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Correlations between word intelligibility under reverberation and speech auditory brainstem responses in elderly listeners

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HIGHLIGHTS

- Auditory brainstem responses to speech sounds (speech ABRs) and word intelligibility scores for reverberant words were obtained from 30 elderly listeners (>61 y).
- Significant correlations were found between components of the speech ABRs and the word intelligibility scores.
- Components of speech ABRs might objectively predict word intelligibility under reverberation in elderly listeners.

ABSTRACT

Objective: To investigate the relationship between speech auditory brainstem responses (speech ABRs) and word intelligibility under reverberation in elderly adults.
Methods: Word intelligibility for words under four reverberation times (RTs) of 0, 0.5, 1.0, 1.5 s, and speech ABRs to the speech syllable/da/ were obtained from 30 elderly listeners. Root mean square (RMS) amplitudes and discrete Fourier transform (DFT) amplitudes were calculated for ADD and SUB responses in the speech ABRs.
Results: No significant correlations were found between the word intelligibility scores under reverberation and the ADD response components. However, in the SUB responses we found that the DFT amplitudes associated with $H_{4\text{-SUB}}$, $H_{5\text{-SUB}}$, $H_{8\text{-SUB}}$, $H_{9\text{-SUB}}$ and $H_{10\text{-SUB}}$ significantly correlated with the word intelligibility scores for words under reverberation. With Bonferroni correction, the DFT amplitudes for $H_{5\text{-SUB}}$ and the intelligibility scores for words with the RT of 0.5 s and 1.5 s were significant.
Conclusions: Word intelligibility under reverberation in elderly listeners is related to their ability to encode the temporal fine structure of speech.
Significance: The results expand knowledge about subcortical responses of elderly listeners in daily-life listening situations. The SUB responses of speech ABR could be useful as an objective indicator to predict word intelligibility under reverberation.

1. Introduction

It is well known that many elderly listeners have difficulty understanding speech, particularly under background noise and/or reverberation (Nábĺek, 1988; Kim et al., 2006; Katz et al., 2009). Although loss of hearing sensitivity often causes a difficulty in understanding speech (Humes, 1996), even elderly listeners with normal hearing have more difficulty understanding speech under degraded listening conditions than younger listeners (Dubno et al., 1984; Gordon-Salant and Fitzgibbons, 1993; Halling and Humes, 2000). It is therefore impossible to explain speech intelligibility problems in elderly listeners only on basis of hearing loss itself. Various studies have been performed to investigate other deficiencies in the aging speech perception system. For example, at cortical levels of the aging auditory pathway, it has been shown that aging alters temporal properties of auditory cortical responses to speech sounds (Tremblay and Piskosz, 2002;

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Harkrider et al., 2005). Furthermore, in a study with functional magnetic resonance imaging, elderly listeners showed reduced activation of the auditory cortex during selective listening to speech, especially in noise (Hwang et al., 2007). Age-related changes at subcortical levels have been investigated with auditory brainstem responses to speech sounds (speech ABRs). The speech ABR includes speech-specific information, i.e., fundamental frequency and vowel formants (Greenberg, 1980), and is made up of two separate elements, the onset response and the frequency-following response (FFR). The FFR is an ensemble response reflecting phase-locked activity from multiple generator sites within the auditory brainstem (Marsh et al., 1974; Chandrasekaran and Kraus, 2010). Studies with elderly and young listeners showed that elderly listeners had delayed speech ABRs to offsets of speech sounds (Vander Werff and Burns, 2011), and to the rapidly changing formant transition (Anderson et al., 2012).

The speech ABR has also been used to study subcortical responses of various subject groups under degraded conditions. Studies with children with various language-based learning impairments, for example, showed that speech ABR components could reflect the children's listening abilities of speech under noise (King et al., 2002; Song et al., 2006; Anderson et al., 2010a). Children with poor speech perception in noise showed impaired encoding of the fundamental frequency and the second harmonic (Anderson et al., 2010b). Studies with adult listeners further reported that adults with poor speech perception in noise demonstrated greater susceptibility to effects of noise on the neural encoding of the fundamental frequency (Song et al., 2011). Elderly listeners in the bottom speech-in-noise perception group had reduced speech ABR to fundamental frequency of speech compared with elderly listeners in the top speech-in-noise perception group (Anderson et al., 2011). These studies show that speech ABR is thus of potential use as an objective means to measure subcortical speech processing under degraded listening conditions.

