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# BIOLOGICAL MECHANISM OF PERCEPTION OF INAUDIBLE HIGH-FREQUENCY COMPONENT INCLUDED IN MUSICAL SOUNDS

**Abstract**

We showed that sounds of various traditional polyphony including *Kartuli Pholyphonia* and various ethnic musical instruments contain inaudible high-frequency component of air vibration above human audible range with conspicuous, non-stationary fluctuation in a micro temporal domain of the order of millisecond. Using a cutting-edge scientific approach, we discovered that inaudible high-frequency components with complex structure activate the reward-generating neuronal system in the brain and make the musical sounds more comfortable to hear. We have called these phenomena collectively "the hypersonic effect." It remains unclear, however, how such inaudible high-frequency components are transduced and perceived by listeners. We have recently succeeded in showing that inaudible high-frequency components of air vibration are perceived via some unknown sensing mechanism situated on the body surface, not via conventional air-conducting auditory system through ears. In this paper, we report the detail of this finding.

## 1. Introduction

We previously reported in this symposium that sounds of various traditional polyphony including *Kartuli Pholyphonia* and various ethnic musical instruments contain inaudible high-frequency component (HFC) of air vibration above human audible range with conspicuous, non-stationary fluctuation in a micro temporal domain of the order of millisecond, and reported these findings in this symposium. In addition, we discovered that a non-stationary sound containing significant quantities of fluctuating HFC activates a function of the fundamental brain network, which is reflected as a significant increase in the regional cerebral blood flow (rCBF) in the brainstem and thalamus, a significant enhancement of the occipital alpha frequency component of the spontaneous electroencephalogram (EEG) which is a marker of pleasantness, improvement of immune function including NK cell activity which works as an initial barrier against cancers, decrease of stress hormones, more pleasant perception of sounds, and induction of behavior that the listeners spontaneously adjust the comfortable listening level (CLL) of the sound to a greater magnitude (Oohashi et all, 1991; 2000;2001; Yagi et all,2002,2003,2003a). We call such phenomena collectively "the hypersonic effect."

Although the hypersonic effect is a set of phenomena closely related to the human auditory function, it contains some unusual characteristics. Among them, in humans, it is known that air vibration frequencies above 20 kHz cannot be perceived as sound through auditory nervous system in humans, it was a big mystery how the human beings sense such inaudible HFC of air vibration.

In this study, we tried to determine if these unique phenomena can be explained by a simple solitary response of the auditory nervous system mediating air-conduction, or if we need to consider the involvement of a non-air-conducting auditory system or any other biological system as the contributing factors. For this purpose, we have divided the sound source, which has been proven to induce the hypersonic effect ( Oohashi et all,2000), into two components: an audible LFC and an inaudible HFC. While the LFC was presented to the air-conducting auditory system, the HFC was simultaneously presented either to the air-conducting auditory system or to the entire body surface; in the latter various vibratory sensing systems other than the air-conducting auditory system might exist. Under each condition, we compared the full-range sound (FRS: simultaneous presentation of LFC and HFC) and LFC alone. In this way we examined if there were any differences in the emergence of the hypersonic effect under these different conditions.As the results, using two differing measurements that were clearly able to detect the emergence of the hypersonic effect in the previous studies: (1) physiological measurement of spontaneous EEG using a portable multi-channel telemetry system and (2) behavioral measurements on CLL (Oohashi et all, 2001; Yagi et all,2002,2003,2003a), we revealed that the hypersonic effect was not induced when the HFC was presented selectively to the air-conducting auditory system, but was induced when the HFC was presented to the entire body surface, including the head but excluding the ears. This surprising finding suggests that the inaudible HFC inducing the hypersonic effect perceived through the body surface which is distinct from the conventional air-conducting auditory system.

## 2. Experimental Procedure

**Subjects.** Healthy Japanese adult volunteers participated in the EEG and behavioral experiments. Data on the number, gender and age of the subjects that participated in each experiment are provided in the Results section. Written informed consent was obtained from each of them before the experiment. The experiments were performed in accordance with the approval of the Ethics Committee, National Institute for Physiological Sciences. All the subjects had more than 5 years exposure to the actual HFC-rich sounds of the musical instruments used as a sound source.

