 150, 200, 300, 400, 500, 650, or 800 ms (Fig-

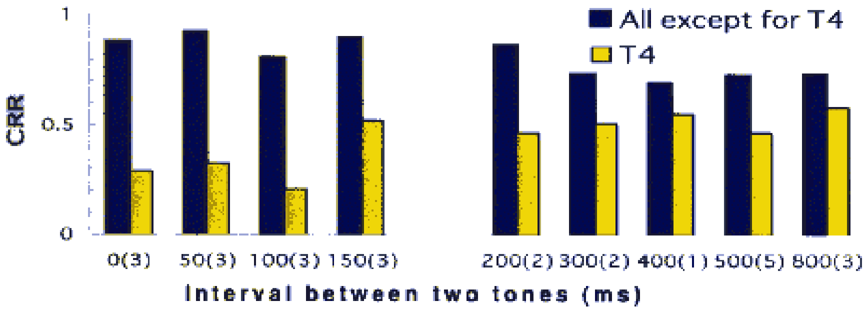


Figure 8. Relationship between inter-tone interval and correct response ratio. Subj: M1. Numbers in parenthesis: sample size.

ure 2b). The interval between tones was not changed within a daily session. Up to 150 ms the interval changed daily repeatedly several times for tests. From 150 ms training was repeated for the interval until discrimination except for T4 pattern improved. For test, the same stimulus sets were used repeatedly with the fundamental frequency of T4 below 500 Hz. For training, the stimulus set was replaced with an unfamiliar set in each session. Two tone bursts were presented repeatedly twice at 1.5 s interval in a trial.

Training

The same as in Experiment 1 except for the matter showed below. When M1 responded to S-, the response was always followed by timeout for 30 s. For M2, until training reached up to 150 ms, there was no consequence to responding in S-. Thereafter when M2 responded to S-, the response was always followed by timeout for 20 s.

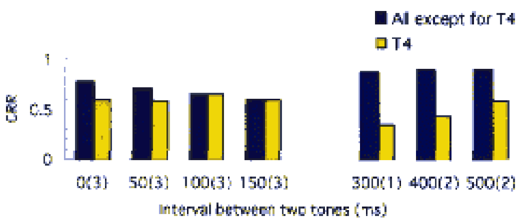


Figure 9 Relationship between inter-tone interval and correct response ratio. Subj: M2. Numbersin parenthesis: sample size.

Results

Figure 10 indicated CRRs from M1 for T4 pattern and for patterns other than T4 separately as a function of the interval between tones. Up to 100 ms CRRs were lower than 0.5 for T4 pattern, and for patterns other than T4 those were higher than 0.8. Above 150 ms CRRs decreased for patterns other than T4, and for T4 pattern CRRs were near 0.5. There might be increasing beyond 0.5 for T4 pattern.

Figure 11 indicated CRRs from M2 for T4 pattern and for patterns other than T4 separately as a function of the interval between tones. From 50 to 150 ms CRRs were about 0.6 both for T4 pattern and for patterns other than T4. The discrimination was disrupted. Above 150 ms, with training with timeout CRRs increased for patterns other than T4. For T4 pattern CRR may also be increasing.

Discussion

Perception of directional pitch change in Japanese monkeys was studied in a situation where a pair of tone bursts and/or harmonically structured complex tone bursts were sequentially presented. The monkeys were successfully trained to discriminate the direction of fundamental frequency or pitch change in the same manner as our previous experiments with the

CRR above 0.9 [1,2] except for the tone pattern T4 [7](Figure 3). Pattern T4 was that the temporal sequence is made of a simple tone burst with a complex tone burst which was composed of the first five harmonics. The frequency of the simple tone burst was in between the fundamental and the second harmonic of the complex tone burst. When a simple tone burst was followed immediately by a complex tone with the fundamental lower than 500 Hz, Monkeys judged the pitch as increasing although the fundamental frequency decreased.

Monkeys persisted in responding to S- in spite of the fact that the response was followed by time out, a punishment. Directions in spectral change for stimulus sets used in Experiment 1 were identical to the direction of change in fundamental frequency except for T4 pattern.

Human subjects trained in music often judged the pitch change only by the fundamental frequency [7]. Thus, a learning process must be involved in the perception of sequentially changing pitch. Concerning with monkeys, M2, experienced much longer in this experimental situation than M1, could judge the change in the fundamental frequency for lower frequency than M1.

The hypothesis that increasing the interval between tones might reduce the difficulty was supported. Monkeys showed tendency of improvement with longer intervals between tones (Figures 8, 9). Usually in closer distance it is easier to compare stimuli. So, improvement with lengthening interval between two tones was interesting. Perhaps some character of memory system of pitch perception may concern.

The difficulty occurred when the fundamental frequency cue had a conflict with the spectral cue with the fundamental frequency below 500 Hz. However, they could perceive the missing fundamentals below 500 Hz. Therefore, it is not a simple resolution problem.

The take-home message of this paper is that a monkey could be a naive model for pitch perception. So, a prototype for human pitch extraction or melody perception may be found in a learning monkey.

ACKNOWLEDGMENTS

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