The research so far has mainly focused on speech ABR correlates of listeners' intelligibility of speech under noise. There is, however, usually not only noise but also reverberation in daily-life listening environments, such as in conversation rooms and station buildings. In acoustic terms, reverberation is the continued movement of sound pressure waves as the result of repeated reflections after the initiating stimulus has stopped (Delk, 1991). Reverberation alters the acoustic waveform by smearing dynamic changes in the temporal structure of speech over time (Sayles and Winter, 2008). Many studies have shown that reverberation declines speech intelligibility (Nábĕlek and Robinson, 1982; Nábĕlek and Letowski, 1988; Nábĕlek et al., 1989), especially in elderly listeners (Nábĕlek and Letowski, 1985; Nábĕlek and Dagenais, 1986; Nábĕlek, 1988). However, it is not yet known whether speech ABR can reflect listeners' abilities to process reverberant speech. In the present study, we investigated the relationship between speech ABRs and word intelligibility under reverberation in elderly adults, and hypothesize that elderly listeners with lower intelligibility under reverberation will show degraded subcortical encoding information for speech stimuli.

2. Methods

2.1. Participants

Participants were 30 elderly females, who had Japanese as their native language [ages 61–73 years; mean 66.9; standard deviation (SD) 3.4]. Only female listeners were employed in this study, because significant differences between males and females in the latency of the click-evoked response and spectral magnitude of speech ABRs have been reported (Burkard et al., 2007; Krizman et al., 2012). We obtained written informed consent from all participants, and all experiments were approved by the Institutional Review Board of Kyushu University.

Audiometric air conduction thresholds were obtained at octave frequencies from 125 to 8000 Hz. In all participants, pure tone averages (calculated as the average threshold from 500 to 2000 Hz) at the right ear were ⩽30 dB HL (see Fig. 1). Individual thresholds at or below 4000 Hz were ⩽30 dB HL, and thresholds at 8000 Hz were ⩽50 dB HL. The pure tone average differences between the left and right ear were ⩽10 dB. None of the participants had a history of neurological disorders and all had normal click-evoked ABRs (defined as a wave V latency ⩽6.1 ms at 101.9 dB peSPL, presented at a rate of 11.1/s).

2.2. Word intelligibility performance task

2.2.1. Stimuli

Test words were selected from Japanese familiarity-controlled word lists 2007 (FW07), within a maximum familiarity range of 5.5–7.0 (Kondo et al., 2008). One list consisted of 20 words, spoken by a male narrator. Sixteen lists were used for test trials and one list was used for a practice trial. Each word consisted of four morae. The mora is a unit with which Japanese speakers segment speech streams (Otake et al., 1993). The test words were convolved with three impulse responses chosen from the environment/architectural acoustics "SMILE 2004" database (Architectural institute of Japan, 2004). The reverberation time (RT) of the impulse responses was set at 0.5, 1.0 and 1.5 s. The impulse responses were composed of a direct sound followed by a reverberant decay. The reverberant decay started 50 ms after the direct sound. Fig. 2 shows the impulse response for an RT of 0.5 s. Only direct sound was convolved for the test words in an anechoic condition (RT = 0 s).

2.2.2. Procedure

A total of 64 lists (16 lists × 4 reverberant conditions; RT = 0, 0.5, 1.0, 1.5 s) was prepared for the test trials. Each participant listened to four lists in total, with one list per reverberant condition. The list for each reverberant condition was selected at random, and all lists presented to each participant included different words. The order of presentation of the four reverberant conditions was counterbalanced between participants. The list prepared for the practice trial consisted of five words per reverberant condition, for a total of 20 words.

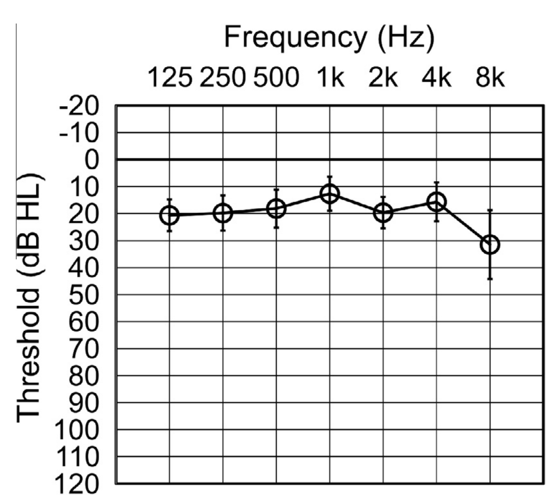

Fig. 1. Mean pure-tone thresholds of the right ear of 30 elderly listeners from 125 Hz to 8000 Hz. Error bars are standard deviations from the means.