**Sound materials and presentation system.** The sound stimulus was a traditional gamelan composition, “Gambang Kuta,” of Bali Island, Indonesia, which contains a wealth of high frequencies with a conspicuously fluctuating structure and has been proven to induce the hypersonic effect. A bi-channel sound presentation system (Oohashi et all, 2000; Yagi et all,2002) was used to present the sound stimulus (Fig. 1). Using high-pass and low-pass filters with crossover frequency of 22 kHz, we divided the source signals into audible LFC and inaudible HFC, and amplified them independently of each other. These signals were presented simultaneously or separately though speaker or earphone. Exact specifications of the sound source and the bi-channel sound presentation system (Authentic Signal Disc ARHS9002 and Authentic Hypersonic Sound System, Action Research Co., Ltd., Tokyo, Japan) have been described elsewhere (Yagi et all, 2002).

The speaker components of the system were placed approximately 2.0 meters from the subjects' ears. Subjects used custom-made closed-air type insert earphones without ear pads. Both the right and left earphones contained two vibratory devices, one for LFC and the other for HFC. Fig. 2 shows the power spectra of the actual air vibration reproduced by the bi-channel sound presentation system and recorded with a microphone at the subject's position. The averaged power spectra of the entire 200-sec piece of music used in the experiments were measured on a Fast Fourier Transform (FFT) analyzer. None of the subjects could distinguish the presentation of HFC alone from silence.

Each of the EEG and behavioral experiments consisted of four sub-experiments: (a) Both LFC and HFC presented through speakers; (b) Both LFC and HFC presented through earphones; (c) LFC presented through earphones; HFC presented through speakers; (d) LFC presented through earphones; HFC presented through speakers but with sound insulators preventing exposure of the subject's head and body surface to HFC. In all experiments, two conditions were compared FRS (simultaneous presentation of LFC and HFC) and LFC alone. Special attention was given to the subjects' immediate environment to avoid discomfort (Fig. 2).

**Measurement of EEG. EEGs** were recorded using a telemetric system from 12 scalp sites according to the International 10-20 System using linked earlobe electrodes as a reference and subjected to the FFT analysis. The square root of the averaged power level in a frequency range of 10.0-13.0 Hz at each electrode position was calculated as the equivalent potential of EEGs in the alpha 2 band. The data obtained from 7 electrodes in the centro-parieto-occipital region (C3, C4, T5, Pz, T6, O1, O2) were averaged across all the analysis epochs (alpha-EEG) and compared between the two conditions: FRS and LFC alone. In addition, the scalp distribution of the change in the alpha 2 component between FRS and LFC alone was also evaluated by constructing colored contour line maps using 2,565 scalp grid points with linear interpolation and extrapolation (Duffy et al.,1979; Ueno and Matsuoka,1976) based on z-values calculated from pair-wise comparisons of the strength of the alpha 2 component at each electrode.

**Measurement of CLL.** The same four sub-experiments were performed for CLL measurement as we did in the EEG experiments. In the first trial, subjects listened to the sound stimulus at the listening position. During the next three trials, subjects were requested to freely adjust the listening level to what they considered to be comfortable using a remote controller with an up-down switch that controlled the motorized fader positioned between the player and the pre-amplifier. No visual or tactile information on the volume was given to subjects when they adjusted the listening level. Then, during the final trial, each subject listened to the sound fixed at the level that they had selected at the end of the preceding trial. The listening level was measured as equivalent continuous A-weighted sound pressure level ($L_A$eq) using an integrated sound level meter. The level measured in the final listening trial and adjusted in terms of $L_A$eq was considered to be the CLL. Statistical evaluation was made using paired Student's t-test between FRS and LFC alone.

### 3. Results

**EEG experiment.** When both LFC and HFC (i.e., FRS) were presented through speakers to subjects (5 males and 7 females), the alpha-EEG power was significantly greater as compared with the presentation of the LFC alone, confirming the emergence of the hypersonic effect (Fig. 3a left and middle).

