An objective measurement of TMTF by using envelope of cABR

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The temporal modulation transfer function (TMTF) has been proposed as a means for estimating temporal resolution. There are several problems that need to be overcome in the measurement of TMTF. For example, the threshold may be misjudged due to a lack of concentration by the measurement person as many judgment efforts are required, and the measurement task may be misunderstood due to limited language recognition ability. An appropriate objective measurement method is needed to avoid interference in the measurement process. We focused on cABR (auditory brainstem response to complex sounds) for objective measurement of TMTF because cABR faithfully represents several temporal acoustical features, including the envelope component of complex sound stimuli. The results for the temporal characteristic of cABR using SAM noise as complex sound stimuli can be used as an objective measurement of TMTF because the degree of cABR fluctuation was found to be related to the modulation depth of the stimuli and might be related to the modulation detection thresholds derived from TMTF.

INTRODUCTION

Some hearing-impaired people have reduced temporal resolution. Zeng *et al.* (1999) said that it is difficult for listeners with reduced temporal resolution to understand speech because speech recognition depends on the detection of temporal cues. The temporal modulation transfer function (TMTF) was proposed as a means for measuring the ability to detect temporal resolution (Viemeister, 1979). The TMTF means the threshold for detecting the amplitude modulation depth as a function of modulation frequency. Bacon and Viemeister (1985) reported that the modulation detection thresholds for hearing-impaired listeners were higher than those for normal-hearing listeners. Use of the TMTF in clinical diagnosis could make it possible to describe the auditory characteristics of hearing impaired patients more precisely, and this information might be useful in the fitting of hearing aids and be applicable to new

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hearing instrument algorithms.

However, application of the TMTF to clinical diagnosis is difficult because its measurement requires seven modulation detection thresholds. Its measurement thus usually requires many subjective trials that take about 40 minutes in total. A simplified TMTF measurement method (S-TMTF), which takes about 10 minutes, was proposed (Morimoto *et al.*, 2013) to reduce the measurement time. Using S-TMTF reduces the total measurement time by about 75 %.

Even though the time has been greatly reduced, much effort is still required to make the many judgments required to measure the modulation detection thresholds. The effort required to make these judgments may affect the measurement person's concentration, causing him or her to make some misjudgments. In addition, it is difficult to measure the TMTF for infants and foreign nationals due to their inability to comprehend the task accurately. This means that an appropriate objective measurement, such as auditory steady-state response or auditory brainstem response, which are established as pure tone audiometry for objective measurement, is needed to avoid interference in the measurement process.

To establish an objective measurement of TMTF, we focused on cABR (auditory brainstem response to complex sounds) as it faithfully represents several acoustical features, including the envelope component fluctuation of complex sound stimuli (Aiken and Picton, 2008). In this paper, two hypotheses are presented and validated through the measurement of cABR. This validation means that it may be possible to estimate the threshold of temporal resolution by using cABR.

Hypothesis 1 : The degree of fluctuation in cABR varies with the modulation depth of the stimuli.

Hypothesis 2 : The fluctuation in cABR disappears as the modulation depth of the stimuli approaches the threshold for the measurement subject.

TEMPORAL MODULATION TRANSFER FUNCTION

Generally, a sinusoidal amplitude modulated broadband noise (SAM noise) is used in the measurement of TMTF to estimate the modulation detection thresholds for each modulation frequency. Figure 1 shows an actual experimental data of TMTF for normal-hearing and hearing-impaired listeners. The modulation detection threshold is often measured using modulation frequencies of 8, 16, 32, 64, 128, 256, and 512 Hz (Eddins, 1993; Shen and Richards, 2013). These thresholds are expressed in decibels as $20\log_{10}(m)$, where m is the modulation depth parameter. If m equals 1.0, the signal is 100%. If m is 0.5 or 0.1, the modulation depth is expressed as -6 dB (50%) or -20 dB (10%), respectively. The modulation detection thresholds are almost constant from a modulation frequency of 8 Hz to about 50 Hz. Above 50 Hz, the thresholds increase at a rate of about 3 dB per octave of modulation frequency (Bacon and Viemeister, 1985).

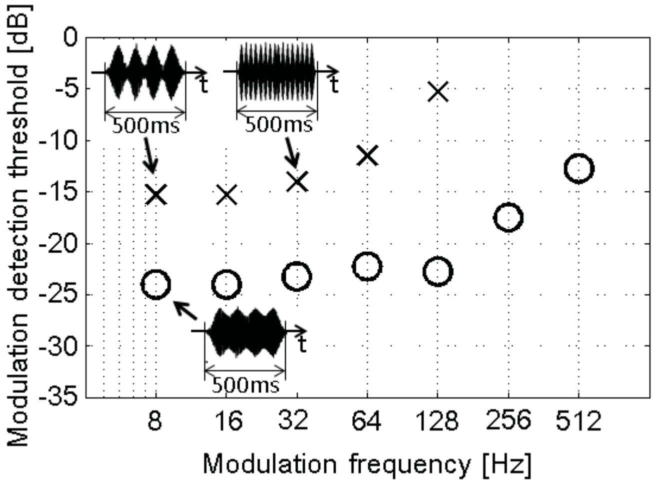

Fig. 1: Example of TMTF measurement data. Circles represent results for normal-hearing listeners, and x-marks represent results for hearing-impaired listeners. Waveforms show an image of sinusoidal amplitude modulated noise for each graph space.

