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HYPER-SYMBOLIC SOUND STRUCTURE OF *KARTULI POLYPHONIA*

Introduction

The Western European concept of music, which is the foundation of conventional music and audio theories, regards articulated musical tones having a stationary sound signal structure as the basic components of music. In applying the sound communication model of the communication science domain, we, however, postulate a biological concept of music in which music is defined as follows: music is an artificial sound system that activates a neuronal auditory system and reward-generating system having an informational structure that, in the macro-temporal domain, provides sustaining patterns encoded by gene and culture and, in the micro-temporal domain, changes continuously and is non-stationary (Oohashi, 2003). Our definition of music whose essential characteristic is its being a non-stationary, continuously changing informational structure of the micro-temporal domain is thus not consistent with the Western concept, which regards stationary "musical tones" as the constituent components of music.

We begin with a brief overview of the general concept of our sound communication model (Fig.1). There are three categories – *sign*, *word*, and *music* – for human information communication making use of sound signals.

A *sign* is a short, temporal, distinctive auditory pattern that occurs as one discrete pulse to convey a single piece of information, then immediately stops. A *word* combines short sound patterns into a temporally single array of transmitted information, which adds information whenever a new group of sounds appear. The transmitted information accumulates through a stair-step process of integration. *Music* has a continuous and non-stationary information structure that starts to transmit information immediately upon the occurrence of a sound signal and continues to accumulate that information until the signal stops.

On the other hand, the Western concept of music posits the existence of musical tones, which are assumed to be stationary sounds with a temporarily uniform structure. Western music is transcribed in a musical score of five lines, which is a discrete coordinate space, in which musical notes are encoded as a temporal array by parameters such as pitch and length. In principle, therefore, the precondition of Western music is a discrete and discontinuous sound signal structure, which makes it analogous to information transmission by words. By contrast, the biological concept of music requires a sound structure having continuous, non-stationary change as its essential attribute. Such a structure is rather difficult to describe by a symbol such as a discrete note in a musical score. The hyper-symbolic sound structure, therefore, plays a critical role in indicating music in our model above.

Consequently, we examined the hyper-symbolic sound structure of *Kartuli Polyphonia* (Georgian polyphonic singing) and compared it with singing voices from other cultures, using a new method to visualize and observe the spectral fluctuation in the micro-temporal domain.

Methods

We analyzed three *Kartuli Polyphonia* songs: *Chakrulo* (solo), *Khasanbegura* (trio) and *Imeruli Tskhenosnuri* (chorus). These were recorded with a 4135 (Brüel & Kjær, Nærum, Denmark) microphone and a high-speed sampling one-bit coding signal processor developed by Y. Yamasaki. This recording system has a sampling frequency of 3.072MHz and a good response over 100kHz. We analyzed singing voices from Asian and Western cultures: Mongolian *Khoomii* (solo), Japanese *Nagauta* (duet), and a Tibetan Buddhist chant (chorus), and singing voices from three Western operas: French *Adriana Lecouvreur* (solo), Italian *Don Carlos* (quartet) and German *Tannhauser* (chorus). In this study, we primarily focus on the fluctuation of the power spectra in the micro-temporal domain within the human audible frequency range as the hyper-symbolic sound structure of music.

A Fast Fourier Transform (FFT) method is widely used in the analysis of music and sound. However, it shows only the averaged power spectrum of sound data. Since this method does not allow us to see how the power spectrum changes in a micro-temporal domain, we developed the maximum entropy spectral analysis method (MESAM) by applying the mathematical formulae of the maximum entropy method and the power spectral estimation from the autoregressive model (Ulrych, 1972; Akaike, 1969; Morimoto, et al., 2004).

First, we digitally sampled the recorded singing voice data by MD8000MkII with a sampling frequency of 250 kHz. For every 20-msec epoch with an overlap of 10 msec, the power spectrum of the sound data was calculated by the maximum entropy method, which is known to be suitable for precise spectral estimation from a short period of data. We used final prediction error to determine the order of auto-regression. The estimated power spectra were displayed in a three-dimensional array and their temporal fluctuations were visually inspected. Spectral estimation and a three-dimensional display were made by MATLAB (The MathWorks, Inc., Natick, USA).

