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EFFECT OF HIGH-RESOLUTION AUDIO ON AUDITORY EVOKED RESPONSE

Noriyuki Tanimoto, Yuki Fukuda and Shunsuke Ishimitsu

Graduate School of Information Sciences
Hiroshima City University
3-4-1, Ozuka-Higashi, Asa-Minami-Ku, Hiroshima 731-3194, Japan
{ n-tanimoto; y-fukuda }@hfce.info.hiroshima-cu.ac.jp; ishimitu@hiroshima-cu.ac.jp

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Abstract. *High-resolution audio, which can play high-frequency sounds (above 20 kHz), has a better performance than compact disc audio. However, the human audible range is generally up to 20 kHz. Therefore, the mechanism behind humans perceiving high-resolution audio is unclear. In this study, the relationship between high-frequency sounds and human brain responses was evaluated using electroencephalography and the analysis of N1. The following two scenarios were evaluated. First, the relationship between the frequency of stimuli and N1 was examined. Pure tones of up to 90 kHz were used as stimuli. The results show that the amplitude of N1 decreases as the frequency increases and N1 becomes unobservable at frequencies above 8 kHz. Second, the relationship between complex sounds and N1 was examined using complex sounds as stimuli. The results confirmed that the high frequency of the complex sounds affects the amplitude of N1. Our results indicate that high frequency affects brain.*
Keywords: High-resolution audio, High-frequency tone, EEG, Auditory evoked response, N1

1. **Introduction.** In recent years, high-resolution audio has become popular because of the proliferation of high-resolution portable audio players. It has better performance than conventional compact disc (CD) audio and is defined as digital audio with a sampling frequency (Fs) above 48 kHz and quantization bit rate (Qb) exceeding 16 bits. A specific digital audio player, which can play high-frequency sounds (above 20 kHz) and reproduce the original sound more effectively than CD audio, is required to play high-resolution audio. A previous study confirmed that heavy music listeners are more likely to discriminate between high-resolution and CD audio than regular listeners [1]. However, since the human audible range is up to 20 kHz, the mechanism behind humans perceiving high-resolution audio is unclear.

In this study, the brain response for high-resolution audio was determined and evaluated to clarify the mechanism behind humans perceiving high-resolution audio. From previous studies, Ohashi et al. reported that the intensity of the alpha-electroencephalogram (alpha-EEG) increases with high-frequency sounds over the audible range [2]. In addition, Yamazaki et al. reported that the proportion of the alpha-EEG is affected by high-frequency sounds [3]. In these studies, the alpha waves were analyzed, but the auditory evoked response was not. Therefore, herein, N1 in auditory evoked responses was used for EEG analysis. The following two scenarios were evaluated. First, the relationship between the frequency of the pure tone and amplitude of N1 was evaluated. Second, the amplitude of N1 for complex sounds was evaluated. The results of these evaluations indicate that high-frequency sounds affect brain responses.

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This paper consists of the following four sections. Section 1 presents the introduction of the study. Section 2 presents the evaluation of the relationship between the frequency of the stimuli and amplitude of N1, as well as the details of this evaluation. Section 3 presents the evaluation of the relationship between complex sounds and the amplitude of N1, as well as the details of the evaluation. Section 4 concludes this study.

2. **Evaluation of the Relationship between the Frequency of Stimuli and Amplitude of N1.** The relationship between the frequency of the stimulus sounds and amplitude of N1 was evaluated using EEG measurements and analysis by N1. The following two experiments were performed: first, the amplitude of N1 for 16 kHz to 90 kHz pure tone was examined; second, the amplitude of N1 for 1 kHz to 16 kHz pure tone was examined.

2.1. **Procedures for analyzing auditory evoked response.** The auditory evoked response is the brain reaction that appears after listening to stimulus sounds. There are several types of auditory evoked responses; for example, P1, P2, and N1. Figure 1 shows these responses [4]. In this case, P indicates a positive reaction, N indicates a negative reaction, and 1 and 2 indicate 100 and 200 ms, respectively. In this study, N1 was selected from these reactions because it was more easily observed compared to the other reactions. The amplitude of N1 is quite small. Therefore, N1 is usually buried in noise and thus cannot be observed. It is necessary to present stimuli several times and obtain an additional mean to observe N1. Figure 2 presents an example of the measured N1. The vertical axis of the graph is negative at the top. As shown in Figure 2, the amplitude of N1 varies with the sound pressure level.

