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Case report

A case study of the changes in the speech-evoked auditory brainstem response associated with auditory training in children with auditory processing disorders

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ABSTRACT

Background: Studies related to plasticity and learning-related phenomena have primarily focused on higher-order processes of the auditory system, such as those in the auditory cortex and limited information is available on learning- and plasticity-related processes in the auditory brainstem.
Design and method: A clinical electrophysiological test of speech-evoked ABR known as BioMARK has been developed to evaluate brainstem responses to speech sounds in children with language learning disorders. Fast ForWord (FFW) was used as an auditory intervention program in the current study and pre- intervention and post-intervention speech-evoked ABR (BioMARK) measures were compared in 2 school-aged children with auditory processing disorders (APD).
Results and conclusions: Significant changes were noted from pre-intervention to post-intervention and reflect plasticity in the auditory brainstem's neural activity to speech stimuli.
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1. Introduction

There is increasing optimism that subcortical encoding of speech sounds is measurable using auditory evoked potentials and can provide a window into the experience-dependent plasticity even when no such activity-dependent changes are seen at higher levels of processing at the auditory cortex [1]. Excellent temporal resolution from auditory evoked responses originating at the brainstem is available because these responses reflect the temporal and spectral characteristics of complex stimuli with remarkable precision [2–4]. Synchronized neural activity in response to sounds can be measured in humans by means of auditory evoked potentials which can evoke a reliable and repeatable pattern of responses from the auditory brainstem nuclei. The auditory brainstem response (ABR) is a noninvasive measure of far-field representation of stimulus-locked, synchronous electrical events recordable from the scalp. ABR is a critical clinical measure of auditory function because it provides information about the functional integrity of brainstem nuclei along the ascending auditory pathway [1,5].

Studies related to plasticity and learning-related phenomena have primarily focused on higher-order processes of the auditory system, such as those in the auditory cortex [6–9].

Recent evidence has the shown the role of the corticofugal system, particularly the medial olivocochlear bundle (MOCB) in auditory perceptual learning phenomena. This was reflected by changes in a consonant–vowel phoneme-in-noise discrimination task [10]. It has been previously assumed that because auditory brainstem neurons specialize in generation of quick and repeatable electrical activity, their synaptic relays may make them ill-suited to study of plasticity. However, recent discovery of cellular behavioral mechanisms for learning and memory in the auditory brainstem make this structure well suited to study of auditory system plasticity in children by means of short latency evoked potentials [1]. The ABR is an aggregate neural response and so it is difficult to identify with certainty the neural correlates of each of the five peaks. However, it is widely accepted that the first peak is generated by the auditory nerve and that the culmination of the synchronous activity resulting in the fifth peak is generated primarily within the midbrain inferior colliculus [11]. The inferior colliculus (IC) acts as the primary relay center between ascending projections from the lower brainstem nuclei to the thalamus and has converging ascending and corticofugal projections [12,13]. Animal studies have shown that the IC as a site of both activity- and experience-dependent developmental plasticity in vertebrate and mammalian brains [14–18]. In the human auditory system, brainstem plasticity studies have been restricted to speech-evoked brainstem response in typically developing children [19].

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Temporal fidelity of the evoked ABR makes it useful in a wide array of studies and clinical applications. While click-evoked ABRs have been the mainstay of clinical ABR recording, recently there has been a great interest in human ABR recording responses to speech syllables (e.g. [2,20]). Although clicks and speech stimulation are both complex stimuli, they impose different encoding demands on the brainstem. Studies have shown that a subset of children with learning and literacy disorders can show abnormal neural encoding of speech even in the presence of a normal click evoked brainstem response [20–28]. A component of the speech evoked ABR is the frequency-following response (FFR) which has been recorded to speech stimuli in adults [29–32]. The FFR reflects encoding of the fundamental frequency and harmonic structure of complex stimuli and also has midbrain origins [33] but its developmental course in children is largely unknown at this time.

In a study of the changes in the frequency-following response (FFR), a subcortical component of auditory evoked potentials, 27 adult listeners received auditory pitch discrimination training in complex tone stimuli with varying pitch contour (rising, falling, and static). Trained participants showed apparent improvements in behavioral and FFR measures of pitch discrimination relative to untrained controls for all three trained stimuli [34].

Auditory processing disorder (APD) refers to difficulties in the processing of auditory information within the central nervous system, such as sound localization and lateralization; auditory discrimination; auditory pattern recognition; temporal aspects of audition, including temporal integration, temporal gap detection, temporal ordering, and temporal masking; auditory performance in competing acoustic signals (including dichotic listening); and auditory performance with degraded acoustic signals [35].