When sound was presented exclusively to the ears through earphones (6 males and 9 females), no difference between FRS and LFC alone in the alpha-EEG was observed (Fig. 3b left and middle). In contrast, when LFC was presented through earphones and HFC was presented through speakers to the front body surface of the subjects (7 males and 8 females), the alpha-EEG power was significantly greater during FRS than during LFC alone in the later period of sound presentation (Fig. 3c left and middle). On the other hand, when the body surface of the subjects was insulated from exposure to HFC presented through speakers with a sound-insulating full-face helmet and a sound-insulating entire-body coat (5 males and 8 females), the increase in the alpha-EEG during FRS was markedly suppressed (Fig. 3d left and middle). These data indicate that the hypersonic effect was evoked only when HFC was presented to the head and/or body surface.

**Behavioral experiment.** Behavioral measurement of CLL was consistent with the results of the EEG experiments. When both LFC and HFC were presented through speakers to subjects (5 males and 5 females) (Fig. 3a right), or when LFC was presented through the earphones and HFC was presented through the speakers to subjects (5 males and 5 females) (Fig. 3c right), the subjects spontaneously adjusted the sound to a significantly greater magnitude for more comfortable listening during presentation of FRS than during presentation of LFC alone. In contrast, subjects adjusted the listening level to similar magnitudes during presentation of FRS and LFC alone when both LFC and HFC were presented through earphones (3 males and 6 females) (Fig. 3b right). When LFC and HFC were presented through earphones and speakers, respectively, with the body surface of subjects insulated from exposure to HFC (4 males and 5 females), the increase in the CLL during FRS was markedly suppressed (Fig. 3d right).

### 4. Discussion

As the first step in exploring the biological mechanism of the hypersonic effect, we considered whether there was a possibility of any biological system other than the air-conducting auditory system involved in the emergence of the hypersonic effect. We tested for the emergence of the hypersonic effect under various sound presentation conditions in which the LFC and HFC were presented over the entire body surface through speakers or selectively into the ears through earphones. As a result, it was revealed that the hypersonic effect was not induced when the HFC was presented selectively to the air-conducting auditory system, but was induced when the HFC was presented to the entire body surface, including the head but excluding the ears. This finding suggests that the emergence of the hypersonic effect can be observed only when some unknown information channel, not the air-conducting auditory nervous system, is activated.

By the simultaneous recordings of EEG and rCBF using PET(Oohashi et al. 2000)it was shown that the alpha 2 component recorded from 7 electrodes in the central and parieto-occipital regions (C3, C4, T5, Pz, T6, O1, and O2) and the averaged alpha 2 potential across these electrodes, which were used as a physiological index for the hypersonic effect in this experiment, were correlated significantly with the activity of the fundamental brain network including the upper brainstem (midbrain), hypothalamus, thalamus, precuneus, prefrontal cortex, and anterior cingulate gyrus. These brain areas, containing distinct neuronal groups that are the major source of the monoaminergic projections and opioid projections to various parts of the brain (Role and Kelly,1991), are considered as the reward-generating neuronal network. Stimulation of these regions introduces pleasurable sensations and strongly controls human behavior (Thomson,1988).

CLL was used as a measure of the perception of subtle differences in sound quality that may not be consciously recognizable or may not otherwise be easily expressed by the subjects (Cullari and Semanchick, 1989; Namba and Kuwano 1998). The basic strategy of this measurement is that subjects tend to receive preferable stimulus at a greater magnitude. It is conceivable, therefore, that the increased or decreased CLL observed in the present study may reflect change in approaching behaviors introduced by the activation or deactivation of the reward-generating system situated in the deep-lying brain structure. This explanation dovetails well with the results of the EEG experiment.

Based on the findings of the present study, it was revealed that the inaudible HFC which is richly contained in the traditional polyphony is perceived through the body surface and increase the pleasure sensation of music by strongly activating the fundamental brain network. These results also support our previously proposed model, the two-dimensional sound perception model, in which inaudible HFC modulate brain functions by activating the fundamental brain network via some non-auditory pathways when presented concurrently with audible LFC, thus evoking the hypersonic effect.