The modulation detection thresholds for hearing-impaired listeners increase more than that of normal-hearing ones, as shown in Fig. 1. This difference reflects the degradation in their ability to recognize temporal resolution (Zeng *et al.*, 1999, 2005). Therefore, it is difficult for hearing-impaired listeners to measure the modulation detection threshold at high modulation frequencies. In contrast, it is easy for them to detect the fluctuation from 8 to 50 Hz because the modulation detection thresholds in this range remain low, as shown in Fig. 1. The modulation detection threshold should thus be measured at 8 Hz because it can be measured even if the subject is hearing impaired.

EXPERIMENT

SAM noises in our cABR experiments were also used as stimuli in the measurement of TMTF in order to validate our two hypotheses. The measured cABR was compared with the characteristics of the stimuli.

Subjects

Seven normal-hearing subjects participated. They ranged in age from 24 to 31 years. The stimuli were presented to their right ear. The subjects had hearing thresholds better than 15 dB HL in the tested ear at all audiometric frequencies from 125 to 8000 Hz.

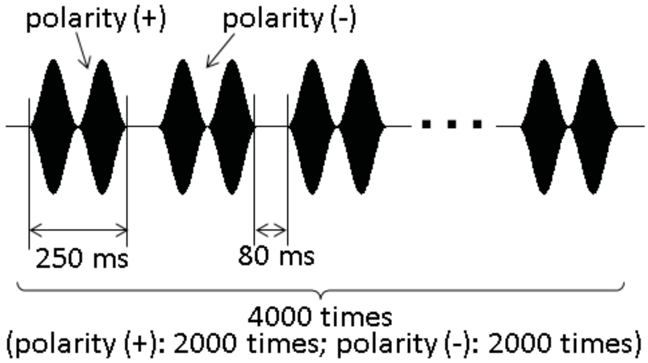

Fig. 2: Example of stimulus waveform with 0-dB modulation depth.

Stimuli and equipment

The stimuli were three SAM noises. The carriers were maximum length sequence (Mseq) noises. The modulation frequency was 8 Hz because it is easy to detect fluctuations at 8 Hz, as mentioned above. The noise duration was 250 ms, including 2.0-ms rise/fall cosine ramps, and the inter stimulus interval (ISI) was 80 ms. The stimuli consisted of alternating condensation and rarefaction polarities. The modulation indices of the stimuli were 0, -5, and -10 dB. A stimulus waveform example with a 0-dB modulation depth is shown in Fig. 2.

The stimuli were generated and presented via MATLAB and delivered through a 16-bit digital-to-analog converter (OCTA-CAPTURE, Roland) and headphone amplifier (A20, Beyerdynamic). The stimuli were presented to the test ear through an insert earphone (ER-3A, Etymotic Research) at an intensity of 80 dB SPL.

Recording and data analysis of cABR

Continuous electroencephalographic (EEG) signals were acquired with a data acquisition system (MP150, Biopac Systems) from Cz-to-ipsilateral earlobe with the forehead as the ground and digitized at 20,000 Hz. All recordings were made with electrodes (Cz and earlobe: EL258S; forehead: EL258; Biopac Systems) (impedance < 5 kΩ). A bandpass filter (from 70 to 2000 Hz) was applied to the recordings to isolate the brain-stem response frequencies. The EEG signals were then divided into 330-ms epochs (40-ms pre-stimulus onset to 290-ms post-stimulus onset). An artifact criterion of ± 20 μV was applied to reject epochs that contained myogenic artifacts.

The stimuli were presented in alternating polarities, allowing for the creation of responses comprised of both the added and the subtracted of the two polarities. When the added response was created, the envelope component of the response was enhanced; conversely, when the subtracted response was created, the temporal fine structure component was enhanced (Aiken and Picton, 2008). To investigate the fluctuations in the cABR, we used added responses with two polarities. We calculated

