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Research article

Elderly listeners with low intelligibility scores under reverberation show degraded subcortical representation of reverberant speech

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HIGHLIGHTS

- Auditory brainstem responses to anechoic and reverberant speech sounds were obtained from 28 elderly listeners (>62 y).
- Listeners with low word intelligibility of reverberant speech showed degraded encoding information of reverberant speech.
- The findings provide initial evidence of subcortical processing deficits in elderly listeners with difficulty in understanding reverberant speech.

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ABSTRACT

In order to elucidate why many elderly listeners have difficulty understanding speech under reverberation, we investigated the relationship between word intelligibility and auditory brainstem responses (ABRs) in 28 elderly listeners. We hypothesized that the elderly listeners with low word intelligibility scores under reverberation would show degraded subcortical encoding information of reverberant speech as expressed in their ABRs towards a reverberant /da/ syllable. The participants were divided into two groups (top and bottom performance groups) according to their word intelligibility scores for anechoic and reverberant words, and ABR characteristics between groups were compared. We found that correlation coefficients between responses to anechoic and reverberant /da/ were lower in the bottom performance group than in the top performance group. This result suggests that degraded neural representation toward information of reverberant speech may account for lower intelligibility of reverberant speech in elderly listeners.

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1. Introduction

Reverberation and noise often exist in our daily listening environment. Many elderly listeners, even those with normal hearing, have difficulty understanding speech under reverberation and noise [1,2]. Degraded neural representation of acoustic sounds in elderly listeners is thought to be one of the factors underlying this difficulty understanding speech in such conditions, e.g., due to decreased neural inhibition [3], and temporal jitter [4].

In order to gain insight into the neural representation of speech sounds in noise, some studies have focused on the characteristics of auditory brainstem responses to speech (speech ABRs). The speech ABR is considered an objective indicator of speech processing in the brainstem, since it reflects speech-specific information, i.e., fundamental frequency and vowel formants [5,6]. Anderson et al. reported that the speech ABRs of elderly listeners with low speech-in-noise (SIN) perception had relatively small amplitudes in response to the fundamental frequency (F_0) of a speech stimulus, and lower correlations between responses in quiet and in noise compared to elderly listeners with high SIN perception [7]. These results indicate that elderly listeners' degraded neural representations of the morphology of a speech sound and its F_0 underlie difficulty understanding speech in noise.

Besides the ABR studies on speech perception in noise, however, few studies have concentrated on speech ABRs under reverberation. Reverberation is the continued movement of sound pressure waves as the result of repeated reflections after the initiating stimulus has stopped [8]. Reverberation, therefore, alters the acoustic waveform by smearing dynamic changes in the fine structure over time and reducing the “peakiness” of the waveform's temporal

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envelope [9]. The relation between speech and reverberation is different from that between speech and noise. Whereas speech and noise are generally thought of as arising from independent sources, speech and reverberation are strongly correlated, since the speech sounds themselves overlap with subsequent speech sounds. Therefore, the F_0 of speech, which is thought to be a cue to discriminate one speaker from other speakers and other sounds, might be useful for understanding speech under noise, but might be useless for understanding speech under reverberation.

Recently, we measured word intelligibility under reverberation and the ABRs to a non-reverberant syllable /da/ in elderly listeners. The measurements showed that word intelligibility under reverberation was related to the elderly listeners' ability to encode the temporal fine structure of speech, especially around the frequency of 500 Hz [10]. There was, however, no significant relationship between the elderly listeners' word intelligibility under reverberation and the amplitudes in the ABRs response to the F_0 of a non-reverberant speech stimulus. This result suggests that the factors affecting the difficulty understanding speech under reverberation might be different from those affecting the understanding of speech in noise as regards frequency bands in the speech signal. The effects of *actual* reverberation on speech ABRs in elderly listeners, however, have not been measured yet.

In this study, we measured the ABRs to an anechoic syllable /da/ and a reverberant syllable /da/ in elderly listeners. Furthermore, we assessed the intelligibility of the elderly listeners of words presented under reverberation. Our purpose was to investigate the effects of reverberation on the speech ABRs of the syllable /da/ and how the reverberant speech ABR characteristics would relate to the word intelligibility under reverberation. We hypothesized that the elderly listeners with low word intelligibility scores under reverberation would show degraded subcortical encoding information of reverberant speech.