Results

Fig. 2 shows the ME spectral array of Kartuli singing voices. Each line corresponds to a power spectrum every 10 milliseconds. Power spectra during a 0.5-second period in total are shown in a three-dimensional array. At frequencies above the fundamental frequency, all the voices showed non-stationary and dynamic spectrum changes no matter how the musical notes changed. Similar spectral patterns hardly ever appeared and the spectrum always changed in a complex way. Such characteristics were observed in the solo and became even more prominent in the trio and chorus.

One other prominent fluctuation of the power spectra was observed in various singing voices from Asian culture. Fig. 3 shows that non-stationary and dynamic spectrum changes were present even in a single musical note. Fluctuation became more prominent in the duet and chorus.

By contrast, singing voices from Western culture showed different characteristics from those in the above two categories of singing voices. As shown in Fig. 4, periodic changes in power spectra within the fundamental frequency area corresponding to *vibrato* are observed. In the chorus, these dynamics became prominent, but the monotonous characteristics of temporal changes in power spectra were still preserved.

We also examined the frequency ranges of the *Kartuli* singing voice (solo) and the *bel canto* singing voice (solo) recorded with an ultra-wide frequency range over 50 kHz (Fig. 5). The *bel canto* singing contained only frequency components below 20kHz. By contrast, we found that *Kartuli* singing contained rich inaudible high-frequency components over 50kHz. These results indicate that another hyper-symbolic structure, that is, high-frequency components above the human audible range, exist in the *Kartuli* singing voice but not in the *bel canto* singing voice.

To examine whether the tendency observed by the above analysis is restricted to the singing voice, we also compared instrumental musical sounds in non-Western and Western cultures. We chose a Japanese *Shakuhachi* and a piccolo as representative wind instruments (Fig. 6). The ME spectral array of the *Shakuhachi*, whose musical score is just one note, allows its harmonic overtone to fluctuate continuously in a complex way. By contrast, that of the piccolo faithfully fluctuated according to the notation of the musical score.

A similar tendency was also observed in keyboard instruments. We analyzed the sound structure of the same musical score played on a Western European piano and a Balinese gamelan (Fig. 7). The spectral array of the gamelan included many more harmonic overtones than basic tones with extreme fluctuation spectra. The fluctuation of spectra was continuous in any interval of the time corresponding to one note of the score. On the other hand, the spectra of the piano were mainly stationary, hardly fluctuating, other than at the keying points. Thus the instrumental musical sounds as well as singing voices of non-Western music were richer in hyper-symbolic structure than those of Western music.

Discussion

Though our studies we have acquired detailed information on a hyper-symbolic sound structure of *Kartuli Polyphonia* as well as various traditional Asian singing voices in the micro-temporal domain, revealing that this sound structure contains obvious, non-stationary and continuously fluctuating features. These characteristics were also observed even in a single musical note. This strongly suggests that the sound structure of *Kartuli Polyphonia* and Asian singing voices is quite compatible with a biological concept of music in which music has as its necessary attribute a continuous and non-stationary sound signal structure. By contrast, the Western singing voice showed monotonous changes in power spectra with periodic fluctuation. Nevertheless, our data showed some fluctuation even in a single musical note. Therefore, the biological concept of music is also applicable to Western music, although it provides scant evidence of non-stationary and continuously fluctuating features. This tendency is not restricted to singing voices; it also applies to various instrumental musical sounds.

In the Western concept of musical composition, a composer creates a composition having a discrete structure by arranging musical notes, while the player of that composition performs it as a continuous and fluctuating structure. Accordingly, musical tones with a stationary sound signal structure are regarded as the basic components of music, so the composer is generally considered more important than the performer. By contrast, since the prominent hyper-symbolic sound structure of *Kartuli Polyphonia* requires players performing polyphonic pieces to construct freely at all times micro information structures that cannot be transcribed into notation, this spontaneous improvisation is its essential attribute. Thus in non-Western music cultures, including *Kartuli Polyphonia* and various Asian singing voices compatible to the biological concept of music, players creating that hyper-symbolic structure of music are accorded a more important role than their counterparts in Western music cultures.