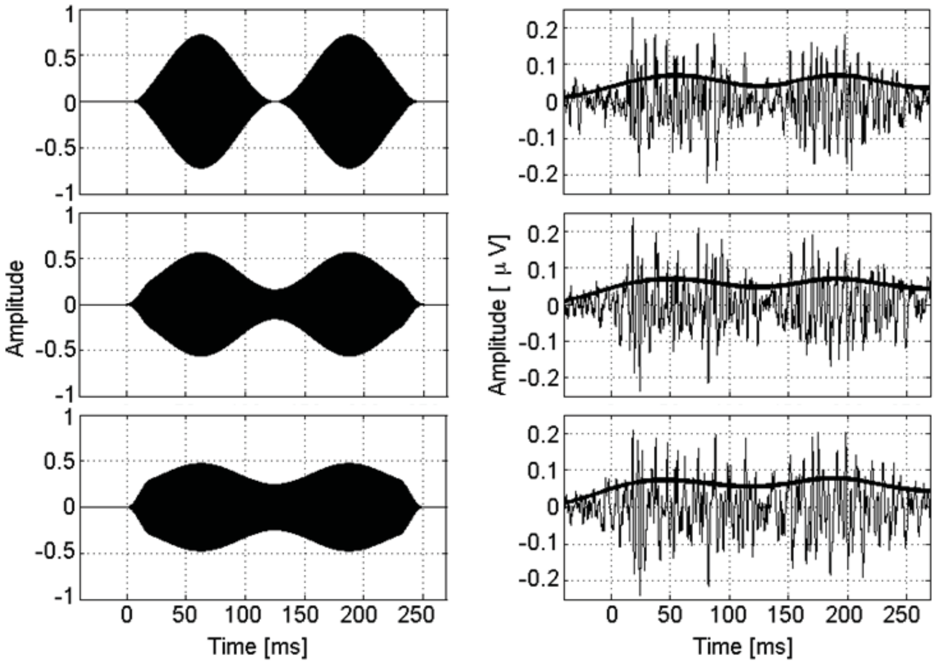

Fig. 3: Example of cABR measurements. Upper, middle, and lower panels on left show waveforms of SAM noise for modulation depths of 0, −5, and −10 dB, respectively. Those on right show added responses for modulation depths of 0, −5, and −10 dB, respectively. In the right panels, thin lines represent added responses and heavy lines represent the envelope of added responses.

the envelope component of the added response by using the Hilbert transform and a lowpass filter with a cutoff frequency of 10 Hz. The difference between the minimal (from 62.5- to 187.5-ms post-stimulus onset) and maximal (from 125- to 250-ms post-stimulus onset) of envelope component of the added response was used as the degree of fluctuation.

RESULTS

Figure 3 shows an example of our cABR measurements. The figures on the left show the waveforms for each stimulus (modulation depths of 0, −5, −10 dB), and the ones on the right shown the added responses from the cABR. The degree of fluctuation in the added responses attenuated as the modulation depth decreased. The transition in the degree of fluctuation for each subject, shown in Fig. 4, was confirmed in order to investigate the attenuation tendency. The heavy solid line represents the average degree of fluctuation, and the error bars represent the standard deviation for each modulation depth. The average of degree of fluctuation exhibited a similar attenuation tendency. In addition, the degree of fluctuation converged to a certain value at a modulation depth of approximately −10 dB.

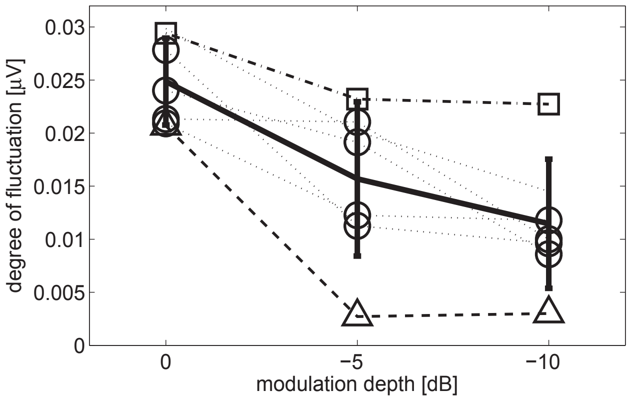

Fig. 4: Transition in degree of fluctuation as function of modulation depth for each subject and average. Dotted lines, dash-dot line, and dashed line show results for each subject. Squares and dash-dot line represent results for the subject with the largest fluctuation, and triangles and dashed line represent results for the subject with the smallest fluctuation at modulation depths of −5 and −10 dB. Heavy solid line represents average of degree of fluctuation, and error bars represent standard deviations for each modulation depth.

DISCUSSION

The degree of fluctuation was attenuated as the modulation depth decreased for most of the subjects. In addition, the degree of fluctuation converged to a certain value at a modulation depth of approximately -10 dB. These results support hypothesis 1, i.e., the envelope component of the added response of cABRs from two polarity stimuli varies depending on the fluctuation of the stimuli.

Considering hypothesis 2, if the fluctuation in cABR disappears as the modulation depth of the stimuli approaches a modulation detection threshold, the threshold can be estimated from the cABR. Therefore, the modulation detection thresholds derived

Subject	Modulation detection threshold [dB]	Marker used in Fig. 4
A	−27.5	□
B	−26.5	○
C	−26.3	○
D	−25.8	○
E	−25.3	○
F	−25.2	○
G	−23.8	△

Table 1: Modulation detection thresholds at modulation frequency of 8 Hz.

from the TMTF measurement at a modulation frequency of 8 Hz were measured for comparison with the degree of fluctuation in cABR. The measured modulation detection thresholds are shown in Table 1.

The subject with the largest fluctuation had the highest threshold while the one with the smallest fluctuation had the lowest threshold. This indicates that the degree of fluctuation in cABR is related to the threshold derived from the TMTF measurement. It might therefore be possible to estimate the modulation detection threshold for each subject from the convergent value, although there was some difference between the threshold and the convergent value derived from our cABR measurements.

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