N1 was also observed in the unconscious state. Therefore, if N1 is observed in the EEG measured when listening to high-frequency sounds above the audible range, the brain responds to high-frequency sounds.

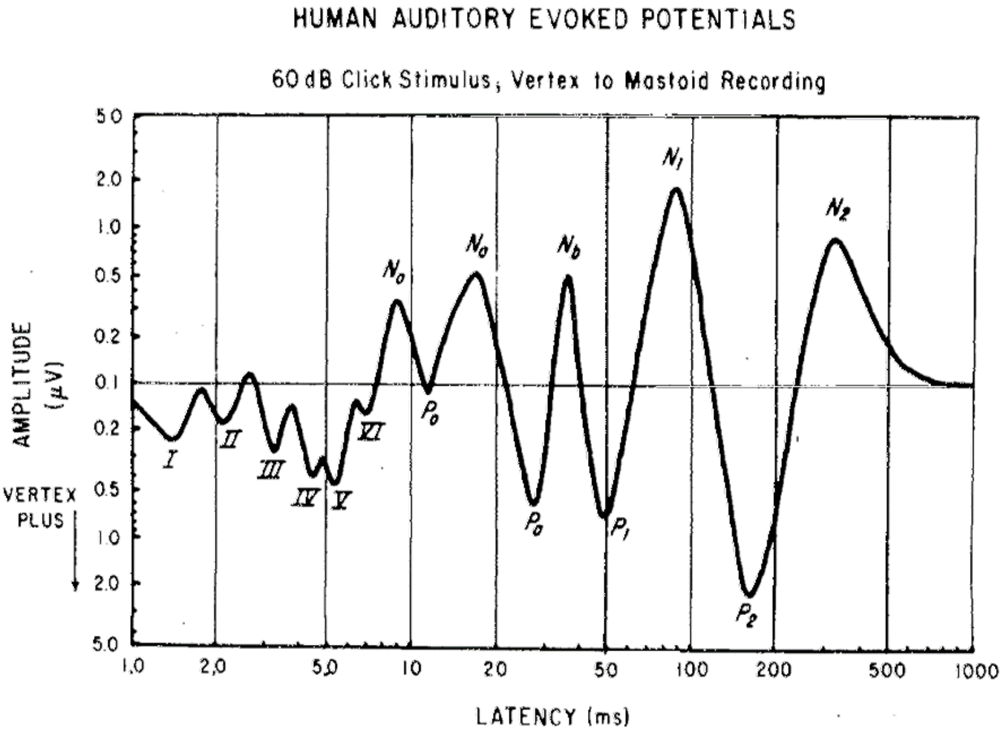

Figure 1. Schema of Picton et al.'s [4]

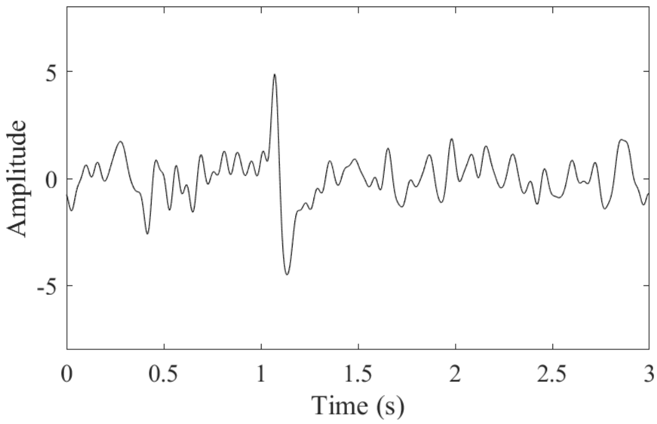

FIGURE 2. Example of a measured N1 (Stimulus was presented at 1 sec.)

2.2. Examination 1: Evaluation of the amplitude of N1 for 16 to 90 kHz pure tones.

2.2.1. *Method.* Four types of pure tones were used as stimulus sounds. The pure tone values included 16, 20, 24, and 90 kHz with 75 dB. Additionally, Fs was 192 kHz, and Qb was 16 bits. The stimuli were presented 100 times by earphones, and the EEG was measured and analyzed. The EEG was measured in the shield room using "EEG-9100" (Nihon Kohden Corporation). Before conducting this experiment, a basic experiment was performed to confirm that N1 could appear using 440 Hz pure tone. A male participant was examined for whom N1 was observed. The participant was able to recognize sounds 16 kHz pure tone.

