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ACOUSTICAL LETTER

Perceptual space for timbre of harmonic complex tones consisting of 20 to 40 components

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1. Introduction

In this letter, the timbre of steady sounds consisting of several harmonic components is examined. The timbre of a steady sound is related to its physical spectrum.[1,2] However, it is considered that some characteristics of the auditory system such as non-linearity, lateral inhibition, and band-pass filtering translate the physical spectrum into an "internal spectrum," which is the sound spectrum representation in the auditory pathway.[3,4] We assume that the internal spectrum is then converted into a "subjective (psychological) spectrum," which is the "internal spectrum" in terms of subjective (psychological) values. As this "subjective spectrum" is assumed to be used as the input to the stage of timbre perception, the timbre would be closely correlated with it rather than with the physical spectrum. Furthermore, if the subjective spectrum could be approximated by a "masked frequency spectrum," which is the frequency characteristic in terms of the masked loudness of each component of the input sound partially masked by the other components,[5] we could examine the rôle of the masked frequency spectrum on the timbre of a sound as an initial step towards understanding the rôle of the subjective spetrum.

We have been conducting a series of studies that aims at finding some appropriate representation of the subjective spectrum or timbre of a complex sound.[5,6] This letter summarizes the method and the results of a psychoacoustical experiment performed to investigate the principal factors affecting timbre perception for steady harmonic-complex-tones.

2. Psychoacoustical experiment

In the experiment, similarities in timbre among 35 stimuli were examined. The spectra of the stimuli are shown in Fig. 1. All the stimuli with a common fundamental frequency of 200 Hz consist of 20 to 40 harmonic components. Table 1 summarizes the parameters of the physical spectra of the stimuli divided into groups according to spectral similarity.

The stimuli from Number 1 to 12 were obtained by variation of the number of the components and the macroscopic slope of the spectral envelopes, with parameters shown in Table 1 (a). For the stimuli from Number 13 to 18, the number of components was 40, while the slope of each was changed at the frequency shown in Table 1 (a).

The stimuli from Number 19 to 23 consisted of the fundamental component and common even-harmonics up to the 40th, with a slope of -3 dB/oct. The parameters for the odd harmonics were varied as shown in Table 1 (b). On the other hand, the stimuli from Number 24 to 28 consisted of common odd-harmonics up to the 39th, with a slope of -3 dB/oct. The parameters for the even harmonics are shown in Table 1 (c).

Althouh the one-third octave band levels of the stimuli Number 29 and 30 were equal to those of the stimulus Number 6, the spectral envelopes in some of the bands were shaped as shown in Fig. 1.

The stimuli from Number 31 to 35 were obtained from the stimulus Number 6 by removing some components. The removed components are shown in Table 1 (d).

To avoid the effects of difference in loudness, the over-all levels of the stimuli were maintained to 10 sone by means of Zwicker's loudness calculation method.[7,8] The stimuli were presented diotically to a subject seated in a soundproof chamber via a headphone (Yamaha YHD-3) with frequency characteristic flattened within 5 dB by an equalizer. We regard this frequency characteristic as flat enough to examine the effect of the spectral envelope of the stimuli used in the present experiment on their timbre. The subjects were four young males with normal hearing acuity. Similarities in timbre for each paired stimuli were rated in seven categories of a scale (category 1: undistinguishable, category 7: entirely different). Each pair was examined eight times in random order by each subject. The obtained judgments were translated into subjective distances by the method of successive categories.[9]

The distances among the stimuli were analyzed by ALSCAL,[10] a computation program for multidimensional scaling, to represent the stimuli as points in a Euclidean space.

