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A mismatch negativity study in Mandarin-speaking children with sensorineural hearing loss

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ABSTRACT

Objective: a) To examine the effects of sensorineural hearing loss on the discriminability of linguistic and non-linguistic stimuli at the cortical level, and b) to examine whether the cortical responses differ based on the chronological age at intervention, the degree of hearing loss, or the acoustic stimulation mode in children with severe and profound hearing loss.

Methods: Mismatch negativity (MMN) responses were collected from 43 children with severe and profound bilateral sensorineural hearing loss, and 20 children with normal hearing (age: 3–6 years). In the non-verbal stimulation condition, pure tones with frequencies of 1 kHz and 1.1 kHz were used as the standard and the deviant respectively. In the verbal stimulation condition, the Chinese mandarin tokens/ba2/and/ba4/were used as the standard and the deviant respectively. Latency and amplitude of the MMN responses were collected and analyzed.

Results: Overall, children with hearing loss showed longer latencies and lower amplitudes of the MMN responses to both non-verbal and verbal stimulations. The latency of the verbal/ba2/–/ba4/pair was longer than that of the nonverbal 1 kHz–1.1 kHz pair in both groups of children.

Conclusions: Children with hearing loss, especially those who received intervention after 2 years of age, showed substantial weakness in the neural responses to lexical tones and pure tones. Thus, the chronological age when the children receive hearing intervention may have an impact on the effectiveness of discriminating between verbal and non-verbal signals.

1. Introduction

Hearing aids (HA) and cochlear implantation (CI) are designed to facilitate or restore the detection of sound signals within a short period in children with sensorineural hearing loss (SNHL) [1]. It is also of interest to investigate whether the auditory system of children with SNHL could mature and develop close to normal after the long-term use of hearing devices. Electrophysiological and behavioral studies have revealed that hearing impairment negatively affects the development of central auditory functions, in that children with SNHL perform more poorly on speech discrimination tasks compared to their normal hearing (NH) peers [2–4]. Mismatch negativity (MMN) is an event-related potential (ERP) that indicates the ability to detect a change in the signal without requiring the subject's selective attention. The ERP measurement is obtained using a passive oddball paradigm, in which infrequent stimulations (called ‘deviants’) are embedded between consecutive repetitions of homogenous stimulus sounds (called ‘standards’) [5]. MMN has been extensively studied in the auditory cortex, the prefrontal cortex, and the salience network in human adults. Previous studies have found that the peak latency and amplitude of MMN is related to speech recognition performance in adults with CI [6,7]. ERP studies of the discrimination of acoustic signal changes by children with SNHL are rare. Given that MMN responses can be obtained from children and infants in waking and sleep states [8], and require no selective attention, MMN can be considered as a useful tool to investigate auditory discrimination in children with SNHL.

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One particular area worthy of attention in the auditory discrimination of children with SNHL speaking Chinese mandarin is tone perception. However, whether SNHL will have differential effects on MMN in linguistic (lexical tone) and non-linguistic (pure tone) changes, especially in categorical perception of lexical tones, in children with and without SNHL remains to be investigated. There are four lexical tones in the Mandarin language: a mild-level tone (Tone 1, such as ā), a high-rising tone (Tone 2, á), a low-dipping tone (Tone 3, ǎ), and a high-falling tone (Tone 4, à). Each serves as a supra-segmental cue over phonemic segments (consonant and vowel, CV) to determine the meaning of the utterance. The perception of lexical tones is extremely important for Chinese-speaking children for them to develop normal communication and comprehension skills. (1) Chinese mandarin includes many cues (intensity, pitch, and contour) that allow people to successfully segregate sound streams. Thus, children with SNHL may not perform well if they cannot make use of the cues provided by these tones [9,10]. (2) MMN has been reliably used as an index for discrimination of tonal changes in lexical tone studies [11–13]. Therefore, it is worth using MMN to investigate whether children with SNHL can detect changes in pitch. In this study, we used both non-verbal and verbal tones to investigate whether children with SNHL can discriminate between simple and complex stimuli.

Based on the aforementioned studies, there is great potential for electrophysiological tests to provide reliable and objective information about the neurophysiological processes of auditory discrimination in children with SNHL. The present study was designed to examine the effects of SNHL on the discriminability of linguistic and non-linguistic stimuli at the cortical level, and whether these cortical responses differ based on the chronological age at intervention, the degree of hearing loss, or the acoustic stimulation mode in children with severe and profound hearing loss.