2.2.2. *Result.* N1 was not observed in any of the stimulus sounds. At this time, although the participant could recognize a pure tone of 16 kHz, N1 for 16 kHz could not be observed. These results indicated that N1 could not be observed even if the participant could recognize the high-frequency sound.

2.3. Examination 2: Investigation of the amplitude of N1 for 1 to 16 kHz pure tones.

2.3.1. *Method.* Five types of pure tones were used as stimulus sounds. The pure tone was 1, 4, 8, 12, and 16 kHz with 75 dB. At this time, Fs was 192 kHz, and Qb was 16 bits. The experimental devices were the same as that used in the previous examination. Two participants were examined for whom N1 was observed. The participants were one male and one female, and all participants were able to recognize all stimulus sounds.

2.3.2. *Results.* The amplitude of N1 is presented in Table 1, and examples of N1 in Participant 1 are shown in Figures 3 and 4. These results confirmed that the amplitude of N1 decreased as the frequency of the stimulus sounds increased, and N1 could not be observed above 8 kHz and 16 kHz in Participants 1 and 2, respectively.

TABLE 1. Amplitude of N1 for pure tone

	Participant 1	Participant 2
440 Hz	2.1101	4.0120
1 kHz	4.7682	3.3833
4 kHz	3.5806	3.2233
8 kHz	–	1.7260
12 kHz	–	–
16 kHz	–	–

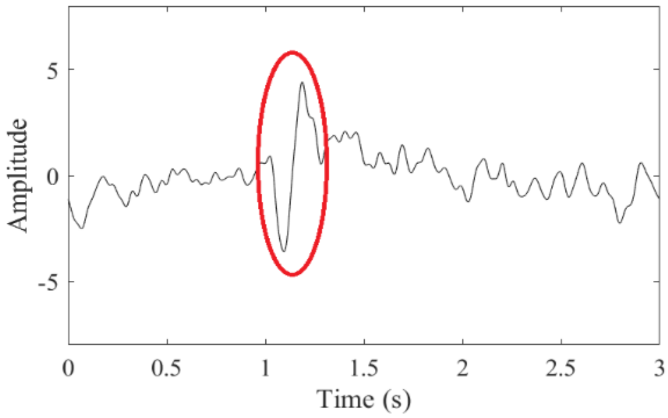

FIGURE 3. N1 of Participant 1 (4 kHz)

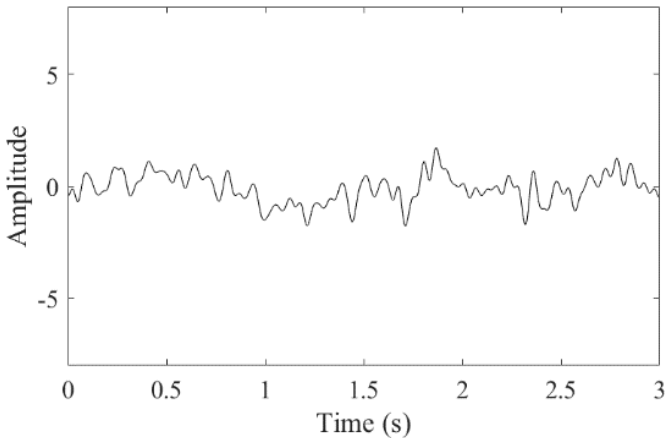

FIGURE 4. N1 of Participant 1 (8 kHz)

2.4. **Results and discussion.** The two examinations showed the following results. First, the amplitude of N1 decreases as the frequency of the stimulus sounds increases. Second, N1 could not be observed above approximately 8 kHz.

3. **Evaluation of the Relationship between Complex Sounds and Amplitude of N1.** Previous experiments confirmed that the N1 for a high-frequency pure tone could not be observed. Therefore, complex sounds were used in this evaluation, and the following two examinations were performed: first, the amplitudes of N1 for two types of complex sounds within the audible range were examined; second, the amplitudes of N1 for two types of complex sounds including high-frequency sounds above the audible range were examined.

3.1. **Evaluation of N1 during listening to complex sounds within the audible range.** Two types of complex sounds were used as stimulus sounds. The complex sounds were 4 kHz, 12 kHz, 4 kHz, and 16 kHz, Fs was 192 kHz, and Qb was 16 bits. Each participant likely has a different perception when hearing complex sounds. Therefore, the auditory thresholds at 4, 12, and 16 kHz for each participant were measured. Complex sounds were created using a 50 dB sensation level pure tone. This experiment involves two investigations. First, it was confirmed that the participants could discriminate between two types of complex sounds. Second, the amplitude of N1 for complex sounds was examined.