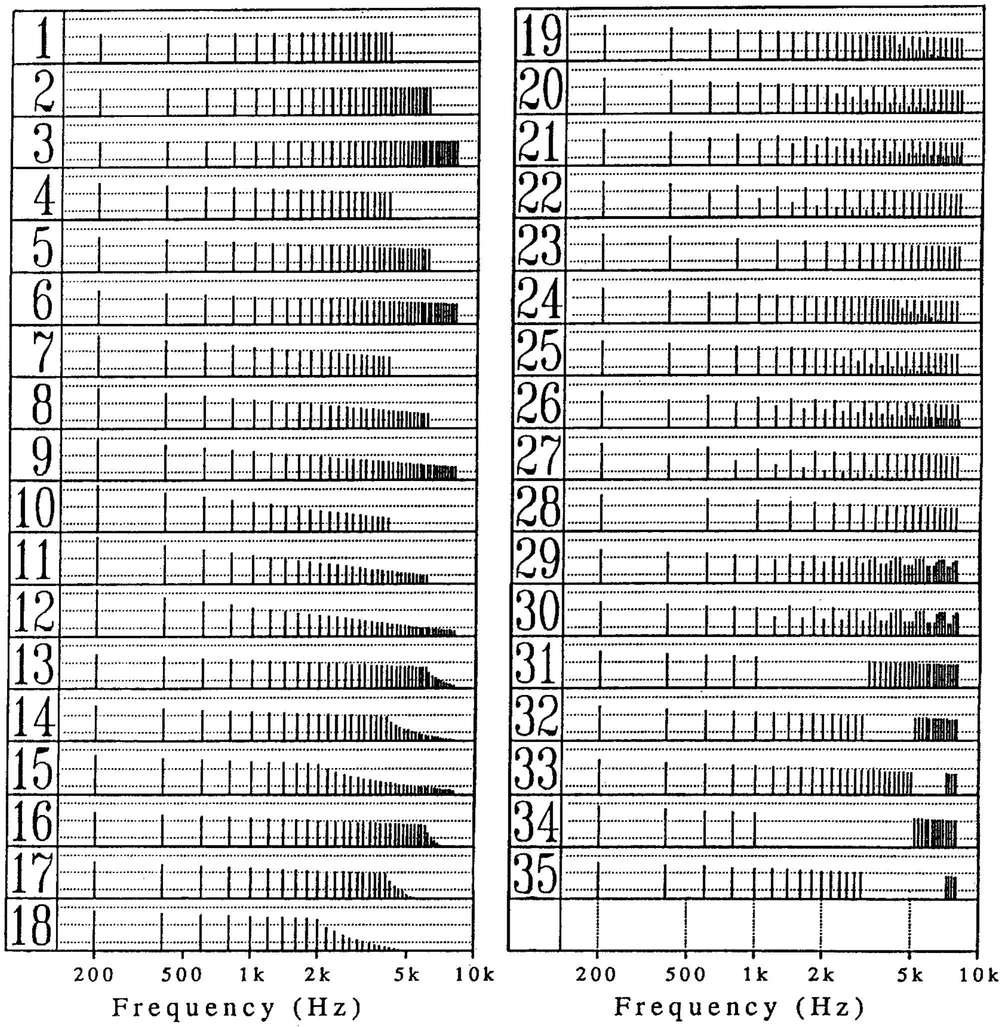


Fig. 1 Spectra of the stimuli. Horizontal dashed lines represent level differences of 20 dB.

3. Results and discussion

The dimensionality of the space was determined by evaluating the stress, which indicates goodness of fit. The three-dimensional solution shown in Fig. 2 was employed, where the stress in three dimensions was 11.8% (one dimension: 37.0%, two: 15.1%, four: 8.8%). However, a two-dimensional solution seemed sufficient for part of the data, *i.e.*, the data on the stimuli from Number 1 to 12 and 19 to 28, wherein the physical spectra of the stimuli were similar. Figure 3 shows the two-dimensional spaces for these stimuli, where the stress was 5.3% for the stimuli from Number 1 to 12, and 6.8% for Numbers 19 through 28, respectively. For the stimuli from Number 1 to 12, the configuration is interpreted according to two features of the physical spectra, *i.e.*, the slope of the spectral envelopes and the highest order of the components present. The configuration could also be interpreted in terms of two subjective attributes; here we can not tell what they are but it could be considered that one of them is "sharpness[2,11]." On the other hand, the stimuli from Number 19 to 28 are configured symmetrically

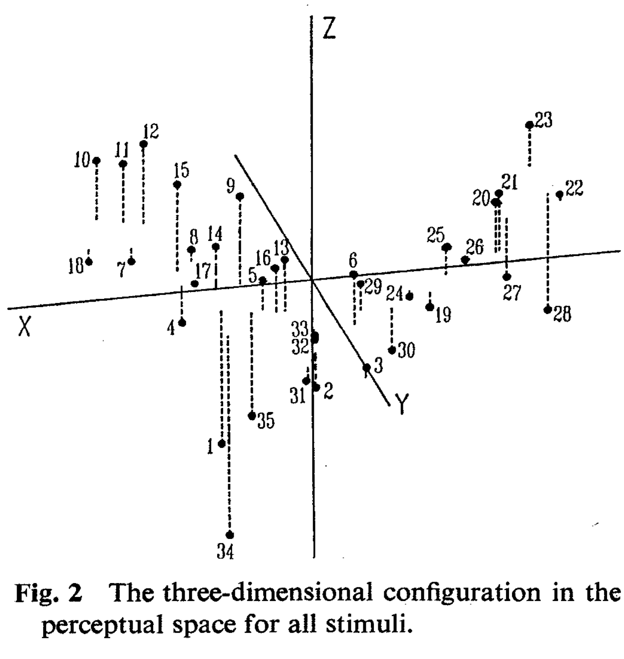


Fig. 2 The three-dimensional configuration in the perceptual space for all stimuli.