It is difficult for the human brain to consciously perceive a change in the spectrum in a micro-temporal domain. It is noteworthy, however, that the natural environmental sounds of tropical rain forests, one of the best candidates for the place from which human beings evolutionarily developed, contains rich inaudible high-frequency components with a non-stationary, conspicuously fluctuating structure in a micro-temporal domain (Nakamura, et. al., 2004). From the anthropogenetic point of view, the sensory system of human beings exposed to a natural environment would stand a good chance of developing physiological sensitivity to the hyper-symbolic sound structure.

We previously reported that sounds containing inaudible high-frequency components with complex fluctuation in a micro-temporal domain activate the neuronal network, including the upper brainstem (midbrain), hypothalamus and thalamus, that extends to the prefrontal cortex and anterior cingulate gyrus via the basal forebrain and thus makes sounds more comfortable for us humans to hear (Oohashi, et al., 2000; Oohashi, et al., 2001; Honda, et al., 2004). The neuronal projection from the upper brainstem to the prefrontal cortex, including monoaminergic neurons, is known to play a crucial role in generating sensations of pleasure and beauty. Therefore, the hyper-symbolic sound structure of *Kartuli Polyphonia* seems to be an efficient expressional strategy that activates the neuronal network for pleasure and beauty for us humans.

Conclusion

In positing a biological concept of music, we examined the hyper-symbolic sound structure of *Kartuli Polyphonia* by measuring the fluctuation of power spectra in a micro-temporal domain using MESAM. The results revealed that the sound structure of *Kartuli Polyphonia* contains rich temporal fluctuation of the power spectra in a micro-temporal domain. These findings suggest the singular importance of *Kartuli Polyphonia* as an expressional strategy.

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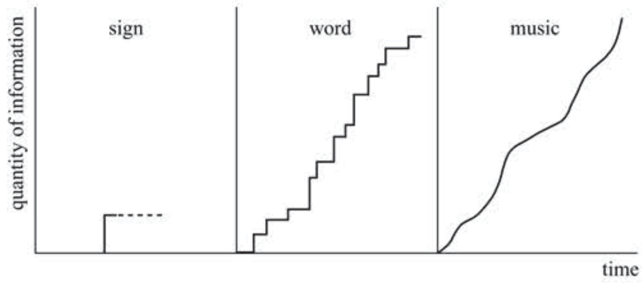
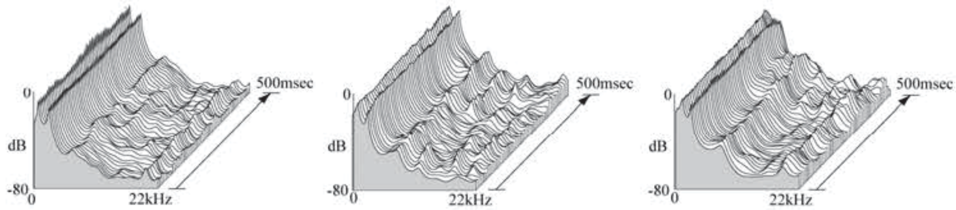
სურათი 1. ადამიანური საკომუნიკაციო მოდელის სამი კატეგორიის დროითი თავისებურებები
FIGURE 1. Temporal feature of the three categories in our human communication model

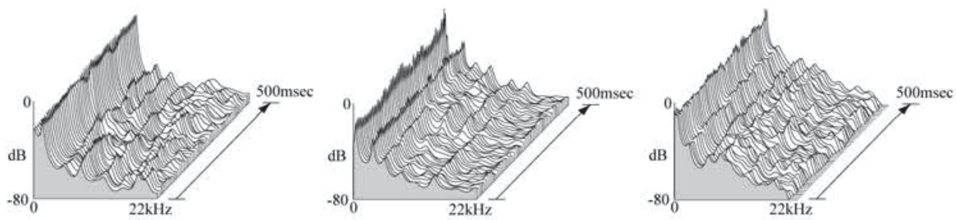


სურათი 2. ქართული სასიმღერო ხმების ME სპექტრული ანალიზი
FIGURE 2. ME spectra array of *Kartuli* singing voices