2. Materials and methods

2.1. Subjects

We recruited 43 pre-lingually deaf subjects (aged 3–6 years) from the Department of Audiology Center at the China Rehabilitation Research Center for Deaf Children (Table 1). As shown in Table 1, the subjects were grouped according to the chronological age at which they were fitted with an amplification device (below and above 2 years old), the degree of hearing loss (severe and profound), or the type of acoustic stimulation mode (bimodal and bilateral hearing aids) in both ears. Therefore, our groups comprised group A (below the age of 2 years, subjects 1–15, subjects 31–37), group B (above the age of 2 years, subjects 16–30, subjects 38–43), group C (severe hearing loss, 60–80 dB HL), group D (profound hearing loss, >80 dB HL), the HA group (bilateral HAs, acoustic stimulation) and the bimodal group (CI in one side and HAs in the contralateral side, electric acoustic stimulation). Pure tone detection thresholds for the children with hearing impairment were assessed using an adaptive method using frequencies ranging from 0.25 to 4 kHz presented in a free field. For the MMN measurements, 20 NH subjects (aged 3–6 years) served as the NH group. The pure tone air-conduction thresholds for the NH subjects were <25 dB HL at octave frequencies ranging from 0.25 to 4 kHz, as measured with an intra-auricular earphone. NH subjects showed normal type A tympanometry and normal acoustic reflex thresholds at 0.5, 1, 2 and 4 kHz. All the subjects were right-handed and had no cognitive or psychiatric impairments. We obtained written informed consent from the parents or legal guardians of all the subjects. The research protocol was approved by the Institutional Review Board of the China Rehabilitation Research Center for Deaf Children.

2.2. Stimuli

Non-linguistic and linguistic stimuli were used for the ERP recordings. The stimuli included (1) 1 kHz and 1.1 kHz tone bursts (50 ms long with a 5-ms rise, a 40-ms plateau period and a 5-ms fall, synthesized by E-prime), and (2) lexical speech syllable/ba2/and/ba4/(200 ms long). The two speech tokens were created using the monosyllable/ba/(200 ms long) that was naturally spoken by a female native Chinese speaker, digitally edited using Sound-Forge (SoundForge9; Sony Corporation, Tokyo, Japan), and resynthesized using Praat (http://www.fon.hum.uva.nl/praat/), so that it differs with the original only in its lexical tones (Tone 2, the high rising tone; Tone 4, the falling tone) [14]. Specifically, the naturally spoken/ba/underwent pitch tier transfer to isolate the lexical tones and keep the rest of the acoustic features identical. Therefore, the two stimuli,/ba2/and/ba4/, were identical except in their pitch contour. The oddball paradigm was used to acquire the MMN response. In the non-verbal condition, the 1 kHz tone burst was used as the standard stimulus, while the 1.1 kHz tone burst was used as the deviant. In the verbal condition,/ba2/was used as the standard stimulus and/ba4/was used as the deviant. A total of 900 standard (occurrence ratio: 90%) and 100 deviant stimuli (occurrence ratio: 10%) were presented in the oddball paradigm. Stimuli were delivered in a pseudo-random sequence with 20 standard stimuli presented at the beginning of the test and at least 3–7 standard stimuli presented between two deviant stimuli. The interstimulus interval (ISI) was 500 ms. Each subject underwent a minimum of two oddball paradigms with a total of 2000 stimuli. Stimuli were delivered in the sound field via a single loudspeaker placed at the subject's ear-level, 1 m from the test ear at a 0° azimuth. The stimuli were presented at 40 dB above the aided hearing threshold; the presentation level varied between 70 and 100 dB. The subject was comfortably seated in a sound-treated booth and watched his/her favorite cartoons in the mute mode at a distance of 50 cm from the eyes. The subject was accompanied by his/her parents or caregivers throughout the testing period.

2.3. Electroencephalographic (EEG) recordings

Subjects were fitted with a 34-channel Neuroscan quick-cap (NuAmps, Compumedics Neuroscan, Inc., Charlotte, NC). The cap was placed according to the International 10–20 system, with the mastoid as the reference. Electrooculary activity (EOG) was monitored so that eye movement artifacts could be identified and removed during the offline analysis. The 1-to-3 electrodes located near the CI transmission coil were not used. Electrode impedances for the remaining electrodes were kept at or below 5 kU. EEG recordings were collected using the SCAN software (version 4.5, Compumedics Neuroscan, Inc., Charlotte, NC) with a band-pass filter of 0.5–100 Hz, and an analog-to-digital converter (ADC) with a sampling rate of 1 kHz. During the testing session, subjects were instructed to avoid excessive eye and body movements. Subjects were asked to ignore the acoustic stimuli and watch the muted cartoons to stay awake. Subjects were given short breaks periodically in order to shift their body position and to ensure they stay fully awake during the experiment. Stimulus presentation and recording of the responses were controlled by E-prime (Psychology Software Tools Inc., Sharpsburg, PA, USA).

2.4. Data analysis

All children with NH and 40 children with SNHL finished both the oddball paradigms, while 3 children with SNHL (subjects