Table 1 Parameters of the spectra of the stimuli.

(a) The slope of the spectral envelope and the number of the components for the stimuli from Number 1 to 18.

No.	Slope of spectral envelope	Number of components
1	0 dB/oct.	20
2		30
3		40
4	−3 dB/oct.	20
5		30
6		40
7	−6 dB/oct.	20
8		30
9		40
10	−9 dB/oct.	20
11		30
12		40
13	−3 dB/oct. (below 6.0 kHz) −50 dB/oct. (above 6.0 kHz)	40
14	−3 dB/oct. (below 4.0 kHz) −25 dB/oct. (above 4.0 kHz)	
15	−3 dB/oct. (below 2.0 kHz) −15 dB/oct. (above 2.0 kHz)	
16	−3 dB/oct. (below 6.0 kHz) −75 dB/oct. (above 6.0 kHz)	
17	−3 dB/oct. (below 4.0 kHz) −40 dB/oct. (above 4.0 kHz)	
18	−3 dB/oct. (below 2.0 kHz) −20 dB/oct. (above 2.0 kHz)	

(b) The slope of spectral envelope of odd harmonics for the stimuli from Number 19 to 23.

No.	Slope of spectral envelope of odd harmonics
19	−3 dB/oct. (below 3.8 kHz) −25 dB/oct. (above 3.8 kHz)
20	−3 dB/oct. (below 1.8 kHz) −15 dB/oct. (above 1.8 kHz)
21	−6 dB/oct.
22	−9 dB/oct.
23	removed

(c) The slope of spectral envelope of even harmonics for the stimuli from Number 24 to 28.

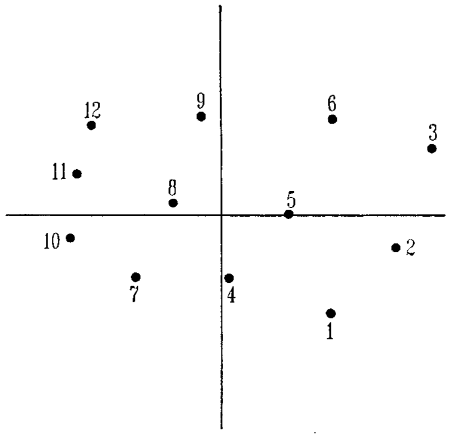
No.	Slope of spectral envelope of even harmonics
24	−3 dB/oct. (below 4.0 kHz) −25 dB/oct. (above 4.0 kHz)
25	−3 dB/oct. (below 2.0 kHz) −15 dB/oct. (above 2.0 kHz)
26	−6 dB/oct.
27	−9 dB/oct.
28	removed

(d) The harmonics removed from the stimulus Number 6 to obtain the stimuli from Number 31 to 35.

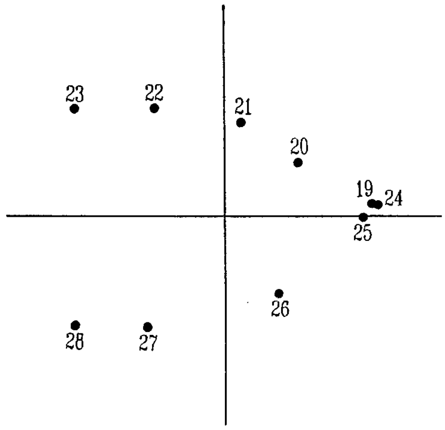
No.	Removed harmonics
31	6∼15
32	16∼25
33	26∼35
34	6∼25
35	16∼35

according to difference in relative amplitudes of odd and even harmonics as shown in Tables 1 (b) and 1 (c). This relative presence of odd and even harmonics is correlated to the subjective attribute of "fullness[12]."

Although the configuration of the stimuli in Fig. 2 seems complex, it contains at least the two configurations shown in Fig. 3. This fact suggests that to some extent the three-dimensional configuration can be characterized in terms of the physical spectra of the stimuli. We would expect that the subjective configuration may be interpreted more accurately in terms of the masked frequency spectra of the stimuli because we assume that the masked frequency spectrum is an approximation of the subjective spectrum or the timbre. We will further



(a) Stimuli Numbers 1 to 12.



(b) Stimuli Numbers 19 to 28.

Fig. 3 The two-dimensional configurations for a part of the stimuli.

consider how the timbre is described by the masked frequency spectrum of the sound.

4. Summary

The perceptual space for timbre was obtained for harmonic complex tones. The space obtained was interpreted to some extent in terms of physical characteristics of the sounds. Consideration based on the subjective frequency spectra of the stimuli might be useful for a full understanding of the space.

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