Solo (*Chakrulo*) Ensemble (*Khasanbegura*) Chorus (Imeruli *Tskhenosnuri*)

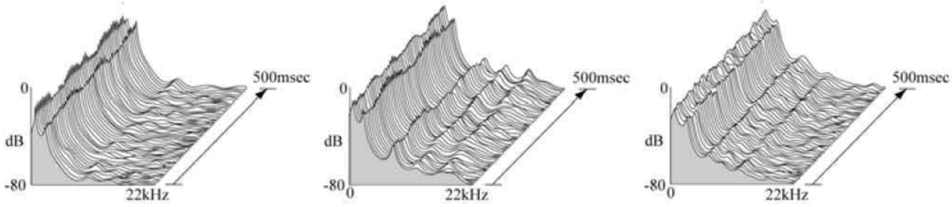
სურათი 3. აზიურ კულტურათა სასიმღერო ხმების ME სპექტრული ანალიზი
FIGURE 3. ME spectra array of singing voices from Asian cultures



Solo (*Khoomii*) Ensemble (*Nagauta*) Chorus (Tibetan chant)

სურათი 4. დასავლურ კულტურათა სასიმღერო ხმების ME სპექტრული ანალიზი

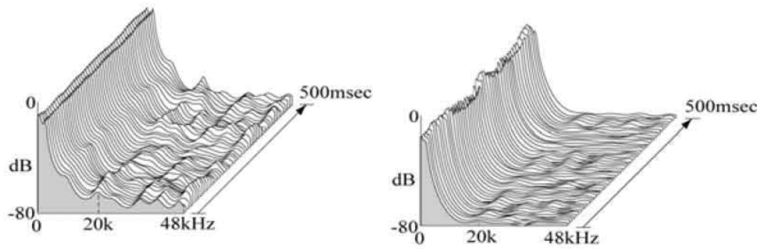
FIGURE 4. ME spectra array of singing voices from Western culture



Solo (*Adriana Lecouvreur*) Ensemble (*Don Carlos*) Chorus (*Tannhauser*)

სურათი 5. ქართული და bel canto კულტურათა სასიმღერო ხმების (სოლო) ME სპექტრული ანალიზი

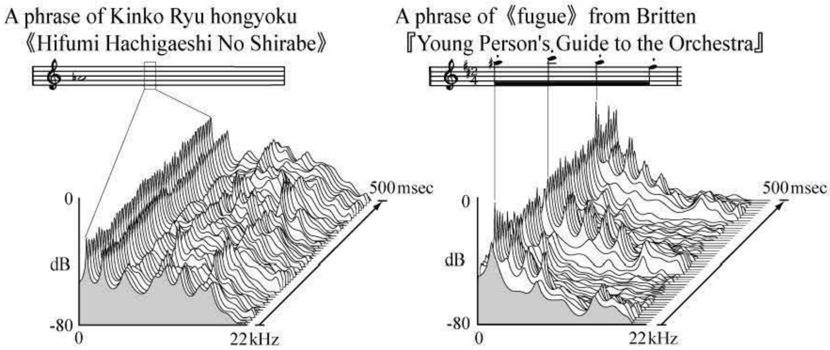
FIGURE 5. ME spectra array of *Kartuli* and *bel canto* singing voices (solo)



Kartuli singing voice (solo) *Bel canto* singing voice (solo)

სურათი 6. შაკუჰაჩი-სა და პიკოლო-ს (სოლო) ME სპექტრული ანალიზი

FIGURE 6. ME spectral array of *Shakuhachi* and piccolo (solo)



Shakuhachi (solo) Piccolo (solo)

სურათი 7. გამელანისა და ფორტეპიანოს ME სპექტრული ანალიზი
FIGURE 7. ME spectral array of gamelan and piano