3.2. Subjective auditory impression test.

3.2.1. *Method.* Two types of complex sounds were created for each participant. In this examination, the double-blind test (ABX test) was used to confirm that participants could distinguish between complex sounds. In the ABX test, two types of complex sounds were randomly stored in stimulus A, stimulus B, and stimulus X stored either stimulus A or stimulus B. In this method, neither the participant nor the examiner knew type of complex sounds stored in each of the stimuli. The participant discriminated whether stimulus X was stimulus A or stimulus B. In this test, participants listened to all stimuli repeatedly until they could interpret the stimulus. Table 2 presents the experimental environment.

Table 2. Experimental environment of the ABX test

Number of participants	5
Gender ratio	Male: 3; Female: 2
Presentation environment	Anechoic room, earphone
Number of trials	10

3.2.2. *Results and discussion.* Table 3 presents the results of the ABX test for each participant. The test used an upper binomial test. The significance level was 0.05. The data shown in Table 3 confirmed that all participants could discriminate between the two types of complex sounds.

Table 3. Results of the ABX test

No.	**Try**	**Success**	***p*-value ($^*p < 0.05$)**
1	10	10	$< 0.001^*$
2	10	8	0.011^*
3	10	10	$< 0.001^*$
4	10	10	$< 0.001^*$
5	10	10	$< 0.001^*$
All	50	48	$< 0.001^*$

3.3. EEG measurement experiment.

3.3.1. *Method.* In this experiment, the participants of the ABX test were examined. Stimulus sounds were the same as those used in the ABX test. The stimuli were presented 100 times by the earphones. The EEG for the stimulus sounds was measured in the shield room and analyzed. Further, N1 could be observed by all participants.

3.3.2. *Results and discussion.* Figure 5 shows the N1 of Participant 1, and Table 4 presents the amplitude of N1 for all participants. Consequently, there was no correlation between the amplitude of N1 and frequency of the complex tones. However, the amplitude of N1 changed depending on the high frequency in the complex sound.

3.4. Evaluation of N1 for complex sounds containing high-frequencies above the audible range.

3.4.1. *Method.* The stimulus sounds used were 4 kHz pure tone, 4 kHz and 20 kHz, and 4 kHz and 24 kHz complex sound; Fs was 192 kHz, and Qb was 16 bits. The stimuli were presented 100 times by the earphones. The EEG for the stimulus sounds was measured in the shield room and analyzed. Four participants were examined for whom N1 was observed. The participants included two males and two females.