APD is a modality-specific perceptual dysfunction that is not due to peripheral hearing loss [36]. APD should be distinguishable from cognitive, language-based, and/or supramodal attentional problems in which modality-specific perceptual dysfunctions are not expected [37]. APD may be broadly defined as a deficit in the processing of information that is specific to the auditory modality that may be exacerbated in unfavorable acoustic environments, and may be associated with difficulties in listening, speech understanding, language development, and learning [38].

There is currently a major interest in developing diagnostic and intervention protocols for evaluation and treatment of children with APD. Children with APD typically exhibit normal hearing function on routine hearing tests but have apparent difficulties in listening, attending, discriminating, and recall of auditory information [38]. Fast ForWord (FFW) is a computer software program developed by Scientific Learning Corporation that is available for the management of children with APD. Use of FFW exercises has been shown to build skills needed for listening, speaking, and reading in children with language-learning impairment [39]. The rationale for the FFW intervention is to improve the temporal processing abilities of children with language impairment so that they can process sounds and words at gradually increasing rates of presentation. Children typically start by listening to speech recorded at slower rates (time altered speech) and are allowed to progress through five levels of time altered speech modification until they reach normal or unmodified speech [40]. More details of the FFW training are provided in the following (i.e. Methods) section of this article.

A clinical electrophysiological test of speech-evoked ABR known as BioMARK (formerly known as BioMAP) has been developed to evaluate brainstem responses to speech sounds in children with language learning disorders [20]. The BioMARK testing includes considerations similar to the click evoked neurodiagnostic ABR. Normal synchronous firing of VIII nerve neurons (reflected by a normal click-evoked ABR) is a good starting criterion. The electrode montage is similar to a single-level neuro-diagnostic ABR (noninverting electrode of C2, inverting electrode or right ear lobe, ground on opposite earlobe or forehead). Unlike click-evoked neuro-diagnostic ABR, the speech stimulus in BioMARK goes in the right ear only and the listener is allowed to watch a quiet video without any need to pay attention to the speech stimulus. Although patient participation is similar to neurodiagnostic click-evoked ABR, BioMARK waveform analysis and recording are different. Three recordings (each recording with 2000 sweeps) are weighted and averaged before analysis. The major peaks (e.g. V, A, D, E, F, and O) are all lobe marked by the audiologist. In the BioMARK procedure, the brainstem response to the speech sound/da/is recorded physiologically by electrodes attached to the ears and vertex. Test considerations for BioMARK are similar to those for click-evoked neurodiagnostic ABR recording and normal synchronous firing of VIII nerve neurons (reflected by normal click-evoked ABR latencies) is a good starting criterion for BioMARK testing.

Analysis of latency and amplitude of BioMARK waveforms is performed using special software available on Auditory Evoked Potentials Systems (Biologic Corporation). The brainstem response to the speech sound/da/has been described in detail in previous reports [21–28,3] and is very reliable between and within subjects. Transient response measures include peak latency and amplitude measures. For each subject, peak latency and amplitude measures are completed for the brainstem onset (peaks V and A), offset (peak O), and the frequency-following peaks (D, E, and F) [19]. This test has the potential to evaluate auditory brainstem changes in humans associated with auditory training interventions. In the animal model, studies by Yu et al. [18] have suggested developmental experience-dependent plasticity in the brainstem inferior colliculus of mice and these processes can now be explored in humans using such electrophysiological tools. While it is known that higher-level cognitive activities such as language and music experience can shape subcortical sensory infrastructure, notably the auditory brainstem response [3,41–43], there is currently a need to study subcortical function associated with auditory training interventions to explore basis for subcortical plasticity. Previous studies have shown evidence of subcortical plasticity relating to speech in noise tasks [10] and pitch perception tasks [34].

The purpose of the current study was to investigate if auditory training (FFW) effects are associated with changes in BioMARK responses in children with APD. Based on the auditory training components of the FFW, we hypothesized that FFW training modifies the neural processing of children with APD. We predicted that following FFW training, there will be improvements in neural encoding of speech syllables, including faster response times (shorter latencies), greater fidelity and strength of encoding (increased amplitude), and responses closer to normative template available for BioMARK.

2. Design and methods

The Institutional Review Board at Auburn University at Montgomery approved all research. Informed consent by the parent or guardian and child assent were obtained prior to participation.

2.1. Participants

Participants selected for this study were referred to the Speech and Hearing Clinic at Auburn University at Montgomery (AUM) for APD evaluation based on parental and/or teacher concerns for listening and learning difficulties. Four participants were selected based on the following test battery: normal otoscopy (visualized and healthy tympanic membranes), normal tympanometry

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