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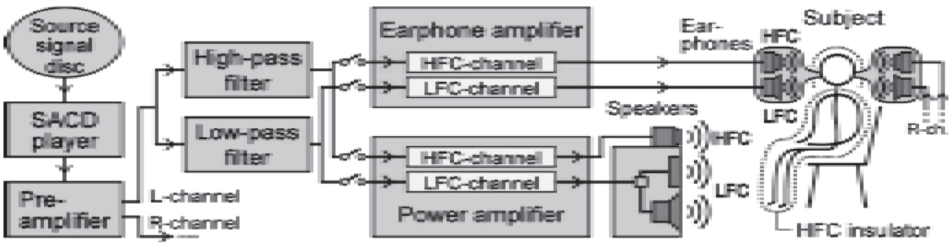
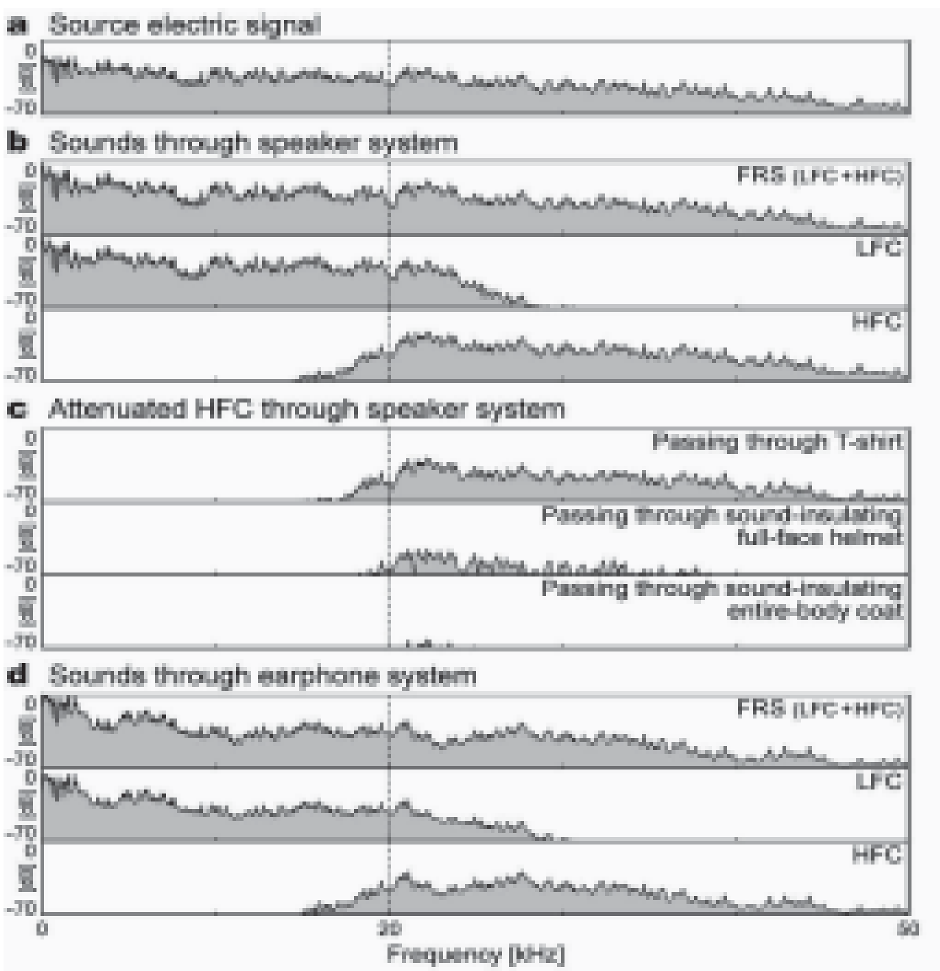
**სურათი 1.** ექსპერიმენტი ამ კვლევისთვის.
**Figure 1.**The experimental setup employed for this study.




**სურათი 2.** მთელი პერიოდის მანძილზე დათვლილი სხვადასხვა ჟღერადი მასალის ძლიერების საშუალო დიაპაზონი.
**Figure 2.** Averaged power spectra of the various sound materials calculated for the entire period of the sound presentation.



**სურათი 3.** სხვადასხვა ექსპერიმენტულ მდგომარეობაში მონაწილეთა სმენითი და ელექტროენცეფალოგრამული აქტივობის დონე.
**Figure 3.** Electroencephalographic activity and listening level adjusted by the sub jects during different experimental conditions.