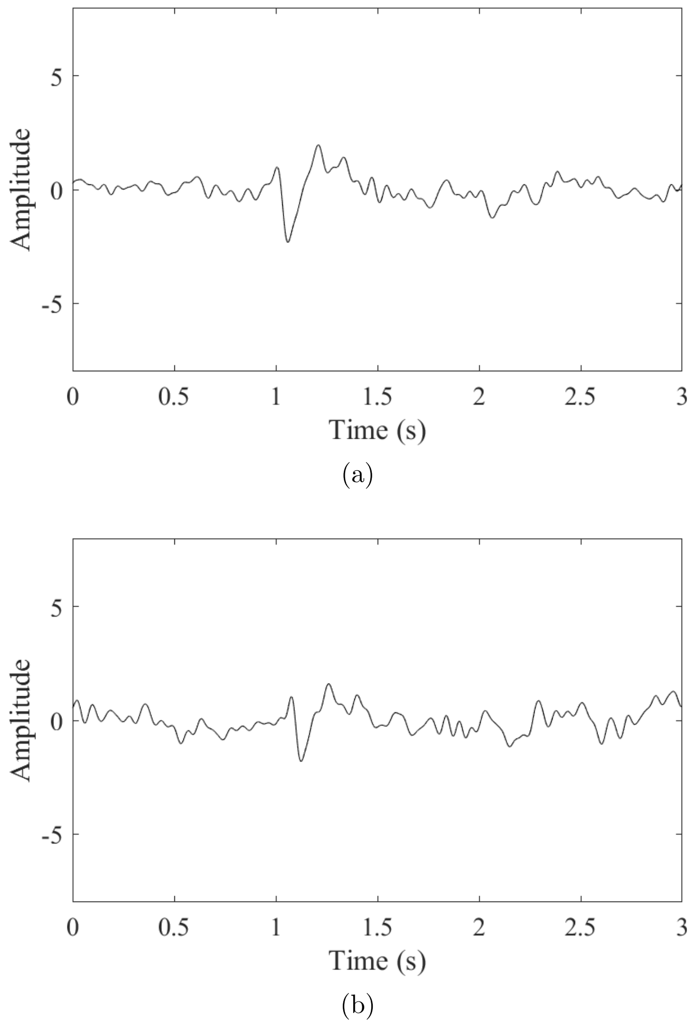

FIGURE 5. Measured N1 of Participant 1: (a) 4 kHz & 12 kHz; (b) 4 kHz & 16 kHz

TABLE 4. Amplitude of N1 for complex sounds

	4 kHz & 12 kHz	4 kHz & 16 kHz
Participant 1	2.3401	1.8195
Participant 2	2.4311	1.8770
Participant 3	1.0580	2.0597
Participant 4	3.0020	2.8160
Participant 5	2.8415	2.9576

3.4.2. *Results and discussion.* Table 5 lists the amplitude values of N1 for complex sounds containing high frequency above the audible range. Table 5 shows that, in three out of four participants, the amplitude of N1 for complex sounds was larger than that of the pure tone. The amplitude of N1 increases as the sound pressure level of the stimulus increases. From these results, it is suggested that the complex tone was louder than the pure tone in the auditory impression.

4. **Conclusion.** In this study, the following two points were evaluated as the effects of high-frequency sounds above the audible range on N1. First, the relationship between the frequency of pure tones and amplitude of N1 was examined. The results revealed that the amplitude of N1 decreased as the frequency of the stimulus sounds increased,

Table 5. Amplitude of N1 for complex sounds containing high frequency (above the audible range)

	4 kHz	4 kHz & 20 kHz	4 kHz & 24 kHz
Participant 1	1.6908	2.686	2.0536
Participant 2	2.5808	2.3704	2.5234
Participant 3	–	2.9245	–
Participant 4	1.6118	2.3972	1.1680

and N1 could not be observed above approximately 8 kHz. Second, the amplitude of N1 for complex sounds was evaluated. The results confirmed that the amplitude of N1 was changed depending on the high frequency in the complex sound, and we deduced that the complex tone was louder than the pure tone in the auditory impression. Our results indicate that high frequency affects brain responses.

REFERENCES

[1] R. Yamamoto et al., Evaluation of sound quality of high resolution audio, *The Japanese Journal of the Institute of Industrial Applications Engineers*, vol.1, no.2, pp.52-57, 2013.

[2] T. Ohashi et al., Inaudible high-frequency sounds affect brain activity: Hypersonic effect, *J. Neurophysiol.*, vol.83, no.6, pp.3548-3558, 2000.

[3] K. Yamazaki et al., On the physiological effect of ultrasound included in the mountain stream sound, *Acoustical Socienty of Japan*, vol.64, no.9, pp.545-550, 2008.

[4] T. W. Picton et al., Human auditory evoked potentials, *Electroenceph. Clin. Neurophysiol.*, vol.36, pp.179-190, 1974.

[5] A. Shukunami et al., Uncomfortable loudness level on auditory-evoked responses and spontaneous activity in the auditory pathway, *Proc. of the 45th International Congress and Exposition on Noise Control Engineering (Inter-Noise2016)*, Hamburg, Germany, pp.4514-4519, 2016.

[6] Y. Fukuda and S. Ishimitsu, Differentiating between high-resolution audio with impulse signals, *ICIC Express Letters, Part B: Applications*, vol.11, no.7, pp.655-660, 2020.

[7] E. Miyasaka, Consideration on perceptual effects of sounds with ultra high frequencies, *Acoustical Society of Japan*, vol.55, no.8, pp.569-572, 1999.

[8] Y. Suo, K. Ishibashi and S. Watanuki, Effects of inaudible high-frequency sounds on spontaneous electroencephalogram, *Japan Society of Physiological Anthropology*, vol.9, no.4, pp.157-161, 2004.

[9] S. Ishimitsu et al., A study on the relationship between auditory impression and cerebral cortex activity for the listening car acceleration engine sound, *Society of Measurement and Auto Control Engineers*, vol.49, no.3, pp.394-401, 2013.