2. Material and methods

2.1. Participants

Twenty-eight elderly females participated in this study [62–73 years; mean 67.2; standard deviation (SD) 3.7]. Two additional participants were recruited but were excluded from this study because of high artifact content in their electroencephalogram. It has been reported that the amplitudes of the speech ABRs for females are larger than for males [11]. Because we focused on the relationship between speech recognition and neural representation of speech sounds, we carried out the experiment only with a single, coherent participant group – females who showed robust ABR responses. Twenty-four of the 28 participants also participated in our previous study [10].

All participants had thresholds from 250 to 4000 Hz that were ≤30 dB HL, and thresholds at 8000 Hz of ≤50 dB HL at the right ear. The pure tone average differences between the left and right ear were ≤10 dB. All participants had normal click-evoked ABR latencies (wave V ≤ 6.1 ms), measured by a 100-μs click stimulus represented at 101.9 dB peSPL at a rate of 11.1/s). All participants gave written informed consent in accordance with the Institutional Review Board of Kyushu University.

2.2. Word intelligibility task

We obtained word intelligibility scores using the same procedure as in our previous study [10]. The words were four morae selected from Japanese familiarity-controlled word lists 2007 (FW07) [12]. The mora is a unit with which Japanese speakers segment speech streams [13]. We prepared words in four reverberant conditions with reverberation time (RT) of 0 s (anechoic), 0.5 s, 1.0 s and 1.5 s. The RT is defined as the time required for sound to decay sixty decibels from its initial sound level. Participants listened to twenty words per reverberant condition at the right ear. The word intelligibility score was the percentage of the test words for which all four morae were written down correctly.

2.3. Speech ABR measurement

2.3.1. Stimulus and presentation

We measured the speech ABRs in two condition, an anechoic condition (RT = 0 s) and a reverberant condition (RT = 0.5 s). A syllable /da/ with five formants was used to obtain the speech ABRs in the anechoic condition (the 'anechoic syllable'). The duration of the anechoic syllable /da/ was 170 ms, consisting of a formant transition period (0–50 ms) and a steady-state period (50–170 ms). The initial 10-ms in the formant transition period was an onset burst, which was centered at frequencies around F_4 (3300 Hz) and F_5 (3750 Hz). The formant transition period after the onset burst (10–50 ms) comprised of a linearly rising F_1 (400–720 Hz), a linearly falling F_2 (1700–1240 Hz) and F_3 (2580–2500 Hz), and a flat F_4 (3300 Hz) and F_5 (3750 Hz). During the steady-state period (50–170 ms), formant frequencies were held constant and consisted of F_1 (720 Hz), F_2 (1240 Hz), F_3 (2500 Hz), F_4 (3300 Hz) and F_5 (3750 Hz). The period after the onset burst period (10–170 ms) remained constant at the F_0 of 100 Hz. The reverberant syllable /da/ was created by convolving the anechoic syllable /da/ with an impulse response with an RT of 0.5 s as used in the word intelligibility task. The duration of the reverberant syllable was set at 170 ms, similar to the anechoic /da/, by removing the extended portion of the reverberation and by shaping the offset with a 20-ms fall time (cosine-curved). Following this, root-mean-squares of the anechoic and reverberant /da/ were set same. The anechoic and reverberant syllable /da/ are shown in Fig. 1.

An AV tachistoscope (IS-703, Iwatsu) delivered the syllables at random, with an inter-stimulus interval of 60 ms. Each stimulus with condensation and rarefaction polarities was presented 2000 times, making a total of 4000 times. The anechoic and reverberant syllable /da/ were presented at 70 dB SPL to the right ear through an amplifier (TA-DE 590, SONY) and a magnetically-shielded, inserted earphone (ER-3A, Etymotic Research).

2.3.2. Recording parameters

The speech ABRs were obtained using an electroencephalography apparatus (EEG 1200, NIHON KOHDEN) in continuous mode. Responses were obtained using Ag-AgCl disc electrodes from Cz referenced to the right earlobe, with the forehead as ground, were digitized at 10 kHz. Electrode impedances were maintained below 5 kΩ. The continuous recordings were filtered between 70 and 2000 Hz, and artifact rejected (±35 μV) with Matlab version 7.7 (The MathWorks, Inc.).

2.4. Data analysis

Two average responses were calculated for subsequent analyses, similar to earlier studies [5,10,14]. First, an equal number of responses to each polarity was added and divided by the total number of responses to minimize the influence of cochlear microphonic and stimulus artifacts on the response [15,16]. The average responses calculated with the addition method were called "ADD responses". Second, responses to the inverted stimulus were subtracted from an equal number of responses to the original stimulus and divided by the total number of responses. These average responses calculated with the subtraction method were called "SUB responses". It has been said that the ADD responses relate to the stimulus envelope, and the SUB responses to temporal fine struc-

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